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ALTERNATING CURRENT SIGNALING

BY

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CHAPTER I.

ALTERNATING CURRENT SIGNALING.

History and Advantages.

more, maintainers, familiar with direct current apparatus only, are quite certain to be pretty much at sea at first when called upon to care for an alternating current installation. It is the purpose of this book to cover in as thorough and yet simple a manner as possible the field of alternating current signaling as applied both to steam and electric railroads.

HISTORICAL SKETCH.

1. Attempt to use Simple D.C. Track Relay on Electric Roads. It is a peculiar fact that, although to-day, for reasons involving economy and dependability, the steam roads are making the most extensive application of alternating current signaling, the invention of the alternating current track circuit, which started the ball rolling, was first taken advantage of by roads using direct current propulsion, and the original installations were made on electrified lines. The idea, however, did not spring into existence Minerva-like at the first call; it was the result of a gradual evolution from the imperfect to the ideal.

The direct current track circuit, credit for whose invention in 1872 is now generally conceded to William Robinson, of Brooklyn, N. Y., came into extensive use in the middle nineties and had reached a high state of development in 1900 when it first became necessary to signal the elevated electric roads whose operating conditions, as regards speed, frequency of service, and weight of rolling stock, were in many ways comparable to those of steam roads. In view of the success of direct current track circuits on steam roads, it was only natural that an attempt should be made to apply them to the roads using electric propulsion. Right here some snags were struck.

As everyone knows, the running rails of electric roads are used as a return for the propulsion current. The automatic block signaling idea, however, involves a division of the track into sections each electrically insulated from the other, so that one of the running rails had to be given up for signaling purposes to act as a "block" rail, not a part of the propulsion current return. In the case of the elevated roads, this was not a serious matter as the elevated structure itself constituted a propulsion return of many times the conductivity of the running rails. On the other hand, the sacrifice of one of the rails on subway and surface lines was a serious handicap, as it doubled the resistance of the return.

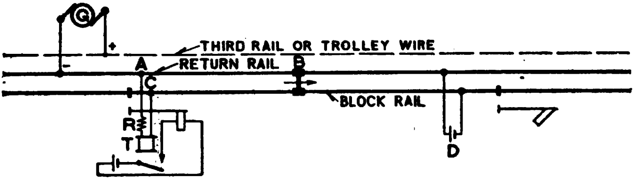

Fig. 1—D.C. Track Circuit Applied to an Electric Road

The difficulties encountered in the application of the direct current track circuit to electric roads will be understood from a study of Fig. 1, where T represents the usual D. C. track relay connected to the rails with a limiting resistance R in series and fed from a track battery D. The main generator for supplying power for propulsion purposes is shown at G. Suppose, now, that a train at B has proceeded 1000 feet in the block, and that the propulsion current in the return rail flowing towards the negative side of the generator is 200 amperes; if the resistance of the return rail (100 lbs. per yard bonded to capacity) is 0.0088 ohms per 1000 feet, there will be a difference of potential of 0.0088 x 200 = 1.76 volts between A and B. A moment's reflection will make it evident that this difference of potential is transmitted directly to track terminals A and C of the relay T, because the resistance of the car axles and the block rail between C and B is negligible; in other words, the axles and the block rail form a low resistance connection between points C and B so that there is a difference of potential of 1.76 volts between A and C. If, say, a 16 ohm track relay, picking up at 0.5 volts were alone used, the signal would be clear with a train in the block due to the relay being picked up by the drop in the propulsion rail. To eliminate this difficulty, series resistance R is inserted in the relay circuit to reduce the maximum propulsion drop across the relay coil terminals to a figure well below the pick-up point—say 50 per cent. to allow a safe margin. For example, if the maximum propulsion drop across the rails opposite the relay is 1.76 volts during rush hours when all trains are running, and it is to be reduced to 0.25 volts across the terminals of a 16 ohm relay, a resistance R of $\frac{(1.76-0.25)}{0.25} \times 16 = 96.6$ ohms, must be used; of course, the same relay wound to a high resistance might be used instead with no external resistance, but the use of the external resistance would be advisable because of the possibility of adjustment in case of an increase in the propulsion drop resulting from heavier traffic.

With an accurate knowledge of the maximum propulsion drop and adequate provision in the way of resistance to prevent the track relay being falsely energized, a system constructed on the above lines would be satisfactory provided the bonding of the return rail is well maintained. It will be seen, however, that a defective bond in the return would cause a rise in the return resistance with a corresponding increase in the propulsion drop across the relay; with a broken bond, this increase might actually cause the relay to pick up with a train in the block. Serious results might also occur in the event of imperfect contact between the return rail and the car wheels, for then the block rail would be in the direct path of the return. This would subject the track relay to practically full propulsion potential with obvious results.

2. Special Polarized D. C. Track Relay Designed for Boston Elevated. The limitations of such a system were, therefore, considerable. It was felt that some better plan was required, and the first step in this direction was the polarization of the track relay against the effect of propulsion drop. The first installation involving this safety feature was made on the Boston Elevated in 1901. This practically marks the beginning of automatic signaling on electrified roads. Track circuits for about 175 one-arm semaphore signals were put in, the signals themselves being electro-pneumatic. Owing to the great capacity of the elevated structure as a return conductor, only a small fraction of the propulsion current flowed through the return rail. This, together with the fact that frequent train service of the elevated rendered short block sections imperative, resulted in a comparatively small propulsion drop per track circuit, normally well below the pick-up point of the relay.

The Boston Elevated track circuit is covered by Fig. 2;

where it will be noted that the positive side of the power generator G at the right of the diagram is connected to the third rail and the negative side to the return rail and the structure as usual, whereas the positive side of the signal generator L is connected to the return rail, and the negative side to the signal main feeding the track circuits through a resistance.

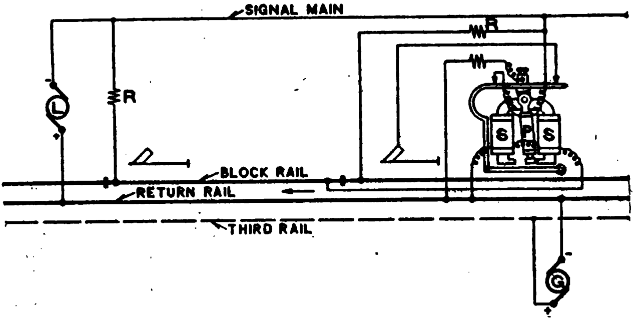

Fig. 2—Boston Elevated Track Circuit

The polarized track relay shown at the right in Fig. 2 consists of a horse shoe electro-magnet energized by two coils SS just as in the case of the well known direct current track relay used in modern steam road service. The armature at the bottom of this magnet is pivoted at its right hand end, so that when coils SS are energized from the track this neutral armature lifts the vertical rod at the left of the coils and actuates the horizontal contact bar at the top of the relay. This contact bar, made of a flexible metal strip provided with a carbon contact block at either end, is carried by, but insulated from the polarized magnet P pivoted at the top of the horse shoe magnet and swinging between its coils. When the block is clear, as shown in Fig. 2, magnets SS are energized, and the neutral armature lifts the vertical rod at its left end, so that the left hand contact on the horizontal contact bar is made, thus energizing the swinging polar magnet P from the signal main.

It will be seen that the horizontal contact bar at the top of the relay is under the joint control of the neutral and polar armatures, so that, if coils SS are energized by current flowing in the proper direction, the lower pole of P will be attracted t the right; then the contact on the right of the horizontal bar will be made to close the signal control circuit. Coils SS and P are connected so that when no train is in the block, current will flow from the positive side of the signal generator, from left to right along the return rail and through coils SS to swing magnet P to the right to close the signal circuit; on the other hand it is to be noted that with the 500 volt main power generator located and connected as shown, propulsion drop in the return rail will tend to send a current across the car axles and from left to right along the block rail, to track coils SS of the relay in opposition to the signaling current.

Thus, whereas the signaling current is of such polarity as to excite coils SS so as to swing magnet P to the right to close the signal circuit, the propulsion current flows in the opposite direction so as to reverse the polarity of coils SS and thus swing magnet P to the left to open the signal circuit and throw the semaphore to danger. Ordinarily, the propulsion drop in the return rail on the Boston Elevated was too small to cause the relay to thus open and delay traffic; in case of sudden unexpected increases in the propulsion drop, however, due to rush hour traffic, poor bonding of the return, or to a poor contact between the car wheels and the return rail, the polarized feature became effective to prevent the signal giving a false clear indication.

3. Limitations of Boston Elevated Polarized Relay.

Certainly the Boston Elevated track circuit as above described was of undoubted merit and the best in the field at the time it was installed. It was later found, however, that its advantages were somewhat limited because the direction of the propulsion drop was not always constant, due to shifting of the load between the three power houses along the right of way. Sometimes most of the return current would flow towards one power house and then again in the opposite direction to another power house, depending on the location and density of traffic at that particular time. For this reason a relay was later placed at each end of the track section in many cases so that at least one relay would be always shunted with a train in the block, the signal control circuit, of course, being broken through the contacts of both relays in series. While, naturally, this precaution tended to lessen greatly the possibility of false indications, absolute safety is secured only through a rigid maintenance of the bonding of the return. Therefore, whereas a system of this type, well installed and maintained, possesses points of merit, it is not ideal in that it is not free from the interference of propulsion drop, the block must be comparatively short if this propulsion drop is to be kept down, and one rail has to be given up for signaling purposes; this latter may be a serious matter in the case of surface lines and subways where there is no structure to serve as a return. However, the Boston Elevated signal system has given perfect service for almost fifteen years now; not a little of the credit for this is due to excellent maintenance enforced by a very able and energetic signal department.

4. Invention of the A. C. Track Circuit. A consideration of the foregoing discussion will make it evident that the successful solution of the track circuit problem on electrified roads yet remained to be found. A brand new idea was wanted—some means of rendering the track circuit absolutely immune to the effects of propulsion current. It remained for Mr. J. B. Struble, an engineer in the employ of the Union Switch & Signal Company, to solve the difficulty once for all. He had been prominent in the Boston Elevated development, but had previously conceived the simple yet rare idea of a true selective relay—one designed to respond to an alternating signaling current, but to be absolutely free from the possibility of closing its contacts no matter how much direct current passed through its energizing coils. This involved a motor device, the so-called Vane Relay, working on the induction principle, which will be fully described in Chapter IV.

The first extensive trial of Mr. Struble's invention was made in 1903 between Sausalito and San Anselmo, on the North Shore Railroad in California. The situation was in a way novel in that the road was originally built for narrow gauge steam service; later, a standard gauge electric service was added over the same permanent way through the addition of another rail. The rail common to both gauges was used as a block rail, so that the remaining two rails constituted a return for the propulsion current—500 volts D. C. Thus, trains of either gauge would operate the signals. The system consisted of thirty style "B" motor signals, covering ten miles of double track, operated by storage batteries through an alternating current track circuit control.

The track circuit conductor system employed was, therefore, much like that of the Boston Elevated previously described, excepting for the presence of two return rails. To feed the track circuits, two wires carrying alternating current at 2300 volts, 60 cycles, were strung on a pole line along the right of way and a step-down transformer located at the exit end of each track circuit supplied current at a low voltage to the track for the operation of the selective alternating current track relay, controlling the signal at the entrance of the block. Some of the track circuits were about a mile long, and, a copious rains are frequent in that district during the wet season, the system was given a severe test. The ballast was of gravel and well removed from contact with the rails. Under the worst conditions the relays operated with a margin of from 30 to 40 per cent. above the failing point. The system was a success in every way.

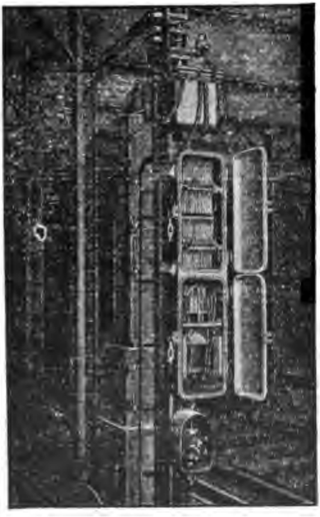

Fig. 3, Track Circuit Apparatus, New York Subway

5. A. C. Track Circuits Installed on New York Subway. About this time the question of signaling the New York Subway came up for settlement. There were about 70 track miles, two, three and four track, to be signaled, the propulsion system being 500 volts D. C. The traffic on this line is undoubtedly the heaviest in America; for example, 2,088 trains pass Ninety-Sixth street every 24 hours,. these trains consisting of 10 cars during the morning and evening rush. It was decided to install electro-pneumatic signals controlled by A. C.

track circuits. The system comprises some 500 track circuits, 700 signals, and 40 electro-pneumatic interlockings, and is one of the three or four greatest installations in the country.

Single rail track circuits, similar to those of the North Shore were installed with Vane type A. C. track relays fed along the rails from transformers located at the leaving end of each block and stepping down from the 550 volt, 60 cycle, signal mains to 10 volts for the track. Fig. 3 shows one of the instrument cases suspended on a column near a signal. The transformer feeding signaling current to the track is shown at the top of the column. Just below it in the instrument case will be seen two resistance grids, one of which is placed in the track leads of the transformer and the other in the track leads of the A. C. track relay immediately below the grids. These grids prevent excessive heating of the transformer and relay due to the flow of propulsion current resulting from direct current drop in the return rail. The relay is still further protected

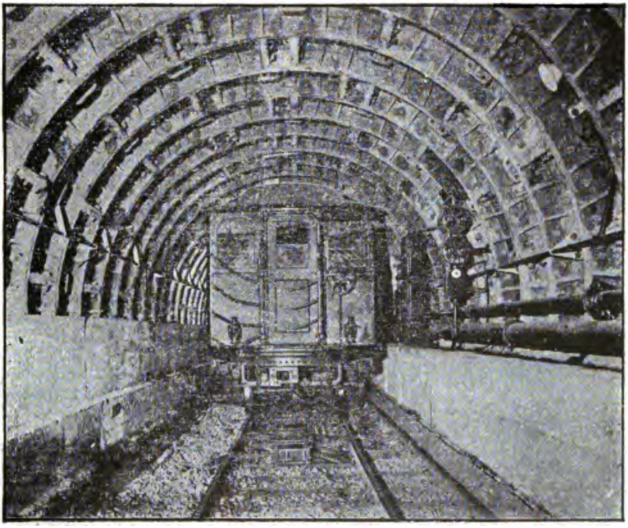

Fig. 4. Signaling on the Hudson and Manhattan R. R. Under the Hudson River, New York

by an impedance coil shown at the bottom of the instrument case; this coil shunts out direct current from the relay, as will be explained in Chapter V.

Because of the density of traffic, the blocks had to be made as short as consistent with safety; the average block length is about 820 feet, this distance being one and one-half times the full speed braking distance. Altogether the conditions were extraordinarily severe, but the signal system has met the requirements magnificently, having a record of one failure of apparatus to 3,359,167 movements. The line carries over 1,000,000 passengers a day and never has a passenger been killed through any fault of the signal system; as a matter fact only one passenger has been killed in the entire history of the road and this was due to panic in a train resulting from a blow out in a high tension power cable. This remarkable performance has made the New York Subway system one of the classics of the signal world.

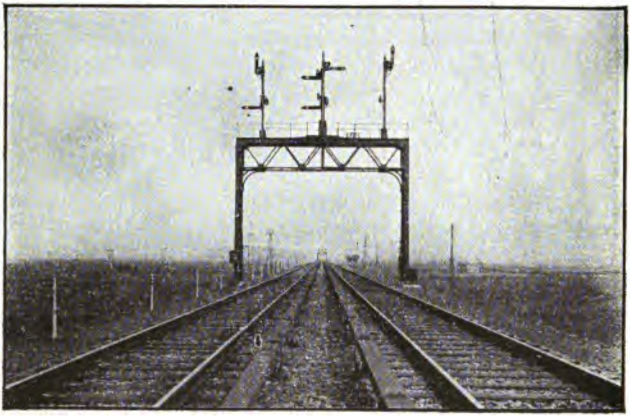

Fig. 5. An Example of Signaling on a Heavy Electric Trunk Line. Manhattan Division, Pennsylvania Railroad

6. Invention of the Impedance Bond. Other installations of single rail track circuits, notably that of the Philadelphia Rapid Transit in 1907, were made, but the fact that one of the propulsion rails had to be given up for signaling was a serious limitation on surface roads where the large conductivity of a structure was absent. This objection was finally removed, through the invention of a practical balanced impedance bond and its application to the so-called double rail track circuit by Mr. L. H. Thullen, then Electrical Engineer of the Union Switch & Signal Company; Messrs. Young and Townsend, of the General Railway Signal Company (then the Taylor Signal Company), were also connected with this development. Mr. Thullen's scheme included the use of an

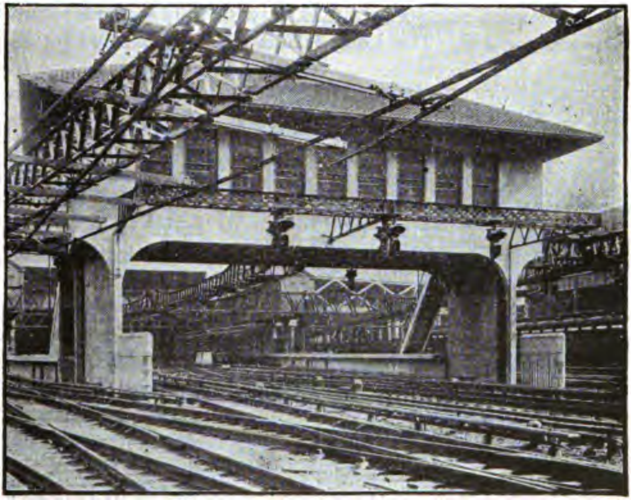

Fig. 6. A Corner of the Great Pennsylvania Terminal, New York City

A. C. track relay fed from a transformer over the rails as usual; but the track circuit was completely isolated, insulation joints being placed at the ends of the block in both running rails. The novel feature of the invention was that the passage of the return propulsion current back to the power house was provided for by the use of balanced impedance bonds connected across the rails at the ends of the blocks; these bonds offer impedance to the passage of the alternating signaling current, but they are provided with a heavy copper winding connected so as to offer negligible resistance to the flow of the direct propulsion current from track circuit to track circuit.

The first installation of double rail track circuits with impedance bonds was made on the lines of the Boston Elevated, where, in 1904-5, about fourteen track circuits of this type were put in on the East Boston Tunnel under the Boston Harbor. On the basis of the satisfactory results there obtained, a much larger system was installed on the electrified lines of the Long Island Railroad in 1906, where 140 track circuits were used on 19 miles of double track, and 4.5 miles of four-track road, the propulsion being 500 volts D. C. with 1100 amperes return current per rail. The Long Island job was followed by an even larger one in the same year on the West Jersey & Seashore Railroad, where 120 block sections, of an average length of 4000 feet, were installed on thirty miles of double track between Camden and Newfield, N. J., on the way to Atlantic City. This propulsion system was the same as that of the Long Island, only the return current amounted to 1750 amperes per rail. Very important track circuit systems of the same type have been installed on the Hudson & Manhattan (1909) in the New York Central Electric Zone and the Grand Central Terminal, New York. (1906-1910), at the Great Pennsylvania Terminal, New York (1910—See Figure 6), and later on the electrified lines of the Southern Pacific in the San Francisco district, where extensive developments, which would surprise the Easterner, have been made. Many other large systems, too numerous to mention, have since been installed The double rail track circuit with impedance bonds is now the andard for long track circuits on electric roads.

Fig. 7. Southern Pacific Electric Zone, Alameda Mole, San Francisco District

7. Where Frequency Relays Were First Used. All the above roads were characterized by D. C. propulsion, but in 1906 when certain portions of the New York, New Haven & Hartford were electrified for 11,000 volt, 25 cycle A. C. propulsion, it became necessary to devise a track relay which would not respond to either D. C. or 25 cycle A. C. propulsion current; foreign direct current had to be guarded against because of the proximity of D. C. propulsion roads. The difficulty was successfully met by the invention of what is known as the frequency relay, in this case an A. C. track relay which will not respond to the low frequency 25 cycle propulsion current, but will work on a higher frequency, say 60 cycle, signaling current; the selective principle is thus again utilized. Messrs. Howard and Taylor, of the Union Switch & Signal Company, are to be credited with the invention of successful relays of this type. The New Haven installation embodied the use of frequency relays on double rail track circuits with

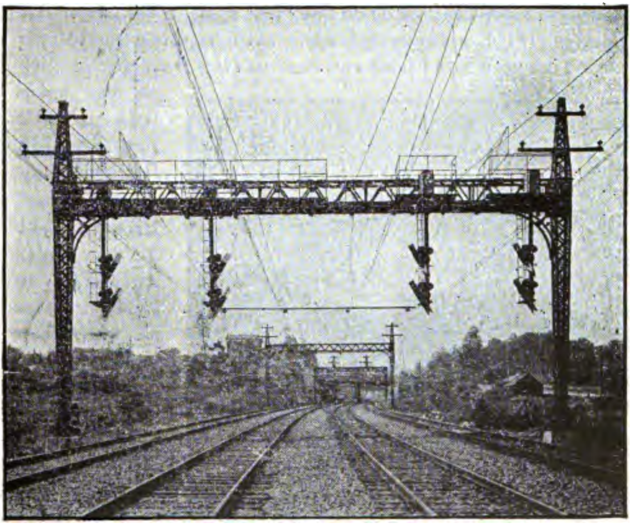

Fig. 8. Signaling on an A. C. Propulsion Road,
New York, Westchester & Boston R. R.

impedance bonds, which latter still maintain the continuity of the propulsion return while choking back the flow of signaling current, as explained in Chapter V. The rapid extension of A. C. propulsion on the New Haven has brought this system into great prominence. The New Haven is remarkably progressive in an engineering way and is now operating both passenger and freight trains electrically on its four and six track main line between New York and New Haven, a distance of 75 miles.

Other extensive installations on roads using A. C. propulsion have since been made on the New York, Westchester and Boston (1911), a heavy suburban road, running north from New York to White Plains and east to New Rochelle; in 1915 on the main line of the Pennsylvania Railroad, running west from Broad Street Station, Philadelphia, to Paoli, where all suburban traffic is handled by multiple unit a.c. trains; and also in 1915, on the Norfolk and Western, where a long stretch of the main line in the West Virginia mountain district has been electrified to handle heavy coal trains.

Fig. 9. Style "B" Signals on the St. Paul

8. **Steam Roads Adopt the A. C. System.** The universal success of A. C. signaling on electric roads, together with advantages in the way of safety and economy, brought about the adoption of the same system on steam roads. The first installation of this kind was made on the Union Pacific Railroad near Council Bluffs, Ia., in 1906, where 16 track circuits were put in. This was shortly after followed by a number of small installations on the Pennsylvania Railroad, where foreign current interfered with the proper operation of D. C. track cir-

cuits. The Pennsylvania later adopted A. C. signaling as a standard for all new blocking, and now, with the exception of certain relatively short stretches, the entire main line between New York, Philadelphia, Baltimore, Washington and Pittsburgh is protected by a. c. automatic block signals. Other great roads, particularly the Santa Fe, the Chicago, Milwaukee & St. Paul, the Norfolk and Western and the Southern Pacific, have made important installations; the St. Paul alone has equipped 1000 track miles of the main line with alternating current signals.

9. Signaling Begins on the Interurban Electric Roads. The latest developments in the alternating current signaling field have been made on the high speed electric interurban roads, where the service is in many ways similar to that of steam roads, especially as regards speed, frequency of service, and weight of rolling stock. Much special apparatus, and many novel control schemes have had to be devised to meet the requirements of single track operation characterizing most of the trolley roads. Fig. 12 illustrates an interurban car on the Indianapolis, Columbus & Southern waiting on a stub siding for an opposing car to pass on the main, the semaphore signals being cleared for a movement in either direction. The first of a large number of extensive signal installations on the interurban roads was made on the Illinois Traction System in 1910, 100 miles of single track being signaled. Automatic electric block signals controlled by continuous a. c. track circuits are now considered the standard for the protection

Fig. 10. T-2 Signals on P. R. R.

high speed interurban roads, trolley contacts and similar devices not being entirely dependable for speeds over 30 miles per hour.

10. Advent of the Light Signal. Along with the new signaling on the interurban roads has come the Light Signal, used for both day and night indication; on single track cross country electric lines, the signal must often show up against a forest of vertical lines constituted by the pole line and trolley supports, so that in many cases a color indication will contrast better with such a background than the position indication of a semaphore blade. The ordinary three position color light signal (Fig. 13) consists of a combination of colored lenses varying in diameter from 5⅜" to 10" illuminated by incandescent lamps (red for "stop", yellow for "caution", and green for "proceed"), the lenses being shielded against sunlight by a deep overhanging hood. Depending on the size of the lenses and the candle power of the lamps back of them,such signals can ordinarily be seen from 2500'-4000' on a tangent, under favorable weather conditions, and from 1500'-2500' at those hours of the day when the sun shines directly on the lenses. Due to its freedom from moving mechanical parts and general simplicity, the light signal is receiving serious consideration even by the signal engineers on the heavy trunk lines, an initial installation of color light signals having been made only a few months ago by the New York, New Haven & Hartford. The latest development in the light signal field is the "position" or "beam" light signal (Fig.14), consisting, in


Fig. 11. Style "S" Signals on the Santa Fe

the case of a three position signal of three rows of uncolored lenses with their incandescent lamps arranged in three radial lines projecting horizontally, diagonally at 45°, and vertically from the central point of divergence; the illumination of the bottom, or horizontal, row of lights indicates Stop, that of the diagonal, or 45° row Caution, and that of the vertical row, Proceed, the control being easily effected over the points of a three position relay. This scheme is the joint invention of Mr. A. H. Rudd, Signal Engineer of the Pennsylvania Railroad, and Dr. William Churchill, of the Corning Glass Works.

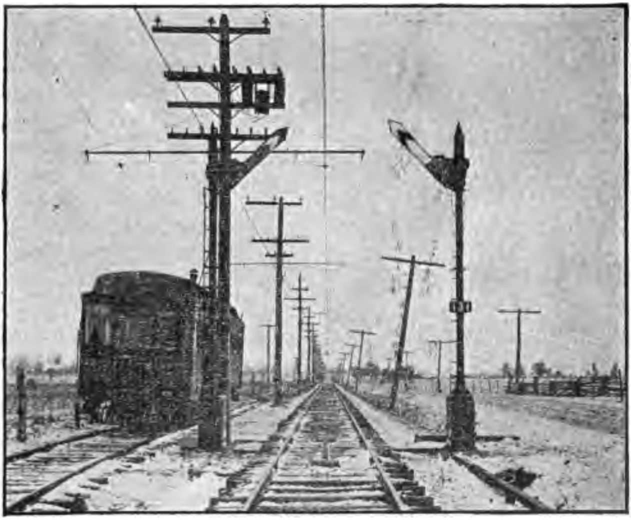

Fig. 12. Interurban Electric Road Signaling
Indianapolis, Columbus & Southern

ADVANTAGES OF A. C. SIGNALING.

It will be fairly evident from a consideration of the discussion at the beginning of this article that the alternating current system is the only really satisfactory method of signaling electric roads. What are its recommendations for steam roads? The following summary of the advantages offered by the alternating current system will supply the answer.

1. **Safety.**

(a) A. C. apparatus, working on the induction principle, is immune to the dangerous effects of direct current. The necessity for such immunity is imperative in the case of track relays on electric roads using direct current propulsion. Where alternating current propulsion is used, the relays may be designed to respond only to a certain frequency, much higher than that of the propulsion system; in this case the track relay is again perfectly selective. On steam roads, foreign current troubles have greatly increased, due to widespread extension of interurban trolley lines during the past few years. With alternating current track relays, such troubles disappear.

Fig. 13. Color Light Signal, Pacific Electric Ry., Cal.

(b) Residual magnetism troubles are eliminated through the use of alternating current apparatus working on the induction principle. This is of great importance in the case of relays, holding devices, etc.

(c) Due to the fact that large amounts of electric energy are available, A. C. apparatus may be designed with good mechanical clearances and thus have a large safety factor.

(d) Complete protection against broken down insulation joints, which might otherwise cause false clear failures, can be secured through the use of two element alternating current relays.

2. Economy.

(a) The maintenance charge on A. C. systems is much less than that for D. C. systems. Track and line batteries are dispensed with and the signals are lighted by electric lamps fed from the signal mains; battery men and lamp men are not required. In many cases one man is maintaining thirty miles of track and he spends his time on the signals, not in cleaning batteries. Often he looks after one or two small interlocking plants in the bargain.

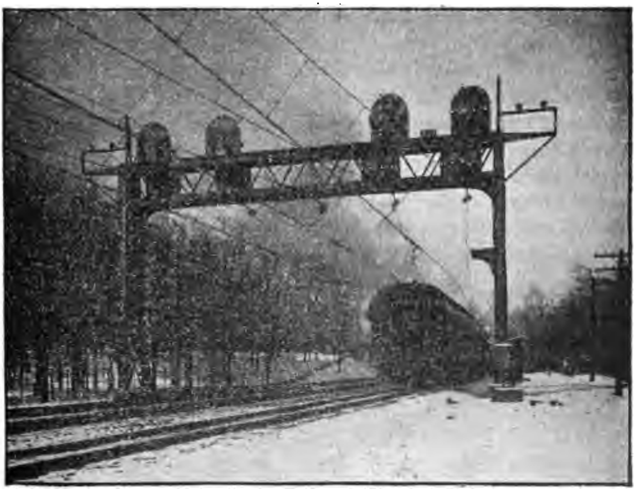

Fig. 14. Position Light Signals, P. R. R.

(b) A. C. power can naturally be produced more cheaply than D. C. power by batteries. Estimates* of the cost of

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*NOTE:—See an interesting article, "The Care and Maintenance of Storage Batteries in Signal Work," written by T. R. Cook, on Page 26, Vol. V, Proceedings. R. S. A.

power delivered by batteries vary from $5.00 per kilo-watt hour for primary batteries to $14.71 per kilo-watt hour for storage cells charged by gravity batteries. The average cost of A. C. power is about 2.5¢ per kilo-watt hour; it will vary from 1¢ per kilo-watt hour to 10¢ per kilo-watt hour, depending on the location and the amount of power used.

3. Simplicity.

(a) Track circuits up to 25,000 feet in length are being successfully operated by alternating current. Cut sections with their relays, housing and other complications are eliminated. Cases have occurred on important stretches of track, where, due to abnormally poor ballast conditions, D. C. track circuits proved impracticable. This situation was met by the use of the A. C. system, because it was a simple matter to supply enough power to compensate for the track losses and work the relays. In fact the length of the track circuit in the A. C. system is limited in most cases only by the length of the block, that is, the permissible distance between succeeding signals, as dictated by the density of traffic. This makes for simplicity.

(b) The mere fact that there are no batteries reduces the complication of the A. C. system; their place is taken by transformers which require no attention.

4. Dependability.

(a) The power supply for A. C. systems is continuous as long as the power house and transmission are in commission; experience has shown that interruptions may easily be guarded against by constructing the transmission line in a substantial manner and by providing duplicate generating apparatus in the power house. Direct current systems occasionally fail because of the freezing of the batteries in cold weather; cracks sometimes appear in the jars, and the liquid leaks out; or perhaps local action in the cell gradually "kills" it. Such interruptions in the current supply throw the signal to danger and delay traffic. A. C. systems are free from this.

(b) Practically constant voltage characterizes the A. C. system, whereas the voltage on D. C. systems, not only falls gradually as the batteries become older, but drops off suddenly as they approach exhaustion. This means that where A. C. is used the signals always clear in the same time, and the track relays never fail to pick-up due to an exhausted track battery.

(c) A comparatively high voltage (110-220) is used in A. C. signaling for operating the signal motors. The voltage drop in relay contacts is, therefore, insignificant; contact resistance is of no importance.

(d) Induction motors are generally used for operating A. C. signals. These motors have no commutators or brushes of any kind. Commutator troubles disappear.

5. Other Advantages.

(a) The installation of an A. C. system on a steam road may be made to anticipate the future electrification of the line and provide for it.

(b) The A. C. mains feeding the signals, track circuits, etc., may be used to supply power along the right of way for other purposes besides signaling—station lighting, for example.

Many extravagant claims have been made for alternating current signaling, most of which, happily, it has been able to meet. It is only fair to state, however, that there are certain sections of the country where the cost of power is relatively high and where, consequently, an alternating current signal system might not be as economical as a direct current installation with batteries; such cases are rare and are gradually disappearing as the country develops and commercial power becomes more and more available. Furthermore, the initial cost of an A. C. system will, in most cases, be greater than that of an equivalent D. C. system, but this is generally more than compensated for by the saving in maintenance and power, so that the alternating current system pays for itself in a longer or shorter time, depending on local conditions, and there is thereafter a constant saving.

Neither ought the alternating current system be considered as a panacea for all troubles met with in signal practice, for A. C. relays, signals, etc., require proper maintenance, just like all other types of signal apparatus. It must also be remembered that new principles and ideas have had to be used in the design of A. C. apparatus, and it is only natural that new problems, having no parallel in direct current work, have resulted. Forty years have been required to bring the D.C. track relay to its present simplicity, and time and experience are bringing alternating current signaling to the same high state of simplicity and perfection.

CHAPTER II.

FUNDAMENTAL THEORY OF ALTERNATING CURRENTS

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FUNDAMENTAL THEORY OF ALTERNATING CURRENTS.

Before proceeding with the study of the design and operation of alternating current signaling apparatus, it is desirable to possess a working knowledge of the physics and mathematics of alternating currents. Unfortunately, there seems to be a general impression that this subject is a bit too abstruse for anyone not a mathematician or a college graduate. Naturally, the designing engineer must have a thorough and detailed knowledge of physics, mathematics and electricity; in addition, he must have a broad practical experience before his theoretical training will be of much value, for there are many pitfalls not mentioned in the text books. Most of the fundamental facts, however, are within the grasp of almost everyone, and this chapter will, therefore, be devoted to a presentation of such alternating current theory as will enable the signalman to understand the most important factors entering into the workings of A. C. apparatus.

GENERATION AND CHARACTERISTICS OF ALTERNATING CURRENT WAVES.

1. Simple Alternator. A generator which produces alternating current is known as an alternator. Alternators generate currents on exactly the same principle as direct current dynamos, and in fact, the two types of machines are alike in all important respects, with the exception that, whereas the direct current machine is provided with a commutator to maintain the direction of current constant in the external circuit, the alternator supplies current to the external circuit just as it is generated without rectification of direction. Currents are, therefore, said to be direct or alternating in character, depending on whether they flow always in one direction with a steady value, or whether their direction and strength vary periodically.

A simple form of alternator is shown in Figure 15, where N and S are the poles of a field magnet, which latter, in some cases, may be a permanent magnet, as for example, in telephone or automobile magnetos, but is always a large electromagnet, excited from some direct current source, in the case of power generators; the point to be remembered is that the field magnet is of constant polarity. Rotating on a horizontal axis in the magnetic field whose flux lines pass from N to S as indicated by the arrows, is a loop of wire terminating in two metallic rings, R and T, carried on, but insulated from, the same shaft which drives the wire loop. R and T are known as slip rings, and brushes A and B bearing on them, conduct the current generated in the loop away to the external circuit to which electric power is to be delivered. It is understood of course, that the alternator shaft carrying the wire loop is provided with a pulley to be driven from an engine or some other source of mechanical power.

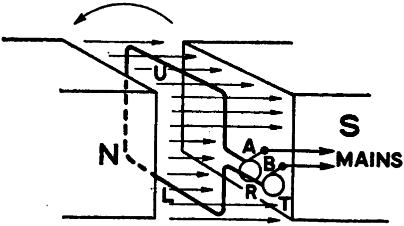


Fig. 15. Simple Bi-Polar Alternator
No-Voltage Position

2. Voltage Generated by Simple Alternator. It is a fundamental fact that when a wire is forcibly moved across a magnetic field so as to cut the lines of magnetic flux, an electromotive force is generated in the moving conductor. The electro-motive force so generated is proportional to the strength of the magnetic field and the speed at which the conductor is moved; or more simply, the voltage varies with the rate at which the lines are cut. When a conductor cuts 100,000,000 flux lines in one second, one volt is generated in that conductor. Of course, when the rotating wire loop consists of many turns, the total voltage generated in the coil is the voltage generated in one conductor, multiplied by the number of conductors moving in the magnetic field, for the conductors comprising the coil may be considered as a number of batteries connected in series. In the case of the 2-pole alternator shown in Fig. 15, the voltage generated is:

$$E = \frac{2n\Phi Z}{100,000,000} \qquad (1)$$

Where E is the voltage across slip rings R and T, and n is the speed in revolutions per second at which the loop, consisting of a total of Z conductors (such as U and L), is being moved in a field of ϕ lines of magnetic force streaming from pole N to pole S; the Greek letter ϕ, (pronounced "phi") is universally used in electrical calculations to represent the total number of flux lines constituting the magnetic field. The factor 2 n in the above formula, representing the speed in half revolutions per second, is introduced because it is during a half revolution that each conductor cuts a total of ϕ lines. If, therefore, the shaft of the simple alternator shown in Fig. 15 is revolving at a constant speed of 50 revolutions per second and there are a total of two (2) conductors (one on either side of the loop) cutting a magnetic field of 1,000,000 flux lines, then the electromotive force generated will be two volts. Equation (1) above serves as the basis for the design of all generators, large and small.

3. **Shape of Generated Wave.** It will now be of interest to investigate the form of the electromotive force wave generated by an alternator such as that shown in Fig. 15, which, by the way, may be considered as representative of commercial machines, for purpose of analysis and calculation. Keeping in mind the fact that the electromotive force generated at any point in the revolution of the loop depends on the rate at which the lines of magnetic flux are being cut, it will be seen that when the loop is exactly vertical, as shown in Fig. 15, both the upper conductor U and the lower one L, merely slide along the magnetic lines for an instant without actually cutting through them, under which circumstances, of course, no voltage is generated in either conductor. However, the moment after the loop leaves the vertical position it begins to cut the flux lines at a low rate for the first few degrees of the revolution, because the movement of the conductor is more horizontal than vertical; in other words, the action is still a sliding one, rather than a cutting action. As the loop progresses in its revolution, the cutting action becomes more and more marked, until the loop is horizontal, as shown in Fig. 16, when the conductors are moving at right angles to the flux lines and the rate of cutting is the greatest; consequently, the highest voltage is generated when the loop is swinging through the horizontal position. Naturally, as the conductors leave this

horizontal position, the rate of cutting the lines falls off again and finally, when the loop is again vertical, but up-side down, the conductors are once more sliding along the lines and no voltage is generated. It will thus be evident that, during each full revolution of the loop, the generated voltage falls to zero twice and twice reaches a maximum.

In addition to the changes in the *value* of the generated electromotive force, there are also changes in its *direction*, which must be considered. If the loop in Figs. 15 and 16 is revolving in the opposite direction to the hands of a clock; then conductor U will be cutting the flux lines in a downward direction and conductor L will be cutting them in an upward direction during the first half of the revolution; this action is, of course, reversed during the second-half of the stroke, for then, after the loop has been turned upside down, conductor U is moving upward and conductor L is moving downward. Now, it is an experimental fact that the direction of the voltage generated in a conductor moving in a magnetic field depends upon the direction in which the conductor is moving with respect to the flux lines, and no better way of representing the relative directions of flux lines, movement of the conductor and resultant generated voltage exists than that offered by a simple law known as "Fleming's Right Hand Rule," illustrated in Fig. 17, where the forefinger Y of the right hand indicates the direction of the flux lines, the thumb X shows the direction in which the conductor is moving in the magnetic field, and the middle finger Z, bent at right angles to both thumb and forefinger, points in the direction in which the voltage is being generated. Applying this rule to Figs. 15 and 16, it will be seen that during the first half of the revolution the voltage generated in conductor U tends to send a current from back

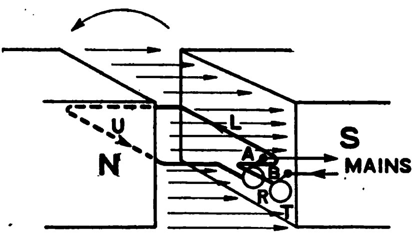


Fig. 16. Simple Bi-Polar Alternator, Full-Voltage Position

to front of that conductor and from front to back in conductor L as the latter is cutting the flux lines in the opposite direction, the direction of the flux lines, of course, remaining the same at all times as previously stated. On the other hand, during the second half of the stroke when conductor U is moving upward, the voltage generated in U tends to send a current from front to back, while in conductor L the opposite is the case. It is also worthy of note that, due to the fact that conductor U and L are connected in series, the voltage generated in one of them tends to send a current around the loop so as to help the voltage generated in the other conductor; hence, the voltage across slip rings R and T is double that generated in one conductor. To sum up, therefore, the voltage generated in such an alternator rises in one direction from zero to a maximum, falls off again to zero, then rises in the opposite direction to a maximum and falls once more to zero, once during each revolution of the alternator shaft.

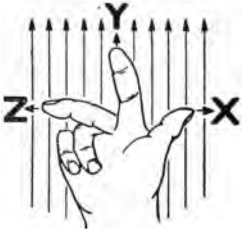


Fig. 17. Fleming's Right Hand Rule

The above discussion covers only the nature of the changes in the direction of the generated electromotive power without reference to magnitude. The successive changes in the magnitude and direction of the voltage generated during one revolution of the loop shown in Fig. 15 is graphically illustrated in Fig. 18, where the line OP, revolving counter-clockwise about point O, represents to scale the maximum voltage generated by the loop (the electromotive force generated when the loop is in the horizontal position in Fig. 16), and the various angular positions of the line OP correspond to similar positions of the loop during its revolution. It is now proposed to represent, in pictorial fashion, the rise and fall in voltage during one revolution of the loop, and for this purpose the circle in which point P swings is divided in twelve parts, P_1, P_2, P_3 — P_{12}. Then a horizontal line at the right of the circle is divided also into twelve equal parts; the line may be drawn to any length, as that is merely a matter of scale. The point to be grasped is that these horizontal positions mark the passage of time as

the loop swings through the corresponding angles.
Now, the voltage generated at any point in the revolution of the loop is proportional to the projection of line OP at

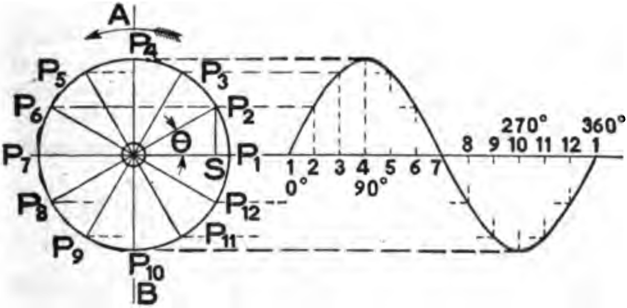


Fig. 18. Sine Wave Development

that point against the vertical line AB, that is, perpendiculars dropped from points P_1, P_2, P_3, etc., against AB, represent the voltages generated in the loop at those positions; this results from the fact that the number of lines of force being cut at any given instant are directly proportional to the corresponding projection of the swinging vector OP on the vertical axis AB. To plot the electromotive force wave generated in the loop as the latter swings through one complete revolution, it is, therefore, only necessary to project points P_1, P_2, P_3, etc., horizontally to the right until they meet their corresponding time verticals. Beginning at position P_1, which represents the vertical position of the loop as shown in Fig. 15, no voltage is being generated, as previously described; the time is zero, since the loop is just on the point of starting its revolution, and, when P_1 is projected horizontally to the right, it coincides with point 1, indicating zero voltage at that time. As the loop continues its revolution, the voltage increases until at P_4, when the loop has turned through 90° and occupies the horizontal position shown in Fig. 16, the maximum voltage is being generated and the projection of the line O P_4 is equal to the length of the line itself. Then, as the loop swings downward, the voltage begins to fall off, until at point P_7, when the loop is upside down, the voltage is zero. Here the loop egins to generate voltage in the opposite direction and the projection of P_8 is below the horizontal line; the voltage once more rises to its maximum and passes through the same set of values as before, only in the opposite direction, and finally the zero position is again reached and the loop is at the starting position for the next revolution. When the loop is in the first half of its revolution, it will be evident that all projections of the line OP are above the main horizontal axis of the diagram, and the corresponding voltage values will be considered as positive (+); when the loop is in the second half of its stroke, the projections are below the horizontal axis and the voltage values are then negative (—). Of course, the voltage passes through the same variations in strength and direction during the second and all succeeding revolutions.

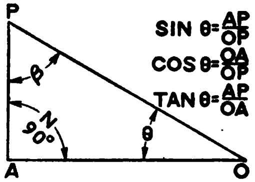


Fig. 19. Functions of the Right Angle Triangle

4. The Sine Wave. For purposes of calculation, it is desirable to reduce the relations shown in Fig. 18 to mathematical form, and an understanding of the trigonometrical functions of right angle triangles will render this analysis easy. A right angle triangle, such as that shown in Fig. 19, is a triangle in which one of the angles is a right angle, i. e., one of 90°; the other two angles are known as acute angles, and are each less than a right angle. The side OP, opposite the right angle end in Fig. 19, is known as the "hypotenuse," while the other two sides PA and OA are the legs of the triangle. The quotient obtained by dividing the length of the leg AP by hypotenuse OP is known as the *sine* of angle θ (Greek letter "theta"). The quotient obtained by dividing leg OA by the hypothenuse OP is known as the *cosine* of θ. The quotient obtained by dividing leg AP by leg OA is known as the *tangent* of θ. In right angle triangles, therefore, the fraction obtained by dividing the side opposite a given angle by the hypotenuse is the sine of that angle; the cosine of that angle is the fraction obtained by dividing the leg adjacent to that angle by the hypotenuse; and the tangent is obtained by dividing the length of the leg opposite the angle by the length of the leg adjacent to that angle. A little study of Fig. 19

will make it plain that the sine of angle Θ is the cosine of angle β, and that, vice versa, the sine of angle β is the cosine of angle Θ. The sine of angle Θ is generally abbreviated to *sin* Θ; the cosine of the same angle to *cos* Θ; and the tangent to *tan* Θ. For an angle of given size, the above values are always constant, regardless of the size of the triangle. Tables of sines, cosines and tangents for various angles will be found in the latter part of this book. For example, the sine of a 30° angle is 0.500, and the cosine is 0.866, and the tangent 0.577; for a 45° angle, the sine is 0.707, as is also the cosine, the tangent being 1.

With the above facts in mind, and referring again to Fig. 18, it will be evident that, as line OP swings around from P_1 to P_2, an angle, say Θ, is covered, and that the vertical projection P_2S of line OP_2, representing the voltage generated at point P_2 is simply equal in length to the ratio $\frac{P_2S}{OP_2} \times OP_2$, which is no more or less than the sine of angle Θ, through which the loop has moved from its starting position, multiplied by the maximum voltage generated when the loop is horizontal as in Fig. 16. At any other point in the revolution, the voltage generated is equal to the sine of the corresponding angle through which the loop has moved from the starting position multiplied by the maximum voltage generated as before. Therefore:

$$e = E \sin \Theta \qquad (2)$$

where e is the voltage being generated at any instant, E is the maximum voltage and Θ is the angular position at the loop at that instant.

With the generator shaft revolving at constant speed, there is, of course, a fixed relation between time and angular position of the loop, and, therefore, angle Θ is capable of further analysis. The unit of length is the foot, and linear speed is often given in feet per second, but, obviously, such a system of measurement would not apply to angular speed, and, consequently, angular speed is always given in radians per second in mechanics. Taking a circle of any diameter, an angle like a piece of pie can be cut out so that the part of the circumference of the circle which the angle cuts out is just equal in length to the radius of the circle; that angle, called a radian, is used as the unit of angular measurement, and is of constant value for circles of all diameters, since the circumference varies directly with the diameter. As everyone knows, the circumference of a circle is 3.1416 times the diameter; the constant 3.1416 is generally represented by the Greek letter π (pi). Since the diameter is twice the radius, a little reflection will show that there are 2π radians in a circle of 360°; a radian is consequently equal to $\frac{360}{2 \times 3.1416} = 57.30°$. If, therefore, the shaft of the alternator shown in Fig. 15 is turning at a speed of n revolutions per second, its angular speed is:

$$p = 2\pi n \qquad (3)$$

where p is the angular speed in radians per second. After t seconds, reckoning time for position P_1, in Fig. 18, as the starting point, the shaft will have turned through some angle, say Θ, of $p \times t$ radians. Hence, at any time t in the revolution the voltage generated will be

$$\begin{aligned} e &= E \sin \Theta \qquad (4) \\ &= E \sin pt \end{aligned}$$

5. **Definitions.** The following definitions are derived from the above discussion:

An *alternating current*, or electromotive force, is one which varies continuously with time from a constant maximum value in one direction to an equal maximum value in the opposite direction, repeating the cycle of values over and over again in equal intervals of time. Alternating currents are not necessarily purely sinusoidal, as shown in Fig. 18, but most commercial alternators produce waves which closely approximate pure sine curves; for our purpose it will be satisfactory to base our calculations on sine waves.

The *period* of an alternating current is the time taken for the current to pass through one complete set of positive and negative values, as shown in Fig. 18.

When an alternating current passes through a complete set of positive and negative values, as shown in Fig. 18, it is said to pass through a *cycle*.

The *frequency*, or number of cycles, per second, is the number of periods per second.

The number of *alternations*, generally given per minute, is the number of times the current changes direction from positive to negative, and from negative to positive, per minute. Obviously, in each cycle, there are two alternations. Fr quency may, therefore, be given either in cycles per second or alternations per minute. On this basis, a 60-cycle generator gives 7200 alternations per minute.

6. Commercial Multipolar Alternators. The above rules and definitions have been deduced from a consideration of the simple alternator shown in Figs. 15 and 16, but they may be applied equally well to all alternators, no matter how large or complicated. Of course, few commercial generators, with the exception of alternators direct driven from high speed turbines, are as simple as the one discussed. Where heavy reciprocating engines are used to drive alternators, the speed is, of necessity, comparatively low, and for commercial frequencies and voltages a generator with a large number of field poles, like that shown diagrammatically in Fig, 20. is used.

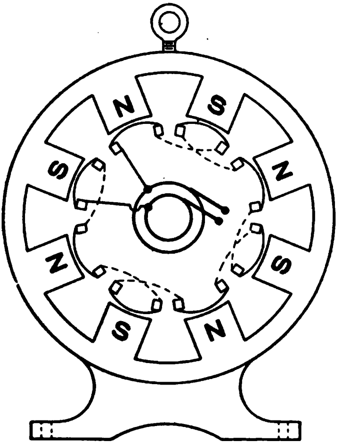


Fig. 20. Armature Winding 8-Pole Alternator

The alternator in Fig. 20 has eight field poles magnetized by direct current fed from a separate small D. C. generator, known as an *exciter*, which latter is generally driven from the same shaft as the armature of the alternator, as at the left in Fig. 21, which shows a large multipolar alternator complete with its slip rings and exciter. It is to be observed in Fig. 20 that the voltages generated in adjacent armature coils are in opposite directions at each instant, but by reversing the connections of alternate coils, as indicated by the dotted lines, these electromotive forces act in series and do not oppose each other. In multipolar alternators the frequency is:

$$f = \frac{P}{2} \times \frac{n}{60} \qquad (5)$$

where P is the total number of field poles and n is the speed of the armature in rev. per min. If the alternator in Fig. 20 is running at a speed of 375 r. p. m., the frequency would be

$$f = \frac{8}{2} \times \frac{375}{60} = 25 \text{ cycles per second}$$

In such multipolar alternators, the total voltage generated across the slip rings is

$$E = \frac{KP\phi nZ \text{ Volts}}{100{,}000{,}000} \qquad (6)$$

where K is a factor depending on the ratio of breadth of pole face to the spacing of the poles, as well as on the distribution of the winding on the armature, P is the number of poles, ϕ is the magnetic flux per pole, n is the armature speed in revolutions per minute, and Z is the total number of armature conductors. This equation, it will be seen, is simply a development of the equation given previously for the simple alternator.

7. Turbo-Alternators. Steam turbines operate most efficiently at high speeds and, in order to accommodate the alternators to these conditions with the commercial frequencies of 25 and 60 cycles, the number of field poles must be reduced to a minimum. Many of these turbo-alternators run at speeds as high as 3600 r. p. m., and have but two field poles. In these cases, the field magnet is the rotating element, as it is easier to support and insulate the high voltage armature conductors on the

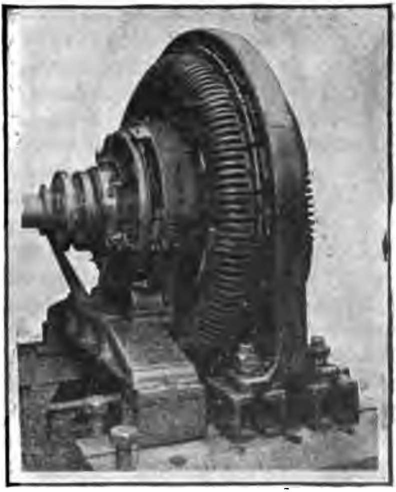


Fig. 21. Alternator With Exciter at Left

outside stationary member; it is hardly necessary to elaborate on the fact that it makes no difference which element rotates, as only relative motion between field and armature is necessary. On account of their high speed, these machines generate a tremendous amount of power for their size, as compared with reciprocating engine-driven alternators.

8. Measurement of Alternating Currents and Voltages. With currents and electromotive forces varying so widely in magnitude from instant to instant as do alternating currents, or e.m.f.'s of sinusoidal form, what is the meaning of the terms *ampere* and *volt* when used in connection with alternating current circuits? The current at any instant t is known as the *instantaneous* current at that time, and is designated as i; the instantaneous e.m.f. is similarly denoted as e. *The maximum* voltage, as before explained, is generated when the number of flux lines being cut is the greatest, and is designated as E, while the maximum current is denoted as I. Referring to Fig. 18, which for the present discussion, we shall take to represent an alternating current of electricity, the *average* value of that current is, of course, simply the average of all the vertical ordinates, or heights, of the half wave extending along the horizontal axis between points 1 and 7; that is, the horizontal half period axis 1-7 would be divided into, say, seven equal parts, as shown, and the average current would be found by adding up the lengths of all seven vertical lines drawn upward to the wave outline from points 1, 2, 3, 4, 5, 6 and 7, and then dividing the sum of these lengths by 7; the average value of the voltage would be similarly found.

None of the above values are, however, convenient for purposes of calculation. In direct current circuits, the rate at which heat is generated by a steady current of I amperes flowing through a resistance R ohms is equal to the square of the current, multiplied by the resistance, or I^2R. Likewise, the rate at which heat is generated by an alternating current of instantaneous value i, through the same resistance, is i^2R; that is, the average rate at which heat is generated in that circuit is R multiplied by the average value of i^2. Now, a steady direct current which would produce the same heating effect as the above alternating current would be one whose square is equal to the average value of i^2 of the alternating current; the actual value of the alternating current would, therefore, be equal to the square root of its average i^2. Thus, instead of taking the average of a large number of ordinates, or heights, of the half wave, as in the previous case, we must now take the square root of the average of the squares of all these ordinates. This square root of the average of the squares of the alternating current over a complete period is called the *root mean square*, or the *effective* value of that alternating current. On this basis, one ampere alternating current will produce the same heating effect in a given resistance as will one ampere D. C. Similarly, the square root of the average of the squares of an alternating electromotive force over a complete half period is called the effective value of that alternating e.m.f.

In specifying the value of an alternating current as so many amperes, or an alternating e.m.f. as so many volts, these effective values are always meant, unless something is stated to the contrary. The principal reason for selecting this particular function of the instantaneous values of an alternating current or electromotive force as the practical measure of current or voltage, is that the deflections or readings of all ammeters or voltmeters used in alternating current measurements are directly proportional to these effective values; furthermore, it makes the direct current ampere and the alternating current ampere equal, in that they will produce the same heating and do the same work in passing through a given resistance. All A. C. instruments indicate effective values, which are obviously quite different from average values.

PHASE RELATIONS—VECTOR DIAGRAMS.

9. Phase. When an alternating electromotive force is

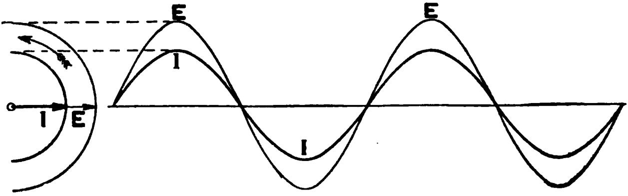


Fig. 22. Current and Voltage in Phase

impressed across a dead resistance, the current varies instantaneously with the voltage; in other words, as the voltage rises and falls, and changes direction, the current flowing through the resistance rises and falls, and changes direction, at the same time as the voltage. This condition is clearly shown in Fig. 22, where current I and electromotive force E are said to be in *phase*, because their maximum and zero values occur at the same instant.

10. Lagging and Leading Currents. In many cases, however, alternating e.m.f.'s are impressed across coils consisting of many turns of wire often wound around iron cores, and in these cases the current is choked back when it tends to increase as the voltage rises, and persists when the voltage falls, as will hereafter be explained. The coil of wire produces an *inductance* effect in the circuit, and causes the current to *lag* behind the electromotive force, as shown in Fig. 23. The base line along which the curves are laid is divided off into degrees—360° for each cycle to correspond to one complete revolution of the loop shown in Fig. 15. The number of degrees by which the current lags behind the voltage is known as the *lag angle* of the current with respect to the voltage, and is designated as Θ in Fig. 23. Conversely, the electromotive force *leads* the current, and in the same sense the angle Θ is the *lead angle* of the voltage with respect to the current. Again, the current and voltage are said to be *out of phase* by an angle of Θ degrees.

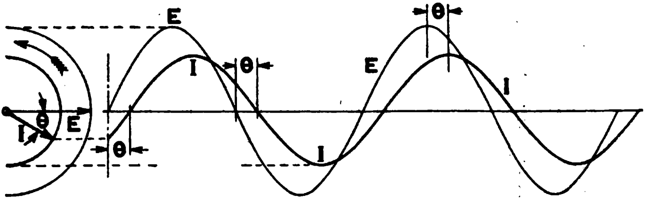


Fig. 23. Current Lagging Behind Voltage

11. Vector Diagrams. Alternating currents and voltages may be represented by the length, position and direction of a line, called a *Vector*. Thus, two currents may be represented (1) in magnitude by two lines having lengths proportional to the intensities of the currents; (2) in relative angular position, or *phase*, by the angle at which the lines, extended if necessary, intersect; and (3) in direction by arrow heads placed upon the lines. Vectors may be combined or resolved into components by the well known parallelogram of forces.

Vector diagrams of sinusoidal currents and voltages render the study of phase relationships quite simple. Simple diagrams of this character are shown at the left of Figs. 22 and 23, where lines OE and OI revolve at a uniform rate of n revolutions per second, equal to the frequency in cycles per second, about point O in the direction of the arrow; since the lengths of the vectors OE and OI are constant the paths of the end of these lines will be circles, not necessarily of the same radius, as there is no connection between the scales to which OE and OI are drawn, one representing in length the maximum volts, and the other, maximum amperes. The rotating lines OE and OI, from whose vertical projections the current and voltage waves shown in Figs. 22 and 23 are constructed in the same manner as the sine curve shown in Fig. 18, are said to "represent" the sinusoidal current I, and the sinusoidal e.m.f. E, respectively. In such diagrams, rotation is always assumed as taking place in the counter-clockwise direction, as indicated by the arrow; when two vectors are separated by a given phase angle, the vector farthest around in the counter-clockwise direction is said to be leading in phase, the other vector naturally lagging by the same angle.

The proper representation of alternating electromotive forces and currents by means of the vector diagram requires that:

1. The given currents and voltages must be of the same frequency, and, in addition, they must be of *harmonic* character; that is, at any instant, the current or voltage must be proportional to the length of the projection of th line OP against the vertical, as shown in Fig. 18.

2. The direction of voltages and currents must be indicated by arrow heads on the vectors.

3. The different vectors entering into the constructior of the diagrams must be constant in their angular relation to each other.

4. In addition to the above, it is desirable to scale the lines of a vector diagram in terms of effective values, rather than maximum values, because effective values are always given by measuring instruments and are used in numerical calculations; of course, when laying out sine waves, as in Fig. 22 and 23, it is more convenient to use maximum values, as the corresponding instantaneous values can be secured by simple projection.

For example, in Fig. 22 the current and e.m.f. are in phase, and, consequently, their vectors shown at the left of the figure are not separated by any phase angle; this relationship is maintained throughout the revolution. On the other hand, in Fig. 23, the vectors OI and OE are separated throughout their revolution by phase angle θ, by which the current lags behind the e. m.f.

12. Vector Addition of E.M.F.'S. Take, for example, two alternators A and B (Fig. 24) connected in series, and assume they are similar in all respects, being driven at the same speed and possessing equal frequency. If the three voltmeters are connected as shown, voltmeters E_1 and E_2, will indicate, respectively, the volts due to alternators A and B, whereas E will measure the volts across the two machines in series. If the volts measured by E are equal to the arithmetical sum of E_1 and E_2, the two alternators would, of course, be in phase, but as a rule the reading of E will be smaller than the simple sum obtained by adding E_1 and E_2. We will suppose these three values, E_1, E_2 and E, to be known. From the center O of Fig. 24, describe a circle of radius OE, the length of which represents voltage E. Now, draw OE_1 in any direction to represent the volts E_1. From E_1 as a center, describe an arc

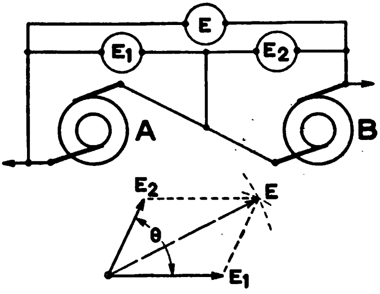


Fig. 24. Vectorial Addition of Voltages

of radius E_1E, the length of which is proportional to the volts E_2; it will cut the arc already drawn at point E. Join OE and complete the parallelogram OE_1 EE_2. The angle θ between the two component vectors OE_1 and OE_2 is then the angle of lag, and is, therefore, the phase difference between the two voltages produced by alternators A and B.

The question of compounding two or more alternating forces in an electric circuit now becomes a very simple matter. Thus, in Fig. 24, had we been given the two voltages E_1 and E_2 and the phase difference θ (instead of the three voltages), we could have calculated the total e.m.f. E and have ascertained its phase relation to its two components by merely constructing the parallelogram of forces OE_1 EE_2 in the usual manner.

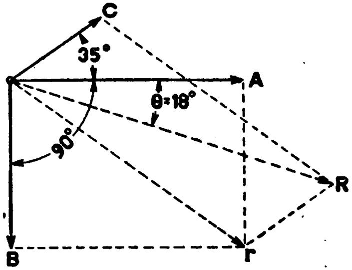


Fig. 25. Determination of Resultant Voltage

As an example, let us suppose that there are three distinct alternating e.m.f.'s—A, B and C—of the following values, all combining to produce one resultant e.m.f. in an electric circuit:

A = 200 volts
B = 150 volts
C = 100 volts

We shall also assume that B lags behind A by exactly 90°, while C leads A by 35°. Draw the three vectors OA, OB and OC in Fig. 25 to a suitable scale, and in such directions that the angles AOB and AOC are, respectively, 90° and 35°, bearind in mind that OB must be drawn behind OA, while OC must be drawn in advance, lead angles being laid off in a counter-clockwise direction, as previously explained. First construct the parallelogram of forces OBrA, giving Or as the vector resultant of voltages OB and OA, then combine resultant Or with voltage OC by parallelogram OCRr, giving OR as the final resultant of all three initial voltages. The length of the line OR, measured by the same scale as the three component vectors, gives us the value of the resultant e.m.f., in this case 297 volts. If angle AOR is scaled it will be found that the resultant voltage OR lags behind component OA by 18°.

CIRCUITS CONTAINING RESISTANCE, INDUCTANCE AND COMBINATIONS THEREOF

13. Ohm's Law Applied to A. C. Circuits. In direct current circuits Ohm's Law is expressed as:

$$I = \frac{E}{R} \text{ and the corollary } E = IR \qquad (7)$$

Where I is the current in amperes caused to flow in a circuit of R ohms by E volts. The same law holds also in alternating current circuits, providing the proper interpretation is put on the term R, for, due to certain inductance effects, presently to be described, the apparent resistance in alternating current circuits is often many times the dead or ohmic resistance in the circuit and Ohm's Law has to be amplified to:

$$I = \frac{E}{Z} \text{ and } E = IZ \text{ and } Z = \frac{E}{I} \qquad (8)$$

where Z is the *impedance*, representing the total apparent resistance of the circuit in ohms.

14. Case I—Circuits Containing Resistance Only. In the case of a circuit containing a dead resistance R only, $Z = R$ and equation (8) becomes:

$$I = \frac{E}{R} \text{ and } E = IR \text{ and } R = \frac{E}{I} \qquad (9)$$

The current and voltage are in the phase. The vector diagram and the corresponding current and voltage waves in proper phase relationship are shown in Fig. 22.

Example: An electromotive force of 220 volts, frequency 60 cycles, is impressed on a circuit of a total dead resistance of 100 ohms. What is the current?

From equation (9) it will be evident that this current in the above circuit will be the quotient obtained by dividing the voltage 220 by the resistance 100 ohms, or 2.2 amp.

15. Case II—Circuits Containing Inductive Reactance Only. Electric circuits possess inertia. In order to form a mental picture of this property of an electric circuit, consider a flywheel rotating in a perfectly frictionless manner. Such a flywheel once it has been put in motion will continue to revolve for any length of time at undiminished speed, without requiring a further application of force. But a force had to be applied to bring it up to speed, and exactly the same amount of energy as was put in it is now available for doing work and will be given back by the time the flywheel has been brought to rest.

The above is a fair physical analogy of what happens in the case of an A. C. generator impressing an e.m.f. on a coil of wire. It is assumed that the reader is aware of the fact that, when a current flows in a wire, that wire is surrounded circularly by a magnetic field of flux lines; when the current starts to flow, the flux lines spring outward circularly with the wire as a center, just like the ripples of water which are created when a stone is thrown into a pond. The intensity of the magnetic field about the wire at any point is dependent on the strength of the current flowing in the wire, as well as the distance of the point from the wire. If the current alters its value, the field is also altered, increasing with increase of current and decreasing with decrease of current, finally collapsing on the wire again when current ceases.

It will be evident, therefore, that, when an increasing electromotive force is impressed across a coil of many turns of wire, and a current starts to flow, lines of magnetic flux spring outwardly in expanding circles from each turn of the coil, and cut the other turns, producing in them a secondary electromotive force, which will be found counter or in direct opposition to the impressed e.m.f. driving the current through the coil; this action cuts the value of the current at any instant down below what it would otherwise have been, for part of the impressed voltage is taken to balance this counter electromotive force. On the other hand, when the impressed voltage falls, and the current tends to decrease in turn, the flux lines start to collapse toward their respective turns, and in so doing cut the other turns, generating in them a voltage in the same direction as, and tending to assist, the falling impressed voltage to maintain the current above what it otherwise would be.

The magnetic field is a definite seat of energy and require for its production, therefore, a definite expenditure of energy, determined in amount by the flux and the turns in the coil with which the flux circles are linked. These linkages of flux with turns constitute one of the most important factors in alternating current circuits. The number of such linkages for an electric circuit carrying one ampere is known as the *coefficient of self induction*, or, briefly, the *self-inductance* of the circuit, being denoted by the symbol L. When the number of linkages of flux with turns due to one ampere flowing in the circuit is 100,000,000, the circuit is said to have a self-inductance of one *henry*. Stated in another way, a circuit has an inductance of one henry when one volt, exclusive of the e.m.f. required to overcome dead resistance, will cause the current to change at the rate of one ampere per second. The choking effect due to self-induction is the seat of an apparent increase in the resistance of the circuit and in this, of course, the frequency is an important factor. As a matter of fact a mathematical analysis will show that in a circuit having a self-inductance of L henrys the apparent increase in resistance due to self-inductance is Lp ohms where $p = 2\pi n$, n being the frequency as in equation (3).

So long as the current in the circuit remains constant in value, there is no expenditure of energy in maintaining the field; this, of course, excludes the energy dissipated as heat in the electric circuit itself. If, however, the field increases, a reaction will be developed which must be overcome, requiring an expenditure of energy in the circuit. If, on the other hand, the field diminishes, there will be a reaction in the opposite direction to that first considered, and, in virtue of this, energy will be returned to the circuit. This reaction in each case takes the form of an electromotive force, called the e.m.f. of self-induction, whose magnitude depends on the rate of change of linkages of flux and turns of wire. Every signalman has noticed that, when the circuit of a pair of high resistance slot magnet coils or relay coils carrying current is opened, there is a bright spark and a "back kick" which is capable of giving a considerable shock; this counter e.m.f., which is many times the original impressed voltage, is simply due to the lines of magnetic flux collapsing on the coils, and thus generating a high voltage when the current is suddenly interrupted. Similarly, if an attempt were made to suddenly stop a heavy rotating flywheel by slipping a bar between the spokes and the engine frame, disastrous results would follow, due to the quick dissipation of the energy stored up in the rotating mass.

Obviously, therefore, in the case of a circuit conveying an alternating current, there will be an alternate increase and decrease in the energy of the magnetic field, and this will give rise to inductance voltages. Considering a complete period of the current, it will be found that during one-half of this period energy is supplied by the circuit to the field, and during the other half of the period energy is returned by the field to the circuit. When the current is increasing in value, the establishment of energy in the field sets up an opposing e.m.f., which does two things: first, it makes the current reach a given value later than would be the case provided no such e.m.f. existed; and, second, it diminishes the maximum value which the current reaches in a complete period. When the current is decreasing, the field contributes energy to the circuit; the value of the current at any instant, however, is not as small as it would be if no energy of the magnetic field were given back to the circuit, and, for this reason, the current again lags with respect to the value which it would have were no such induced e.m.f. present. Again, the greatest negative value which the current reaches is less than the value which it would attain provided no energy from the field were returned to the circuit. In the flow of a sinusoidal current in a self-inductive circuit, the value of the current will be less than if the self-induction were not present and the current will lag by a certain angle with respect to the impressed voltage. In this sense, an alternating current circuit containing inductance possesses inertia just as does the rotating flywheel above mentioned.

As has previously been stated, the voltage generated in a conductor is proportional to the rate at which the flux lines cut that conductor. Now, when an alternating current is flowing through a coil, the rate at which the flux lines spring outward from their respective turns is greatest when the current is just starting to rise from zero, whether in one direction or the other; then the current is increasing most rapidly, for there is an instant when the current increases from zero to a definite quantity—from nothing to something, and then the rate of increase of current, and consequent magnetic flux, which varies simultaneously with the current, is the greatest. Conversely, when the current is at its maximum, it is steady for an instant at the top of the wave, and there the rate of increase in current and flux is zero. The electromotive force of self-induction, resulting from the change in magnetic flux, is, therefore, greatest when the current is zero. Now, if any current is to flow through the coil, this counter e.m.f. of self-induction must be balanced by an equal and opposite e.m.f. from the generator.

This is illustrated in the wave diagram in Fig. 26, where I represents the current wave and — ILp the e.m.f. of self-induction, which, it should be noted, is at its maximum when the current is zero, and is zero when I is maximum; also, since — ILp is a counter e.m.f., it is laid off negatively, as it is opposing the change in current. The balancing component wave + ILp must be laid off in opposition and equal to — ILp: a voltage E equal to + ILp volts, must therefore be impressed on the circuit in order that current I may flow.

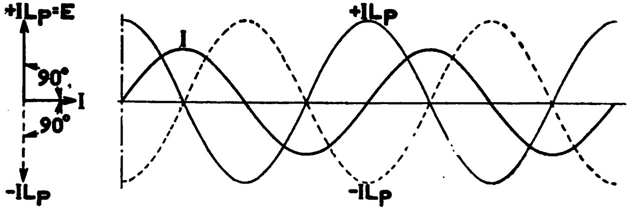


Fig. 26. Circuit Containing Inductance Only

The above conditions are represented vectorially at the left of Fig. 26, which diagram may easily be derived from the current and voltage waves, or may be constructed independently, as follows: first, lay off the vector I horizontally to correspond in scale to the given current. As before stated the equivalent resistance of the inductance L is numerically equal to the quantity Lp in ohms, where $p = 2\pi n$, as shown in equation (3). The term Lp is known as the *inductive reactance of* the circuit, and is always expressed in ohms. The reactive voltage drop in Lp is equal to the *inductive reactance* Lp multiplied by the current I, that is ILp volts, just as the drop in a dead resistance R is IR volts. This reactive drop vector — ILp lags 90° back of the current, as previously explained, the balancing impressed e.m.f. vector + ILp being exactly equal in length and opposite in direction to —ILp. When the two vectors are separated by an angle of 90°, such as I and —ILp or I and + ILp, they are said to be in *quadrature*. In such a circuit, containing only pure inductive reactance, as just described, Ohm's Law in equation (8) becomes:

$$I = \frac{E}{Lp} = \frac{E}{X} \qquad (10)$$

$$E = IX \qquad (11)$$

$$X = \frac{E}{I} \qquad (12)$$

where X denotes the reactance Lp.

16. Case III—Circuit Containing Capacity Reactance Only. We have now to consider briefly the case of a circuit containing pure *capacity reactance*, this latter effect accompanying the alternate charging and discharging of a condenser whose two terminals are connected to an alternator. The capacity might consist of a *condenser*, formed by a long dead ended cable containing two conductors carefully insulated from each other, or the condenser might be composed of a number of sheets of tinfoil piled up with sheets of glass or paper between them, alternate layers of tinfoil being connected together to give the effect of two large metal sheets close to, but thoroughly insulated from each other just as in the case of the cable; in either case as long as the alternating current is flowing in a positive direction, current flows into the condenser, which, therefore, becomes charged, but, as soon as the current reverses, the condenser begins to discharge. The maximum charge of the condenser, and, consequently, its maximum back pressure or counter e.m.f., occurs just at the moment when the current is about to reverse, and this back pressure or counter e.m.f., therefore, tends to help the current reverse, the latter growing to a negative value much quicker than it otherwise would do; this is just the opposite of what occurs in a circuit containing inductive reactance, and, as a consequence, in a circuit containing pure capacity reactance, the current leads the impressed voltage E by a quarter of a period, or 90°, whereas, as previously explained, the current lags 90° behind the impressed voltage E in a purely inductive circuit.

Capacity effects are so minute in signal work as to be negligible, with the single possible exception of transmission systems, and then only in the case they are very long; if, however, by any chance it becomes necessary to run the transmission underground in a cable, the capacity effect will be more noticeable, and had best be investigated. The cable manufacturers will furnish data covering the capacity reactance of their product, and from this the capacity reactance drop may be calculated, this latter, of course, helping to neutralize the inductive reactance voltage, with the result that a less voltage will have to be impressed on the transmission to force the required current through it than would be the case if capacity were not present.

17. Case IV—Circuits Containing Resistance and Inductance. In Case I above, we considered a circuit containing resistance only, and later, in Case II, one containing pure inductance only; the latter case is purely theoretical, as all circuits contain some resistance, however small, and, conversely, all circuits, particularly A. C. signal circuits, contain inductance. The general case, therefore, is one in which the circuit contains resistance and inductance.

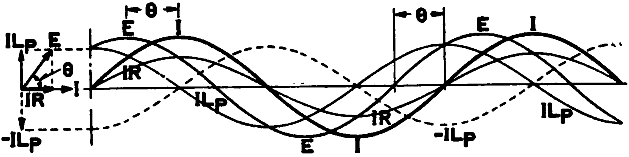


Fig. 27. Circuit Containing Resistance and Inductance

Fig. 27 illustrates this general case, I being the current wave, —ILp the wave of the counter e.m.f. of self-induction, ILp the balancing wave for the latter, and IR, naturally in phase with the current, the wave corresponding to the drop in the given resistance R. In order that current I may flow through this circuit, the alternator must not only supply enough voltage to compensate for the resistance drop IR, but, in addition, it must supply the component wave ILp to balance the inductive drop; the total impressed voltage E must, therefore, be equal to IR+ILp, the wave E, therefore, being plotted by adding, algebraically, the verticals of waves IR and ILp at each instant along the horizontal time axis, due attention being paid to the fact that IR and ILp are sometimes in opposition.

The corresponding vector diagram is shown at the left of Fig. 27, which diagram may be derived directly from the current and voltage waves, or may be constructed independently, as follows: first, lay off the current vector I horizontally, and superimpose on it the voltage drop IR, obtained by multiplying the current I amperes by R ohms, I and IR, of course, being directly in phase. The impressed voltage for balancing the inductive reactance voltage is ILp volts in quadrature with and leading the current. The total impressed voltage E is the vectorial sum of IR and + ILp, and is simply the diagonal of the parallelogram of which IR and ILp are two right angle components. This resultant E is the hypotenuse of a right angle triangle, and is equal, in volts, to the square root of the sum of the squares of IR and ILp, since the hypothenuse of a right angle triangle is equal to the square root of the sum of the squares of the two legs.

Therefore,

$$E = \sqrt{(IR)^2 + (ILp)^2} \qquad (13)$$

and by Ohm's Law, equation (8)

$$I = \frac{E}{Z} \qquad (14)$$

$$= \frac{\sqrt{(IR)^2 + (ILp)^2}}{Z} \qquad (15)$$

and

$$Z = \frac{\sqrt{(IR)^2 + (ILp)^2}}{I} \qquad (16)$$

$$= \sqrt{(R)^2 + (Lp)^2} \qquad (17)$$

$$Z = \sqrt{R^2 + X^2} \qquad (18)$$

finally,

$$X = \sqrt{Z^2 - R^2} \qquad (19)$$

where Z is the total apparent resistance, called the *impedance* of the circuit and the quantity X is the abbreviation for the term Lp, the inductive reactance.

From the explanation of trigonometrical functions given in the first part of this chapter, it will be evident, from Fig. 27 that the lag angle Θ of the current I, with respect to the impressed total e.m.f., can be easily calculated in advance for:

$$\operatorname{Cos}\Theta = \frac{IR}{E} = \frac{IR}{\sqrt{(IR)^2 + (ILp)^2}}$$

$$= \frac{IR}{\sqrt{I^2\,(R^2 + X^2)}}$$

$$= \frac{R}{\sqrt{R^2 + X^2}} \qquad (20)$$

and on looking up the number representing this ratio in the table of cosines in the back of the book, the corresponding angle in degrees will be found.

18. Amplitude Factor. It is to be noted that equations (10) to (20), inclusive, are based on effective values, whereas the vector diagrams in Figs. 26 and 27 are laid out with vectors representing maximum values, in order to show their direct connection with the development of the current and voltage waves. Of course, effective values are less than the corresponding maximum values, but there is a definite relation between the two values. The ratio of the maximum value to the effective value is known as the *amplitude factor*, which, for sine waves, is equal to 1.414. Therefore, in the above case the maximum values shown in the diagrams in Figs. 26 and 27 may be arrived at by multiplying the values in equations (10) to (20) by 1.414.

19. Practical Measurement of Impedance and Reactance. In actual practice, the numerical value of X can be determined as follows: The dead resistance of the wire in the coil or instrument in question can be calculated when the length of wire and its resistance per foot is known, or the same result can be arrived at by passing a direct current of I amperes through the wire; by Ohm's Law, equation (7) R, the resistance of the coil in ohms, is equal to the voltage E, necessary to force the current through the coil, divided by the current I in amperes. When an alternating e.m.f. E volts of a given frequency is impressed across the same coil or instrument, a certain current of I amperes will flow, which may be measured by an ammeter, so that, by equation (8), $Z = \frac{E}{I}$ ohms; then, since R is already known, the inductive reactance X in ohms is $X = \sqrt{Z^2 - R^2}$ from equation (19) With a higher frequency, X would be greater, since $X = Lp$ and $p = 2\pi n$, where n is the frequency in cycles per second, as per equation (3). With a lower frequency, the term X would be smaller, since n is smaller. In fact, if n were zero, as would be the case with a direct current, then the term X, the inductive reactance, would disappear entirely, and then the flow of current would be limited by dead resistance only. So, with a given voltage, the current flowing through a coil of wire will increase in volume with decrease in frequency, and will fall off as the frequency increases.

20. Calculation of the Inductance of a Coil of Wire. The inductance of a coil wound on a given spool is proportional to the square of the number of turns N of wire. For example, a given spool, wound with No. 16 has 500 turns and an inductance, say, of 0.0025 henry; the same spool wound with No. 28 wire would have about eight times as many turns, and its inductance would then be about 64 times as great as before, or 0.16 henry. The inductance of a coil of given form is also proportional to its linear dimensions, the number of turns remaining constant. For example, say a given coil has an inductance of 0.022 henry, a coil three times as large in diameter, length, etc., but having the same number of turns of wire, has an inductance of 3 x 0.022, or 0.066 henry.

The inductance in henrys of a coil of wire wound in a thin layer on a long wooden core of a length of l centimeters and a radius of r centimeters, is

$$L = \frac{4\pi^2 r^2 N^2}{l \times 1,000,000,000} \qquad (21)$$

in which N is the total number of turns of wire in the coil. The equation is strictly true for very long coils wound in a thin layer; but the same equation is also useful in calculating approximately the inductance of short thick coils. Thus, a coil of 50 centimeters long, containing 100 turns of wire wound around an average radius of 4 centimeters, has an inductance closely equal to:

$$L = \frac{4 \times (3.1416)^2 \times (4)^2 \times (100)^2}{50 \times 1{,}000{,}000{,}000} = 0.00013 \text{ henry} \qquad (22)$$

Of course, if the wire in the above coil were wound around an iron core instead of one of wood, the inductive action would be enormously increased in proportion to the permeability of the iron core.

POWER IN ALTERNATING CURRENT CIRCUITS.

21. Apparent Power or Volt-Amperes. In direct current circuits, the power W in watts is:

$$W = EI \qquad (23)$$

Where E is the electromotive force necessary to force a current of I amperes through the circuit. In alternating current circuits, the same equation holds, provided the current and voltage are in phase, which, however, is rarely the case. Of course, the instantaneous power is:

$$w = ei \qquad (24)$$

where e and i are the instantaneous volts and amperes respectively, but sometimes the generator is supplying power to the circuit, and at other times the circuit is returning power to the generator, as has previously been explained. What we are interested in is the average power supplied to the circuit.

In an alternating current circuit, the *apparent power* is given in *voltamperes*, this term covering the simple product of the volts E necessary for forcing a current of I amperes through the circuit, the voltage and current values being effective values, as indicated by the ordinary meters.

$$\text{Voltamperes} = IE \qquad (25)$$

The apparent power in voltamperes is greater than the true or average power, because part of the apparent power is returned to the generator.

22. True Power or Watts. It will be shown below that the true *watts* or *average power* delivered to the circuit is:

$$W = IE \cos \Theta \qquad (26)$$

Where I and E are the effective current and impressed voltage, respectively, and Θ is the phase angle between the current I and the voltage E.

23. Power Factor. The quantity $\cos \Theta$ is known as the *power factor*, and is the ratio of the true power or watts to the apparent power in voltamperes.

$$\text{Power Factor} = \cos \theta = \frac{W}{IE} \qquad (27)$$

Of course, the power factor cos θ can never be more than unity, since the watts cannot be greater than the voltamperes.

24. Case I—Power in an A. C. Circuit Containing Resistance Only. In this case, the current and impressed e.m.f. are in phase, as has been pointed out. In the general equation (26) for power in an alternating current circuit, $W = EI \cos \theta$ but when the current and e.m.f. are in phase, the lag angle θ is zero, and its cosine is unity. Therefore, the power equation becomes, simply:

$$W = EI \qquad (28)$$

The above equations are illustrated graphically in Fig. 28 where the watt curve is obtained by multiplying the instantaneous volts and amperes at the various points in the period.

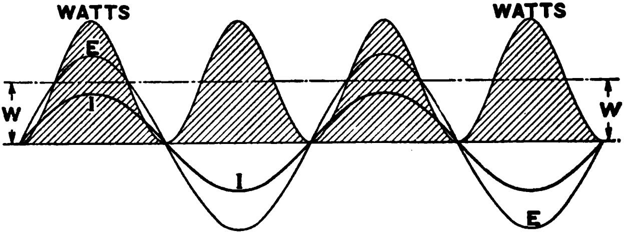


Fig. 28. Power in a Circuit Containing Resistance Only

It is to be noted that the power curve is a wave of double frequency, as compared with the curves of e.m.f. and current. The axis of symmetry of this power curve is distance W, corresponding to the average watts above the axis of the e.m.f. and current waves. Of course, the product *ie* is always positive, even in the second or lower half of the period, because the product of two negative numbers (—e) x (—i) is always positive in value; looking at the matter from what physically takes place, the circuit is always receiving power positively, and is never delivering power back to the generator. The apparen* power in voltamperes is equal to the watts, and, consequently.

$$\text{Power Factor} = \frac{EI}{EI} = 1 \qquad (29)$$

25. Case II—Power in a Circuit Containing Inductive Reactance Only. Of course, it would be impossible practically to create a circuit containing inductive reactance only, due to the fact that all circuits must have some resistance, no matter how small; at the same time, the study of what takes place in such a circuit is instructive, for here the current lags 90° behind the impressed e.m.f., and the two are therefore, in quadrature.

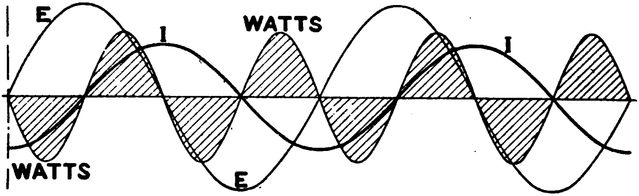


Fig. 29. Power in a Circuit Containing Inductance Only

This condition is illustrated in Fig. 29, where the sine curve W, obtained by multiplying the instantaneous volts and amperes, with due regard to positive and negative values (a positive $(+i)$ multiplied by a negative $(-e)$, and vice versa, gives a negative $(-w)$, is a sine curve of double frequency, and its axis of symmetry coincides with the axis of e.m.f. and current.

Here the power:

$$\begin{aligned} W &= EI \cos \theta \\ &= EI \times O \qquad (30) \\ &= O \end{aligned}$$

because the cosine of the lag angle 90° is zero. An examination of the watt or power curve in Fig. 29 will show that the average power is zero, because, during the complete period, just as much power is returned to the generator as it delivers the circuit: the negative and positive portions of the power ve are equal, and their sum is therefore zero.

The power factor (abbreviated P. F.)

$$PF = \frac{EI \cos\theta}{EI} = \frac{\text{Watts}}{\text{Voltamperes}} \qquad (31)$$

$$= \frac{O}{EI}$$

$$= O$$

26. Case III—Power in a Circuit Containing Resistance and Inductive Reactance. This is the general case, met with in alternating current circuits. The resistance R and inductive reactance X are such as to cause the current to lag θ° behind the impressed e.m.f., as shown in Fig. 30, where θ is an angle such that

$$\cos\theta = \frac{R}{\sqrt{R^2 + X^2}}$$

as per equation (20).

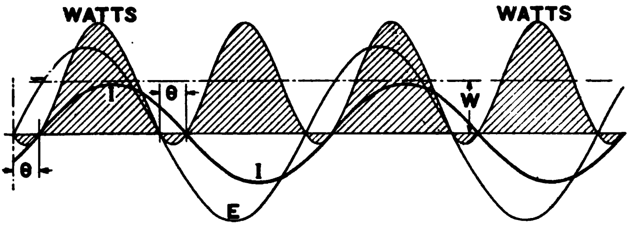


Fig. 30. Power in a Circuit Containing Resistance and Inductance

This condition is shown graphically in Fig 30, plotted in the manner previously described, where it will be seen that the power curve is again a curve of double frequency with its axis at a distance W above the axis of the e.m.f. and current waves. At certain instants, the power is negative, at certain other times positive, and the average power is the difference between the two. This is shown on the diagram by the loops in the power curve coming part below and part above the axis of the e. m. f. and current curves. The average power is found by subtracting the total area below from the total area above the axis of the e.m.f. and current waves. It is important to note, therefore, that in the ordinary alternating current circuit the power is fluctuating. Part of the time the generator delivers power to the circuit, and the rest of the time the circuit is returning power to the generator to run it as a motor. This, then, is the general case, where:

$$W = EI \cos \theta \qquad (32)$$

and the value of cos θ is somewhere between zero and unity.

In the preparation of this chapter an attempt has been made to explain the more important fundamentals of alternating current theory. Those who are interested in the subject and desire to learn more about it are advised to consult the standard text books, among which the following are easily available, either at the public libraries or through local book sellers.

1. Estey—Alternating Current Machinery.
   American School of Correspondence, Chicago, Ill.
2. D. C. and J. P. Jackson—Alternating Currents and Alternating Current Machinery.
   The MacMillan Co., New York.
3. Pender—Electrical Engineering.
   McGraw-Hill Book Co., New York.
4. Hay—Alternating Currents.
   D. Van Nostrand Co.
5. Steinmetz—Alternating Current Phenomena.
   McGraw-Hill Book Co., New York.
6. Steinmetz—Theoretical Elements of Electrical Engineering.
   McGraw-Hill Book Co., New York.
7. Karapetoff—The Electric Circuit } 2 Vol.
   The Magnetic Circuit }
   McGraw-Hill Book Co., New York.

Of all the books on alternating currents the most complete are perhaps those by E. Arnold of Karlsruhe, published by Julius Springer of Berlin under the general title of *Die Wechselstromtechnik*. They have been written with painstaking thoroughness and cover both from the theoretical and practical standpoints, almost every phase of alternating current working. At the present time they are available in German only.

CHAPTER III.

ELEMENTS OF THE ALTERNATING CURRENT TRACK CIRCUIT

CHAPTER III

ELEMENTS OF THE ALTERNATING CURRENT TRACK CIRCUIT.

1. **Elements of an A. C. Signal System.** In general, a complete A. C. signal system consists of the following:

(A) The track circuit control system, made up of

(a) Track relays, over whose points the signals are controlled, sometimes jointly with line relays, depending on the type of automatic block circuits used.

(b) The transformers for feeding the track circuits and signals.

(c) The limiting resistance or impedance used between the transformer and the track to prevent an injurious short circuit current flowing through the track transformer with a train in the block.

(B) The signals, which may be either of the semaphore or light type.

(C) The transmission system paralleling the right-of-way and supplying power to the transformers at the various locations.

(D) The power generating system in the power house supplying power to the transmission.

It is the purpose of this chapter to discuss the elements of the track circuit, the other elements of the complete signal system being covered in later chapters.

STEAM ROAD TRACK CIRCUITS.

End Fed and Center Fed Track Circuits.

2. **End Fed Track Circuits.** Practically all A. C. steam road track circuits are end fed, that is, the track transformer is located at the leaving end of the track circuit and the relay which it feeds at the entering end; this arrangement is, therefore, exactly similar to the general practice in D. C. track circuit work, where a battery takes the place of the track transformer. Fig. 31 illustrates the A. C. end fed track circuit

with its elements as used on steam roads. The standard symbol for an alternating current relay is that of the direct current relay marked with an X across the coils as shown.

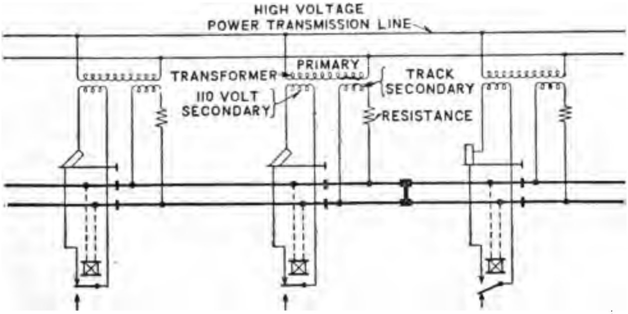


Fig. 31—Element of the End Fed Track Circuit

3. Center Fed Track Circuits. There is no limit to the possible length of an end fed track circuit, except the amount of power rquired for its operation. While the amount of power required at the track relay terminals is, of course, constant, regardless of the length of the track circuit, it must be remembered that a large proportion of the current fed into the track by the transformer is lost through leakage across the track from rail to rail over the ballast and ties, just as is the case in D. C. track circuits; in track circuits much over a mile in length, this leakage factor increases rapidly as the track circuit is extended, especially in the case of poorly drained cinder ballast and old water or brine soaked ties. The current lost in ballast leakage naturally causes a corresponding IZ drop in the rails, which piles up in almost geometrical ratio as the track circuit is made longer, so that, in the case of very long track circuits, the transformer must supply a comparatively high voltage to the track before the relay will pick up; at that point in the track where the transformer is connected the voltage across the rails is obviously the highest, and here, consequently, the current lost in ballast leakage is the greatest, the leakage current falling over gradually with the decrease in voltage across the rails as we proceed down the track toward the relay. It is desirable, therefore, from the standpoint of power economy, to keep the voltage at the rails opposite the transformer as low as possible.

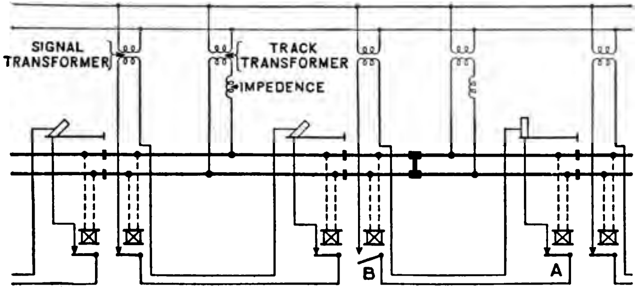


Fig. 32—Element of the Center Fed Track Circuit

So, if, for example, it is desired to operate a 15,000-foot track circuit with a given type of relay, and the calculations show that an unreasonable amount of power would be required for an end fed track circuit, then a center fed track circuit, shown in Fig. 32, may be resorted to. In this arrangement the track transformer is located at the middle of the track circuit, feeding in either direction a relay at the end of the section; thus, the voltage at the track opposite the transformer is much less than would be the case with an end fed track circuit of equal length, and, due to this lower voltage, the leakage current across the ballast near the transformer is cut down, the saving, of course, falling off as we proceed in either direction from the transformer toward the relays. For purposes of calculation, a center fed track circuit may be considered as two end fed track circuits joined together and fed jointly at their meeting point. With the center fed track circuit, the voltage at the track opposite the transformer will be the same as that required for one of the component end fed circuits, but the current fed in the track from the transformer must evidently be twice as great.

Where center fed track circuits are used, the signal operating circuit must be broken through points on both track relays, for there is a time when the train is on the leaving end of the track section, that relay A (Fig. 32) may pick up, due to the fact that, as the train proceeds out of the leaving end of the block, its shunting action on the track transformer decreases and the voltage on the relay at the entering end of the block rises. At that time, though, relay B at the leaving end is shunted dead as the train is practically across it, so that, if the signal control circuit is passed through the points of both relays in series as shown, at least one relay is bound to be open whenever there is a train on the track section, no matter at what point.

Single and Double Element Relays.

4. Single Element Relays. All direct current track relays receive their power over the track; that is, the battery connected to the rails at one end of the track circuit supplies all the power for the operation of the relay. The same may also be said of the alternating current track relays shown in Fig. 31 and 32, where the transformer takes the place of the before mentioned batteries; there are, of course, two track relays per track circuit in Fig. 32, but both of them receive all of their power over the rails. Such relays are called *single element* relays; they have but one winding, although they may have two or more coils interconnected in series or multiple, just as in the case of the two coils on a direct current track relay.

5. Double Element Relays. Long track circuits operating with single element A. C. track relays are seldom used nowadays, because such track circuits are extravagant in the way of power. A track circuit is nothing more nor less than a small power transmission system, and a mighty inefficient one at that. The usual high voltage power transmission consists of a generator located at one end of the system, feeding current at a high voltage over carefully insulated wires to a motor or other receiving device at the far end of the system; the leakage between the carefully insulated transmission wires is comparatively insignificant. In the case of a track circuit, the track transformer takes the place of the generator in the high voltage transmission system above mentioned, the rails take the place of the transmission wires, and the track relay takes the place of the load at the end of the system. But the rails are not carefully insulated from each other, as are the transmission wires in the first case; the rails are spiked down the ties, which may be water or brine soaked, and the ballast across the rails may be cinder, or some other more or less conductive material. In any event, the ties and ballast constitute a leak across the rails, and the track circuit transmission is, therefore, bound to be inherently inefficient. A track circuit is a poor line over which to transmit power. The less power transmitted over it, the better.

It was with the above facts in mind that the so-called two-element relay was invented. This type of relay is provided with two separate and distinct elements on windings, one of which, called the *track element* or winding, is connected to and receives power over the rails as usual from the track transformer, while the other, called the *local element* or winding, receives power directly from a transformer.

The turning effort exerted on the moving member of the relay to close the contacts, is proportional to the product of the current flowing in the track and local elements, with due regard to phase relations, as will be explained in Chapter IV. A given turning effort can be produced on the contact operating member by the interaction of two currents of medium value in the two elements, or by a very small current in one element and a very large one in the other element.

Only a very small amount of power, therefore, is used in the track element of two-element relays, and so comparatively little power is lost in the track circuit transmission, as only a little has to be transmitted; only a small voltage is required at the track transformer end of the track circuit. On the other hand, a comparatively large amount of power is delivered to the local element of the relay from its local transformer; of course, there is practically no loss of power between this transformer and the local coil of the relay which it feeds, because the feeding wires are always well insulated, and they are also generally very short.

Such two-element relays work on the motor principle; that is, both track and local elements must be simultaneouely energized before any turning movement is produced in the moving member of the relay to close the contacts. The local element is permanently connected to its transformer, and is consequently always energized, regardless of whether there is a train on the track circuit or not. The track element is, of course, energized only when the track circuit is unoccupied, for, when a train is on the track circuit, all the current is shunted out of the track element of the relay. Some of these two-element relays operate on exactly the same principle as does the ordinary direct current signal motor. In this analogy, the field coils and armature of the signal motor would represent, respectively, the local and track elements of the relay. It will be realized that, as long as current flows through both field coils and armature, the motor will continue to rotate; but, if for example, the armature were short-circuited, the motion would then cease, even though current were still flowing through the field coils. The contacts of a two-element track relay are never closed, except when current is flowing through its track element, as well as its local element.

Two and Three-Position Relays.

6. Two-position Relays. Single element A. C. relays are necessarily two-position relays; there is no element of permanent character to respond to changes in the polarity of the single energized element, and, consequently, these relays are exactly comparable to the usual neutral direct current track relays met with in steam road services. Single element relays have but two positions; their front contacts are closed when no train is on the track circuit, and these front contacts open and the back contacts make, as shown in Fig. 31, when a train enters on the track circuit.

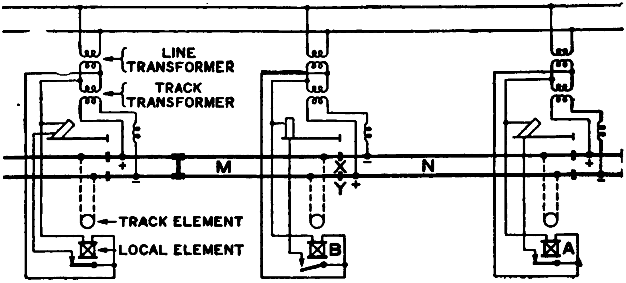


Fig. 33—Two-element, Two-position Relays on an End Fed Track Circuit

7. Three-position Relays. Two element relays, on the contrary, may work in either two or three positions. Fig. 33 represents the two-element relay working in two positions only on an end fed track circuit, although it would work equally well on a center fed track circuit.

Due to the motor action previously described, the moving member of two-element relays may be caused to rotate in one direction or the other, depending on the relative direction of the magnetic flux produced in the track and local coils by their respective currents. As previously stated, the local element is permanently connected to its feeding transformer, but by means of a pole changer, as shown in Fig. 34, the polarity of the track element, with respect to the local element, may be controlled. In such a relay, the moving member is counterweighted to return to a central or neutral position, with all contacts open, as shown at A, in Fig. 34, when a train is in the block, and the track element of the relay is short-circuited. When the track element is energized in one direction, as shown at B, one set of contacts is closed, while, when the pole changer between the track transformer and the track is swung over, the direction of the moving element of the track relay is reversed, so that another set of contacts are closed, as at C, in Fig. 34. In fact, Fig. 34 represents a polarized wireless system of signaling, with alternating current track circuits, where the usual polarized track relay used on D. C. track circuits is replaced by the three-position A. C. track relay. The two relays fulfill the same function, and, of course, may be used for controlling signal indications in either three-position or home and distant signaling.

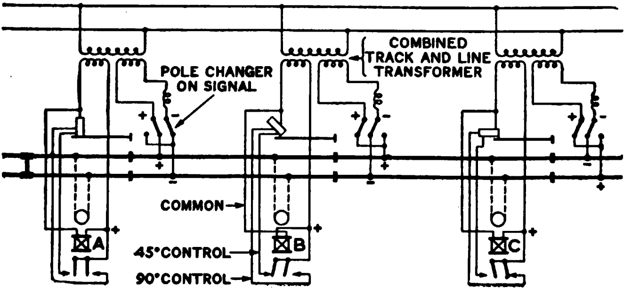


Fig. 34—Polarized Wireless Track Circuit with Three-position Relays

8. Protection Against Broken Down Insulation Joints with Two-element Relays. It is to be noted that, on account of the possibility of reversing the direction of movement of the rotating element which actuates the contacts, perfect broken down insulation joint protection can be secured with two-element two-position relays by staggering or reversing the polarities of adjacent track circuits. For example, in Fig. 33, the polarities of track circuits M and N are opposite at any given instant, and, if insulation joints X and Y were to break down, relay B would be forced on its back contacts to open the signal circuit. On the other hand, under similar circumstances, a single element relay might pick up with a short train at the far end of a long track circuit, because, if the insulation in joints X and Y were in very bad shape, the adjacent transformer would be practically across track relay B. A moment's reflection will make it evident that equal protection cannot be ~~secured with three~~-position relays, although certain schemes, ~~not~~ within the scope of this book, have been suggested However, even with three-position relays, it is customary and advisable to stagger polarities on adjacent abutting track circuits, so that, if both insulated joints break down, a caution, and not a clear, indication will result. This is illustrated in Fig. 34 where, with the track circuits unoccupied, their polarities are staggered; the local windings of alternate relays, such as B, are reversed so that the same contacts may always be used for the caution and clear indications respectively.

Statements have been made above that "the polarity of the track element, with respect to the local element, can be reversed," and that "the polarities of adjacent track circuits can be reversed." Of course, the alternating currents are periodically changing in direction, and the above statements simply mean that at any given instant the polaritites are opposite. During other portions of the cycle, positive polarities will change to negative polarities, and vice versa, but opposite relationship will always be maintained.

Transformers.

9. Track Transformers. This transformer, as its name indicates, is used to supply current to the track. It may receive power directly from the high voltage transmission line, as is the case in Fig. 32, or from the secondary coil of the main line transformer shown in Fig. 33; track transformers are always provided with a number of taps on the track, or secondary, side, so that, depending on the length of the track circuit and its ballast leakage factor, the necessary voltage may be impressed on the track to insure proper working of the relay. Track transformers which receive power directly from the transmission, as shown in Fig. 32, are generally housed in an oil filled cast iron case. hung on a cross arm carried by the pole on which the transmission is strung; track transformers which receive power from the secondary of the line transformer as shown in Fig. 33, are generally built up on a wooden base, and are housed in the relay box at the signal location.

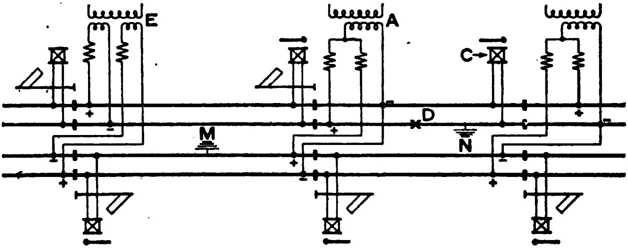


Fig. 35—Multiple Feeding of Parallel Track Circuits

In double or multiple track work, it is the custom to feed the two or more parallel track circuits from one transformer, but in this case the track transformer should be provided with a separate and independent secondary for each track circuit. This practice is advisable since the rails of a track circuit are more or less grounded, depending on the nature and condition of the ballast. Hence, relay C, Fig. 35, might remain picked up with a broken rail at D, since current could flow from the positive side of transformer A to the upper rail of the lower track circuit, from M to N over the ground and direct to relay C, the other side of which is connected to the negative side of the transformer over the upper rail of the track circuit in which the break D is located; furthermore, there is a bare possibility in the case of exceedingly poor wet ballast, of the relay adjacent to transformer A being picked up with a train at the extreme end of its track circuit (near E) if one of the insulated joints between A and the relay broke down.

This effect is naturally entirely dependent on the extent to which the rails are grounded and also on the ballast conductance. To guard against it, each track circuit had best be fed from a separate secondary as at E, Fig. 35, the transformer being provided with two secondaries for this purpose. In the case of detector circuits, as used in interlockings, each track circuit should likewise be separately fed, transformers with four secondaries being of a convenient size.

10. Line Transformers. Any transformer connected directly to the transmission line might, with perfect accuracy, be called a line transformer, but in actual signal practice the term has become restricted to a transformer with a primary connected to the transmission, and one secondary of 55, 110 or 220 volts, this secondary being jointly used for supplying power to the signal motors, slots and relay locals, and also in the majority of cases to the separate track transformer shown in Fig. 33; the signal lights may also be fed from the secondary of the line transformer, but in most cases the primary of the separate track transformer is provided with a 10-volt tap to handle the lights. Such line transformers are commercial articles, made in quantity and kept in stock by the manufacturers at all times, and are, consequently, quickly replaced, in case of burnouts; furthermore, through their use, the separate track transformer shown in Fig. 33 becomes relatively inexpensive, as it need not be elaborately insulated for connection to the transmission line, since it is fed from the low tension, or secondary, side of the line transformer, and may be housed in the relay box, without the oil filled case which would otherwise be required.

11. Combined Line and Track Transformers. In some cases, a combined line and track transformer is used; its primary is connected to the transmission, and it is provided with two secondaries, one being wound for 55, 110 or 220 volts, for feeding motors, slots, and the local coils of the track relays, the other being a low voltage secondary for feeding the track. Such a transformer, shown in Fig. 34, generally costs more than would be the case if a commercial line and a separate track transformer were used, due to the fact that the combined line and track transformer has generally to be specially made up by the signal manufacturer to suit the conditions.

Track Resistances and Impedances.

12. Function. The gravity batteries used with the direct current track circuit have an internal resistance varying from one to four ohms per cell, depending on their physical condition, and this inherent internal resistance prevents a wasteful, and possibly injurious, short circuit current from flowing from the cells when a train is on the track circuit. In the case of lead storage batteries, and some primary batteries of the caustic soda type, the internal resistance per cell is only a very small fraction of an ohm, and, consequently, when such cells are used for feeding track circuits, an external resistance coil must be connected in series with the track battery to prevent waste of energy and injury to the battery elements when a train is on the track circuit. Similarly, in the alternating current system, the transformer feeding the track has a comparatively low internal resistance, and either a resistance coil or an impedance coil must be inserted between the transformer and the track to cut down the short circuit current when the track circuit is occupied; otherwise, the transformer might seriously heat or burn up, due to the short circuit overload, particularly if a train were held on the track circuit for several hours, due to a wait for orders, for eaxmple.

Such a resistance coil needs little description; it consists simply of a few turns of wire of high specific resistance and of large enough current carrying capacity to carry the short circuit current without heating. The impedance coil consists of a few turns of heavy wire wound around an iron core; such a coil has a high self-inductance, which serves to choke down the heavy short circuit current, which would flow with a train in the block were no impedance coil in the circuit.

13. Selection of Impedance or Resistance. The decision as to whether a resistance or an impedance is to be employed between the transformer and the track, on steam road track circuits, depends on the type of track relay used. In the case of a single element relay, either a resistance or an impedance could be used, but the use of the latter is advisable, for, even though it costs more than the simple resistance, the extra cost will be compensated for by the power saved with the impedance; it must be remembered that, when a current passes through a resistance, the entire voltage drop results in an I^2R heating or power loss, as explained in Chapter II, whereas, with an impedance, the choking effect due to self-induction causes a voltage drop in quadrature or 90° out of phase with the current, so that but little power is lost; in fact the power factor of the impedance used in signal work is about 0.2, whereas, with a resistance, it is, of course, unity.

When two-element track relays are used, however, the question is more complicated, as the phase relations between the two elements must be considered, and the use of resistance or impedance between the transformer and the track will have a bearing on these relations. In the great majority of cases met with on steam roads, an impedance is used, but no rule can be set down. The decision rests on the result of the track circuit calculations described in Chapter XIII.

14. Bonding of Steam Road Track Circuits. For this purpose, any one of the following combinations may be used:

(a) Two No. 8 B. W. G. galvanized iron bond wires;

(b) One No. 6 B. & S. gage semi-annealed solid copper bond and one No. 8 B. W. G. iron bond.

(c) Two No. 6 B. & S. gage copper clad wires (30 or 40 per cent. conductivity).

The D. C. resistance of iron is about seven times that of copper, and, when alternating current is used, this ratio is much greater, due to the fact that iron is magnetic, and, therefore, an appreciable amount of power is continuously lost; calculations show that, although combinations (b) or (c) cost more than (a), their extra cost will be more than compensated for by the power saved through their use. In most cases, however, the use of two solid copper bonds would not be justified, as the power saved thereby over that required with combinations (b) or (c) would not pay for the extra copper.

ELECTRIC ROAD TRACK CIRCUITS.

15. Characteristics of Electric Road Track Circuits. In general principle, electric road track circuits and steam road track circuits are identical, and save for the extra apparatus required with the former to take care of the propulsion current, the elements of both types of track circuit are the same. Electric road track circuits may be end fed or center fed, and either single element relays or double element two or three-position relays may be chosen, for the same reasons as govern their choice on steam road track circuits; of course, such relays must be immune to the propulsion current, and the reader is referred to Chapter IV for full descriptions of the various types. Furthermore, limiting resistances or impedances must be used between the transformer and the track, as on steam road track circuits, due attention being paid to phase relations, when two element relays are used; however, in the case of single rail track circuits, a resistance is always used, as, due to the possible circulation of current from the propulsion system, through the track transformer and its short circuit current limiting auxiliary, an impedance might be useless, because of the partial loss of its choking effect consequent to the saturation of its iron core. Where phase considerations do not dictate otherwise an impedance is used on double rail circuits to save power. A detailed consideration of electric road track circuits will be found in Chapter V.

Here, the similarity between steam and electric road track circuits ends, for, whereas in the case of the former the track circuit may be completely isolated electrically from the abutting track circuits by insulated joints in both rails, this course cannot be followed on electric roads, as the propulsion current, coming through the motors from the trolley or third rail, must have a continuous electrical path over the running rails from track circuit to track circuit, back to the negative side of the power generator in the substation or powerhouse. This difficulty may be solved through the use of either the single rail track circuit, or the double rail track circuit with balanced impedance bonds.

16. Single and Double Rail Track Circuits. In the single rail scheme, the track circuits are isolated on one side only; that side, or rail, of the track in which the insulated joint is placed is known as the *block rail*, which, of course, cannot be used for propulsion purposes, while the other side or rail of the track having no insulated joints and carrying the propulsion current, is known as the *return rail*, as the propulsion current returns over it to the negative side of the power generator; however, as explained at length in Chapter V, the passage of the propulsion current over the return rail causes a voltage drop, as a consequence of which a certain portion of the propulsion current passes through the track relay and its feeding transformer. If the block is very long, or if the propulsion current is very heavy, the track circuit apparatus may be seriously injured by overheating. Furthermore, the conductivity of the track propulsion return system is cut in two, through the sacrifice of one of the rails for signal purposes.

In the case of the double rail track circuit, insulated joints are placed in both sides of the circuit, and both rails are used to carry the return propulsion current as well as the signaling current; by the use of the so-called balanced impedance bonds, the propulsion current passes from track circuit to track circuit, around the insulated joints, but the signal current may not pass. See Chapter V.

17. Track Circuits for Roads Using A. C. Propulsion; Frequency Relays. Where either single or double rail track circuits are used on electric roads operating with direct current propulsion, a track relay which is immune to direct current, but which will work on alternating current, is, of course, perfectly satisfactory. When, however, we encounter the problem of track circuiting on electric roads employing alternating current propulsion, it is evident that the ordinary alternating current track relay is inadequate, as it might be caused to falsely close its contacts with a train in the block, due to leakage currents passing through it from the propulsion system. This difficulty is solved through the use of a higher frequency for the signaling current than for the propulsion current, and the employment therewith of a track relay which will pick up only when the higher frequency signaling current passes through its energizing coils. Such a relay is known as a *frequency relay*, and full descriptions of the various types will be found in Chapter IV. In all other respects, the track circuit apparatus for roads using A. C. propulsion is the same as that used on roads using D. C. propulsion, with the exception that in the former case the impedance bonds may be smaller; see Chapter V.

CHAPTER IV.

RELAYS.

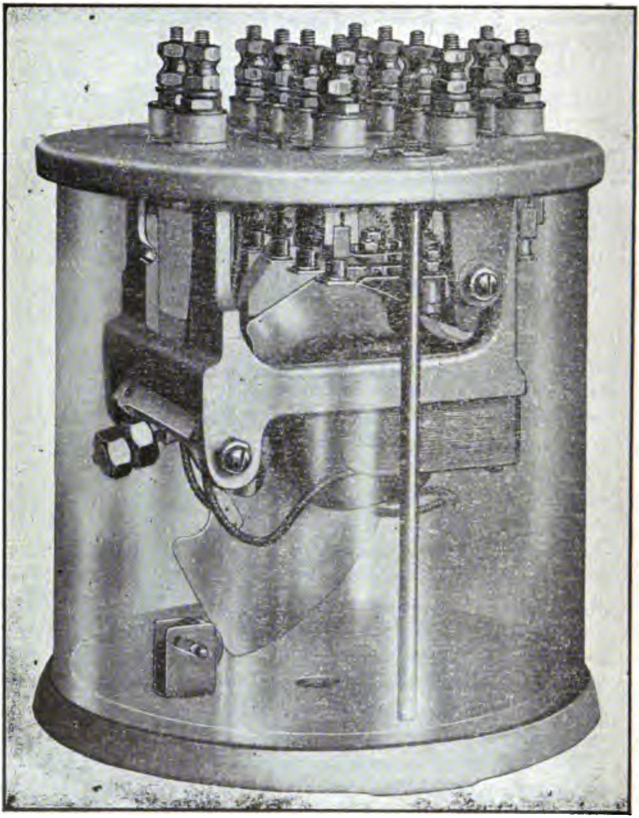


Fig. 36—Single Element Vane Relay

CHAPTER IV.

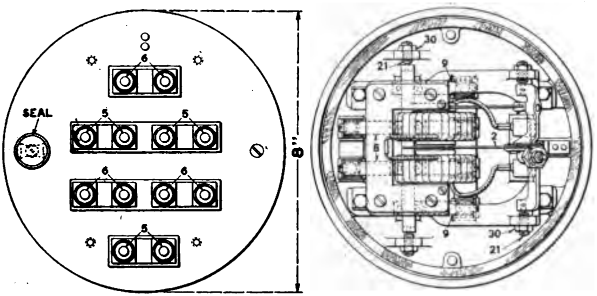
RELAYS.

SINGLE ELEMENT VANE RELAY

1. Description. The vane relay is the simplest, the most economical, and altogether the best of single element relays; it was the first alternating current relay used for signaling purposes, and its twelve years of development have brought it to a high state of perfection. The standard vane relay is shown in Fig. 36.

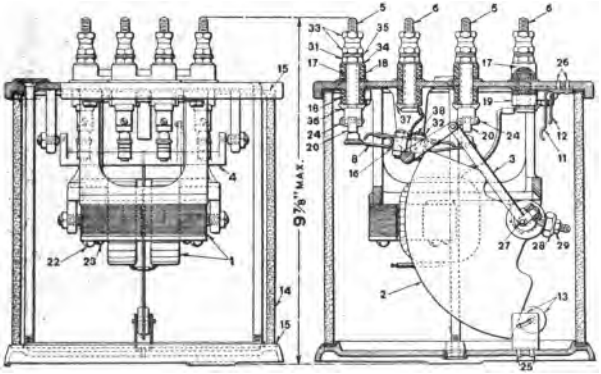
The detail design of the vane relay and its principal dimensions are shown in Fig. 37, where the prime mover, the aluminum vane 2 actuates the contact spring bar 4, through link 3, both the vane 2 and the bar 4 turning on jeweled bearings. The contact springs 8 are supported on insulating studs 16, screwed into bar 4; the relay is here shown in the de-energized position with back contact 8 closed, so that, when the vane swings upward, this contact will be broken, and the front contact on the other side of the bar closed. The magnetic field structure 1 consists of a set of two coils, connected in series, slipped over the legs of a horizontal C-shaped laminated magnet core, the vane swinging vertically in the air gap between the ends of the C, as shown. When the coils are sufficiently energized, the vane is pulled upward through the air gap by an electro-magnetic action, as will presently be explained; the instant the coils are de-energized, the vane drops immediately by gravity, the momentum of its downward motion being taken up by a small fibre roller 13, which is caused to roll uphill against gravity when struck by the vane. This protects the vane against jar and rebound, the same action on the upward stroke being secured through a flexible front stop 11.

2. Theory of the Vane Relay. When two circuits are placed near each other, a current sent through one will, in general, produce an appreciable magnetic flux through the other, some of the magnetic flux of the first circuit becoming linked with the second. The circuits are said to possess mutual inductance, and, by taking into account the principle known as Lenz's Law, it is easy to arrive at the general nature o



PLAN VIEW

INVERTED PLAN VIEW
BOTTOM PLATE REMOVED



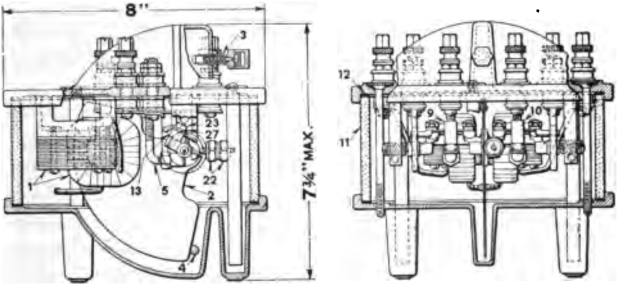
BACK VIEW
GLASS SECTIONED

SECTIONAL SIDE VIEW

CONTACT EQUIPMENTS.

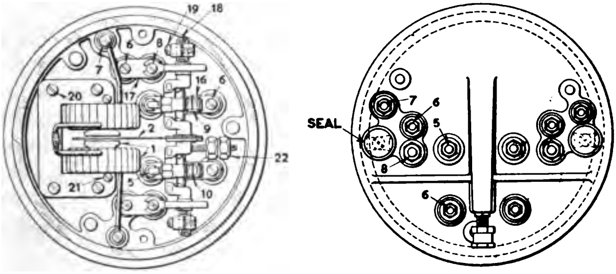
4 fronts 2 backs	2 fronts 4 backs
4 fronts 0 backs	3 fronts 3 backs
2 fronts 2 backs	

Fig. 37—Single Element Vane Relay 4 Points



SECTIONAL SIDE VIEW

SECTIONAL FRONT VIEW



INVERTED PLAN VIEW

PLAN VIEW

CONTACT EQUIPMENT.

2 fronts only	1 front 1 back

Fig. 38—Single Element Vane Relay 2 Points

results produced by mutual inductance when the first circuit is supplied with an alternating current, and the second circuit, which contains no impressed e.m.f., is simply closed on itself. According to Lenz's Law, the current induced in any circuit by a varying flux always opposes the changes in flux which give rise to it; and the circuit in which the current is induced is subject to mechanical forces tending to move the circuit, so as to reduce the extent of the flux variations.

Let us now suppose that the first circuit is fixed and the second movable. If we assume the two circuits to be parallel to each other, the second circuit will be repelled by the first, since the result of such motion would be to reduce the amplitude of the flux variations. Thus, a ring of copper or aluminum slipped over a pole of an alternate-current electro-magnet will be projected upwards as soon as a sufficiently strong current is sent through the coil of the electro-magnet, and, if provided with suitable guides, the ring may even be kept floating in the air above the electro-magnet, gravity being neutralized by electro-magnetic repulsion.

If the second circuit is prevented from having motion of translation, but is free to rotate about an axis, rotation will take place until the plane of the second circuit is parallel to the inducing field; for this is the position in which the flux fluctuations are completely suppressed. Since action and reaction are always equal and opposite, an equal and opposite couple will be experienced by the first circuit. A coil of wire, for example, conveying an alternating current will, when pivoted or suspended in front of a sheet of metal, experience a couple, tending to turn it into a position at right angles to the conducting sheet.

The principles just explained find a practical application in the vane relay, in which case an alternating current field magnet is made to act on two secondary short-circuited circuits. Let us suppose that two rings of copper of the same size are suspended parallel to, and nearly in contact with, each other in the field of such a magnet. The currents induced in the rings by the alternating magnetic field will be nearly in phase with each other, the rings being nearly in the same region of the field, so that there will be attraction between them, since conductors conveying currents flowing in the same direction attract each other. Let us now suppose that the rings are displaced relative to each other, as in Fig. 39 (A), in a direction parallel to their planes. In Fig. 39 (A), the shaded portion represents the pole of the alternating current electromagnet, which, for the sake of simplicity, is shown of circular shape. The attraction between the rings will tend to pull them into coincidence, and there will be a component of stress in a direction parallel to the planes of the rings. Next, suppose one of the rings to be replaced by a conducting sheet of metal, as in Fig. 39 (B), in which the dotted circle shows the position of the pole, and let the ring be fixed, while the conducting sheet is free to move. If the ring were removed, then, by symmetry, it is clear that the currents induced in the conducting sheet by the alternating flux from the magnet pole would (assuming the sheet to be of large extent, so as to project well beyond the polar edges) follow circular paths having their centers in the axis of the magnet. But, with the ring in place, according to Lenz's Law the currents induced in it give rise to a magnetic field in opposition to the main field, and the result of this is to cause a shifting of the main magnetic flux (whose distribution with the ring removed would be uniform) toward the right hand "unshaded" crescent-shaped portion of the polar surface. But, with this shifting of the flux, the currents induced in the conducting sheet will also be shifted to the right, following the paths similar to that roughly indicated by the dot and dash line. Now, the portion of the conducting sheet forming the closed circuit indicated by the dot and dash line and the ring will behave relatively to each other in the manner of the two rings in Fig. 39

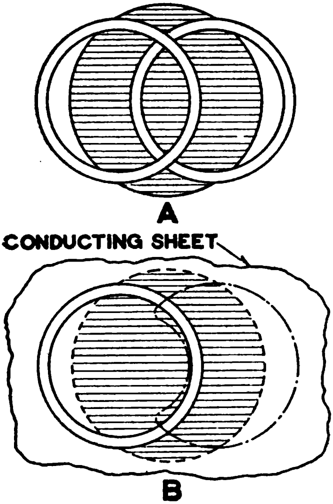


Fig. 39—Illustrating Attraction Principle of Vane Relay

(A), and, since the ring is fixed, the sheet will move from right to left—i. e., from the unshaded to the shaded portion of the magnetic pole. Since, however, the conducting sheet is continuous, as it moves successive portions of it come into the position of the dot and dash line, and so the pull is maintained and the motion is continuous.

In the vane relay, whose operating elements are illustrated diagrammatically in Fig. 40, the aluminum vane is free to rotate, and takes the place of the conducting sheet above mentioned in connection with Fig. 39 (B). Around one-half of each pole face is placed a "shading" coil or ferrule, consisting of a simple heavy band of copper, which takes the place of the fixed ring in Fig. 39 (B). Coil C and its laminated iron field core constitute the alternating current electro-magnet, and cause magnetic flux to induce currents in the aluminum vane, which by the continuous attraction action described above, swings upward in the direction of the shaded pole faces (those surrounded by the ferrules) when coil C is energized.

3. Characteristics of the Vane Relay; Where Used.

(a) The vane relay is particularly attractive from the standpoint of design, because of its simplicity of construction, and the large mechanical clearances between all fixed and moving parts; only a small portion of the vane is enclosed by the pole faces, and, as the large air gap is vertical, there is little possibility of the vane sticking to the field structure because of foreign particles falling in the air gap. Furthermore, all its parts, especially the air gap, are open to easy inspection through the glass shield, without taking the relay apart.

(b) From what has been said above in regard to its theory of operation, it is evident that the relay will operate only on alternating current. It is perfectly immune to direct current, and is, therefore, suitable for use on electric roads using D. C. propulsion, as well as on steam roads.

(c) It is quick and positive in its action as the vane shoots down by gravity immediately the relay is de-energized. It is, therefore, admirably suited for use on short automatic block track sections and detector circuits in interlockings where quick shunting is indispensable; if a slow shunting relay were used in the former case, a train might run through a considerable portion of the block before the signal went to stop, and in the latter case, a switch might be thrown under a train. In fact, the vane relay is the only one which can be logically used for such service.

(d) The single element vane relay, from the standpoint of power, economy is not well suited for use on very long track circuits, because it is a single element relay, receiving all its power over the rails, and cannot, consequently, equal the power economy of two-element relays on long track circuits, particularly where the ballast is poor. Depending on ballast conditions, the power economy of the vane relay will not justify its use on steam road track circuits of more than a nominal length of 2500 feet. On electric roads, with double rail track circuits, this limit will be reduced to about 1500 feet, as the signaling track voltage must be kept down to the minimum to keep the leakage current through the impedance bonds within bounds; the operating voltage of the relay must, therefore, be comparatively low, so that the current will be correspondingly increased, in consequence of which the drop in the rails is greater, and the limiting track circuit length is less than it would be on a steam road; of course the preceding limits are not ironclad, because such variables as ballast, the impedance of the bonds, etc., are important factors, and only an actual calculation of the track circuit power, carried out according

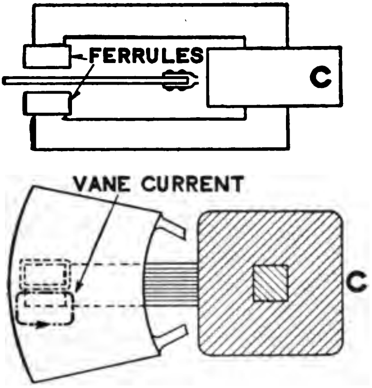


Fig. 40. Operating Element Vane Relay.

to the method described in Chapter XIII, will establish the exact limit in track circuit length where a two-element relay becomes more economical than a single element relay. The above limits are simply convenient approximations applying to average conditions.

(e) Having but one element, the vane relay here described is a two-position relay, and cannot, consequently, be used for polarized track or line control.

On short track circuits on either steam or electric roads, the vane relay will generally prove to be more economical than a two-element relay because the latter is burdened with the power required for its local winding, which latter power is constant regardless of the length of track circuit. For this additional reason the vane relay is the best for use on detector circuits or for single rail track circuit work on D. C. electric roads where the track circuits are comparatively short.

4. **Power Data**—The curves shown in Figs. 41, 42, 43 and 44 cover the approximate power required for the operation of both steam and double rail D. C. electric road track circuits of various lengths employing single element vane relays; for single rail track circuits on D. C. electric roads, the same relay winding is employed as for steam road circuits (2.65^{V}—1.5^{A} 0.56 PF on 25 cycles and 4.5^{V} 1.5^{A} 0.56 PF on 60 cycles) and after determining the amount of resistance to be inserted between the relay and the track and between the transformer and the track to take care of the known propulsion drop, the power at the transformer may be calculated according to the method described in Chapter XIII. It was by this method that the curves in Figs. 41, 42, 43 and 44 were determined.

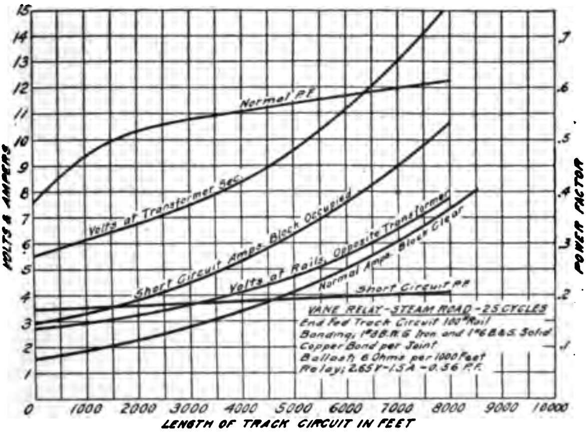


Fig. 41. Power Curves for 25 Cycle Single Element Vane Relay on End Fed Steam Road Track Circuits of Various Lengths.

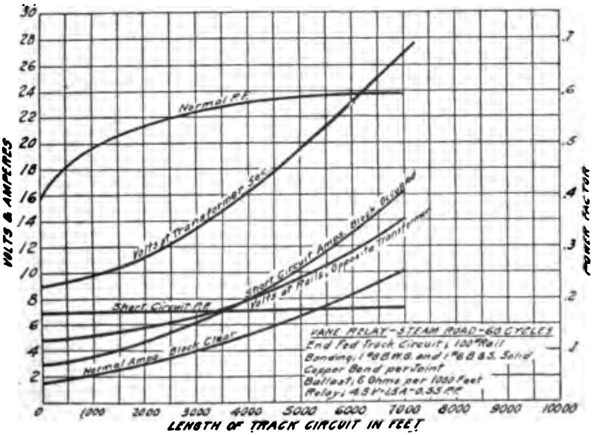


Fig. 42. Power Curves for 60 Cycle Single Element Vane Relay on End Fed Steam Road Track Circuits of Various Lengths.

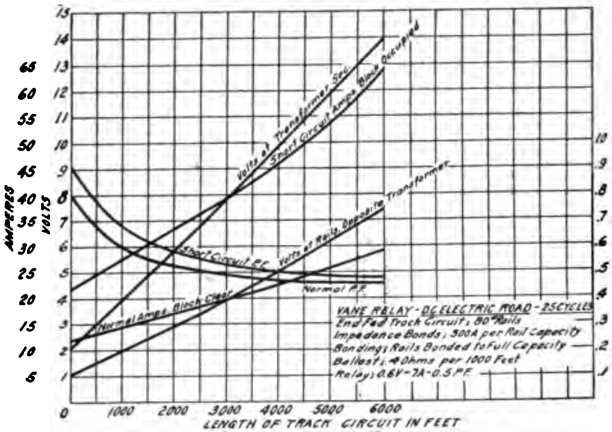


Fig. 43. Power Curves for 25 Cycle Single Element Vane Relay on Double Rail End Fed D. C. Electric Road Track Circuits.

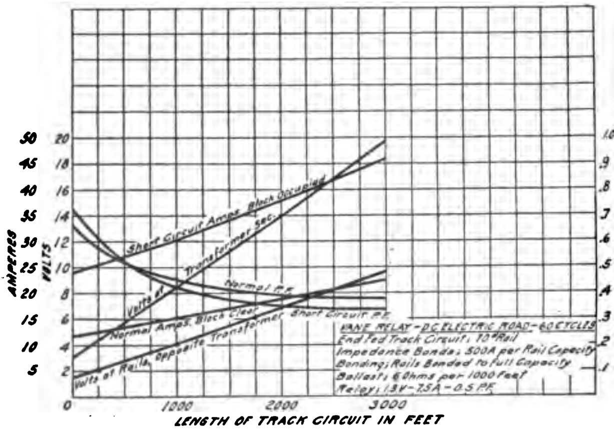


Fig. 44. Power Curves for 60 Cycle Single Element Vane Relay on Double Rail End Fed D. C. Electric Road Track Circuits.

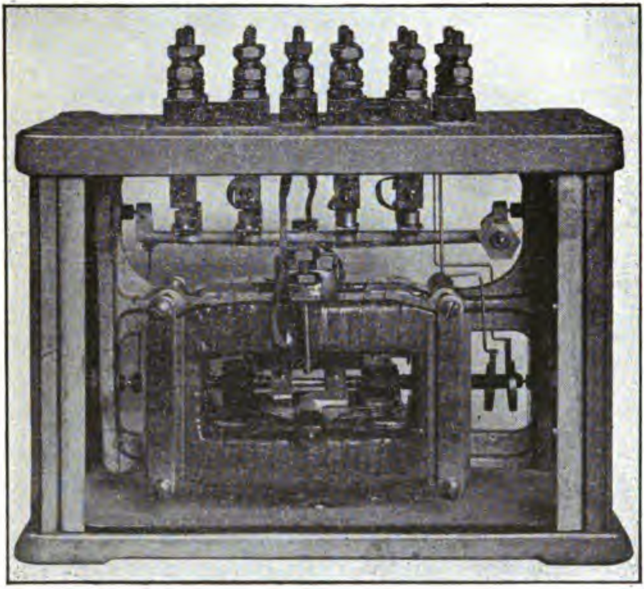


Fig. 45. Ironless Galvanometer Relay.

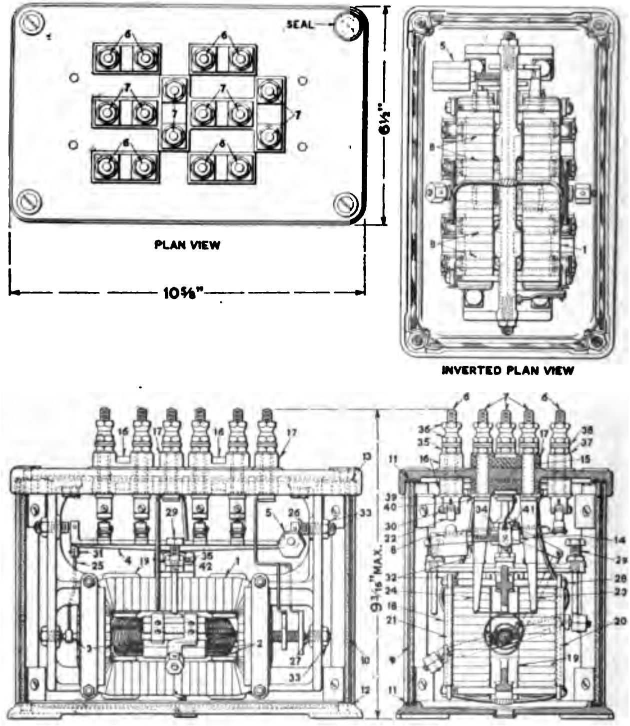
THE IRONLESS GALVANOMETER RELAY.

1. Description. Of two-element relays, those working on the galvanometer principle are, perhaps, the simplest and most easily understood, and it is now proposed to describe the construction and theory of operation of the well-known Ironless Galvanometer Relay shown in Fig. 45.

The vital parts of this relay (Fig. 46) are the local coils 1, and the armature or track element 2; the local coils 1 are firmly secured to a brass supporting frame attached to the top plate, while on jeweled pivots 27, armature 2 swings inside the local coils as shown. The armature shaft carries a crank at its left end, which is connected to an operating link 25, actuating the bar 4, pivoted at 26, carrying the contact fingers 8. The detailed construction of the contact posts, with their terminals and blocks, insulating them from the cast iron top plate, will be evident from an inspection of Fig. 46, the relay being in the de-energized position, with the front contacts open.

The armature consists of a comparatively few turns of heavy wire formed, and then clamped to, but carefully insulated from, a kind of swinging frame attached to the armature shaft; in order to secure a perfect balance, small adjustable counterweight nuts are provided on each side of the frame. Current is lead into the armature coil from the track terminals at the right of the front view, through the vertical brass extension strips 23 and 24, to flexible copper spirals soldered at their inner ends to the terminals of the armature coil, these terminal wires running along the right hand portion of the armature shaft. The stationary local coils are connected by vertical terminal leads to posts near the middle of the top plate. The armature is prevented from striking the local coils when it picks up, by stop screws 29.

2. Theory of Galvanometer Relay. The electrical principle on which the galvanometer relay operates will be readily grasped from a study of Fig. 48, which shows the local coils, armature and operating mechanism. of a two-position relay in simple diagram form. The local coils L are connected so that when a current flows through them, magnetic fields of the same instantaneous direction as shown are created; it is a fundamental fact that, whenever a current flows through a



PLAN VIEW

INVERTED PLAN VIEW

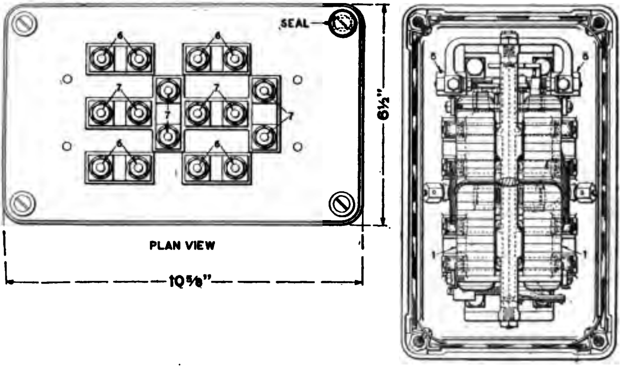
FRONT VIEW
GLASS SECTIONED

SECTIONAL END VIEW

CONTACT EQUIPMENTS.

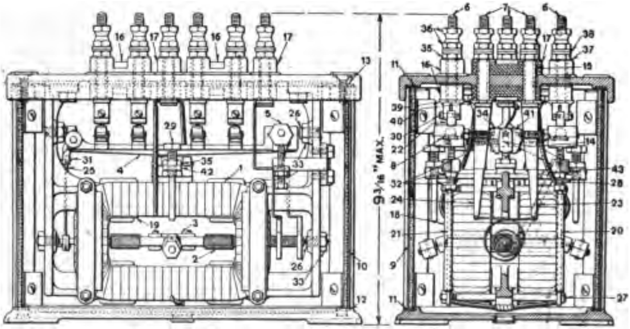
4 fronts 4 backs	4 fronts 0 backs
4 fronts 2 backs	2 fronts 0 backs

Fig. 46. Two Position Ironless Galvanometer Relay.



PLAN VIEW

INVERTED PLAN VIEW



FRONT VIEW
GLASS SECTIONED

SECTIONAL END VIEW

CONTACT EQUIPMENTS.

4 contacts each direction
3 contacts each direction
2 contacts each direction

Fig. 47. Three Position Ironless Galvanometer Relay.

conductor, a magnetic field is created about that conductor, and the direction of the magnetic flux circles about the conductor can be predetermined by what is known as the "Corkscrew Rule," which states that, if the forward motion of a corkscrew which results as it is turned in a clockwise direction is taken to represent the direction in which the circuit is flowing in the conductor, then the magnetic flux circles are circulating around the conductor in the same direction as the corkscrew is being turned. Of course, as the corkscrew is backed out of the cork, it has to be turned counter-clockwise, and, consequently, the flux circles turn in a counter-clockwise direction when the current is flowing in the conductor in the same direction as the corkscrew is being backed out.

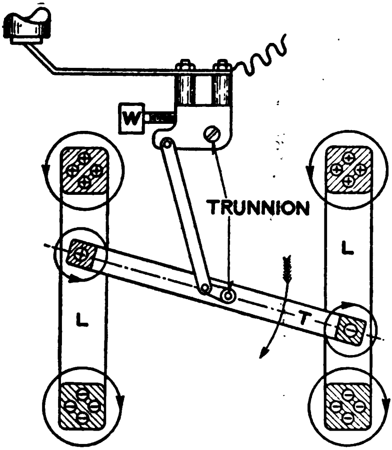


Fig. 48. Magnetic Flux Relationships Ironless Galvanometer Relay.

The fields produced in the upper and lower halves of the local coils, are of course, opposite in direction, because the currents are flowing, say, *toward* the observer in the top halves and *away* from the observer in the lower halves, due to the fact that the current has to flow continuously in loop fashion around the coils. When the current flows around armature A toward the observer in the left hand side of the armature, a field is created according to the Corkscrew Rule, which is in the same direction as the field in the top half of the left hand local coil, so that *attraction* results and the left hand side of the armature is pulled upward; the field in the lower half of the left hand local coil is in opposition to the field created in the left hand side of the armature, so that *repulsion* results, and the armature is again thrust upward. By a similar process of reasoning, it will be found that the right hand side of the armature is attracted toward the bottom half of the right hand local coil, and is repelled from the top half of the same local coil. Of course, the above directions in polarity hold only for one-half of the alternating current period; however, during the second half of the period, when the current is reversed, it is reversed in all coils, and the same attractions and repulsions result as before, so that there is a continuous torque tending to turn the armature in a clockwise direction to close the contacts, as shown in Fig. 48. When current ceases to flow in the armature, the attractions and repulsions cease and counterweight W acts, by gravity, to open the contacts.

It will be noted that by means of a pole changer, as shown in Fig. 34, Chapter III, the direction of current in the relay armature can be separately controlled, so that the magnetic fields produced in the right and left hand sides of the armature may be reversed in direction, causing the armature to swing in one direction or the other, as desired; it is to be remembered that the pole changer does not reverse the current in the local coils, as they are permanently connected to their feeding transformer. Therefore, by means of a pole changer, the currents in the track and local elements may be placed in phase or 180 degrees out of phase, depending on the position of the pole changer.

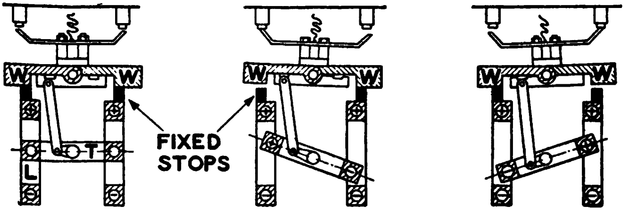


Fig. 49. Method of Counterweighting Three Position Relays.

This means that the relay may be caused to operate in three positions, as shown in Fig. 49. In such a relay, the armature lifts a counterweight, W, no matter which way it swings; when the armature is de-energized, one or the other of the counterweights causes the armature to return to the horizontal, or neutral, position, where all contacts are open. Thus, the relay may be used for controlling home and distant, or three-position, signals, without the use of line wires for the distant, or caution, indication, as will be gathered from Fig 34, Chapter III.

It ought to be noted that the greatest turning force is exerted on the armature, and the greatest pressure results on the contacts only when the armature current and the local current are either in phase or 180 degrees out of phase; then full attraction or full repulsion occurs. With other phase relations, the torque on the armature falls off; for example, if the armature and local currents were in quadrature, the armature would not pick up, even with a heavy current flowing it in, for there would be four times during each period when one or the other of the two currents would be zero, while the other were a maximum, under which conditions no torque would be produced in the armature. It will be evident, therefore, that it is highly important to approximate in practice as closely as possible the ideal phase displacement of zero degrees or 180 degrees between track and local currents, if good pressure on the contacts is to be obtained with a fair amount of power.

With only an alternating current flowing in the local coils of the ironless galvanometer relay, foreign direct current in the armature would not pick the armature up; the rapid reversals of the alternating magnetic field due to the local coils would be too rapid for the armature to follow, it being of constant polarity, due to the D. C. flowing through it. The relay is consequently immune to direct current.

3. Characteristics of the Ironless Galvanometer Relay and Where it is Used. (a) Although the ironless galvanometer relay is not so economical in power as some of the other two-element relays, it is of a very simple rugged construction, and all its parts are in full view so that they can be readily inspected. Furthermore, the mechanical clearances are large and there are no air gaps to clog. Like the vane relay, many thousands of these relays are in service and are giving excellent results.

(b) The relay is perfectly immune to direct current, and hence is especially adapted for use on electric roads using D. C. propulsion, as well as on steam roads. As it is a two-element relay, it is intended for use on long track circuits, where a single element relay would take too much power.

(c) From what has previously been said, it is evident that the galvanometer relay may be used as either a two-position or a three-position relay.

4. Power Data. The curves shown in Figs. 50-55 cover the approximate track circuit power required for the operation of the ironless galvanometer relay on both steam and electric road track circuits of various lengths; the relay local is of course fed separately, the power required by the local being given in the heading of each diagram. The power data given for the track element in each heading is based on the track and local currents being in phase, but the track circuit vector diagram, constructed as described in Chapter XIII will in many cases indicate that when the relay is actually operating under the given set of track circuit conditions, the track and local element currents are not exactly in phase; hence the voltage and current at the track transformer must be increased to compensate for this imperfect phase relationship and the curves shown in Figs. 50-55 have been so corrected so as to apply to actual conditions. For a full discussion of this correction factor see Chapter XIII.

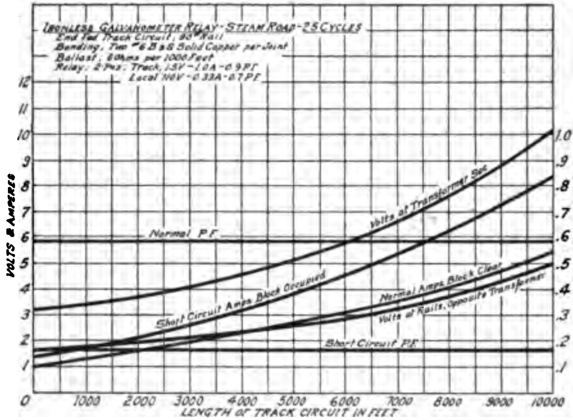


Fig. 50. Power Curves 25 Cycle Ironless Galvanometer Relay on Steam Road Track Circuit.

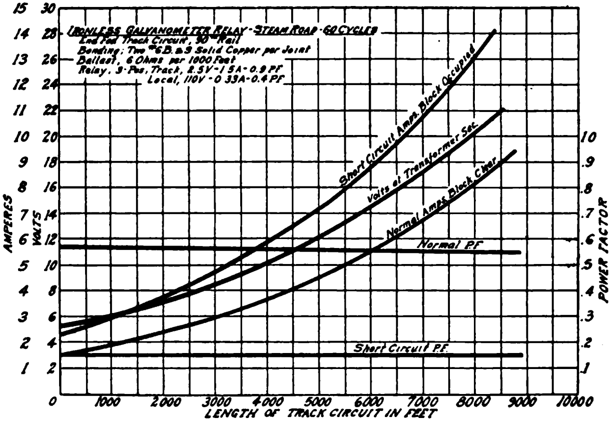


Fig. 51. Power Curves, 60 Cycle Ironless Galvanometer Relay on Steam Road Track Circuit.

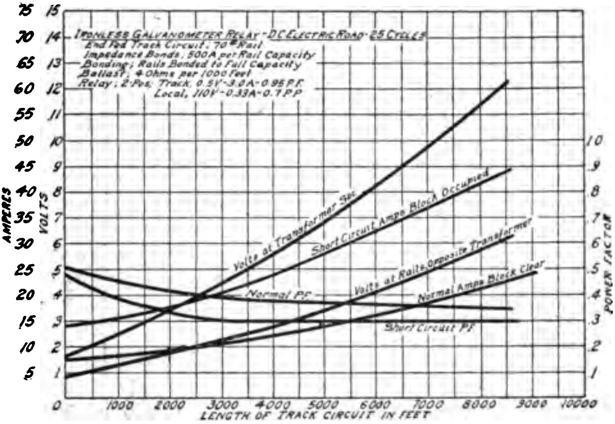


Fig. 52. Power Curves 25 Cycle Ironless Galvanometer Relay on Double Rail End Fed D. C. Electric Road Track Circuit

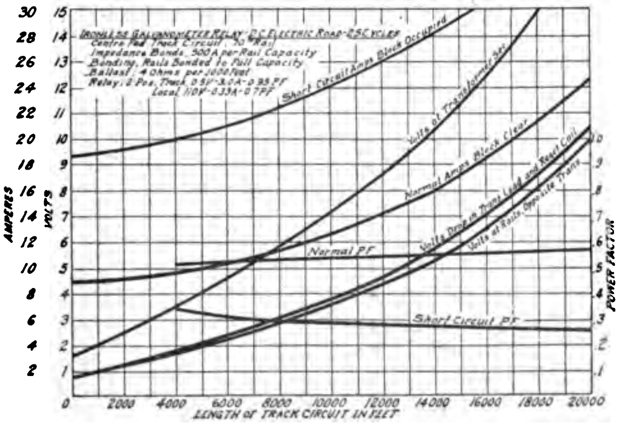


Fig. 53. Power Curves 25 Cycle Ironless Galvanometer Relay on Double Rail Center Fed D. C. Electric Road Track Circuit.

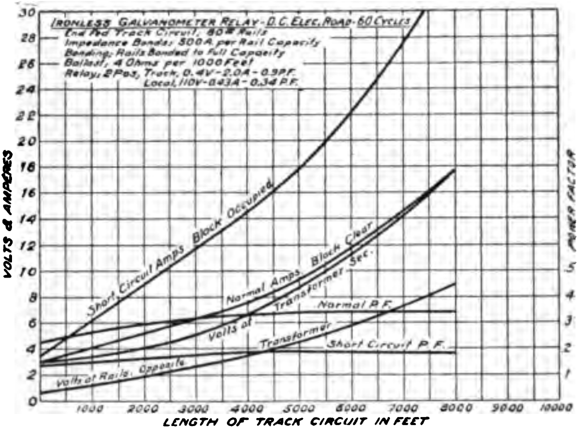


Fig. 54. Power Curves 60 Cycle Ironless Galvanometer Relay on Double Rail End Fed D. C. Electric Road Track Circuit.

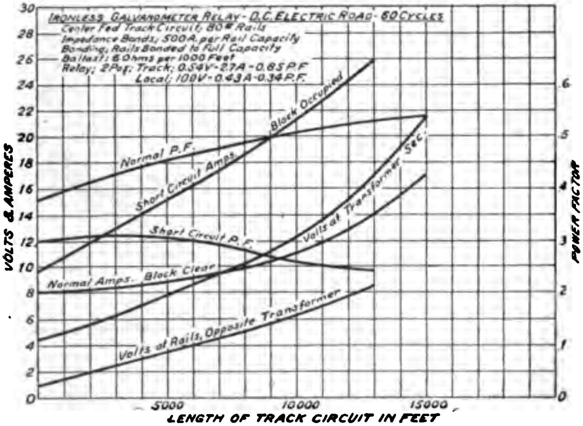


Fig. 55. Power Curves 60 Cycle Ironless Galvanometer Relay on Double Rail Center Fed D. C. Electric Road Track Circuit.

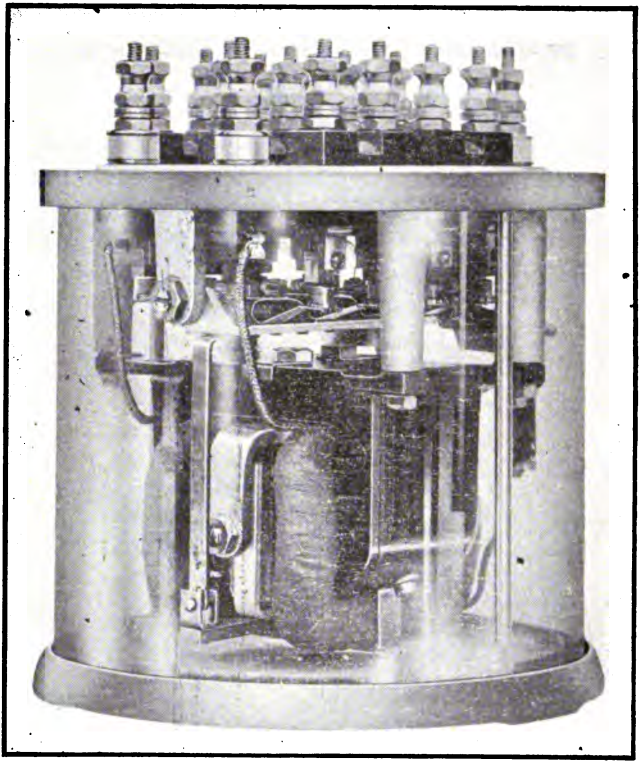


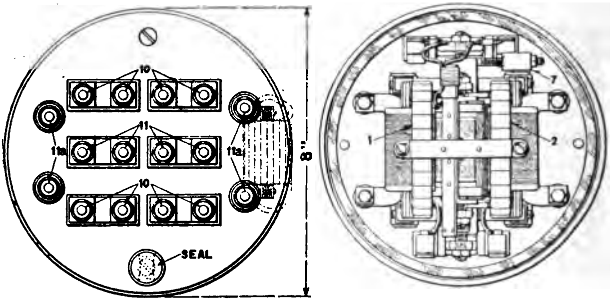
Fig. 56. Iron Galvanometer Relay.

THE IRON GALVANOMETER RELAY.

1. Description and Theory. Another important two-element relay, known as the Iron Galvanometer Relay, is illustrated in Figs. 56 and 57. This relay is exactly the same in principle as the Ironless Galvanometer Relay previously described, and the constructive design of the two relays would be very much the same, if it were not that an iron magnetic circuit is used in the Iron Galvanometer Relay. As with the Ironless Galvanometer Relay, this relay operates most economically when its track and local elements are exactly in phase or 180 degrees out of phase.

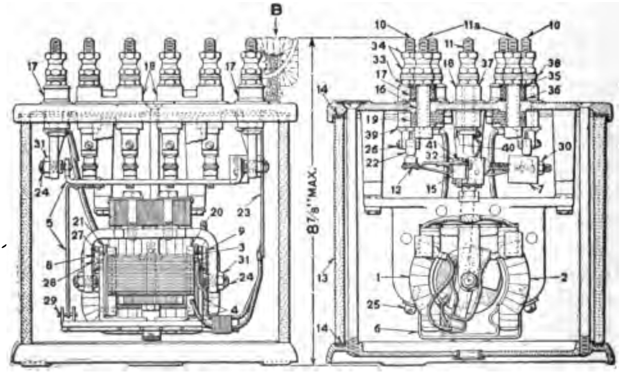
The inverted U-shaped iron field magnet is clearly shown in the sectional side view of Fig. 57, where it will be seen that the local coils 1 and 2 are supported on the poles of the field magnet; the local coils are connected in series. A cylindrical iron core visible in the sectional back view is hung from the field yoke down within the interior circular bore of the field magnet, so that the hollow armature coil 3 may swing on its pivots 24 in the air gap between the cylindrical core and the field magnet. The contact bar 5 with its operating lever is actuated from the armature through pin 29 carried on a bar attached to the bottom of the armature shown in Fig. 57.

The object of using iron field cores is to make the relay more economical in the way of power than a similar ironless relay, as, of course, a strong magnetic field can be produced with a small energization of the local magnetizing coil when an iron core is used. Due to the fact that the magnetic flux is rapidly alternating in the cores, they are built up of thin sheets of steel painted on both sides to prevent the alternating magnetic flux from inducing heavy currents in the field structure, just as the flux induces the operating currents in the vane of the vane relay. These induced currents, known as eddy currents, tend to flow, of course, at right angles to the direction in which the flux is moving as per Fleming's Rule described in Chapter II, so that, if the field structure is built up of thin painted steel stampings (known as laminations), piled in the direction of the armature shaft, the eddy currents cannot flow, because they are of low voltage and the paint on the laminations is of comparatively high resistance. Practically all alternating current apparatus is made up with laminated cores to save the



PLAN VIEW

INVERTED PLAN VIEW
BOTTOM PLATE REMOVED



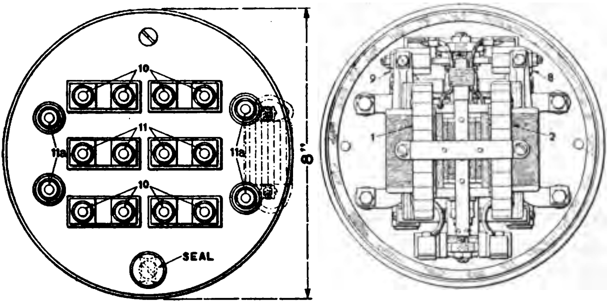
SECTIONAL BACK VIEW

SECTIONAL SIDE VIEW

CONTACT EQUIPMENTS.

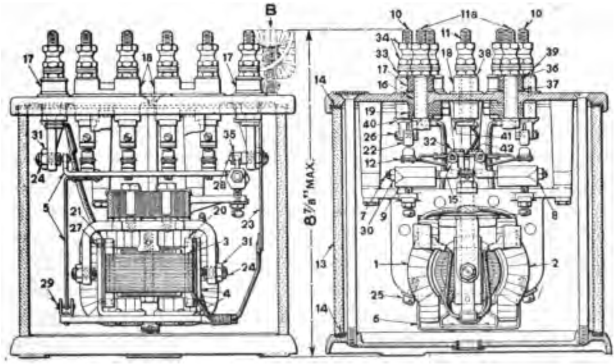
4 fronts 4 backs	4 fronts 2 backs
4 fronts 0 backs	

Fig. 57. Two Position Iron Galvanometer Relay.



PLAN VIEW

INVERTED PLAN VIEW
BOTTOM PLATE REMOVED



SECTIONAL BACK VIEW

SECTIONAL SIDE VIEW

CONTACT EQUIPMENTS.

4 contacts in each direction
3 contacts in each direction
2 contacts in each direction

Fig. 58. Three Position Iron Galvanometer Relay.

losses in power which would otherwise result from the heating due to the eddy currents. This statement applies not only to the iron galvanometer relay, but to the vane relay as well.

2. Characteristics of the Iron Galvanometer Relay and Where it is Used. (a) The iron galvanometer relay can be made for operation in either two or three positions, and is, therefore, adapted to polarized wireless signaling.

(b) Having an iron core, it is more economical than the ironless galvonometer relay previously described, but due, to the use of the iron core, the iron galvonometer relay is not absolutely immune to very heavy direct currents under certain conditions. Consequently, it is intended for use only on steam roads, where it has seen an extensive and successful application.

3. Power Data. The curves shown in Figs. 59 and 60 cover the approximate track circuit power required for the operation of the iron galvanometer relay; the relay local is of course fed separately, the power required by the local being given in the heading of each diagram. The power data given for the track element in each heading is based on the track and local element currents being in phase, but the track circuit vector diagram constructed as described in Chapter XIII, will in many cases indicate that when the relay is actually operating under the given set of track circuit conditions, the track and local element currents are not exactly in phase; hence the voltage and current at the track transformer must be increased to compensate for this imperfect phase relationship and the curves shown in Figs. 59 and 60 have been so corrected so as to apply to actual conditions. For a full discussion of this correction factor see Chapter XIII.

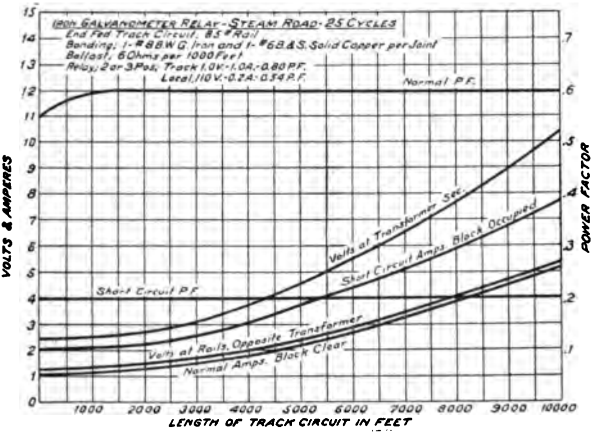


Fig. 59. Power Curves 25 Cycle Iron Galvanometer Relay End Fed Steam Road Track Circuit.

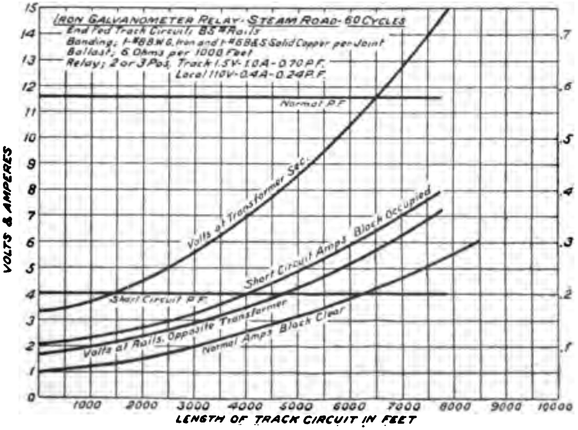


Fig. 60. Power Curves 60 Cycle Iron Galvanometer Relay End Fed Steam Road Track Circuit.

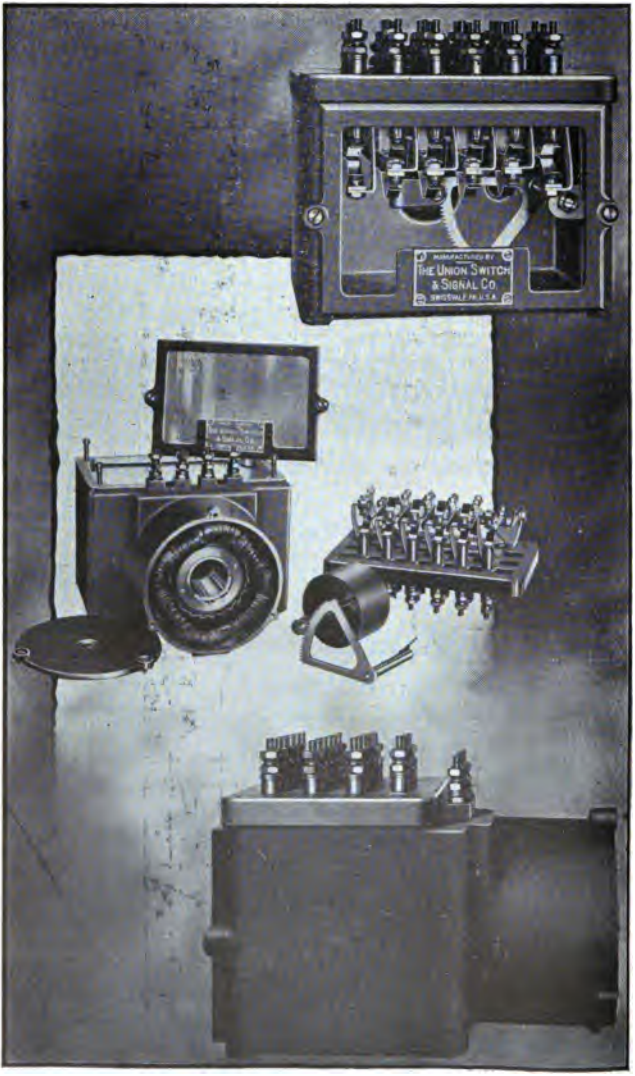


Fig. 61. Model 12 Polyphase Relay.

MODEL 12 POLYPHASE RELAY.

1. **Description.** Polyphase relays are, perhaps, the most economical relays for track circuit work, although they are characterized by a more delicate construction than the vane and galvanometer relays previously described. Polyphase relays are of the two-element type, with two separate and individual coils, wound, however, on the same iron core and producing motion in a metal drum without windings, in much the same fashion as the vane in a vane relay is caused to rotate; in fact, the metal drum of the polyphase relay corresponds exactly to the vane of the vane relay. The outside laminated core, with its two windings, is known as the *stator* and the metal drum is called the *rotor*. The Model 12 polyphase relay is shown in Fig. 61.

Its construction is shown in Figs. 62 and 63, the first of which shows the elements of the operating mechanism, and the second the relay in detail. The case of the relay consists of a rectangular front portion which houses the contact fingers, operating gears and links, and supports the slate top plate carrying the contact posts and terminals; cast integral with the rectangular portion of the case is a cylindrical por-

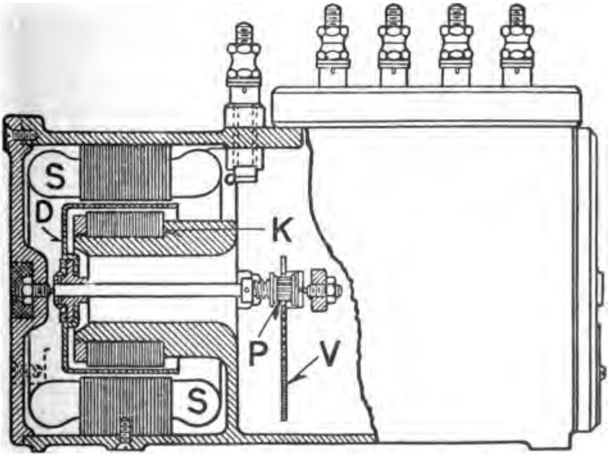
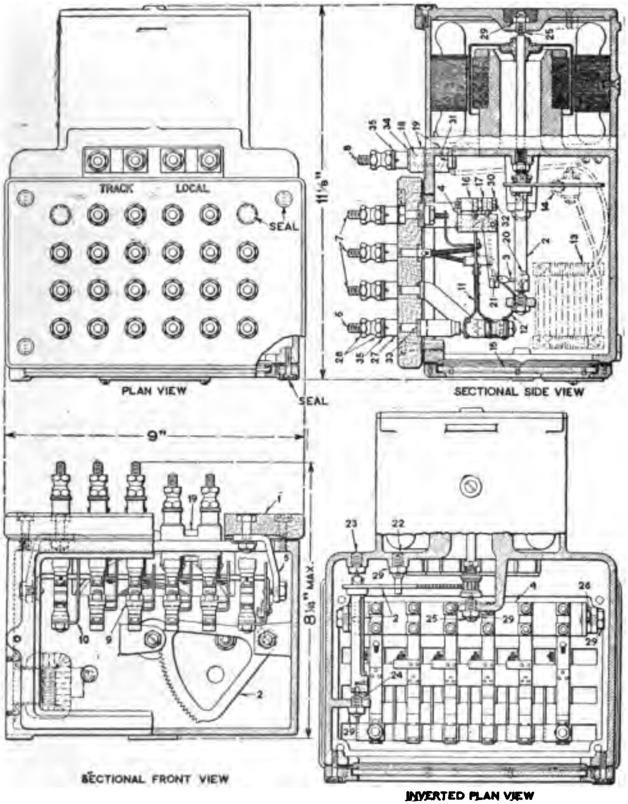


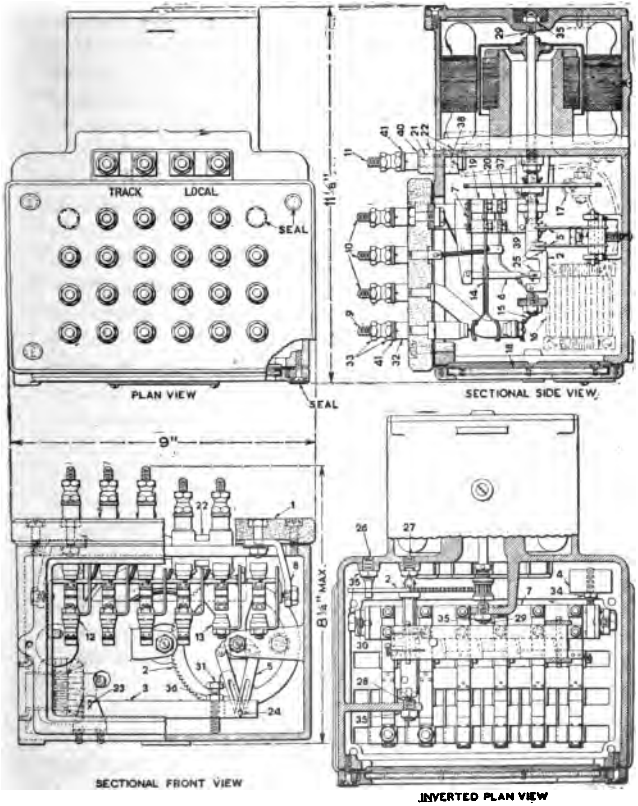
Fig. 62. Operating Mechanism Model 12 Polyphase Relay.



CONTACT EQUIPMENTS.

10 fronts 2 backs	10 fronts 0 backs
8 fronts 4 backs	8 fronts 2 backs
8 fronts 0 backs	6 fronts 6 backs
6 fronts 4 backs	6 fronts 2 backs
6 fronts 0 backs	4 fronts 6 backs
4 fronts 4 backs	4 fronts 2 backs
4 fronts 0 backs	2 fronts 6 backs
2 fronts 4 backs	2 fronts 2 backs
2 fronts 0 backs	

Fig. 63. Two-Position Model 12 Polyphase Relay.



CONTACT EQUIPMENTS.

6 pos. 6 neg.	6 pos. 4 neg.	6 pos. 2 neg.
4 pos. 6 neg.	4 pos. 4 neg.	4 pos. 2 neg.
8 pos. 4 neg.	8 pos. 2 neg.	10 pos. 2 neg.
2 pos. 6 neg.	2 pos. 4 neg.	2 pos. 2 neg.

This relay may also be provided with contacts closed only in the de-energized position of the relay; such a contact takes the same as one complete three-position (pos. and neg.) contact.

Fig. 64. Three-Position Model 12 Polyphase Relay.

tion at the back, which houses the motor operating mechanism—that is, the stator and the rotor. The stator S, with its coils, is shown assembled in the cylindrical portion of the case in Fig. 62; the four terminals of the two stator coils are located on the rectangular portion of the case just at the right of the stator in Fig. 62, which also illustrates the metal drum or rotor D, which turns in the air gap between the stator and central laminated core K shown in cross section. The rotor is pivoted at its closed end in a jeweled bearing 25, Fig. 63, carried by the end plate of the stator case, while at its open end it is supported in a similar bearing carried by a stud projecting from the rectangular portion of the case, also shown in the sectional side view, Fig. 63. The right hand end of the rotor shaft carries a small pinion P, Fig. 62, driving a segmental gear V, which in turn operates the shaft carrying the contact fingers through a crank and operating link 3, Fig. 63. One of the windings on the stator is a local coil, which is, of course, continuously energized directly from a transformer or some other source of alternating current power; the other element or winding is fed from the track, and, when both elements are energized, the rotor is caused to spin around so as to close the relay contacts through the pinion, segmental gear and links above mentioned. When the contacts are fully made, the rotor stalls, still maintaining torque to keep the contacts closed. A counterweight is attached to the shaft of the segmental gear, so that it drops by gravity, causing the rotor to spin backward to open the contacts when the relay is de-energized. As will presently be explained, the relay can be made to operate in either two or three positions, as desired, depending on the direction in which the rotor is made to move. The relay shown in Fig. 63 is shown in the de-enegized position, with its front contacts open.

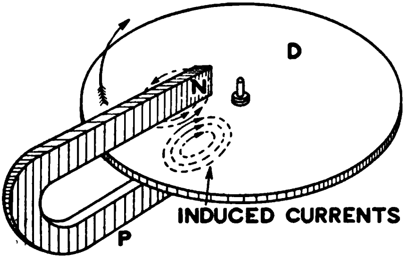


Fig. 65. Metal Disc, Dragged around by Induction.

2. Theory of the Polyphase Relay.

Polyphase

relays operate on what is known as the Induction Motor principle, which will be understood from a consideration of Figs.65, 66 and 67. If, in the former drawing, the permanent magnet P is caused to revolve about the periphery of the metal disc D, then the disc will be dragged around in the same direction in which the magnet is being moved. The motion of the metal disc results because of the fact that the strong moving field, due to the permanent magnet P, induces currents in the disc, which themselves set up a field, reacting on the field of the magnet in such a manner as to pull the disc toward the moving magnet. In other words, these mutual forces, according to Lenz's Law, tend to diminish the relative motion of magnet and disc; as the magnet is moved positively around by hand, the disc, consequently, has to follow.

We must now consider how it is possible to induce such currents in the metal drum, or rotor, of the polyphase relay in such manner that a continuous turning effect will be produced by the mutual action between the rotor currents and the field which causes them. Evidently, it would be impossible to obtain such a result with but one inducing current in the stator, because the magnetic field produced thereby would merely oscillate in direction along one line, and the field due to the currents induced in the rotor would likewise oscillate along the same line. If we can cause the current in the stator coils to produce a field which, instead of oscillating along a fixed line, always oscillates along a line which constantly rotates around the center, always in the same direction, then the desired result can be obtained. Fortunately, such a rotating field can be produced, if, instead of a single stator winding, we employ two similar but distinct windings on the field, taking care to supply these two elements with two alternating currents of the same frequency, but differing in phase by a

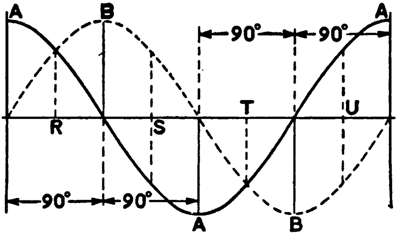


Fig. 66. Quadrature Currents in Polyphase Relay.

quarter of a period, or 90 degrees, as shown in Fig. 66, where it will be observed that, when one current A is at its maximum, the second current B is zero, and vice versa, while at four points in a complete cycle they have equal numerical values; at two of these points they are of the same sign, either both positive, as at R, or both negative, as at T; in the other two cases, they are of opposite sign, as at S and U.

We have now to show how much such currents can, when passed through two distinct windings, produce a rotating magnetic field; Fig. 67 shows two windings in their simplest form, AA representing, in section, a single coil or loop of wire placed horizontally, and BB a similar coil fixed at right angles thereto. A current passing through coil AA will produce a field in the vertical direction, as represented at XY, while a similar current in coil BB will set up a horizontal field RS. Now, what we have to consider is the strength and direction of the resultant field produced by two coils, which field will, of course, be determined by the relative values of the respective instantaneous currents in the two coils, as shown in Fig. 66. For example, when A is at its maximum and B is zero, the field due to A may be represented in strength and direction by line OC, and this is the resultant field, since the current in B is then zero; 45 degrees later, as at R in Fig. 66, the two currents are equal. Let OE in Fig. 67, drawn to the same scale as OC, represent the field due to A; then the equal line OD will represent the field produced by B. Complete the parallelogram and we obtain line OF, representing the strength and direction of the resultant field at this instant.

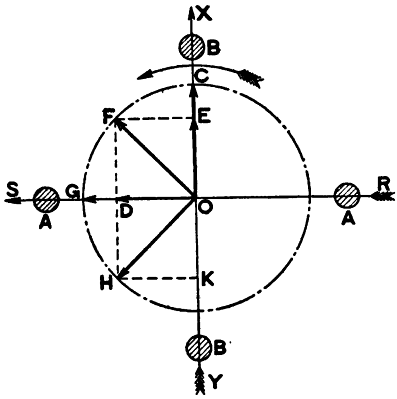


Fig. 67. Illustrating Production of Rotating Magnetic Field.

In the same manner, we can find line OG, representing the resultant field 45 degrees later still, when B is maximum and A is zero. Obviously, the resultant field has rotated 90 degrees from the direction OC to the direction OG, during a quarter cycle, and, by proceeding further, we should find that the resultant field rotates uniformly about point O, making a complete revolution for every complete cycle of the currents in the stator coils. OH, for example, corresponds to the time S in Fig. 66. This rotating field induces current in the metal drum, or rotor, of the polyphase relay and causes it to rotate, just as the disc shown in Fig, 65 is dragged around by the magnetic field of the moving permanent magnet. A study of Figs. 66 and 67 will make it evident that the rotor can be dragged around in one direction or the other, as desired, depending on the time phase relation of the currents in the track and local windings; for example, if the track current lags 90 degrees behind the local current, the rotor will turn, say, clockwise, while, if, by means of a pole changer, as shown in Fig. 34, Chapter III, the track current is caused to lead the local current by 90 degrees, the rotor would rotate counterclockwise. The relay may, therefore, be made to operate in either two or three positions. Furthermore, it will be noted from Figs. 66 and 67, that the relay works best when its track and local currents are in quadrature; if the two currents were in phase, the magnetic field would not rotate at all, and the contacts would not be closed, even if both elements were fully energized. Polyphase and galvanometer relays are, therefore, contrary in this respect, as the galvanometer works best when the currents in the two elements are in phase. Of course, the winding usually connected to the track could be connected to a line, if necessary, so that the relay could be used for line work, in which case the line element would generally be wound for 110 volts.

3. Characteristics of Model 12 Polyphase Relay and Where it is Used. (a) In the matter of power consumption this relay is the most economical of all relays.

(b) It is absolutely immune to direct current, and may, therefore, be used either on electric roads using D. C. propulsion, or on steam roads.

(c) It is also operable in either two or three positions, and

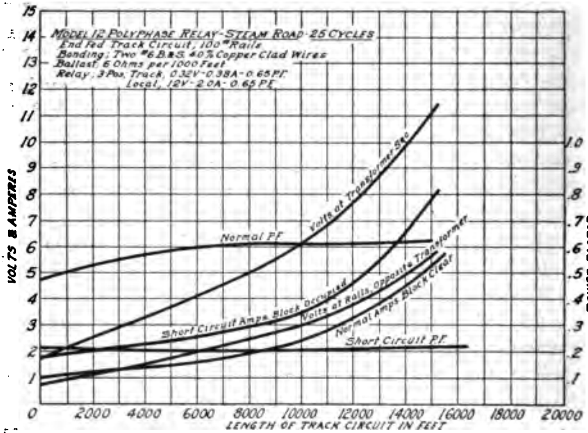


Fig. 69. Power Curves 60 Cycle Model 12 Polyphase Relay End Fed Steam Road Track Circuit.

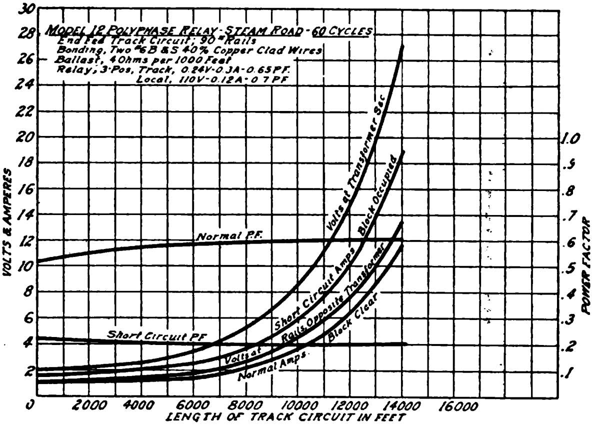


Fig. 68. Power Curves 25 Cycle Model 12 Polyphase Relay End Fed Steam Road Track Circuit.

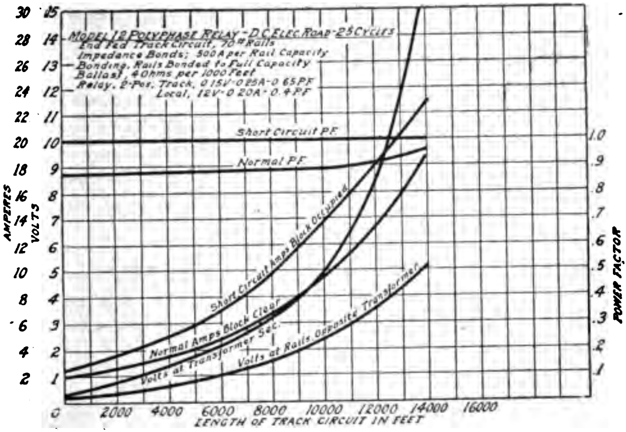


Fig. 70. Power Curves 25 Cycle Model 12 Polyphase Relay on End Fed Double Rail D. C. Electric Road Track Circuit.

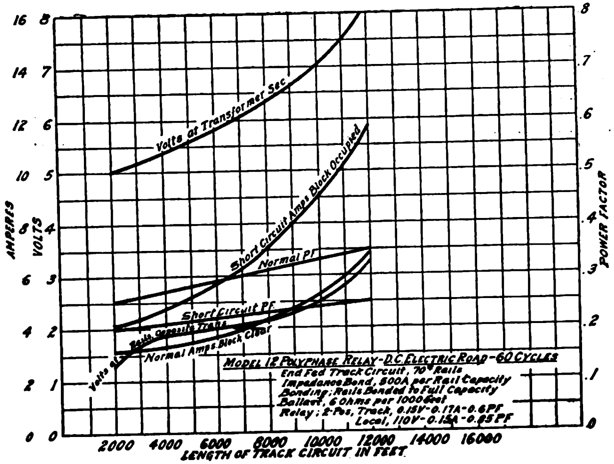


Fig. 71. Power Curves 60 Cycles Model 12 Polyphase Relay on End Fed Double Rail D. C. Electric Road Track Circuit

is, consequently, adapted to polarized wireless signaling, the polarity of the track element in this latter case being controlled by a pole changer shifted by the signal mechanism, as shown in Fig. 34, Chapter III.

(d) Like all polyphase relays, the Model 12 relay is more costly than simpler relays, such as the galvanometer or vane, and its construction is necessarily more delicate. With careful manufacture, however, polyphase relays can be depended on to give excellent service, and many thousands of them are in use.

4. Power Data. The curves shown in Figs. 68-71 cover the approximate track circuit power required for the operation of the Model 12 polyphase relay; the local element of the relay is of course fed separately, the power required by the local being given in the heading of each diagram. The power data given for the track element in each heading is based on the track and local element currents being in quadrature, but the track circuit vector diagram constructed as described in Chapter XIII, will in many cases indicate that when the relay is actually operating under the given set of track circuit conditions, the track and local element currents are not exactly in quadrature; hence the voltage and current of the track transformer must be increased to compensate for this imperfect relationship and the curves shown in Figs. 69-71 have been so corrected as to apply to actual conditions. For full discussion of this correction factor see Chapter XIII.

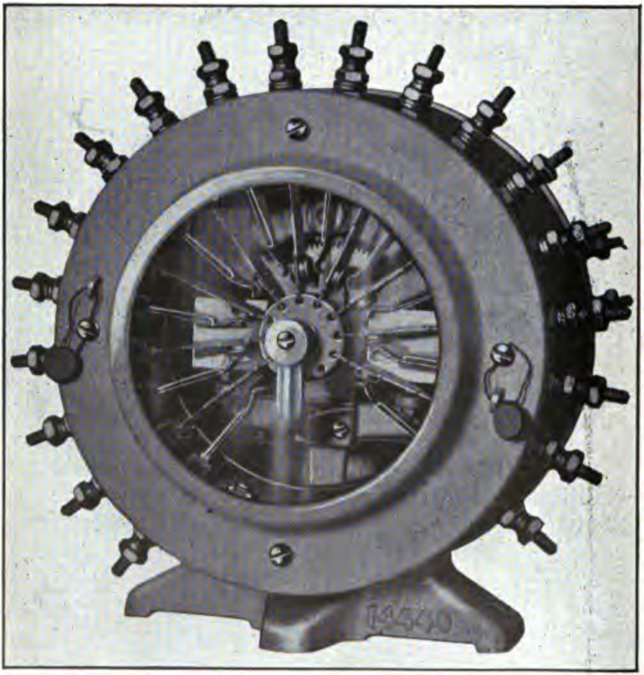


Fig. 72. Radical Polyphase Relay.

THE RADIAL POLYPHASE RELAY.

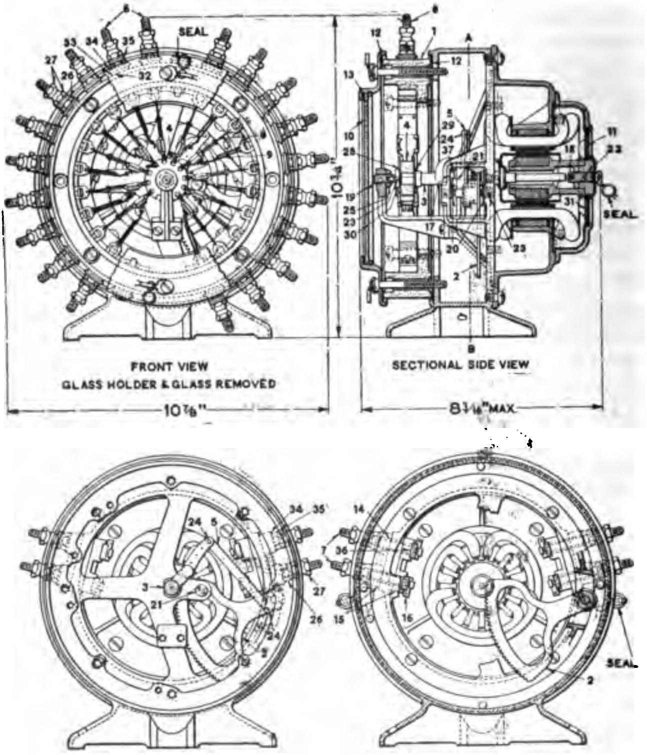
1. Description. Another very efficient and compact polyphase relay, illustrated in Figs. 72, 73 and 74, is known as the Radial Type, and is characterized by a very ingenious arrangement of the contact fingers and terminal posts. The induction motor movement is housed at the right of the relay, as illustrated in the sectional side view of Figs. 73 and 74. The four terminals for the track and local coils project from the stator case, two on either side, as shown in the lower front views of Figs. 73 and 74. The motor mechanism itself is exactly similar to that of the Model 12 polyphase relay previously described, but it operates through link 5, Figs. 73 and 74, a porcelain wheel 4, shown at the exact center of the upper front view; this porcelain wheel is slotted, or toothed, as shown, and as it rotates one way or the other, it moves the movable contact members projecting in the slots in the wheel. The contact members and terminal posts are carried on a large porcelain ring, so that it is easy to secure a nice arrangement of connecting wires. It will be seen, from Fig. 72, that the contacts, and many of the moving parts, are within full view, and the back of the stator case is provided with glass windows to allow inspection of the induction motor movement.

2. Theory of the Radial Polyphase Relay. The theory on which this relay operates is exactly the same as that of the Model 12 polyphase relay previously described.

3. Characteristics of the Radial Polyphase Relay and Where It Is Used. (a) The induction motor movement of the radial relay is smaller than that of the Model 12 polyphase relay, and, as a consequence, the radial is somewhat less economical in the way of power.

(b) Working on the induction rotor principle, the radial, like the Model 12 polyphase relay, is absolutely immune to direct currents, and is, consequently, suitable for use on electric roads using D. C. propulsion, or on steam roads.

(c) Being a two-element relay, the radial can be made to operate in either two or three positions, and is, consequently,



FRONT VIEW
GLASS HOLDER & GLASS REMOVED

SECTIONAL SIDE VIEW

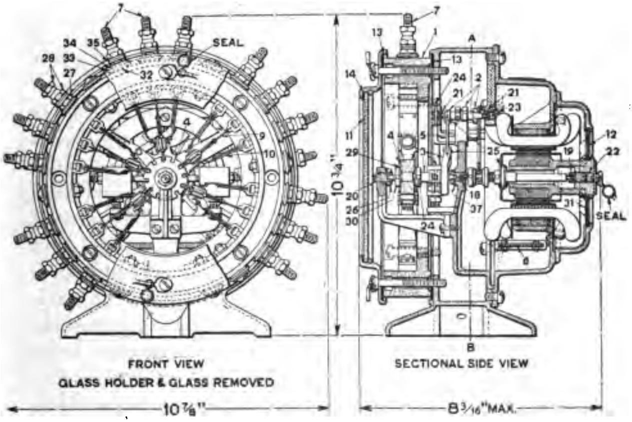
FRONT VIEW
CONTACT RING REMOVED

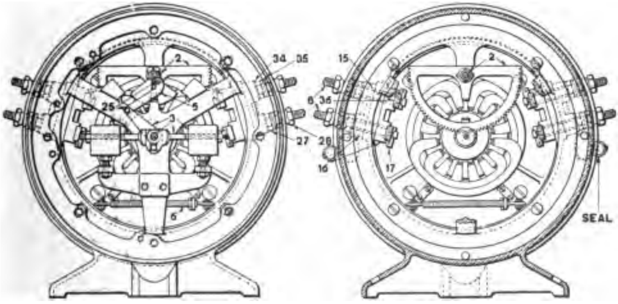
FRONT VIEW
SECTION THROUGH A-B

CONTACT EQUIPMENTS.

5 fronts 5 backs	10 fronts 0 backs
4 fronts 2 backs	8 fronts 2 backs

Fig. 73. Two-Position Radial Polyphase Relay.





FRONT VIEW
CONTACT RING REMOVED

FRONT VIEW
SECTION THROUGH A-B

This relay may also be provided with contacts closed only in the de-energized position of the relay; such a contact takes the same space as one complete three-position (pos. and neg.) contact.

CONTACT EQUIPMENTS.

5 pos. 5 neg.	4 pos. 4 neg.
3 pos. 3 neg.	

Fig. 74. Three Position Radial Polyphase Relay

suitable for use with the polarized wireless control system illustrated in Fig. 34, Chapter III.

(d) The arrangement of binding posts of the radial relay is preferred by some to that of the Model 12 relay.

4. **Power Data.** The curves shown in Figs. 75-76 cover the approximate track circuit power required for the operation of the Radial Polyphase relay; the relay local is of course fed separately, the power required by the local being given in the heading of each diagram. The power data given for the track element in each heading is based on the track and local element currents being in quadrature, but the track circuit vector diagram constructed as described in Chapter XIII, will in many cases indicate that when the relay is actually operating under the given set of track circuit conditions, the track and local element currents are not exactly in quadrature; hence the voltage and current of the track transformer must be increased to compensate for this imperfect relationship and the curves shown in Figs. 75-76 have been so corrected so as to apply to actual conditions. For a full discussion of this correction factor see Chapter XIII.

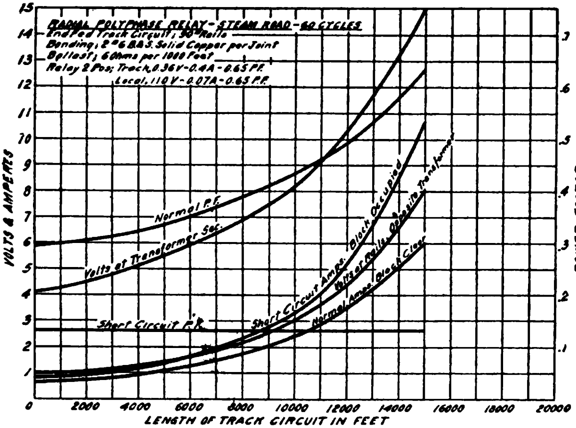


Fig. 75. Power Curves 60 Cycle Radial Polyphase Relay End Fed Steam Road Track Circuit.

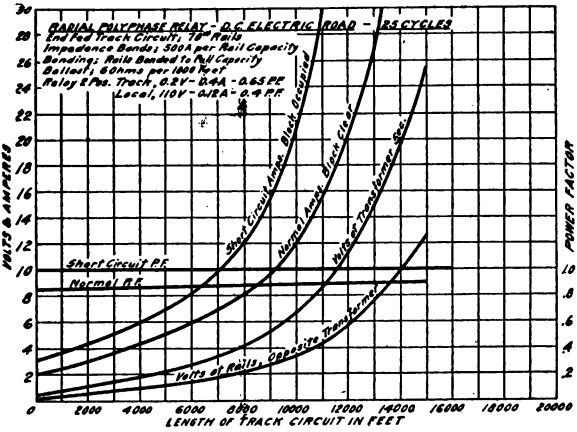


Fig. 76. Power Curves 25 Cycle Radial Polyphase Relay on End Fed Double Rail D. C. Electric Road Track Circuit.

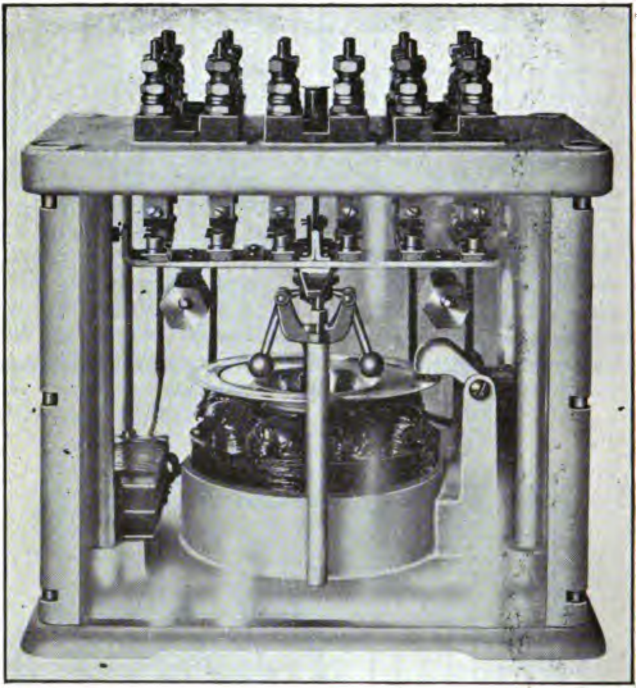


Fig. 77. Centrifugal Frequency Relay.

THE CENTRIFUGAL FREQUENCY RELAY

1. Function. The characteristic feature of track circuit apparatus for electric roads employing alternating current for propulsion purposes is the track relay. Thus far, all the alternating current roads in this country employ a propulsion current having a frequency of 25 cycles. Differentiation between the propulsion current and the signaling current is secured by using a higher frequency for signaling than for propulsion; a 60 cycle current is now quite generally used for signaling purposes. The track relay must, therefore, be immune, not only to direct current (for foreign direct currents leaking from adjacent D. C. interurban trolley roads must be guarded against, as on many steam roads), but, in addition, it must be able to select between the 25 cycle propulsion current and the 60 cycle signaling current, closing its contacts only on the latter.

2. Description of the Centrifugal Frequency Relay. This relay, shown in Fig. 77, has an induction motor movement consisting of a metal shell rotor A, Fig. 78, rotating inside a wire wound stator B, because of the rotating magnetic field produced in the stator by two windings carrying currents in quadrature. In fact, the motor portion of the centrifugal relay is exactly similar to that of the polyphase induction motor relays previously described, and is, of course, immune to direct current.

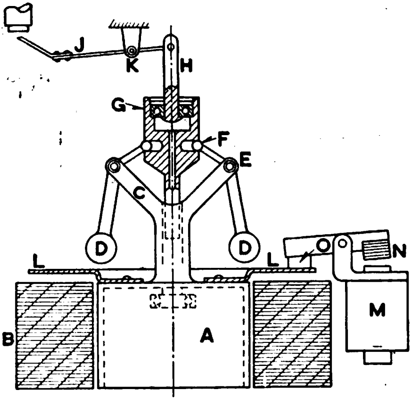
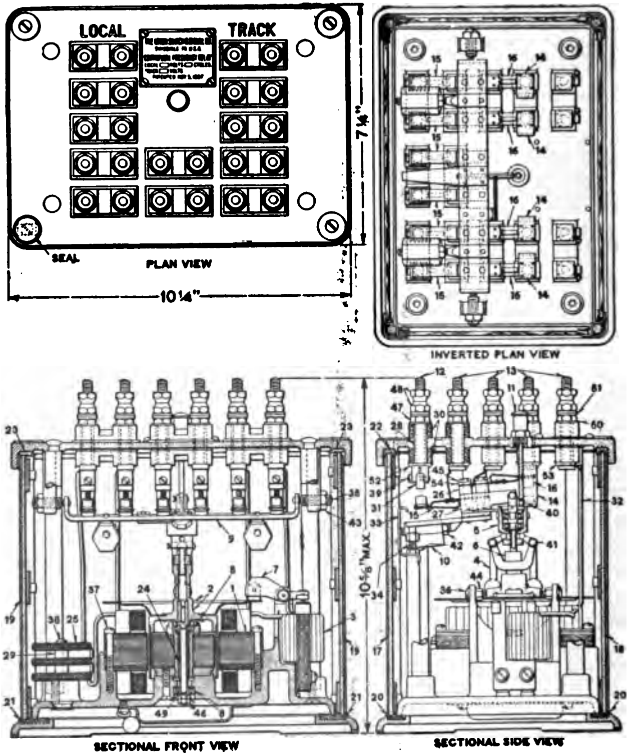


Fig. 78. Operating Mechanism Centrifugal Frequency Relay.

The shell rotor A, Fig. 78, is integral with a Y shaped metal



CONTACT EQUIPMENTS.

10 fronts 0 backs	6 fronts 4 backs
6 fronts 0 backs	4 fronts 2 backs
4 fronts 0 backs	

Fig. 79. Centrifugal Frequency Relay.

yoke C, carrying at E the pivots of the ball centrifuges D, which, at their upper end F, engage in a slot in the sliding collar G. When the rotor of the relay is running, the ball centrifuges are thrown outward at their lower ends D, swinging about points E to pull the collar G downward; this collar is attached, through a ball bearing, to a link H hooked to the contact operating bar J pivoted at K.

3. Theory of the Centrifugal Frequency Relay. The centrifuge arms and collar above mentioned work on the same well known principle as the ball governor of a steam engine. The speed at which an induction motor operates in revolutions per second is equal to twice the frequency of the currents flowing in the stator windings, divided by the total number of poles of the stator. Now, the stator winding of this relay is composed of two elements, so that the relay may be either a single or double element relay, as required; in the single element relay, the currents in the two windings are displaced in phase by such artificial means as resistance or reactance in either winding, while, in a two element relay having separate track and local coils, proper phase displacement between the track and local current is secured by the use of a reactance between the transformer and the track. In any event, one element of the winding is always connected to the track, so that leakage 25 cycle current from the propulsion system might enter the relay. Due to the fact, however, that the speed at which the rotor operates varies with the frequency, the centrifuge arms will not fly out so far on 25 cycle propulsion current as they will on 60 cycle signaling current, and it is by utilization of this characteristic that the relay is made selective between propulsion and signaling currents. The centrifuge member is designed so that on 25 cycles the balls will not fly out far enough to lift the operating collar sufficiently to close the contacts. On 60 cycles, however, due to the fact that the speed is over double what it is on 25 cycles, the centrifuge balls fly out much further and the contacts close. It will be seen, therefore, that, even on a two element relay, where 25 cycle propulsion current might not only circulate through the track element, due to unbalancing (see Chapter V), but might also reach the local coil, on account of being stepped up into the transmission system by the track transformers as a result of unbalancing, the relay is still immune to the propulsion current, because the speed of the rotor will not be sufficient to close the contacts of the relay. For these reasons, the relay is truly selective between the propulsion and signaling currents.

The operating movement of the relay, therefore, runs continuously. When a train enters the track circuit, the track element of the relay is short circuited, and the relay starts to slow down. Due to momentum, however, the moving element has a tendency to keep rotating for a time, particularly because it runs on ball bearings. Were it not for a braking arrangement, the relay would be very sluggish in opening its contacts. This braking arrangement consists of a magnetic brake M (Fig. 78), actuating an armature N, carrying a brake pad O, which engages with the brake disc L carried by the rotating element of the relay. The coils of the magnetic brake are connected in series with the track element of the relay, so that, when there is no train on the track circuit the full operating current flows through the track winding of the stator and the brake coil in series, energizing the brake coil so as to lift the brake pad O to free the disc L. The moment a train enters the track circuit, current ceases flowing through the brake coil and track element of the relay, and the brake pad engages the disc, bringing the rotor to a stop, so that the contacts are opened in about one-quarter of a second after the track circuit is shunted. The brake is shown clearly at the right of Fig. 77.

4. Characteristics of the Centrifugal Frequency Relay and Where it is Used. (a) The contacts are never closed, unless the rotor is running at the proper speed, as determined by the frequency of the signaling current. Hence, if, for *any* reason, the rotor is jammed, the centrifuge balls drop by gravity, and the contacts are opened. This is an important safety feature.

(b) Even as a single element relay, the centrifugal type is the more economical than any other frequency type now on the market. As a two element relay, it possesses the well known economy characteristics of all two element relays, in that only a small amount of power need be transmitted over the track.

(c) It is, of course, distinctly a two-position relay, and perfect broken down insulation joint protection may be secured when it is used as a two element relay, by staggering polarities on opposite sides of the insulation joints, so that direction of rotation of the induction motor movement will be reversed in case both insulation joints break down. To prevent the contacts being closed if the rotor reverses its direction of movement, the rotating collar G, Fig. 78, operated by the centrifuge arms, is provided on its periphery with ratchet teeth engaging in one direction with a thin spring pawl when the relay is de-energized. When the rotor moves in the proper direction, the spring pawl simply slides over the ratchet teeth on the collar G at pick-up, but, as the collar is raised as the centrifuge arms speed up, the ratchet teeth are lifted out of engagement with the spring, and this slight element of friction is, therefore, eliminated when the relay operates at full normal speed. When the relay is wound for single element work, the direction of rotation of the induction motor movement never changes, and, of course, the ratchet is then useless; in other words, as a single element relay, the centrifugal type does not afford broken down joint insulation protection, which, however, may be said of all other relays of the single element type.

It will be evident from the above description that the operating element of the relay rotates continuously, and to those familiar with only D. C. relays for steam roads, a question will no doubt arise as to whether the bearings of the relay and other moving parts are not liable to wear out. Such would very probably be the case if a great deal of care were not used to provide the rotating movement with a fine set of ball bearings, which are almost frictionless and will wear indefinitely, because the weight of the operating movement is purposely reduced to a minimum, so as to make the weight on the bearings very slight. On account of its safety and power economy, this relay has generally superseded the vane type frequency relay next described, except in the case of electric detector circuits in interlockings.

5. Power Data. The curves shown in Fig. 80 cover the approximate track circuit power required for the operation of the Centrifugal Frequency Relay; the relay local is of course fed separately, the power required by the local being given in the heading of the diagram. The power data given for the track element is based on the track and local element currents being in quadrature, but the track circuit vector diagram constructed as described in Chapter XIII, will in many cases indicate that when the relay is actually operating under the given set of track circuit conditions, the track and local element currents are not exactly in quadrature; hence the voltage and current of the track transformer must be increased to compensate for this imperfect relationship and the curves shown in Fig. 80 have been so corrected as to apply to actual conditions. For a full discussion of this correction factor see Chapter XIII.

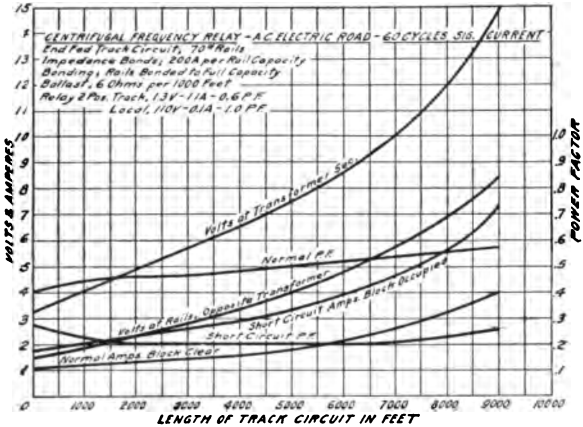


Fig. 80. Power Curves Centrifugal Frequency Relay on Double Rail End Fed Track Circuit, Single Track A. C. Electric Road.

The winding and power data given in Fig. 80 apply to a relay primarily intended for a single track road. Where a multiple track road is to be signaled and the tracks are cross bonded, a special winding must be provided if adequate broken rail protection is to be secured. The track element for this special winding takes 0.35 volts—4.8 amperes at 0.65 P. F. and the local winding takes 0.1 ampere at 1.0 P.F. on 110 volts.

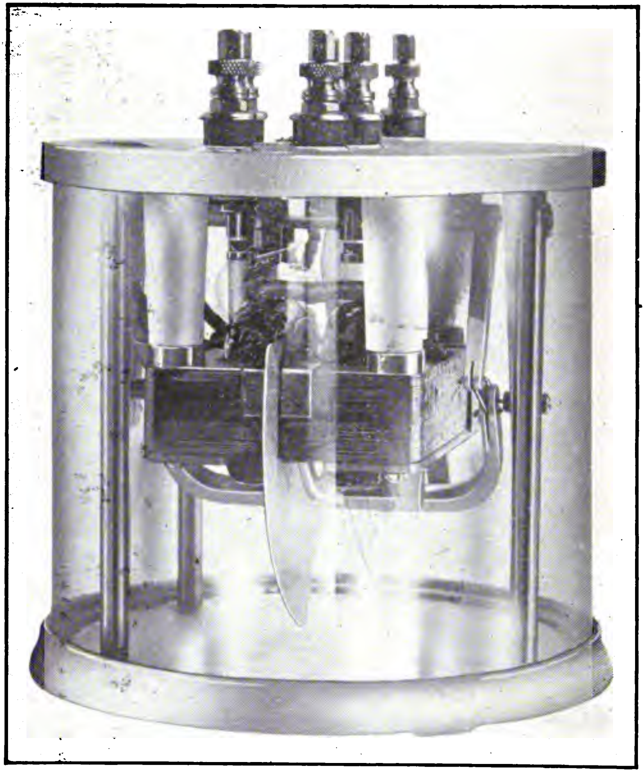
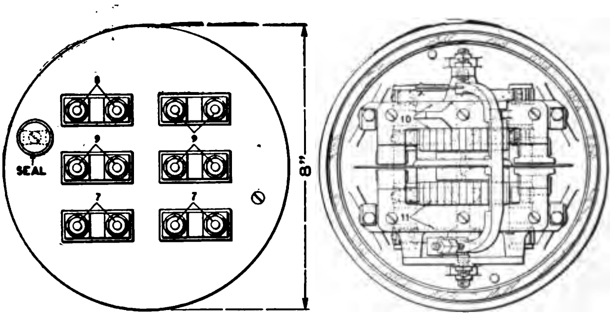


Fig. 81. Vane Frequency Relay.

THE VANE FREQUENCY RELAY.

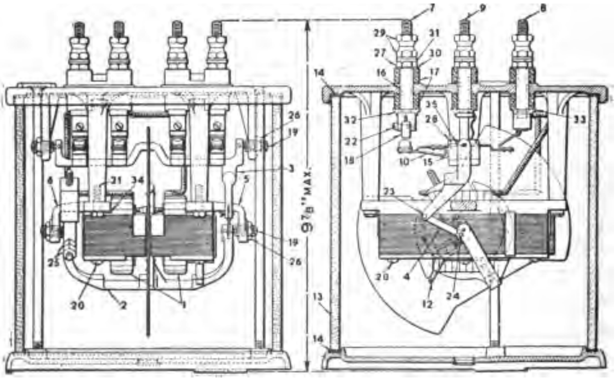
1. **Description.** The essential elements of this relay, illustrated in Fig. 81, are a laminated H-shaped iron core, carrying magnetizing coils, energized from the track, which induce currents in a moving vane, operating the front contact 10, through a link 4, as shown in Fig. 82, the relay here being shown in the de-energized position, with the back contacts closed. The vertical legs of the H-shaped iron core I, Fig. 83, are bent inwards to enclose the vane V, which is cut out in the middle, so as to not interfere with the middle leg of the H-shaped core. This middle leg carries the magnetizing coils TT connected in series and receiving energy from the track. All four bent-in legs of the H-shaped core are partially surrounded by copper ferrules F, which split the magnetic flux and cause the vane to be dragged upward toward the ferrules by a rotating magnetic field, just as in the case of the ordinary single element vane relay described previously. The vane, therefore, is acted upon by two opposing forces, since the two sets of ferrules at opposite ends of the core are both trying to make both ends of the vane rotate upward about its axis PP.

2. **Theory of the Vane Frequency Relay.** At the left end of the core, however, the air gap in which the vane swings, is greater than that at the right end, and this tends to cut down the flux, and consequently, the upward pull on the left half of the vane. The main portions of the legs of the right half of the core are surrounded by copper ferrules CC, which choke back the flux somewhat in that part of the core, so that, in turn, the upward drag on the right half of the vane is diminished. The air gap at the left end of the core, and the ferrules CC on the right half of the core, are so proportional that when 25 cycle propulsion current flows in coils TT, the upward pulls on the opposite ends of the vane will just be equal, and, of course, opposite, so that the resultant torque exerted on the vane is zero; the vane is counterweighted, however, to rest on a back stop, keeping the front contacts open. Now, when 60 cycle signaling current flows through the coils TT, the above balance is destroyed, for, whereas the reluctance of the left hand air gap remains unchanged, the choking effect of the ferrules CC is greatly increased so that the greater



PLAN VIEW

INVERTED PLAN VIEW
BOTTOM PLATE REMOVED



FRONT VIEW
GLASS SECTIONED

SECTIONAL SIDE VIEW

CONTACT EQUIPMENTS.

4 fronts 2 backs	2 fronts 2 backs
4 fronts 0 backs	3 fronts 0 backs
2 fronts 0 backs	

Fig. 82. Vane Frequency Relay.

part of the flux flows through the left half of the core; under these circumstances, the upward pull on the left half of the vane is the greater than the pull on the right hand half, and the vane is dragged upwards on the left hand end to close the relay contacts. The torque effects created in the two ends of the vane by the 25 cycle propulsion current are always balanced; this balance is destroyed on 60 cycles so that the relay can close its contacts on the high frequency signaling current. Such a relay is, therefore, immune to direct current and to the alternating propulsion current.

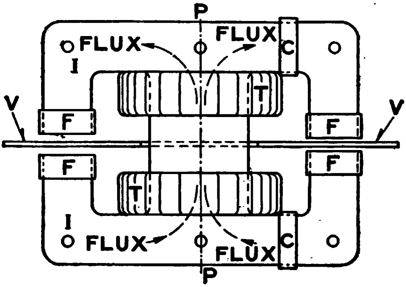


Fig. 83. Operating Element Vane Frequency Relay.

3. **Characteristics of the Vane Frequency Relay and Where it is Used.** (a) Vane type frequency relays possess the advantage of simplicity, but they naturally can be wound only as single element relays. Due to this fact, they are not as economical of power as Centrifugal Frequency relays and are nowadays used principally on short track circuits, as, for example, in electric detector circuit work, to which they are well fitted by their quick action.

4. **Power Data.** The curves shown in Fig. 84 cover the approximate power required for the operation of the vane frequency relay on an end fed single rail track circuit on a four track road. In making up the curves sufficient resistance has been inserted between the relay and the track and between the transformer and the track to take care of a propulsion drop of 15 volts per 500 ft. of track circuit. Depending upon the number of tracks and the distance of the trolley above them the impedance of the rail circuit is variable and the reader is referred to the series of tests made on the New York, New Haven & Hartford under the direction of Messrs. Scott and Copley and described in the 1908 Proceedings of the A. I. E. E.

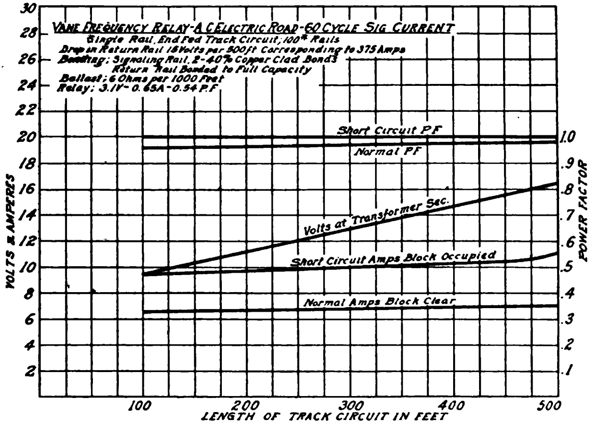


Fig. 84. Power Curves Vane Frequency Relay on Single Rail End Fed Track Circuit A. C. Electric Road.

CHAPTER V.

TRACK CIRCUITING ON ELECTRIC ROADS

CHAPTER V.

TRACK CIRCUITING ON ELECTRIC ROADS.

General Considerations. Perhaps the most interesting application of alternating currents in railway signaling occurs in their use on the track circuits of roads using electric propulsion. This in a way may be considered as the general or broadest case of the A. C. track circuit, for here we meet with all the problems usually encountered in the steam road A. C. track circuit, and, in addition, are forced to provide an electrically continuous return path for the propulsion current from track circuit to track circuit, while still, in a signaling sense, preserving between adjacent track circuits the insulation essential for their individuality. At first glance, these requirements seem paradoxical, and, in fact, a considerable amount of inventing and experimenting was done before a successful solution of the problem was arrived at. It is the object of this chapter to describe the present day methods employed in the track circuiting of roads using electric propulsion, whether direct or alternating.

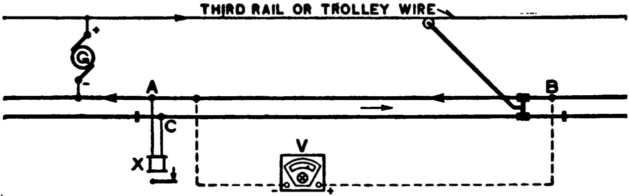


Fig. 85. Illustrating Effect of Propulsion Drop.

Their immunity to direct current has been the prime factor in bringing A. C. track circuits into extensive use on steam roads, while their simplicity and economy in maintenance has, incidentally, added to the attractiveness of this system. On electric roads, the employment of A. C. track circuits is imperative, as will be evident from a study of Fig. 85, where it will be noted that the continuity of the upper rail has been maintained for the return of the propulsion current back to the negative side of the main power generator G, the lower rail being cut and insulated for track circuit signaling purposes; with this arrangement, there is a voltage drop all the way along the continuous return rail, proportional to the strength of the propulsion current and the resistance of the return rail, this latter quantity depending, of course, on the weight of the rail and the length of the track circuit. With a train at B, traveling in the direction of the arrow, a voltmeter V, connected as shown, will, therefore, in the case of a direct current road, indicate a considerable D. C. drop, and this drop will appear directly across terminals A and C of the track relay X, since there is a low resistance connection over the lower rail and the axle of the train between points B and C. If a direct current track relay were used, it would pick up, even with a train in the block, providing the above drop in the return rail due to the propulsion current were high enough. This can be guarded against, first, by making the track circuits short and by increasing the carrying capacity of the return, either by bonding the return rail to an elevated structure, when the latter is available, or by providing a heavy cable in multiple with the return rail, both of which expedients will diminish the resistance of the return, and, second, by arranging the polarities of the signaling current and the propulsion current in opposition, so that, if a polarized track relay is used, the relay will be caused to close its contacts when signaling current flows through its coils, but will open its contacts with an excess of propulsion current. Even with a polarized relay, however, the direct current track circuit scheme leaves much to be desired, because the direction of the propulsion current may vary, due to a change in the distribution of the load, depending on the geographical location of the trains in relation to the power house. Altogether, therefore, the direct current track circuit is limited in its scope and is not fitted for use on electric roads. On the other hand, alternating current track circuits using relays of the vane, galvanometer, or induction motor type, are absolutely immune to direct current, regardless of both its volume and direction. Such relays respond only to alternating current and are inherently strictly selective. Alternating current track circuits have, therefore, come into general use everywhere on electric roads.

SINGLE RAIL TRACK CIRCUITS FOR DIRECT CURRENT ROADS.

1. Description and Theory. The first and simplest scheme involving a division of a road into independent track circuits, while still providing an unbroken return path for the propulsion current, is the single rail return track circuit illustrated in Fig. 86, where it will be noticed that the upper rail provides a continuous path for the return current to the power generator G, the lower rail being blocked off by insulation joints into sections for signaling purposes. Depending upon the volume of the propulsion current in the continuous rail, as well as upon its resistance and the length of the track circuit, a certain D. C. voltage will be impressed across the terminals of the A. C. track relay X, as explained in connection with Fig. 85, and even when there is no train in the block, as for example in Fig. 86, a direct current will still flow through not only the relay, but also through the secondary coil of the track transformer T. This results from the fact that the transformer secondary, the lower or block rail and the relay coil in series constitute a multiple path for the propulsion current around the return rail between A and the point where the transformer is connected to the return rail. The strength of the direct current flowing through the relay and transformer will, of course, follow Ohm's Law, varying directly with the D. C. propulsion drop between the above points on the return rail, and inversely with the sum of the resistances of the relay and transformer secondary with their

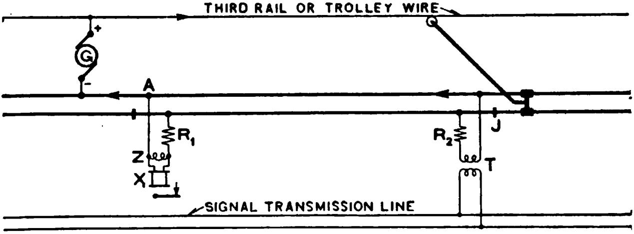


Fig. 86. Single Rail A. C. Track Circuit.

track leads, together with the complete rail circuit connecting relay and transformer.

The direct current thus caused to flow through the relay and transformer secondary in no way affects the safety of the track circuit, because the relays (vane, galvanometer, or induction motor type) are purposely designed to respond only to alternating current, as explained in Chapter IV. It is immediately apparent though, that while the relay and transformer secondary may have a high impedance or choking effect on the signaling current because of its alternating character, the ohmic resistance to a steady direct current may easily be quite low; consequently, if some means are not provided to cut down the direct current flowing from the return rail, the relay and the transformer may actually burn up. Aside from this, however, is the fact that the laminated iron cores of both relay and transformer may be highly magnetized by the direct current flowing through the coils. If sufficient direct current flows through the transformer secondary, its core may be magnetically saturated, with the result that the impedance of the primary coil falls, and an excessive current is drawn from the signal transmission line. As for the relays, those of the vane and induction motor type would likely be sluggish in their movements, due to the damping effect of the heavy direct current field, while those of the galvanometer type would likely chatter badly.

2. Limiting Resistances and Impedances. The most apparent way to limit the strength of the direct current flowing through the relay and transformer secondary is to insert resistance in the circuit, and this is quite generally done. The typical case illustrated in Fig. 86 shows resistances R_1 and R_2 inserted between the relay and the track, and between the transformer and track respectively. In the case of short track circuits of 200 feet or 300 feet in length, where only relatively small currents of say 1000 amperes flow in the propulsion rail, resistances R_1 and R_2 may be simple tubes of the proper capacity, as shown in Fig. 135, page 221, but on heavy traction roads, such, for example, as the Interborough Rapid Transit, where the currents in the propulsion rail may run as high as 3000 amperes and the track circuits are nearly 1000 feet long, heavy cast iron grids of great radiating capacity such as that shown in Fig. 144, page 237, must be employed in both the transformer and relay circuits. In the case of the transformer, of course, the series resistance R_2 not only serves to cut down the direct current, but in addition limits the short circuit A. C. signaling current with a train on the track circuit.

In very heavy propulsion systems the track relay may be still further protected by the use of an impedance coil Fig. 141, page 233, connected across the track terminals of the relay, as shown at Z in Fig. 86; this coil, which consists simply of a few turns of heavy wire wound around a laminated iron core, has a dead or ohmic resistance much less than that of the relay coil, so that the impedance coil acts as a by-pass to shunt the larger part of the direct propulsion current out of the relay, the alternating signaling current being choked back out of Z, due to the latter's self-induction.

Impedances, consisting of a coil of wire wound on an iron core, are never used on single rail track circuits for D. C. electric roads to limit the short circuit current flowing from the transformer to the track with a train in the block, as is the case on steam road track circuits. From what has already been said regarding transformers for single rail work it will be realized that the magnetizing action of the direct current flowing from the return rail because of the propulsion drop would saturate the iron core of an impedance, and then the reactance or choking feature of the impedance would be lost; the ohmic resistance of the coil would then constitute the only limit on the transformer short circuit current. For this reason, a simple resistance is always used on single rail track circuits for D. C. electric roads.

3. Transformers for Single Rail Track Circuits. To guard against the core of the track transformer becoming saturated due to the passage of propulsion current through its secondary, it is customary to provide an air gap in the magnetic circuit; such transformers are generally used on single rail track circuits, particularly on D. C. electric roads, and are known as open magnetic circuit transformers. They are fully described in Chapter VI.

4. Relays for Single Rail Track Circuits. While any of the usual A. C. relays, the vane, ironless galvanometer or polyphase induction motor type, may be used in connection with single rail track circuits, the general practice has been to use the vane, because of its simplicity and relatively high economy on short track circuits to which the single rail scheme in generally limited.

In some cases, where the propulsion current in the return rail is not too heavy and the track circuit is not too long, the relay may be wound to such a high resistance that no external limiting resistance will be required between the relay and the track as at R_1, Fig. 86. In the case of the detector circuits in the Pennsylvania New York terminal it was found possible to follow this scheme; here, however, the propulsion drop in the return rail amounted to only 4.5 volts D. C. On the other hand, in the New York Subway (Interurban Rapid Transit), a propulsion drop of 22 volts D. C. had to be allowed for, the track circuits being longer than in the case of the Pennsylvania, and both resistance R_1 and impedance Z, Fig. 86, had to be used to protect the relay.

5. Characteristics of Single Rail Track Circuits and Where They are Used. Single rail track circuits may be used wherever one of the running rails can be given up for signaling purposes. This may be a sacrifice, however, on heavy traction roads, especially where there is no elevated structure to be bonded to as an auxiliary return, and the power department of the road is likely to object to single rail circuits because of the increased drop in the return system. On the other hand, there are many cases where single rail track circuits may be used and still have sufficient return capacity for the propulsion system, as, for example, in interlockings, where many return rails may be bonded together.

Granted that one of the rails may be given up for propulsion purposes, the signal engineer may make his single rail track circuits just as long as the propulsion drop will permit. The first thing to be determined, then, is the exact amount of propulsion current to be taken care of, so that, knowing the resistance of the rail, the propulsion drop per hundred feet of continuous rail may be calculated. Knowing just what D. C. voltage the track relay and transformer can stand (taking into account if necessary the limiting resistances and shunt impedance above described), it is then a simple matter to determine the maximum permissible length of single rail track circuit. Theoretically, of course, relays, resistances, transformers, etc., might be designed to work on any length of track circuit, but practically a limiting length is reached, which, if passed involves excessive power losses in the resistances and very expensive track circuit apparatus generally. This is a matter which should receive the joint attention of the signal engineer of the road and the company manufacturing the apparatus.

On account of their relative simplicity and adaptability to fouling protection and complicated track circuit layouts through switches, single rail track circuits find their broadest application in interlockings and terminals, where due to the shortness of the track circuits, the propulsion drop limitation is not a factor. Here the double rail system, next described, requiring impedance bonds and insulation joints in both rails, is apt to be very cumbersome. Under such circumstances, the single rail track circuit has the important advantages of low first cost, simplicity in apparatus, and economy in power, besides its marked suitability to interlocking layouts. Practically all detector circuits are consequently of the single rail type.

In conclusion, it is to be noted that, while satisfactory broken rail protection is provided by single rail track circuits used on a single track line (with an isolated continuous return rail), where, if either the block rail or the continuous return rail were to break, the relay would open its contacts, equal protection is not afforded where single rail track circuits are employed on a double or multiple track road where the continuous rails are all cross bonded together, for in this latter case if the continuous rail on the track were to break, the relay on that track circuit might still be picked up with a train in the block, due to the fact that the break in the continuous rail would be bridged around by the cross bonding and the continuous rails on the other track or tracks, as the case may be; these remarks also apply of course to a single track line where the continuous rail is bonded to an elevated structure or to any other such auxiliary return.

DOUBLE RAIL TRACK CIRCUITS FOR DIRECT CURRENT ROADS.

1. Description. On account of the limitations of single rail track circuits previously discussed and to permit of both rails of a track being utilized for power returns purposes, the double rail track circuit shown in Fig. 87 was devised. As above suggested, this involves insulating both rails of abutting track circuits from each other in a signaling sense, and the novel feature of the double rail track circuit is the so called impedance bond B installed in the track circuit, as shown in Fig. 87, to provide a path for the propulsion current from track circuit to track circuit back to the negative side of the power generator. These are called *bonds* because they are low resistance connectors between adjacent track circuits, and they are *impedance bonds* because they impede, or choke back, the flow of A. C. signaling current from one rail to the other of the same track circuit across which they are connected.

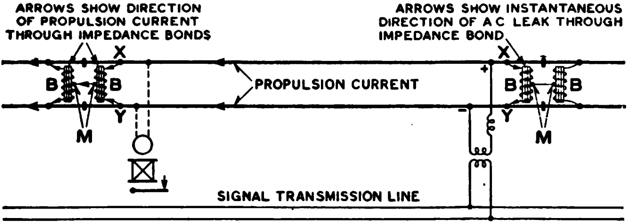


Fig. 87. Elements of the Double Rail Track Circuit.

2. Theory of Impedance Bonds. In principle, the impedance bond consists of a laminated iron core provided with two heavy copper windings wound in opposite directions and so connected, as shown at the left of Fig. 87, that the magnetizing action of the direct propulsion current in one-half of the winding is opposite to that of the other half of the winding, under which circumstances, if there are the same number of turns and amperes in each winding, the magnetizing forces will balance or neutralize each other and no magnetic flux will flow in the iron core. Now, while the propulsion current divides up in multiple through the oppositely wound halves of the bond, the A. C. signaling potential across the rails tends to force an A. C. current through the two windings *in series and not in opposition*, so that the full impedance of both halves of the bond is present to choke back the flow of signaling current from X to Y across the track. At first glance this statement may not seem to agree with what has been previously said regarding the balancing action of the propulsion current, but this balancing action results only from the fact that the two coils are wound in opposite directions, starting from the outer rail terminals X and Y from which the propulsion currents enter the bond, leaving it at the middle point M, known as the *neutral* terminal of the bond. The signaling current, however, tends to flow from X to Y, through both coils, in the same direction, as shown at the right of Fig. 87, the direction of the propulsion current being shown at the left of the same figure; of course, both the propulsion current and the signaling current flow simultaneously through the bond windings. Four separate impedance bonds are shown in Fig. 87—two at each end of the track circuit. Each set of bonds are jointed across their middle or neutral points M by a heavy cable known as the *neutral connection*, which serves to carry the propulsion current from one track circuit to the other through the bonds.

Fig. 88. Illustrating Location of Impedance Bonds in the Track. New York State Rys.

Were it not for their choking effect, the bonds would act as a short circuit across the track circuit, and indeed at all times they allow a certain amount of signaling current to leak from one rail to the other, depending on the A. C. voltage and the impedance of the bonds between rail terminals. While the windings necessarily have a very low ohmic resistance to allow the direct propulsion current to pass easily, the impedance to the A. C. leak across track is generally many hundred times the ohmic resistance, due to the fact that the bond has an iron core. With a perfect neutralization of the D. C. magnetizing forces due to the balancing action just described, the core presents a high permeability to the flux produced by the A. C. signaling current, which would not be the case if the core were saturated by the D. C. flux.

3. **Unbalancing.** With perfect bonding of the rails in a double rail track circuit, the resistance of both complete rail conductors of the track circuit should be the same, so that the propulsion current would divide equally between the rails; then the currents in the two windings of the bond would be equal and the bond would be perfectly balanced with no D. C. flux in the core. This ideal condition cannot always be assured, however, because with a loose or broken rail bond any where in the track circuit the resistance of that side of the return will be increased and less current will flow in that rail than in the other, with the result that the magnetizing action of one-half of the bond will be more than that of the opposing half, under which circumstances the balance will be upset. The difference between the direct current in the halves of the bond is known as the *unbalancing current* and its action is to magnetize the iron core; this lowers the permeability of the core, with a consequent decrease in the impedance to the leakage of A. C. signaling current through the bond. With a heavy unbalancing current, the core might actually become saturated with D. C. flux, in which case the impedance of the bond would be destroyed. To prevent this, most bonds are made with an air gap in the iron core so that the iron is not apt to become saturated with the direct current flux. By the same token, of course, the A. C. impedance of the bond is lowered, due to the high reluctance of the air gaps. Therefore, a bond with an air gap will allow a greater amount of A. C. signaling

current to leak through it than would be the case of a bond without an air gap in its magnetic circuit; but, whereas the former allows greater A. C. leakage, it is comparatively free from the action of unbalancing current, which cannot be said of the bond without air gap, whose impedance may be completely ruined by a comparatively small amount of unbalancing. Fig. 89 shows the unbalancing curves for a bond capable of carrying 2000 amperes propulsion current per rail, the air gap being 5-64 inch; the abscissa (horizontals) show the D. C. unbalancing in amperes, while the ordinates (verticals) indicate the amount of 25 cycle signaling current, which will leak through the bond with voltages as indicated on the various curves. It will be noted that the impedance of the bond is practically constant up to about 700 amperes unbalancing, particularly on the lower voltage curves. It is the general practice to design bonds to handle 20 per cent. unbalancing, without a serious decrease in the impedance; that is, the difference of the currents in the rails shall not exceed 20 per cent. of their sum.

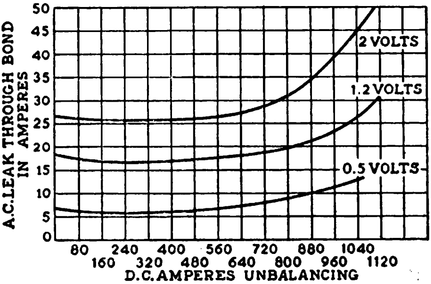


Fig. 89. Unbalancing Curves for a 2000 Amp. Impedance Bond.

Money is saved at the coal pile when the rail bonding of an electric road is kept in good condition, for, not only are losses avoided in the propulsion return, but the wasteful leakage of the alternating current through the impedance bonds, resulting from unbalancing, is eliminated. If the rail bonding becomes so bad that the unbalancing capacity of the bonds is passed, so much A. C. signaling current leaks through the bonds that the relay does not receive sufficient current to keep it picked up, in which case, of course, the signal goes to danger, even with no train in the block.

4. Impedance Bond Construction. A good idea of the actual construction of large capacity impedance bonds may be secured from Fig. 90, where it will be seen that the iron laminations are built up into a shell type core around heavy copper coils composing the winding. The copper is bare, but adjacent turns are prevented from touching each other by wooden or fibre strips employed as spacers. The two terminals projecting to the right at the top are connected together in the finished bond to form the neutral point M, in Fig. 87, while the other two straps projecting at the sides are the rail terminals shown at X and Y in Fig. 87. The air gap between the two parts of the iron core, employed to prevent saturation following unbalancing, is distinctly visible as a horizontal white line on the front face of the core; of course, there is a similar air gap in the back leg of the core, as well as in the middle leg projecting down through the coil, as would be expected with a symmetrical shell type construction. This particular bond has a capacity of 1500 amperes per rail. Its ohmic resistance (each half from rail to neutral point) is 0.00045 ohms, and its impedance to a 60 cycle signaling current is 0.21 ohms, the unbalancing capacity being about 700 amperes; on 25 cycles, the impedance would be in proportion, or 0.088 ohms.

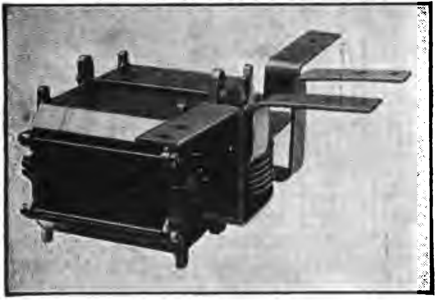


Fig. 90. Finished Core and Coils 2000 Amp. Impedance Bond.

The core, complete with its coils and insulation, is enclosed in an iron case filled, sometimes with oil, but better, with *petrolatum*, a vaseline compound which is not only an excellent insulator and protects the windings from moisture, but is a solid which cannot be forced out like oil in case the bond is flooded with water, as sometimes happens on low tracks. Fig. 91 shows two bonds of the Fig. 90 type, enclosed in their cases, and installed in a track circuit, the neutral connection between bonds being plainly visible at the left as two heavy copper cables connected in multiple. This type of bond, having a continuous capacity of about 1500 amperes per rail, is suitable for the heaviest trunk line service; for short intervals it will, of course, handle several times its normal 1500 ampere capacity. On interurban lines, the service is not so heavy, and, consequently,

Fig. 91. Track Layout of Two Heavy Traction Impedance Bonds.

Fig. 92. Track Layout of Two Interurban Road Impedance Bonds.

the currents in the rails are less—in most cases normally not over 500 amperes per rail; here, then, smaller bonds may be used, as illustrated in Fig. 92.

5. **Cross Bonding.** Cross bonding between tracks is effected by connecting the neutral points of the bonds, as at A, B and C, in Fig. 93. The negative return connection to a power house, or substation, should always be made from the neutral point of a bond inserted, if necessary, in a track circuit, as at E, in Fig. 93; preferably, however, the negative return should be connected to the neutral point of one of the bonds at the end of a track circuit, if the location of the power house will allow of this, as it is undesirable to insert an extra bond in the midst of a track circuit, not only on account of the cost of the bond, but particularly because of the extra leak it constitutes in the track circuit. Short stub sidings, used merely for car storage purposes, may be insulated as at D, Fig. 93, for even if their is considerable unbalancing with a train beyond the insulation joint J on a short siding, the main line switch would be reversed anyway, opening the signal control circuit and throwing the signal to danger, regardless of the effect of unbalancing on the bonds, and the consequent reduction of voltage on the track relay. Again, if the fouling point on siding D is close to point C, at the end of the track circuit on the main line, two joints, instead of one, may be placed in the siding at fouling point, the return current from the rails out of the fouling back of the joints being carried by a cross bond to neutral point C, both of the rails in the siding back of the joints in the dead section being bonded together; with such an arrangement, of course, unbalancing of the main line track circuit will be avoided. Finally, where

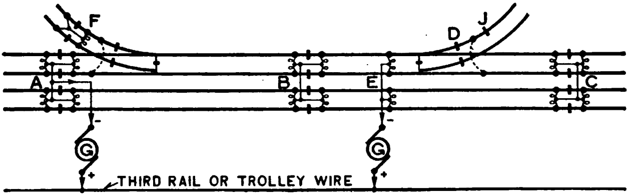


Fig. 93. Methods of Cross-Bonding, Insulating and Bonding of Sidings, and Making Return Connection to Power House.

there is considerable traffic on a long siding, and there is no main line neutral point C at hand, then a single impedance bond may be installed, as shown on the spur track F, where the neutral point of the bond is connected to both dead rails beyond the insulation joints in the spur.

6. Relays for Double Rail Track Circuits on D. C. Electric Roads. Vane, galvanometer, or induction motor, relays (see Chapter IV), are used on double rail track circuits just as on steam or single rail electric road track circuits; in order to keep down the leakage of A. C. signaling current across track through the impedance bonds, however, it is desirable to use a comparatively low A. C. voltage on the track, and, therefore, relays for double rail track circuits are always wound for a low voltage, and a proportionately higher current; otherwise, these relays are exactly the same as the steam road relays.

7. Transformers, Resistances and Impedances for Double Rail Track Circuits on D. C. Electric Roads. Either adjustable filler or constant potential track transformers (sec Chapter VI) may be used, but they must have a greater capacity than steam road track transformers, because the electric road transformers must be large enough to supply the current leaking through the bonds, in addition to that required for the relay. Due to the fact that there is little or no D. C. propulsion drop to guard against, as in single rail track circuits, impedances with iron cores may be used, when required, between the transformer and the track, to limit the short circuit current with a train on the track circuit. Either a simple resistance coil or an impedance may be used between the transformer and the track, on vane relay track circuits, because phase relations are of no importance in the case of a single element relay like the vane; the use of an impedance, however, is advisable, as it is more economical in power, because, whereas the drop through the impedance is almost wattless, the drop through a dead resistance is wasted in heating. With the galvanometer relay, impedance is generally required between the transformer and the track to bring the track current in phase with the current in the local. The induction motor or polyphase relay, on the other hand, generally works best with a resistance between the transformer and the track, because this type of relay is most economical of power when its track and local currents are in quadrature. For a description of the various resistances and impedances in standard use, see Chapter VII; for a full discussion of the factors governing their selection see Chapter XIII.

8. **Characteristics of Double Rail Circuits.** As has been pointed out, single rail track circuits are limited in their length by D. C. propulsion drop, but no such restriction holds with double rail circuits; for this reason the double rail circuit is particularly adapted for heavy electric traction, and there are many cases where 10,000-ft. end fed, and 25,000-ft. center fed, double rail circuits are being successfully operated. Adequate broken rail protection can be insured with this type of track circuit. Finally, double rail track circuits are very stable, and not so liable to be affected by variations in ballast leakage; this stability results because the impedance bonds connected across track are of such low resistance, as compared with the ballast, that changes in the value of the latter are not of much influence on the track circuit as a whole.

9. **Standard Bonds and Layouts for D. C. Electric Roads.** At the end of this chapter, a number of plates will be found, showing the standard bonds used in direct current propulsion work, together with drawings showing how they may be set and connected into the track.

TRACK CIRCUITING ON ELECTRIC ROADS USING A. C. PROPULSION.

1. **General Scheme and Relays Used.** The characteristic feature of track circuit apparatus for electric roads using alternating current propulsion is the track relay. Thus far, all the alternating current roads in this country employ a propulsion frequency of 25 cycles. Differentiation between the propulsion current and the signaling current is secured by using a higher frequency for signaling than for propulsion; a 60 cycle current is now generally used for signaling purposes under such circumstances. The track relay must,

therefore, be immune, not only to direct current (for foreign currents leaking from adjacent D. C. interurban roads are not uncommon), but in addition, it must be able to select between the 25 cycle propulsion current and the 60 cycle signaling current. Either the Centrifugal Frequency relay or the Vane Frequency relay, both of which are fully described in Chapter IV, fulfill these requirements.

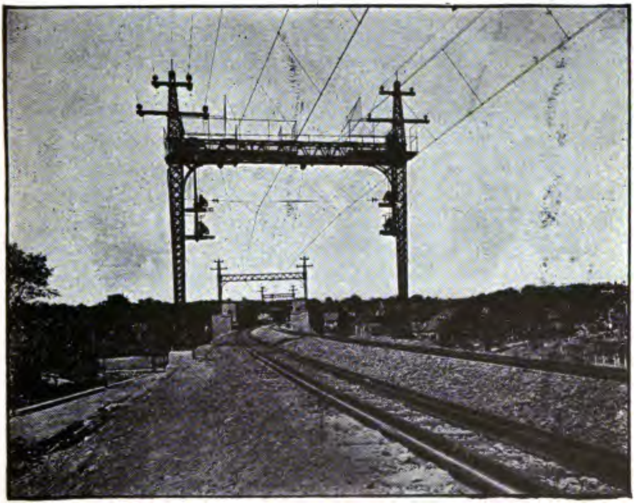


Fig. 94. Signaling on an A. C. Propulsion Road, New York, Westchester and Boston R. R.

2. Single Rail Track Circuits on A. C. Propulsion Roads. On alternating current roads, as well as on steam roads and lines using direct current propulsion, short single rail track circuits are used through interlockings for detector circuit work, and the vane type frequency relay is generally used for this purpose, because of its exceedingly rapid action. Here, as in all cases where the single rail scheme is used, the length of the track circuit is limited by the A. C. propulsion drop in the return rail, and, in laying out the track circuits, care must be taken so that this drop is not sufficient to to cause an injurious heating current to pass through the relays and transformers.

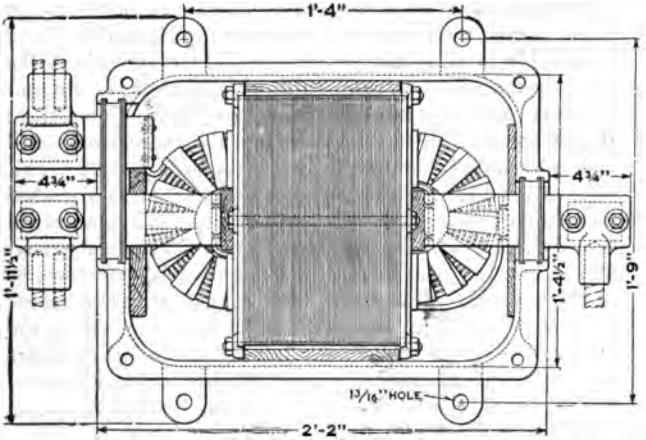
3. Double Rail Track Circuits and Impedance Bonds for A. C. Propulsion Roads. In all cases where the track circuits are of considerable length, as in automatic block signal territory, double rail track circuits are used, and, for this service, the centrifugal type relay is generally employed, for reasons of power economy. The impedance bonds for double rail track circuits, on roads using alternating current propulsion, employ the same principle of magnetic balancing as characterizes the bonds for direct current roads, for, although the propulsion current is of an alternating character, still it is divided up, presumably equal, between the two opposing windings of the bonds, so that the alternating magneto-motive forces are equal and opposite, and hence neutralize each other. The iron core of the bond remains, therefore, unmagnetized, so that it offers a high permeability to the magneto-motive force generated by the alternating signaling current flowing through the two coils in series, as prevoiusly explained in connection with the bonds for direct current propulsion.

The principle claim made for the alternating current system of propulsion is that it dispenses with rotary converters and other auxiliary apparatus required in the direct current system of propulsion to translate the alternating current energy received from the main transmission line to direct current for propulsion purposes. Rotary converters are not suitable for voltages much over 1200 or 1500 volts, and therefore, the trolley, or third rail must be of considerable conductivity, because of the heavy current being carried. This does not apply to the alternating current systems, as transformers can be built nowadays for almost any voltage, so that 11,000 volts is now generally used for propulsion on A. C. roads. With such high voltages, the propulsion currents themselves are very small, and, therefore, the impedance bonds do not have to carry so much current, and are much smaller than on D. C. roads. As a matter of fact, the current per rail on most alternating current propulsion systems generally will not run over 75 or 100 amperes per rail normally, which is only about 5 per cent. of the current used on heavy traction D. C. systems.

Impedance bonds for roads using alternating current propulsion are, therefore, much smaller than would be the case if direct current were used; as a matter of fact, it is often found practicable to place two of these small bonds,one above the other, in the same iron case, which makes the bond layout connecting two adjacent track circuits rather simple. One of these double bonds, with the two cores and their windings housed in the same case, is shown in Fig. 98; a novel feature of this type of bond is that the iron case itself serves as a neutral connection between the two parts of the bond, the neutral terminals of both windings being simply bolted to the case. Hence, in this type of bond, only four terminals project outside of the case. It will be noted, from Fig. 98, that the copper winding is wound flat-wise, like an oblong roll of ribbon; the copper forming each winding is bare, but adjacent turns are separated from each other by a fibre ribbon wound between the turns. Of course, the windings themselves are very carefully insulated from the iron core.

4. Unbalancing. Unbalancing troubles are rare on roads using alternating current propulsion, not only because the propulsion currents themselves are small in volume, but especially because, if more current flows in one-half of the bond than the other, the half winding carrying the heavier current induces a voltage in the weaker half, tending to pull a larger current through that weaker half. Thus, an automatic action exists, which tends to keep the bond well balanced. For this reason, the bonds are not liable to be unbalanced, and no air gap is required in the magnetic circuit to prevent saturation of the core, which would otherwise occur.

5. Standard Bonds and Layouts for A. C. Electric Roads. At the end of this chapter, a number of plates will be found showing the standard bonds used on electric roads using A. C. propulsion, together with drawings showing how the bonds may be set and connected in the track.



PLAN VIEW
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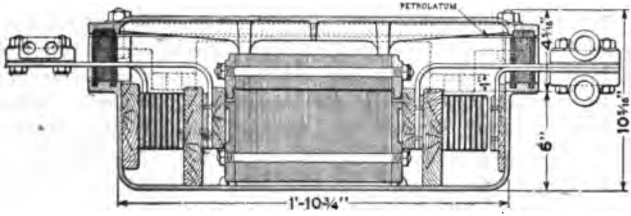
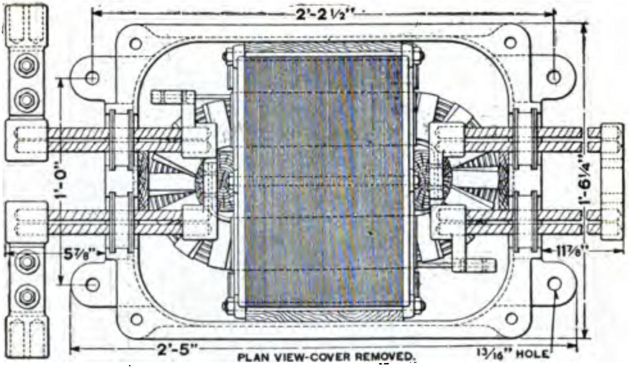


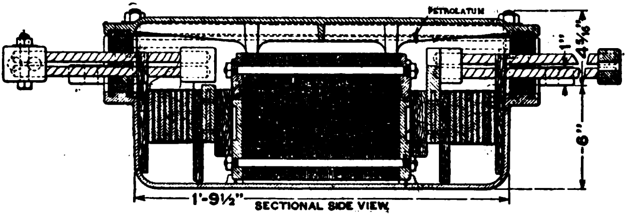
SECTIONAL SIDE VIEW

CHARACTERISTICS.

Propulsion	Capacity Amps. per Rail (continuously)	Layout Fig. No.
D. C.	1500	101

Fig. 95. Impedance Bond for D. C. Propulsion For Heavy Traction Service.

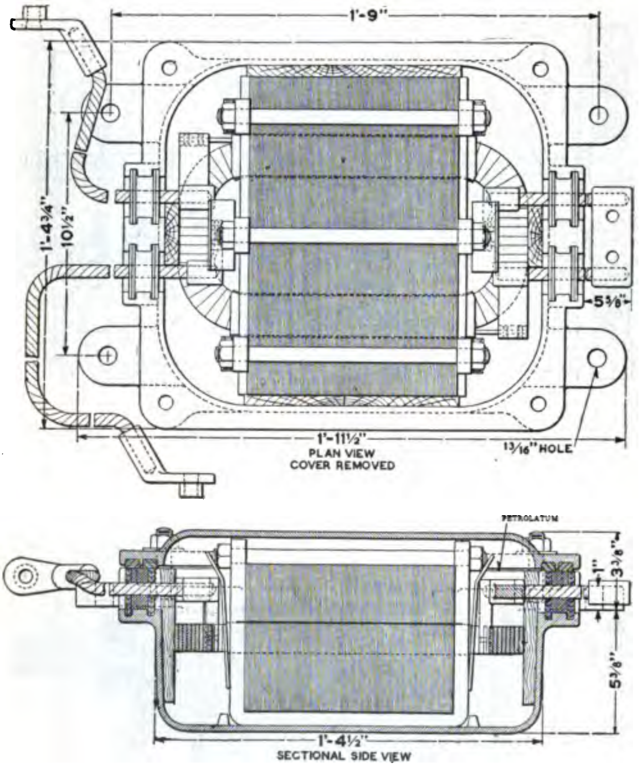




CHARACTERISTICS.

Propulsion	Capacity Amps. per Rail (continuously)	Layout Fig. No.
D. C.	1500	100

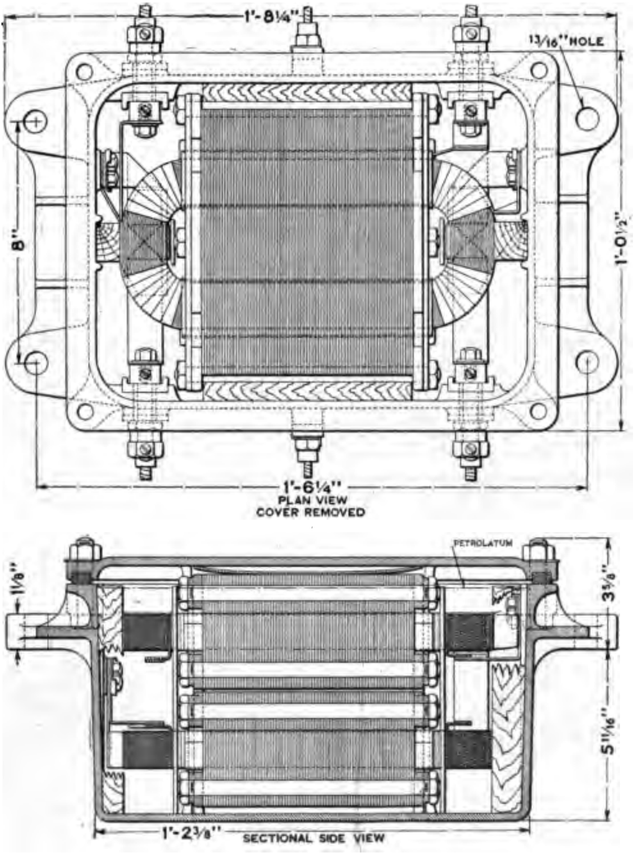
Fig. 96. Impedance Bond for D. C. Propulsion For Heavy Traction Service.



CHARACTERISTICS.

Propulsion	Capacity Amps. per Rail (continuously)	Layout Fig. No.
D. C.	500	102,103
A. C.	200	104,105

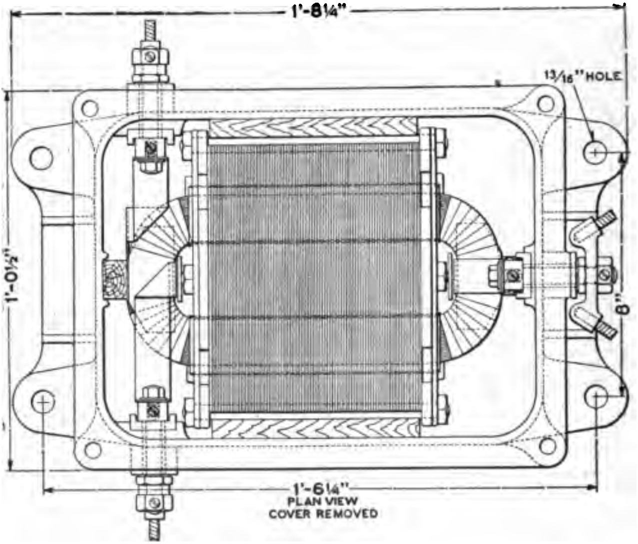
Fig. 97. Impedance Bond for D. C. or A. C. Propulsion.



CHARACTERISTICS.

Propulsion	Capacity Amps. per Rail (continuously)	Impedance (between rails) 60 cycles	Layout Fig. No.
A. C.	50	10.0 ohms	106
A. C.	75	2.3 ohms	106

Fig. 98. Double Impedance Bond for A. C. Propulsion.



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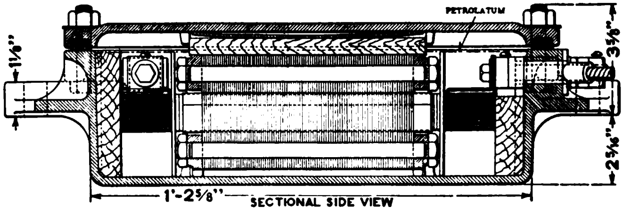


SECTIONAL SIDE VIEW

CHARACTERISTICS.

Propulsion	Capacity Amps. per rail	Impedance (between rails) 60 cycles	Layout Fig. No.
A. C.	50	10.0 ohms	Similar to Fig. 106
A. C.	75	2.3 ohms	

Fig. 99. Single Impedance Bond for A. C. Propulsion.

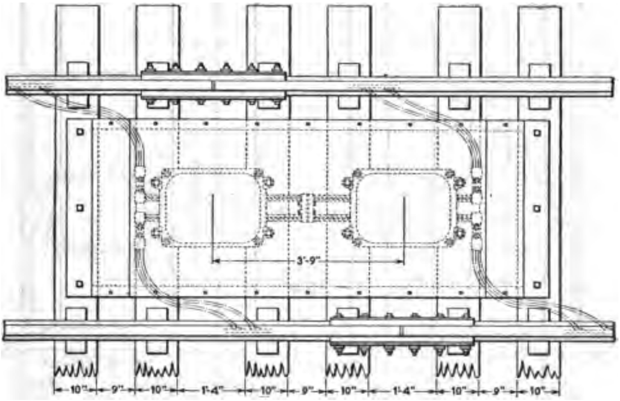


Fig. 100. Double Layout for 1500 Amp. Bond, Fig. 96; the Two Bonds Shown Above are Provided with a Sheet-Iron Cover for Protection Against Dragging Car Rigging.

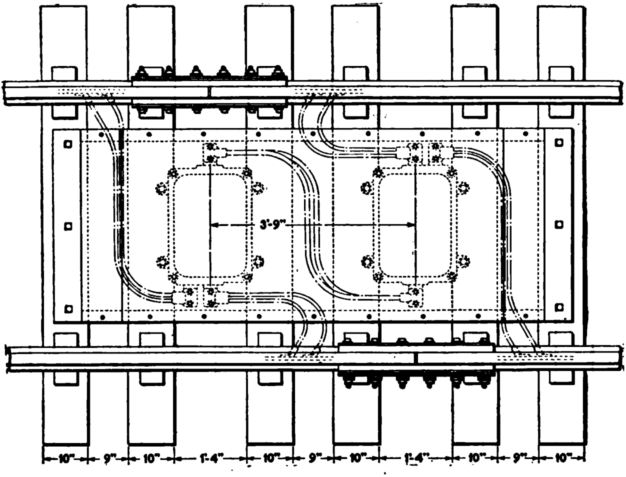


Fig. 101. Double Layout for 1500 Amp. Bond, Fig. 95; the Two Bonds Shown Above are Provided with a Sheet-Iron Cover for Protection Against Dragging Car Rigging.

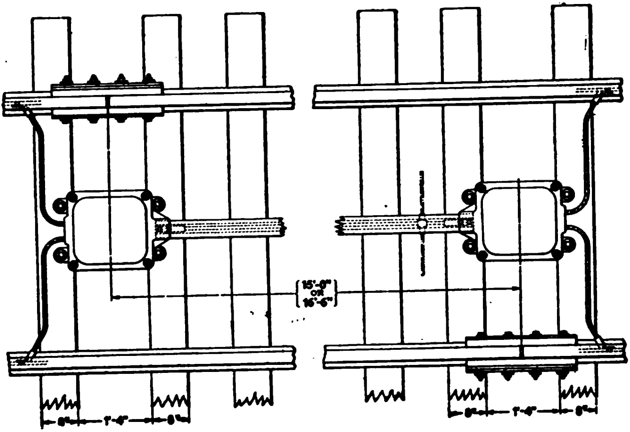
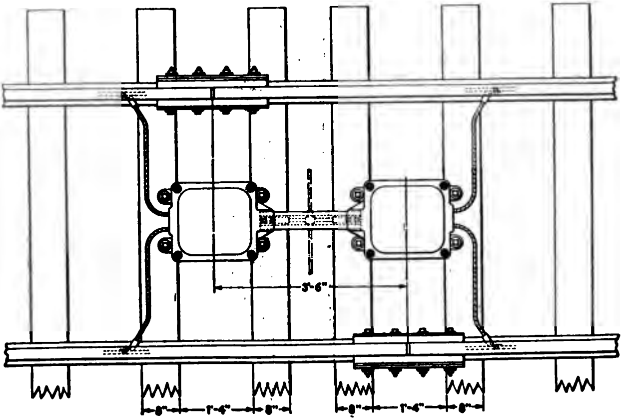


Fig. 102. Double Layout for 500 Amp. Bond Fig. 97. In This Layout the Neutral Connection Between Bonds is Made Long Enough to Eliminate the Necessity of Cutting the Rails to Make the Insulation Joints Come Opposite; Compare With Fig. 103.



3. Double Layout for 500 Amp. Bond Fig. 97. In This Layout ls are Cut to Permit the Bonds Being Placed Close Together.

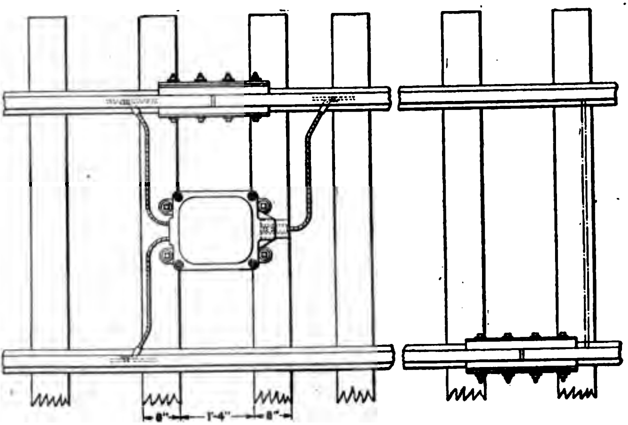


Fig. 104. Single Layout for 500 Amp. Bond Fig. 97 For Use at the End of Track Circuited Territory. The Single Lead at the Right Connects to Non-track Circuited Road.

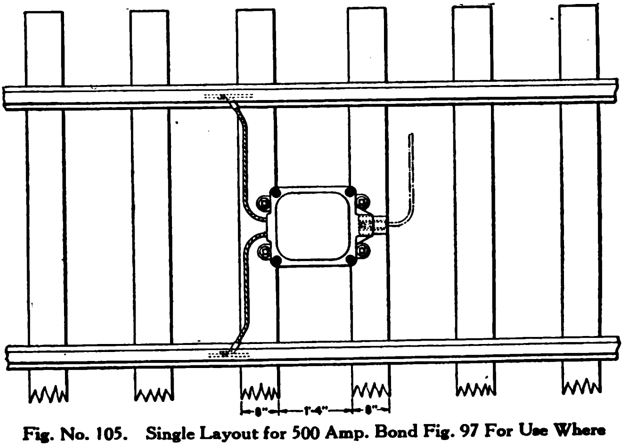


Fig. No. 105. Single Layout for 500 Amp. Bond Fig. 97 For Use Where it is Desired to Make Connection to a Power House or to Cross Bond to a Switch or Siding.

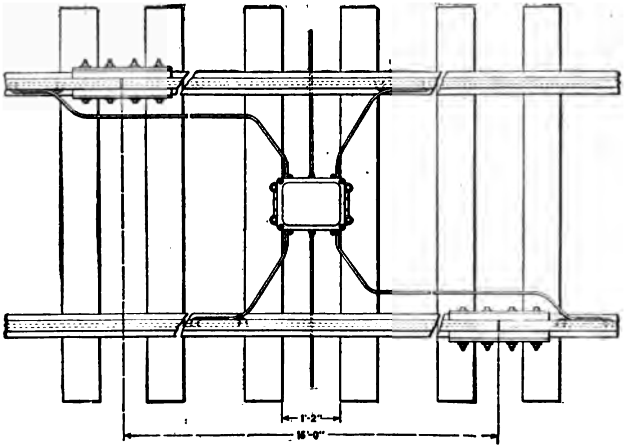


Fig. 106. Layout for Double Bond Shown in Fig. 98. The Rail Cables are Soldered at Their Bond Ends Into Eye Connectors Bolted to the Bond Terminals; the Rail Ends of the Cables are Soldered to U-shaped Connector, Fastened at Each End to the Rail by Channel Pins.

CHAPTER VI.

TRANSFORMERS.

CHAPTER VI

TRANSFORMERS

1. General. Transformers fulfill the same function in alternating current signaling systems as do the batteries in direct current systems; that is, power is drawn from the transformers or batteries for the operation of the track circuits and signals. *Line transformers* are those which supply the relatively high voltage, generally 55 or 110 volts, best suited to the operation of signal motors and slots. *Track Transformers,* supplying lower voltages of from 5 to 15 volts, feed the track circuits. In broad theory and general construction, all transformers, whether line or track, are the same, and the present chapter will, therefore, be devoted to a description of the theory and construction of transformers as used in signal work.

When it is desired to convey power over a transmission line from a power house to some distant point, the wires ought to be made as small as possible to save money in copper. At the same time, the power lost in the transmission must not be large if the system is to be economical. The power loss in a transmission line is $I^2 R$, the square of the current flowing in the wires multiplied by their total resistance. The electric transmission of a given amount of power can be made through the use of a large current at a small voltage, or by a small current at a proportionately higher voltage. In the first case, large and expensive copper wires would have to be used if the $I^2 R$ loss is to be kept within reasonable bounds. In the second case, comparatively small and inexpensive transmission wires may be employed. It is therefore necessary in the interest of economy to use high voltages in the long distance transmission of power. In alternating current signal systems, the power is generally conveyed at 2200 volts or higher over the transmission. Of course, it would be out of the question to utilize such a high voltage directly on signal motors, relays, and the like, not only because of insulation difficulties, but especially because of the personal danger element. Therefore, means must be provided along the line to transform the power from the high electro-motive force and small current to a low electro-motive force and proportionately higher current.

The transformer fulfills this function. It does not generate power; it merely changes the power from one voltage to another.

2. Elements. The transformer in its simplest form consists of two separate and distinct coils of wire wound around the same iron core as shown in Fig. 107. The coil which receives alternating current at the original voltage from some outside source is known as the *primary* coil. The coil which delivers power from the transformer is known as the *secondary* coil. The transfer of power from the primary to the secondary takes place through the medium of the magnetic flux produced in the iron ring by the alternating current flowing in the primary coil; this flux, being consequently of an alternating character, rising, falling, and changing direction, cuts the turns of wire composing the secondary and induces an electro-motive force in the secondary coil. The voltage induced in the secondary coil depends on the rate at which the flux lines cut the secondary turns, and can be calculated once the frequency, total flux, and number of turns are known.

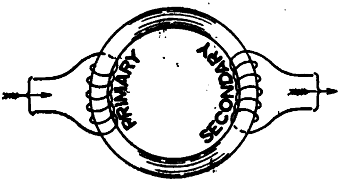


Fig. 107. Elements of the Transformer.

3. Step-up and Step-down Transformers; Ratio of Transformation. A *step-up* transformer is one which receives power at a low voltage and delivers it at a higher voltage; in this case, of course, the primary voltage is lower than that of the secondary. *Step-up* transformers are used for example, in power houses to transform the low voltage of the generators up to the high voltage of the transmission. *Step-down* transformers receive power at a high voltage and deliver it at a low voltage; such transformers are located out along the transmission line to transform the high transmission voltage to a low one for feeding track circuits, signals etc. The *ratio of transformation* is the ratio of the primary voltage to the secondary voltage; thus a transformer with a 2200 volt primary and a 110 volt secondary has a 20 to 1 ratio.

THEORY OF TRANSFORMER

4. No Load. When the secondary of a transformer is on open circuit, no current is, of course, flowing in that coil, under which condition the transformer is said to be operating at *no load*. The primary coil receives some current from the mains, however, and the flux resulting from the magnetizing action of the primary, rapidly alternating with frequency, cuts both primary and secondary coils, inducing a voltage in each of them as a consequence. The voltage induced in the primary coil is opposite in direction and very nearly equal in magnitude to the voltage impressed on the primary by the supplying circuit. In other words, the primary circuit is highly inductive so that only a little current flows into the primary from the mains because of this choking action; the small current which flows is proportional to the difference between the voltage E_1 impressed on the primary and the voltage e_1, induced in the primary coil by its own flux.

These relations will be more clearly understood from a study of the vector diagram (A) at the left of Fig. 108, covering an ideal transformer—one whose iron core is so perfect that no losses are produced in it, one in which the ohmic resistance of both primary and secondary coils is negligibly small, and finally one whose primary and secondary coils are so interlaced with one another that all the flux which links with one also links with the other so that there is no magnetic leakage. Of course, the flux generated in the iron core of such a transformer

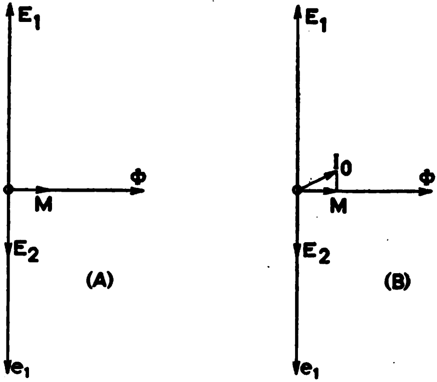


Fig. 108. Vector Diagrams of Transformer Working on No Load.

varies periodically and accompanies in phase the magnetising current which produces it. It is also fundamental that the voltages induced in the primary and secondary coils by the changing flux must lag 90 degrees behind the flux because it is when the flux is changing most rapidly at the zero point of the sine curve that the induced voltage is the greatest. These relations are illustrated by the diagram (A) at the left of Fig. 108, where e_1 and E_2 are the voltages induced in the primary and secondary coils respectively, by the flux caused to flow in the iron core of the transformer by the primary magnetizing current M, itself proportional to the difference between E_1, the voltage impressed on the primary by the mains, and e_1, the primary induced counter e.m.f. These relations hold for an ideal transformer working at no load.

In an actual transformer, however, the periodical alternating magnetic flux causes certain losses in the iron core which manifest themselves in heating. These losses, known as *iron losses*, consist first of the *hysteresis loss* spent n overcoming the friction between the molecules of iron as they move backward and forward with the changes in the direction of the flux, and second of *eddy current loss* spent in the heating action of the currents induced in the iron core by the varying flux. The eddy currents are in phase with the induced voltages producing them, and, of course, these voltages lag 90 degrees behind the flux, so that the corresponding opposite voltages and currents which must be supplied to the primary to compensate for the iron loss are 90 degrees ahead of the flux. Therefore, an iron loss component MI_0 must be added to the magnetizing current OM shown vectorially in diagram (B) at the right of Fig. 108, where the total primary no load current is represented by OI_0. The two components OM and MI_0 cannot be added arithmetically, as they are not in phase; they must be added geometrically as shown, in the same manner as two forces are combined by the well-known parallelogram of forces.

5. Loaded. When the secondary of a transformer is on open circuit, no current flows through that coil, but, of course, full voltage is generated in it by the alternating flux. The instant the secondary circuit is closed, current flows in the secondary and then the transformer is said to be *loaded*. The direction of the secondary current is, of course, opposite to that of the primary current, and, consequently, the magnetizing action of the secondary current opposes and neutralizes to a certain degree the flux produced by the primary, so the counter electro-motive force generated in the primary by the alternating core flux falls. Instantly, however, the primary current increases, because the difference between the impressed and counter e.m.f.'s of the primary is larger than it was with the transformer working on no load. In fact, the increase of primary current due to the loading of the transformer is just great enough to balance the de-magnetizing action of the current flowing in the secondary coil. *The result is that the flux in the core is maintained practically constant by the primary, regardless of the load on the secondary.* The transformer is, therefore, automatic in its action; the power taken by the primary from the supply mains increases and decreases as the load on the secondary rises and falls.

6. Voltage and Current Relations. It has been stated that the voltage induced in the secondary can be calculated once the total maximum flux Φ at the top of the sine wave, the secondary turns N_2, and the frequency in cycles per second are known. Just one-quarter of a cycle or 90 degrees after the flux Φ has reached its maximum value, it has decreased to zero. If the flux is alternating at the rate of f cycles per second, then the time corresponding to one-quarter of a cycle is $\frac{1}{4f}$ seconds, and the average rate of change, per second, of flux from Φ to zero during that time is $\frac{\Phi}{\frac{1}{4f}} = 4f\Phi$ lines. If this average rate of change of flux occurs through N_2 secondary turns, then the total average induced secondary voltage is $\frac{4f\Phi N_2}{100{,}000{,}000}$ volts, since 100,000,000 flux lines must cut a conductor in one second to induce a volt in that conductor. For a sine wave, the effective value of the voltage, as indicated by the ordinary voltmeter, is 1.1 times the average value, so that the effective secondary voltage is:

$$E_2 = \frac{4f\,\phi\,N_2}{100{,}000{,}000} \times 1.1 \qquad (1)$$

$$= \frac{4.44\,f\,\phi\,N_2}{100{,}000{,}000}$$

which is the fundamental equation used in transformer design.

Of course, the primary induced voltage can be similarly calculated from the flux and primary turns. From equation (1) above, it is evident that the voltage induced in the primary and secondary coils is simply proportional to their respective turns, since the same amount of flux cuts each coil. Because of the automatic action of the transformer already described, the core flux remains constant in quantity regardless of the load and hence the primary induced voltage is always sensibly equal to the voltage impressed by the primary from the mains. Hence:

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \qquad (2)$$

Where E_1 is the voltage at which power is supplied to the primary, E_2 is the voltage at which the secondary delivers power, and N_1 and N_2 are the number of turns in the primary and secondary coils respectively.

The magnetizing force exerted on the iron core by a load current of I_1 amperes flowing in the primary coil of N_1 turns may be expressed as the product I_1N_1, this product of amperes times turns being known as *ampere turns*; a given magnetizing force can be produced either by a large number of amperes flowing through a small number of turns, or vice versa. The magnetizing action of the secondary current may be expressed by the prodnct $I_2\,N^2$, where I_2 and N_2 are the secondary current and turns, respectively. It has been shown that the magnetizing action of the load currents in primary and secondary balance each other; in other words, they are equal. Hence,

$$I_1\,N_1 = I_2\,N_2 \qquad (3)$$

and

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} \qquad (4)$$

Where I_1 is the load current in the primary; that is, the increase in current due to the load over and above the no-load magnetizing current. In a well-designed transformer, this no-load current for magnetization is insignificant as compared with the normal load current, so that, for all practical purposes it may be said that the *the primary and secondary currents are inversely proportional to their respective turns, as shown by equation (4)*.

To illustrate the above relations, suppose a transformer has 5500 turns in its primary coil, 275 turns in its secondary, and power is supplied to the primary at 2200 volts. By equation (2) above, the secondary voltage must be 110 volts, since the primary and secondary voltages are to each other in direct proportion to their respective turns. If the secondary coil is to deliver 5 amperes, then from equation (4) the primary must be supplied with 0.25 amperes in addition to a slight no-load current, for the primary and secondary currents are in *inverse* proportion to the number of their respective turns.

7. Effect of Power Factor. If the secondary of a transformer is to supply, say, 1100 watts at 110 volts at unity power factor, the secondary current will, of course, be 10 amperes, since

$$\text{Watts} = I\,E \cos\Theta \qquad (5)$$

Where $\cos\Theta$, the power factor, is unity. If, however, as is very often the case in signal work, the secondary is required to furnish the same amount of power as before, at say 0.5 power factor, instead of unity factor, then from equation (5) the secondary current will be 20 amperes, and the transformer windings must be large enough to supply this heavier current without overheating. For this reason the capacity of transformers should always be stated in K. V. A. (the usual abbreviation for Kilo-Volt-Amperes, where one K. V. A. is equal to 1000 volt-amperes) and not in K. W. (abbreviation for Kilo-Watts, one of which is equal to 1000 watts).

When a transformer is supplying power at approximately unity power factor, the secondary current is, of course, approximately in phase with the secondary voltage; the corresponding load current in the primary is opposite to the secondary current and of such a volume that the product I_1N_1, of primary load current by primary turns, just balances the

the secondary ampere turns to maintain the automatic transfer of power between primary and secondary above explained. These relations are illustrated in diagram (a) at the left of Fig. 109, where OI_2 is the secondary current, OA is the corresponding balancing primary load current, OI_0 is the no-load primary current, and OI_1 the total primary current composed of load and magnetizing components OA and OI_0 as shown, OE_1 being the impressed primary voltage as usual. It will be noted from diagram (a) Fig. 109 that with the secondary operating at nearly unit power factor on a non-inductive load, the total primary current OI_1 is much nearer in phase with the primary impressed voltage than the no-load current OI_0. When, on the other hand, the secondary is feeding power to a highly inductive load at a low power factor, the secondary current OI_2 in diagram (b) at the right of Fig. 109 lags away behind the secondary voltage E_2 and consequently the total primary current OI_1 lags farther behind the primary impressed voltage than does the no-load current OI_1.

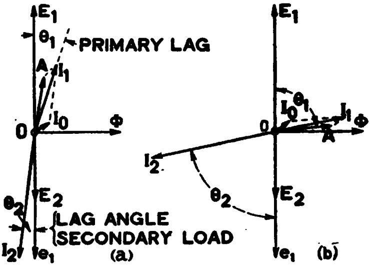


Fig. 109. Effect of Secondary Power Factor on Primary Current Vector.

8. **Effects of Coil Resistances and Magnetic Leakage.** The terminal pressure on the primary of a transformer has not only to balance the counter electro-motive force induced in the primary by the magnetic flux, but also has to be in excess of it to overcome the ohmic resistance of the primary winding and the inductive reactance caused by magnetic leakage. Magnetic leakage in transformers is produced by a certain number of magnetic lines not being interlinked with both primary and secondary winding. This amount of leakage is very small in good modern transformers, because the primary and secondary windings are interlaced in several layers. This leakage cannot, however, be completely eliminated and must be taken into account. The leakage lines of force induce a counter e.m.f. in the primary which is not transmitted to the

secondary and, therefore, causes a loss of voltage, much like the loss of voltage due to the dead resistance of the primary winding. The same two factors also diminish the secondary terminal voltage. An actual transformer with resistance and leakage losses acts just like an ideal transformer free from such losses, but having connected in series with it a dead resistance equal to that of the actual transformer and a reactance coil possessing an inductive reactance equal to that due to the magnetic leakage in the actual transformer; Fig. 110 shows an ideal transformer so connected.

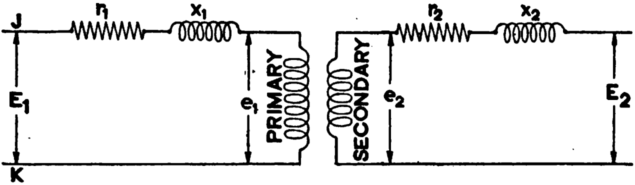


Fig. 110. Practical Equivalent of an Ideal Transformer.

The corresponding complete vector diagram for the actual transformer is shown in Fig. 111, where oe_1, and oe_2 are the induced primary and secondary voltages respectively, while OI_1 and OI_2 are the total primary and secondary currents; the same lettering applies to both Figs. 110 and 111. The voltage E_1 applied across points J and K in Fig. 110, has to be larger than e_1 by an amount necessary to overcome the ohmic drop in r_1, and the inductive drop in x_1. In Fig. 111 this ohmic drop is represented by the vector e_1 C_1 naturally in phase with and parrallel with the primary current OI_1, which produces the drop. The inductive drop across x_1 is represented by C_1 E_1 at right angles to the primary current OI_1. A total voltage of O E_1 must therefore be applied to the primary terminals. Similarly, the secondary terminal voltage is less than the full secondary induced voltage e_2, by the amount lost in the secondary resis-

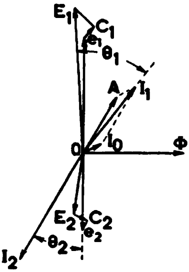


Fig. 111. Complete Transformer Vector Diagram.

tance r_2, and the reactance x_2; the ohmic drop lost in the secondary is represented in Fig. 111 by vector $e_2\ C_2$ and the inductive drop by vector C_2E_2, respectively, parallel and perpendicular to the secondary current OI_2. These losses must be subtracted from the original induced voltage e_2 so that the net secondary terminal voltage is $O\ E_2$. Fig. 111, therefore, covers the general case met with in commercial practice of a transformer with iron losses, copper losses, and magnetic leakage.

9. Efficiency. The efficiency of a transformer may be expressed as:

$$\text{Efficiency} = \frac{\text{Output of secondary in watts}}{\text{Input of primary in watts}} \qquad (6)$$

which is simply the ratio of secondary watts to primary watts as indicated by watt meters in the two circuits. However, it is generally more convenient for purposes of analysis to regard the efficiency as:

$$\text{Efficiency} = \frac{\text{Secondary output}}{\text{Secondary output} + \text{total losses}} \qquad (7)$$

The losses in a transformer consist of (a) core losses in the iron and (b) copper losses.

(a) Iron Losses. The losses which take place in the iron core of a transformer are divisible into hysteresis losses and eddy current losses. *Hysteresis* losses may be roughly ascribed as due to friction between the molecules of iron as the flux alternates, and depend upon the frequency of the magnetizing current, the value of the magnetic flux, and upon the volume of the iron and its quality. According to a formula devised after much experiment by Dr. Steinmetz, the hysteresis loss in watts in a given volume V cubic centimeters of iron, working at a flux density of B lines per square centimeter is:

$$W_h = \frac{B^{1.6}\,f\,V\,n}{10{,}000{,}000} \qquad (8)$$

where f is the frequency and n is a factor depending on the quality of iron; in modern silicon steel n is about 0.00093. It is apparent from this formula that with a given quality of iron the hysteresis loss will increase with the frequency and the flux density.

Voltages are induced in the iron core itself by the alternating flux, just as in the coils on the core, as, of course, the flux in reversing cuts the whole magnetic circuit. These voltages cause *eddy currents* to flow in the iron core in a plane at right angles to the flux lines, and if the core were not built up of thin sheets, painted on both sides to insulate one sheet from another and piled in a direction such that eddy currents would have to flow through the insulation between sheets, then the watts lost through eddy currents would be excessive; if solid iron cores were used in A. C. apparatus, even a small voltage would cause enormous eddy currents to flow. The eddy current loss in watts is in a volume of V cubic centimeters of iron at a frequency of *f* cycles per seconds is:

$$W_e = \frac{V\ f^2\ B^2\ t^2\ b}{10{,}000{,}000} \qquad (9)$$

where B is the flux density, *t* is the thickness of each lamination in centimeters, and *b* is a factor depending on the resistance of the iron; where silicon steel is used, b is about $\frac{0\ 57}{10^{11}}$ Evidently, therefore, the thinner the laminations, the less the eddy current losses.

A graphical illustration of the significance of the above important formulas is afforded by Fig. 112, which shows the total iron loss in watts per pound of a well known grade of silicon steel rolled in laminations, 0.014-inch thick, and worked at varying flux

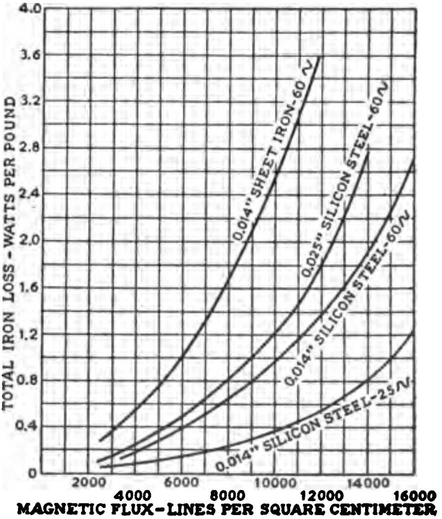


Fig. 112. Iron Loss Curves.

densities at frequencies of 25 and 60 cycles. From the two lower curves, it will be seen that at a flux density of 10,000 lines per square centimeter the iron loss at 60 cycles is about two and one-half times the loss at 25 cycles. It will also be seen from the next to the top curve that the loss in laminations 0.025-inch thick at 60 cycles and 10,000 lines is about 20 per cent. greater than the loss at the same density and frequency in laminations 0.014-inch thick. Silicon steel is a development of the last few years; it is not only remarkable for its low initial losses, but also because of the fact that its losses do not increase after a transformer has been in service for a long time. The top curve in Fig. 112 is the characteristic of a common cheap grade of sheet iron whose losses increase with ageing; from an examination of this curve, it is evident that even the initial losses of the sheet iron are not to be compared with those of the better silicon steel.

(b) **Copper Losses.** These losses are simply due to the heating effect I^2R of the currents flowing in the primary and secondary coils. Therefore, if a current of I_1 amperes is flowing in a primary of R_1 ohms resistance, and I_2 amperes are flowing through a secondary resistance of R_2 ohms, the total copper loss is:

$$W_c = I_1{}^2 R_1 + I_2{}^2 R_2 \qquad (10)$$

Because of the fact that only a small current flows when the transformer is running on no-load, the copper loss at that time is almost insignificant, the principal loss being the iron loss, which is constant at all loads, since the magnetic flux is constant. Therefore, where transformers are always connected to the primary feeding mains (as is generally the case) regardless of whether the transformer is loaded or not, it is important that thin laminations of good steel be used in the core to keep the core loss down, as it is going on all the time, even when power is not being drawn from the secondary. On the other hand, copper must not be sacrificed in the construction of the transformer, lest the copper losses at full load be excessive.

The copper losses in a transformer can easily be calculated from equation (10). So also may the core loss be calculated from equations (8) and (9); these equations are fundamental in transformer design, but after the transformer is built it is easier to actually measure the core loss by open circuiting the transformer secondary and measuring the watts input in the primary at normal voltage and frequency; knowing the primary current and resistance, the primary copper loss can be determined and, when subtracted from the total input as indicated by the watt meter, the quantity left is the core loss. Of course, there is no secondary copper loss since the secondary is open circuited.

10. Regulation. The open circuit voltage of the secondary of a transformer is necessarily greater than the full load voltage because of the fact that when the transformer is loaded, the load current causes a drop in both the primary and secondary coils due to their resistance; in addition to the resistance drop there is the reactance drop due to magnetic leakage. These two factors cause the available primary and secondary voltages to be less than they otherwise would be as prevoiusly explained in connection with Fig. 111. Therefore, the secondary voltage rises as the load decreases. The *regulation* of a transformer is the rise of secondary terminal voltage from full non-inductive load to no-load, expressed in per cent. of the full load secondary terminal voltage, the impressed primary voltage being constant. For example, if the secondary terminal voltage of a transformer is found to be 110 volts on full non-inductive load, and it is found that this voltage rises to 112.5 volts at no-load, then the regulation by foregoing definition is:

$$\text{Regulation} = \frac{112.5 - 110}{110} = 2.27 \text{ per cent.} \qquad (11)$$

Of course, in actual practice, the simplest way to determine the regulation of a transformer is to measure the change in voltage from full load to no load with a voltmeter, using the above formula. In many cases it is necessary, however, to calculate the regulation from predetermined values of the resistance and reactance drops, particularly because these quantities vary with the load and power factor, as will be evident from an inspection of Fig. 111. No very practical formula has been devised for the absolutely accurate calculation of the regulation of a transformer. The following simple and quite accurate method, however, is recommended by the Government Bureau of Standards and by the Railway Signal Association. According to this method, the regulation is computed from the measured primary and secondary resistance and reactance voltages with the aid of the following equations:

At unity power factor (non-inductive load)

$$\text{Regulation} = \left(\frac{100\,IR}{E}\right)\% \qquad (12)$$

At 60 per cent. power factor

$$\text{Regulation} = \left[100\left(\frac{0.6IR + 0.8P}{E}\right)\right]\% \qquad (13)$$

where E is the rated primary voltage, P the reactance voltage drop an I the full load primary current exclusive of the exciting current. The equivalent resistance R of the primary and secondary combined is found by multiplying the secondary resistance by the square of the ratio of primary to secondary turns and adding the primary resistance.

The impedance voltage *e* is found by short-circuiting the secondary and measuring the voltage required to send full load current through the primary. The impedance voltage is then:

$$e = \sqrt{P^2 + I^2 R^2} \qquad (14)$$

and consequently the reactance voltage drop P at full load is:

$$P = \sqrt{e^2 - I^2 R^2} \qquad (15)$$

It is hardly necessary to explain that the percentage regulation ought to be small; otherwise, as soon as the load comes on the transformer the secondary voltage will fall rapidly.

From an inspection of Fig. 111 and equations (12) and (13), it is obvious that the way to improve the regulation of a transformer is to use plenty of copper in the coils to minimize IR drops, and to so interlace the primary and secondary windings, one with the other, that the magnetic leakage, (the seat of reactance voltage drop), will be small.

11. Performance; Rating. Table I, shows what may be expected of modern high grade commercial transformers in the way of losses, efficiencies and regulations, at various loads and power factors. In the case of transformers of the smaller capacities listed, it will be noted that the regulation is actually better at 60 per cent. power factor than 80 percent; this results from the fact that as the power factor decreases, the resistance drop becomes of less and less importance, as will be evident after a study of Fig. 111. The characteristics of a large 100 K. V. A., 25 cycle, transformer are shown in Fig. 113.

Transformers are rated according to the power they can deliver continuously on non-inductive load, without overheating. In order to secure uniformity in rating, the American Institute of Electrical Engineers recommends that, where transformers are intended for continuous service, the temperature rise at full load shall not exceed a room temperature of 25 degrees C. by more than 50 degrees C. Transformers for signal work are rarely, if ever, subjected to continuous full load, and, consequently, the Railway Signal Association recommends that the final temperature, maintained for one hour under constant full load at normal voltage and frequency, shall not exceed a room temperature of 25 degrees C by more than 50 degrees C, the ultimate rise of temperature having previously been hastened if necessary by overloading and over-excitation before the test run of one hour.

TABLE I.
PERFORMANCE OF COMMERCIAL TRANSFORMERS.

K.V.A.	Watts Loss		Percent Efficiency			Percent Regulation		
	Iron	Copper	Full Load	½ Load	¼ Load	100% P. F.	80% P. F.	60% P. F.
½	15	13	94.7	93.2	88.7	2.62	3.28	3.16
1	20	24	95.8	95.1	92.0	2.42	3.12	3.04
1½	25	35	96.0	95.5	92.7	2.36	3.07	3.00
2	30	42	96.5	96.2	93.8	2.12	2.88	2.86
2½	33	51	96.8	96.5	94.5	2.08	2.83	2.83
3	34	64	96.8	96.8	95.2	2.16	2.91	2.88
4	40	75	97.2	97.1	95.7	1.90	3.00	3.12
5	45	93	97.3	97.3	96.1	1.90	2.99	3.11
7½	62	125	97.6	97.6	96.4	1.70	2.84	3.00
10	80	148	97.8	97.7	96.5	1.51	2.68	2.89
15	105	212	97.9	97.9	97.0	1.44	2.63	2.85
20	131	268	98.0	98.0	97.1	1.39	2.87	3.21
25	147	319	98.2	98.2	97.4	1.33	2.82	3.17
30	163	374	98.2	98.3	97.6	1.32	2.82	3.16
37½	197	433	98.3	98.4	97.7	1.20	2.72	3.09
50	240	550	98.4	98.5	97.9	1.15	2.68	3.07

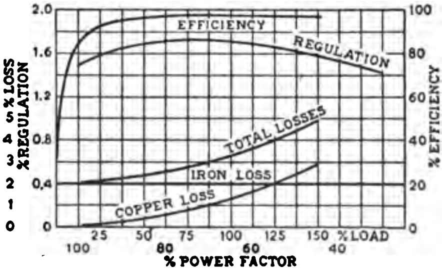
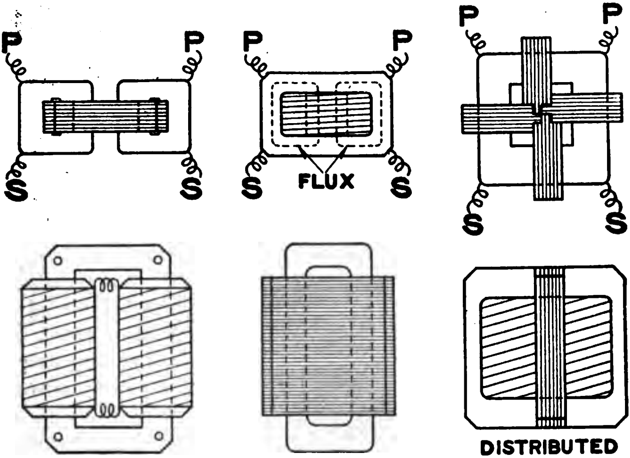


Fig. 113. Test Characteristics 100 K. V. A. Transformer.

TRANSFORMER CONSTRUCTION.

12. Types of Transformer. The essential elements of a transformer are the iron core, the coils and their insulations, the terminal board and leadout wires, and the case with its insulations. Depending on the relative arrangement of iron core and coils, transformers may be classified as (a) Core type, (b) Shell type, or (c) Distributed Core type. In all cases. of course, the iron core is built up of laminations painted on both sides to minimize eddy current losses.



CORE TYPE SHELL TYPE DISTRIBUTED CORE TYPE

Fig. 114. Types of Transformer Core Construction.

(a) Core Type Transformers. This construction is illustrated at the left of Fig. 114, where it will be seen that both of the vertical legs of the iron core are surrounded by a winding; to cut down magnetic leakage half of the primary and half of the secondary are wound, one over the other, on each leg so that the coils may be said to be interlaced.

(b) Shell Type. This construction is shown in the middle of Fig. 114; here both primary and secondary are wound interlaced, one with the other, over the center leg of the iron core which almost entirely surrounds the coils. Fig. 115 is an actual photograph of such a transformer. the core and windings complete with their terminal board and leads being clearly shown at the left.

Fig. 115. Shell Type Transformer.

(c) **Distributed Core Type.** This construction illustrated at the right of Fig. 114, is a combination of (a) and (b) above. The iron core consists of four magnetic circuits of equal reluctance, in multiple; each circuit consists of a separate core. One leg of each magnetic circuit is built up of two different widths of punchings, forming such a cross-section that, when the four circuits are assembled together, they interlock to form a central leg, upon which the winding is placed. The four remaining outside legs occupy a position surrounding the coil at equal distances from the centre on the four sides. The complete core with its coils and terminals is shown in Fig. 116.

Fig. 116. Distributed Core Type Transformer.

As to the relative advantages of core and shell types, it may be said that the core type has a lighter core of smaller sectional area than the shell type, so that more copper with a larger number of turns is required with the core type, although the turns are of a lesser mean length. Then, again, cylindrical form wound coils can be rapidly wound for the core type, and these coils have a large surface exposed for cooling. Altogether, the core type, with its large available winding space, is better adapted for high voltages which require many turns with considerable space for insulation. The shell type, on the contrary, is particularly suited to transformers of moderate voltage, requiring few turns and little insulation. The distributed core type combines the best features of both core and shell constructions; i. e., a short mean length of turn in the coils, and a short length of magnetic circuit; the magnetic circuit is of very low reluctance since the four circuits are all in multiple.

13. Coils; Insulations. As previously stated, it is advisable that the primary and secondary coils be well interlaced with each other, if magnetic leakage is to be avoided. However, on account of the fact that a high voltage is generally impressed on the primary coil, extreme care must be taken not only to insulate the primary from the secondary, but also the primary from the iron core, because, in case of a breakdown in the primary insulation, the secondary coil or the case might be at a dangerously high potential. For transformer working on primary pressures of from 550 to 5,000 volts, and secondary pressures of from 55 to 220 volts, the generally accepted rule is that the insulation between primary and secondary, and between primary and core, shall be capable of withstanding a high voltage breakdown test of 10,000 volts A. C. for one minute; for transformers whose primary voltage is over 5,000 volts, the testing voltage is twice the rated primary normal voltage. In such cases, the insulation test between the secondary and core is 3,000 volts A. C. for one minute, although this is often exceeded. As an additional safeguard a metal plate, known as a *ground shield*, is sometimes placed directly between the primary and secondary coils, so that, if the primary insulation breaks down the high potential will be carried away from the secondary by the ground shield which is connected to the iron transformer case, itself connected to a plate or pipe buried in the ground at the transformer location. After winding, the completed transformer core is thoroughly heated and dried in a vacuum tank; after this drying the core is flooded over with a hot insulating compound which is forced into every part of the winding and insulation at a very high pressure. This treatment, called *impregnation*, improves the insulation of the transformer and protects it from moisture. The transformer core shown at the left of Fig. 115, was so treated, as will be evident from its shiny appearance.

Fig. 117. Complete Core and Terminal Board Distributed Core Type Transformer.

Fig. 118. Oil Cooled Line Transformer.

14. Terminal Board and Leads. In most cases, the ends of the secondary winding are brought to a terminal board carried by the iron core body, as shown at the right of Fig. 115. At the right of this view the core body is shown assembled complete in its case with the cover of the latter removed; the terminal board, made of impregnated maple, carries four terminals, the two outside terminals being the ends of the secondary winding, and the two inside terminals are taps from the interior of that winding. Heavy flexible leads, not easily broken, lead from the brass terminal posts on the board through porcelain bushings, or ducts, to the outside of the case. The primary voltage of most transformers of fair size is dangerously high, so that primary leads are not brought to the terminal board, where some one might receive accidentally a severe shock; consequently, in Fig. 115, the primary leads are carefully taped and insulated and lead directly out of the case through porcelain bushings, these leads being made of heavy flexible wire. A distributed core type transformer with a circular porcelain terminal board, is shown in Fig. 117.

15. Case, Air and Oil Cooling. Small transformers of one-half K. V. A. capacity or less, which are housed in relay boxes or other shelters, are generally not provided with a case; small track transformers, such as the one shown in Fig. 119, are generally of this type, and are, consequently, said to be *air cooled*.

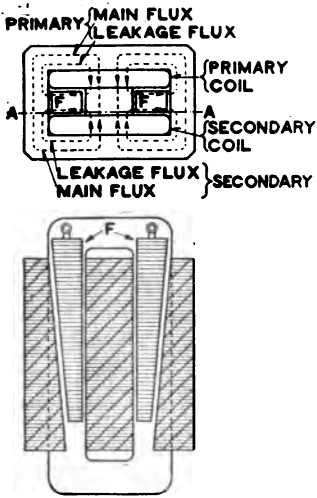
Most transformers of over one-half K. V. A. capacity are hung on a pole in the open, where a case must be provided, as shown in Figs. 115 and 118, to protect the core and winding from the weather; in addition to this protection, the case is generally filled with a fine grade of mineral oil free from acid, alkali and moisture. Oil carries the heat generated in the windings and core out to the case much better than would air, so that such an *oil-cooled* transformer will show a much lower temperature rise than a similar air-cooled transformer. In addition to this, the oil serves to keep moisture out of the windings and keeps them soft and pliable. Of course, oil is also an excellent insulator and acts in a way as a seal to repair a break in the insulation after the latter has been damaged by lightning. However, by means of a special impregnating process, transformers of the line type shown in Fig. 118 may be

Fig. 119. Air Cooled Track Transformer.

so protected against moisture as not to require oil in the case.

16. Adjustable Filler Track Transformers. As has been previously pointed out, the regulation of a transformer depends, not only on the resistance of its coils, but also on its magnetic leakage. In connection with Fig. 110, it was shown that a practical transformer might be considered as an ideal transformer with external resistances and reactances connected in series with both primary and secondary coils; as the secondary current increases, the resistance and reactance drops begin to cut down the secondary terminal voltage more and more. This fact is taken advantage of in the design of the so-called *adjustable filler* track transformers which are intentionally designed with a large and easily variable magnetic leakage. so that they can be used for feeding a track circuit direct, eliminating the usual external impedance between the transformer secondary and the track,

The construction of the adjustable filler transformer is illustrated in Fig. 120, where it will be seen that the transformer is of the shell type. The primary and secondary coils are wound as usual on the middle leg of the laminated core, but they are separated from each other considerably to allow room for two laminated wedge-shaped iron filler blocks FF. These filler blocks in the finished transformer are supported from the terminal board on the top of the core, and can be raised and lowered within the core by a screw adjustment accomplished from the terminal board. It is, of course, perfectly evident that practically all the flux can be shunted out of the secondary coil, if the filler blocks are dropped far



SECTION A-A

Fig. 120. Adjustable Filler Transformer.

down into the body of the core; with this adjustment, the magnetic leakage would be so great that the secondary coil would be practically dead, whereas, with the fillers all the way out full voltage would be secured at the secondary terminals. By intermediate adjustments of the fillers, the magnetic leakage can be regulated as desired, so that when the secondary coil is connected to a track circuit, the proper voltage can be secured at the relay. However, the moment a train enters the track circuit, the reactive drop due to magnetic leakage rapidly increases and the voltage at the secondary terminals falls. This action is illustrated by Fig. 121, which shows how rapidly the secondary terminal voltage falls as the current increases, the filler being about one-quarter of an inch out of the core in one curve and nearly all the way in for the other or (lower) curve, which latter, it is to be noted, is very steep. Were it not for the reactance drop secured through the use of the fillers, the secondary short-circuit current would be many times more than indicated by the curves. The transformer shown in Fig. 120 is generally provided with a case and is oil-cooled.

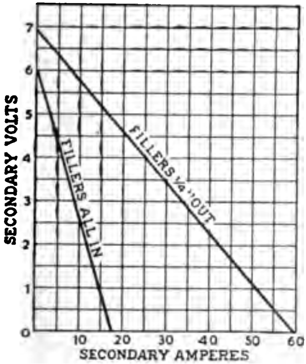


Fig. 121. Characteristics of the Adjustable Filler Transformer.

Adjustable filler track transformer are generally used only on center fed track circuits on electric roads, being then provided with a high voltage primary, connected directly to the transmission line and one track secondary; this arrangement is generally cheaper than one using a 2200^v-110^v line transformer and an auxiliary air-cooled track transformer with its limiting reactance or impedance. Where a simple adjustable filler track transformer is used to supply a centre fed track circuit, only a commercial 2200^v-110^v line transformer is required at the end of the block for feeding the signal motor, slot, lights, and local coils of the track relays.

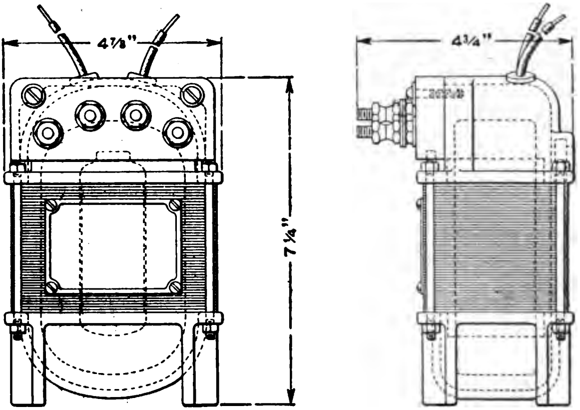
17. Reactive Track Transformers. A smaller air-cooled *reactive* transformer, working on the sample principle, is shown in Fig. 128. This transformer is of the core type, the primary coil being wound on the upper leg and the secondary coil on the lower leg. Here the fillers shown in Fig. 120 are replaced by a U-shaped magnetic shunt which sets with the U upside down on top of the upper leg of the transformer; the U-shaped piece may be adjusted vertically so as to vary the air gap between it and the upper leg of the transformer. It will thus be seen that thus U-shaped block shunts flux out of the secondary coil, just as do the fillers in Fig. 120. The electrical action of the two transformers is identical.

18. Transformer Specifications. The general requirements for commercial line transformers in the way of performance and material are excellently covered in the standard specifications compiled by the U. S. Government Bureau of Standards; copies of these specifications may be obtained gratis from the Supt. of Documents, Washington, D. C. The reader should, of course, also consult the standard specifications included in the Railway Signal Association Manual.

AIR COOLED TRACK TRANSFORMER.

(Single Secondary)

Capacity { 200 V. A.—60 cycles
100 V. A.—25 cycles



FRONT VIEW SIDE VIEW

Fig. 122.

Characteristics. The above transformer is used for feeding steam road track circuits, and is generally provided with a 10-volt tap on its primary for feeding signal lamps and relay locals; the primary cannot be wound for more than 220 volts.

It is provided with but one secondary having four terminals, by means of which six voltages can be obtained. The maximum continuous output of the transformer is given above; within these limits, the secondary can be wound for any track voltage, some of the standard windings being given below:

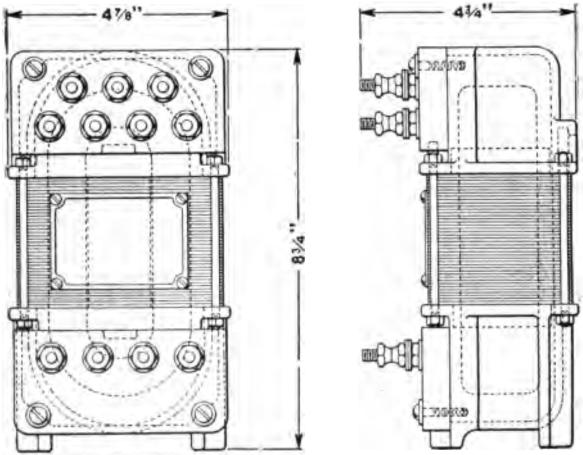
WINDINGS.

Cycles	Primary Volts	Secondary	
		Volts	Amperes
25	110	2, 4, 6, 8, 10, 12	8.3
60	110	2.5, 5, 7.5, 10, 12.5, 15	13

AIR COOLED TRACK TRANSFORMER.

(Double Secondary)

Capacity { 200 V. A.—60 cycles
100 V. A.—25 cycles



FRONT VIEW SIDE VIEW

Fig. 123.

Characteristics. The above transformer is used for feeding two steam road track circuits, being provided with two secondaries having four terminals each, giving six different voltages on each coil The maximum continuous total output of the transformer is given above; within this limit, the secondaries can be wound for any track voltage, some of the standard windings being given below. The primary coil, which cannot be wound for more than 220 volts, is generally provided with a 10-volt tap for feeding signal lamps and relay locals.

WINDINGS.

Cycles	Primary Volts	Each Secondary	
		Volts	Amperes
25	110	2, 4, 6, 8, 10, 12	4.1
60	110	2.5, 5, 7.5, 10, 12.5, 15	6.5

AIR COOLED TRACK TRANSFORMERS.

(Single or Double Secondary)

Capacity { 220 V. A.—60 cycles.
100 V. A.—25 cycles

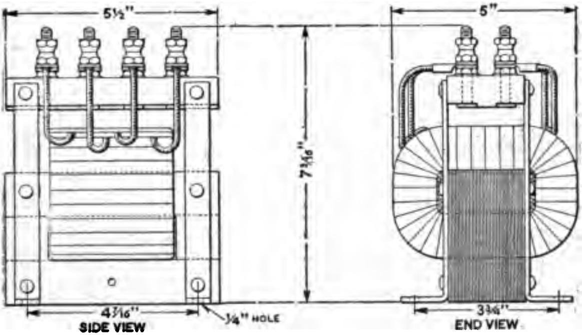


Fig. 124.

Characteristics. The above transformer is used for feed-steam road track circuits, and is generally provided with a 10-volt tap on its primary for feeding signals lamps, relay locals, etc.; the primary cannot be wound for more than 220 volts.

As shown in Fig. 124, it has but one secondary, having four terminals, by means of which six voltages can be obtained; however, it may also be provided with two secondaries, with four terminals each, so that two track circuits may be fed separately. The maximum continuous total output of the transformer is given above; within this limit, the secondary can be wound for any track voltage, some of the standard single secondary windings being given below; with two secondaries, the ampere capacities per secondary would be half those given below.

WINDINGS.

Cycles	Primary Volts	Secondary	
		Volts	Amperes
25	110	1, 2, 3, 4, 5, 6, 7, 8, 9	10
25	110	2, 4, 6, 8, 10, 12	10
60	110	3, 5, 7, 10, 12, 15	15
60	110	5.5, 6, 6.5, 7	16
60	220	3, 6, 9, 12, 15, 18	10
60	55	3, 5, 7, 10, 12, 15	15

AIR COOLED TRACK TRANSFORMER.

(Single Secondary)

Capacity { 550 V. A.—60 cycles
250 V. A.—25 cycles

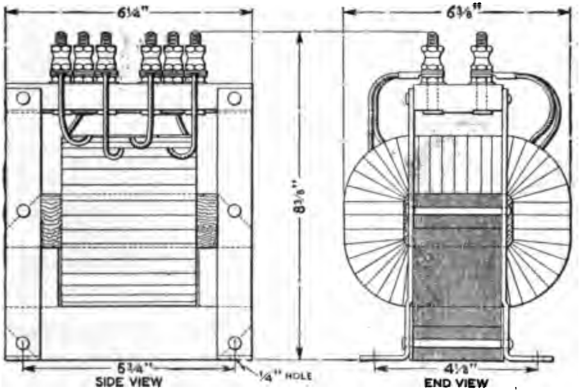


Fig. 125.

Characteristics. This transformer may be used for feeding either steam or double rail electric road track circuits. It is provided with one secondary, having four terminals, from which six different voltages may be obtained.

The primary can be provided with a 10-volt tap for feeding lamps and relay locals, but cannot be wound for an impressed voltage of over 220. Some of the standard windings are given below.

This transformer may also be made with an open magnetic circuit for use on single rail tracks circuits on D. C. electric roads, in which case its capacity is about 300 V. A. on 60 cycles, and 150 V. A. on 25 cycles.

WINDINGS.

Cycles	Primary Volts	Secondary	
		Volts	Amperes
25	110	2.5, 5, 7.5, 10, 12.5, 15	13.5
25	110	0.9, 1.6, 2.5, 3.4, 4.1, 5	40
60	110	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	30

AIR COOLED TRACK TRANSFORMER.

(Double Secondary)

Capacity { 550 V. A.—60 cycles
250 V. A.—25 cycles

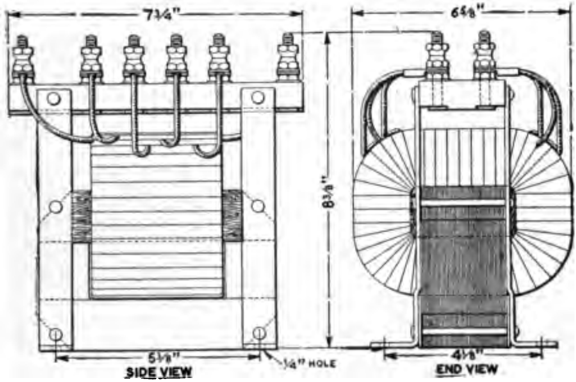


Fig. 126.

Characteristics. This transformer is provided with two secondaries for feeding two steam or double rail electric road track circuits, where the total output required is not over the limits above given; each secondary is provided with four terminals, so that six different voltages can be obtained on each coil, and the primary, which cannot be wound for more than 220 volts, is generally provided with a 10- or 12-volt tap for feeding signal lamps and relay locals. With the capacity limits given, the secondaries can be wound for any track voltage; a common standard winding is given below.

WINDINGS.

Cycles	Primary Volts	Each Secondary	
		Volts	Amperes
*60	110	3, 6, 9, 12, 15, 18	15

*This particular transformer is provided with two primary taps for 120 and 10 volts, respectively; the 10 volt part of the primary winding has a capacity of 6.5 amperes.

AIR COOLED TRACK TRANSFORMERS.

(2 or 4 Secondaries)

Capacity { 0.6 K. V. A.—60 cycles
0.3 K. V. A.—25 cycles

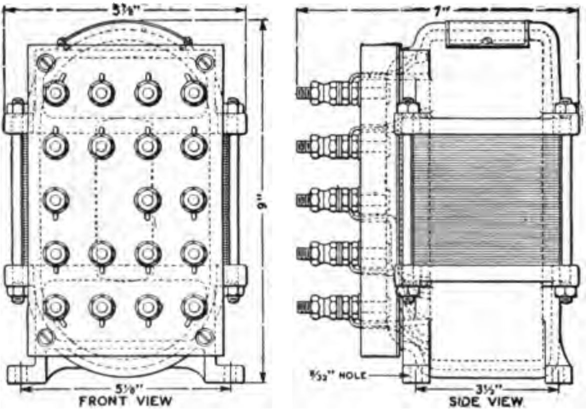


Fig. 127.

Characteristics. The above transformer may be used for feeding either steam or A. C. electric road track circuits and is generally provided with a 10-volt tap on the primary for feeding signal lamps and relay locals; the primary cannot be wound for more than 220 volts.

It may be provided with either four secondaries, as shown above, or with two secondaries each having four taps to give six voltages. The maximum total output of the transformer is given above; without these limits the secondaries may be wound for any track voltage. Two common windings are given below.

WINDINGS.

Cycles	Primary Volts	No. of Secondaries	Each Secondary	
			Volts	Amperes
60	110-10	2	3, 5, 9, 12, 14, 17	17
60	110-10	4	3, 5, 9, 12, 14, 17	8

AIR COOLED TRACK TRANSFORMERS.

(Reactive Type.)

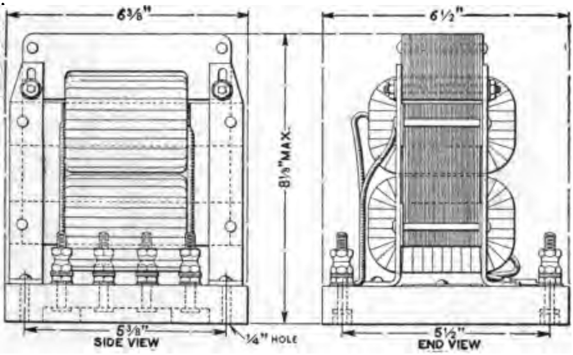


Fig. 128.

Characteristics. This transformer is provided with but one track secondary and is intended for feeding a single track circuit on electric roads using A. C. propulsion. No limiting resistance or reactance is required between this transformer and the track, as it is self-regulating; for a description of the principle on which it works, see page 194. Primary voltages of over 220 are not recommended. The common secondary windings are given below, the secondary being provided with four taps, giving six different voltages.

WINDING.

Cycles	Primary Volts	Secondary	
		Open Circuit Volts	Short Circuit Amperes
60	110	2.7, 5.3, 8, 10.7, 13.3, 16	20

Fig. 129. Line Transformer.

LINE TRANSFORMERS.

(All Capacities and Voltages.)

1. Function. In 1 K. V. A. capacity, or thereabouts, these transformers (Fig. 129) are used at signal locations for stepping down the transmission voltage to a lower voltage, generally 110 or 220 volts, to feed signal motors, slots, and the primary side of track transformers. As step-up transformers, they are used in larger sizes in the power house to step up the alternator voltage to that of the transmission. *These transformers are not provided with track secondaries.*

2. Voltages. The high tension side may be wound for 2200, 3300, 4400 or 6600 volts. The standard voltages for the low tension side are 110 or 220 volts, although other voltages can be provided where required. At a slight additional cost, 5 and 10 per cent. taps can be furnished on the primary to compensate for variations in the primary voltage.

3. Capacities and Weights. These transformers can be furnished in the standard sizes listed in the table below. The data given for shipping weight and oil is for 2200-volt transformers.

TABLE I.

Fig. No.	K. V. A	25 Cycles		60 Cycles	
		Approximate Shipping Weight	Quarts Oil	Approximate Shipping Weight	Quarts Oil
1	0.6	180	10	130	6
2	1.0	180	10	130	6
3	1.5	200	13	145	7
4	2.0	235	16	160	9
5	2.5	275	21	195	10
6	3.0	350	32	210	13
7	4.0	375	32	245	16
8	5.0	455	40	295	21
9	7.5	615	68	395	32
10	10	755	88	455	40
11	15	955	116	660	68
12	20	1110	135	800	88
13	25	1280	170	925	116
14	30	1550	225	1045	135
15	40	2070	230	1410	170
16	50	2350	240	1635	225
17	75	2400	280	1930	220

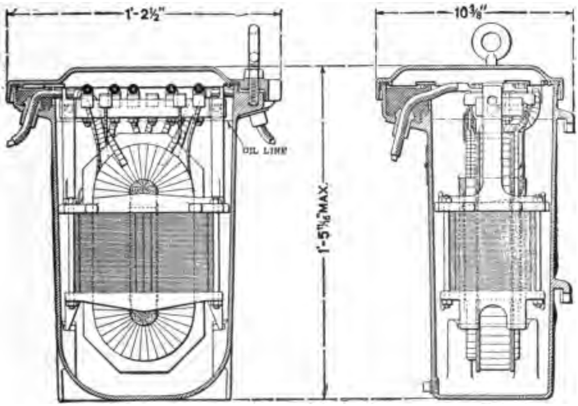
4. Construction. These transformers are of the distributed core type, illustrated in Fig. 117, and are provided with an oil-filled case; they are ordinarily furnished complete with oil for filling the case, and also straps, or hangers, for supporting the transformer on the pole

The distributed core construction, the use of plenty of copper, and the employment of silicon steel having a low hysteresis and eddy current loss, result in a remarkable high efficiency and good regulation; furthermore the silicon steel is subjected to a peculiar heat treatment before assembly in the core, and this prevents a so-called ageing effect. which would result in a serious increase in the core losses after the transformer had been in service for a time, the losses increasing as the transformer becomes older. Silicon steel prevents this.

Special care is taken in the insulation of the windings, as upon this depends the safety with which the transformer may be handled; for example, 2200 volt transformers of this type are required to pass an insulation test of 10,000 volts for one minute between the primary and the core, and between the primary and the secondary; when required they can be furnished insulated to withstand a 15,000 volt ground test. The workmanship is of the highest order, and it is believed that these transformers, the result of twenty years experience, are unequalled for safety, durability, efficiency and regulation.

COMBINED LINE AND TRACK TRANSFORMER.

$$\text{Capacity}\begin{cases}\text{1 K. V. A.—60 cycles}\\ \text{0.5 K. V. A.—25 cycles}\end{cases}$$



SECTIONAL FRONT VIEW

SECTIONAL SIDE VIEW.

Fig. 130.

1. Coils. This transformer may be provided with one, two or three secondaries, any of which may be wound for either track feed or signal operation.

2. Voltages. The primary may be wound for any voltage up to 2300. The secondaries may be wound for any ordinary track or signal voltage, a list of standard voltages being given in Table II, following, where it will be noted that in some cases the transformer is not fully loaded.

3. Capacity. The maximum total continuous output of all coils is 1 K. V. A. on 60 cycles or 0.5 K. V. A. on 25 cycles.

4. Construction. The transformer is of the oil immersed shell type. A high grade specially heat treated nonageing steel is used in the core to insure continuous high efficiency and the primary is insulated to stand a 10,000 volt break-down test to core and each secondary; when required, the primary can be insulated to withstand a 15,000 volt ground test.

5. Weights; Oil Required. Transformers with winding numbers 2, 3, 21 and 22 below require 6½ quarts of oil, and the weight without oil is 105 lbs.; all others require 8½ quarts of oil, the weight without the latter being 115 lbs.

TABLE II.

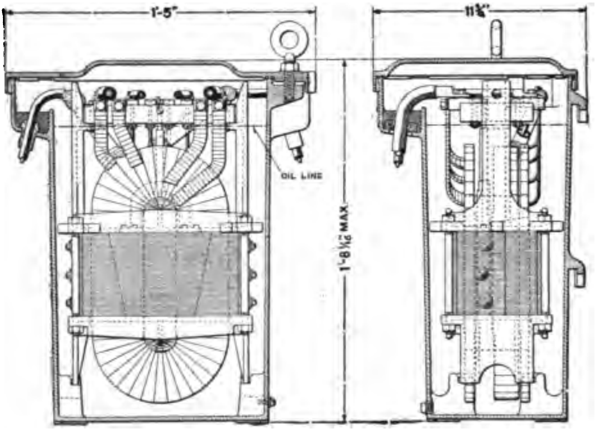
Fig.	Cycles per Second	Primary Volts	LIGHTING		TRACK		
			Volts	Amperes	No. Coils	Volts	Amperes
1	60	2200	61–58–56–53	10	1	15–12.5–10–7.5–5–2.5	20
2	60	110	55	3	1	11	10
3	60	225			1	15.7	25
4	60	110			1	23–19.5–14.4–10.9	50
5	60	2200	122–116–110–105	1.5			
6	60	2200	115–110–105	1	1	19.7–16–14.5–10.5	40
7	60	220	120–115–110	7	1	15–12–9–6	20
8	60	500	58–55–52–49	1.5	1	13–10 6.5–3.3	50
9	60	2200	115–110–109–106	1	1	28–24.5–16–12–8.5–3.5	28
10	60	2200	60–57.5 55–52.5	4	1	18–15–12.5–9 5.8–3.4	40
11	60	110			2	12–10.3–8.2–6.2–4.1–2	50
12	60	1100	120–117–114–110	9.1			
13	60	220	120–117 114–110	9.1			
14	60	110			1	21.2–15.9 11.3–6	50
15	60	110			1	11.3–10.6–10–9.4	100
16	60	110			1	15.2–14.5 13.7–13	75
17	50	2200	120–115–110–105–10	2	2	3.7–3.1–2.5–1.9–1.2–0.6	5.6
18	40	2300	120–117–113–110	7.2	1	12–9.4–6.7–5.3–2.7	24
19	40	2300	120–117–113–110	7.2	1	12.6–11.9 11.2	24

TABLE II (Continued).

Fig.	Cycles per Second	Primary Volts	LIGHTING		TRACK		
			Volts	Amperes	No. Coils	Volts	Amperes
20	40	2300			1	18.1–14.1–10.2–6.2	48
21	25	400			1	15	24
22	25	500 455	2 coils 55–52	2.6	1	9.6	5
23	25	2300	120–115–110–105	3.6		12–6–4–2	20
24	25	55			2	7.5–6.2–5–3.8–2.5–1.3	54

COMBINED LINE AND TRACK TRANSFORMER.

Capacity $\begin{cases}\text{1.5 K. V. A.—60 cycles}\\ \text{0.75 K. V. A.—25 cycles}\end{cases}$



SECTIONAL FRONT VIEW SECTIONAL SIDE VIEW

Fig. 131.

1. **Coils.** This transformer may be provided with one, two or three secondaries, any of which may be wound for track feed or signal operation. See Table III on next page for a few of the standard windings; in some cases it will be noted that the transformer is not fully loaded.

2. **Voltages.** Same as those given for Fig. 130.

3. **Capacity.** The maximum total continuous output of all coils is 1.5 K. V. A. on 60 cycles or 0.75 K. V. A. on 25 cycles

4. **Construction.** Same as that of transformer described in connection with Fig. 130.

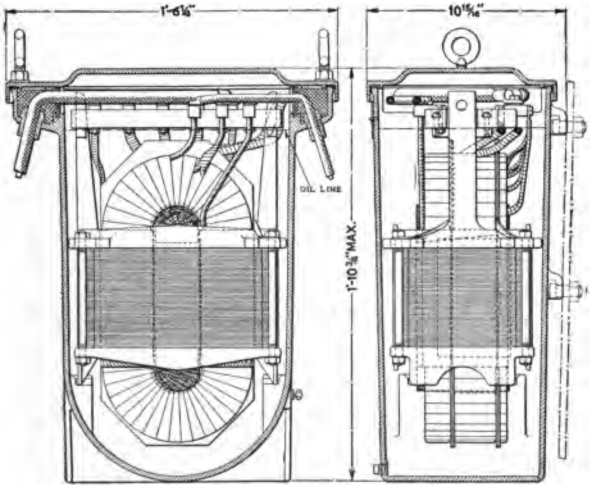
5. **Weight; Oil required.** Weight without oil, 175 lbs. oil required, 15 quarts.

TABLE III.

Fig.	Cycles per Second	Primary Volts	LIGHTING		TRACK		
			Volts	Amperes	No. Coils	Volts	Amperes
1	25	2200	60–57.5–55	2	1	10.5	4
2	25	55			2	6.1–4.9–3.7	140
3	25	2300	146–134–120–115–110	4.5	1	15.3–12.6 10–7.3	75
4	25	2300	135–127–120–115–110	5	1	20–16–12–7.5	40
5	25	55			4	7.5–6.2–5–3.8–2.5–1.3	54
6	25	2200	135–125–115–110	6	2	7.3–6–5.3 4.6–4–3.3 2.7–2–1.3 0.7	30
7	25	2200	120–115–110–105	3.4	2	10.6–8.6–7.2–5.2–3.3–2	37
8	25	2200	135–130–125–120–115–110	6.5	2	8–6.7–5.3 4–2.6–1.	36
9	60	220	66–63–60	21			
10	60	2300	120–115–110	7	1	9	60
11	60	220			1	20–15	70
12	60	2200	148–134–120–115–110	2.5	1	28–21.3–15.7–9	80
13	60	2400	150–135–120–115–110	6	1	20–16–12–8	20
14	60	2200	170–155–140–118–110	10.5	1	12–9.3–6.6–4	52
15	60	110			4	12–10–8 6–4–2	50
16	60	2200	120–115–110	20			
17	60	2200	115–110	4.75	1	16.5–14.3–13.2–11–9.9–7.7	60
18	60	2080	115–110	8	1	18–14.5–10.8–7–6–2.5	60
19	60	110			1	15–14–13	180

COMBINED LINE AND TRACK TRANSFORMER.

Capacity { 2 K. V. A.—60 cycles
1.0 K. V. A.—25 cycles.



SECTIONAL FRONT VIEW SECTIONAL SIDE VIEW

Fig. 132.

1. **Coils.** This transformer may be provided with from one to three secondaries, any of which may be wound for track feed or signal operation

2. **Voltages.** Maximum primary, 4400; the secondary coils may be wound for any ordinary track or signal voltage, the standard windings being given in Table IV on next page.

3. **Capacity.** The maximum total continuous output of all coils is 2 K. V. A. on 60 cycles and 1.0 K. V. A. on 25 cycles.

4. **Construction.** Same as that described in connection with Fig. 130.

5. **Weight; Oil required.** Weight without oil, 240 lbs.; oil required, 20½ quarts.

TABLE IV.

Fig.	Cycles per Second	Primary Volts	LIGHTING		TRACK		
			Volts	Amperes	No. Coils	Volts	Amperes
1	60	2200	115–110	15	1	16–13–10–7	55
2	25	4400	120–115–110	7	1	22.5–18–13.5–9–4.5	64

COMBINED LINE AND TRACK TRANSFORMERS.

ADJUSTABLE FILLER TYPE.

1. Function. The transformers shown in Figs. 130, 131 and 132 may be provided with adjustable magnetic leakage fillers, (page 194), in which case no limiting resistance or reactance is required between the transformer and the track. They may be provided with two secondaries, one of which may be wound for track feed and the other for signal or lighting operation; or they may be provided with one large track coil, but not with two.

2. Voltages. The primary may be wound for any voltage up to 2300. The secondaries may be wound for any ordinary line or track voltage, a list of the standard voltages being given below.

3. Capacity. The data given below in Tables V, VI and VII indicate the capacity of these transformers with various windings.

TABLE V.
(Transformer Fig. 130

Fig.	Cycles per Second	Primary Volts	LIGHTING.		TRACK.	
			Volts	Amperes	Open Circuit Volts.	Short Circuit Amperes
1	25	1100			8–4	37
2	25	400			9.5	40
3	40	60–50–40			3.5–1.75	20
4	40	120–100–80			3.5–1.75	20
5	40	220–200–180			3.5–1.75	20
6	60	2200			8	31
7	60	2200			10.6	84
8	60	110			10.3–7.3	50
9	60	200			8.6	120
10	60	2200			9–4.6	126
11	60	440			11.4–6.6–2.2	50
12	60	220			14.5–9–8.3–2.8	48
13	60	440			14.5–9–8.3–2.8	40
14	60	2200			18.8–14.4–9.8–5.2	40
15	60	112	115–112–109	0.71	6.9	12
16	60	60			4.1–3.4–2.9	10

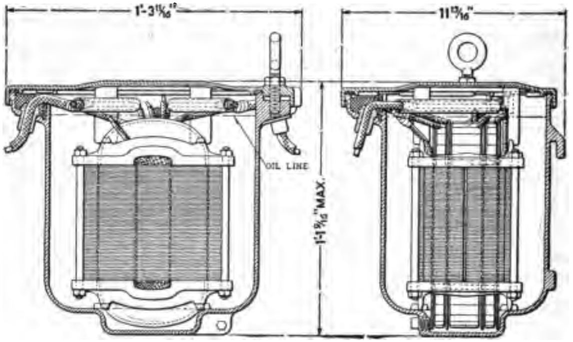
TABLE VI.
(Transformer Fig. 131)

Fig.	Cycles per Second	Primary Volts	LIGHTING.		TRACK.	
			Volts	Amperes	Open Circuit Volts.	Short Circuit Amperes
1	25	550	59–57–55–53	2.5	10–8–6–4	100
2	25	50			11.8–8.8–5.9–3	150
3	25	2000			11.4	68
4	25	2200	55	2.7	7.4	130
5	25	2200			6.7–5–3.4	60
6	25	330	120–115–110	4.9	3.35	140
7	25	330	120–115–110	4.9	6.8	70
8	25	2200	128-122-117-116–113–110	1.45	20–16–10–6	40
9	60	2000			20.6	46
10	60	2200			12–8–4	82
11	60	110			25–17.5–8.7	125
12	60	2200			32.9–25.6 18.3–10.9	144
13	60	2200			29.6–18.7–7.7	60
14	60	220	120–115–110	1.8	29–21.7–14.5–7.2	46
15	60	2200	61–59–57–55	15	16–13–10–6	40
16	60	2200	125-120-115-110	7.5	16–13–10–6	40
17	60	2200	136-126-120-118-115-110	4.6	22–16–10–5	45

TABLE VII.
(Transformer Fig. 132)

Fig.	Cycles per Second	Primary Volts	LIGHTING.		TRACK.	
			Volts	Amperes	Open Circuit Volts	Short Circuit Amperes
1	25	1100	60–57.5–55	3	5.2–3.6–2.1	135
2	25	2200	119–115–110	8.5	18–15–12	140

COMBINED LINE AND TRACK TRANSFORMER.
OPEN MAGNETIC CIRCUIT TYPE.



SECTIONAL FRONT VIEW SECTIONAL SIDE VIEW

Fig. 133.

1. **Function.** The transformer shown above is intended for feeding single rail track circuits on electric roads using D. C. propulsion. The core has an open magnetic circuit (as shown by the vertical white line between the halves of the core in the right hand view), so that the direct current passing through the track coil will not saturate the iron. The transformer can be equipped with two secondaries, one of which is a track coil, and the other a line coil for feeding signals or lights.

2. **Voltages.** The primary may be wound for any voltage up to 2200, while the secondary may be wound for any of the usual voltages required for track feed or signal operation. A few of the standard windings are given in Table VIII below.

3. **Capacity.** The maximum total continuous output is 1 K. V. A. on 60 cycles or 0.5 K. V. A. on 25 cycles.

4. **Construction.** Shell type, oil immersed. Specially heat treated non-aging steel used in the core to insure a continuous high efficiency. Primary is insulated to stand a 10,000 volt test to each secondary and core.

5. Weight; Oil Required. The weight of the transformer without oil is 135 pounds. Ten quarts of oil are required.

TABLE VIII.

Fig.	Cycles per Second	Primary Volts	LIGHTING		TRACK		
			Volts	Amperes	No. Coils	Volts	Amperes
1	60	220	55	8	1	13.5	40
2	60	500	50	1.5	1	10	22.5
3	60	440	55	1.5	1	9	22.5
4	60	2200	55	8	1	13.5	40
5	60	440	110	0.8	1	8.5	22.5
6	60	110			1	18–14	15
7	60	500	50	1.5	1	10	22.5
8	60	220	120-115-110	2	1	15	20
9	50	110			1 1	13.5–8–5.5	25
10	25	220	48.5	1.5	1	8.5	22.5
11	25	1100	48.5	1.5	1	9	22.5
12	25	550	48.5	1.5	1	9	22.5
13	25	55			1	8.5	22.5
14	25	1100			1	6.75	24
15	25	1100	60–57.5–55	1.5	1	9.5–6	12
16	25	110			1	10	22.5
17	25	550	60–57.5–55	1.5	1	9.5	12
18	25	550	60–57.5–55	6	1	9.5	27
19	25	2200			1	10.5–8.1	7.5
20	25	340	60	1.5	1	10	20

CHAPTER VII.

RESISTANCES AND IMPEDANCES FOR TRACK CIRCUIT WORK.

Fig. 134. Detector Track Circuit Impedances, Transformers and Vane Relays. Pittsburgh Division, Pennsylvania R. R.

CHAPTER VII

RESISTANCES AND IMPEDANCES FOR TRACK CIRCUIT WORK.

1. Function. The track secondary coil of a well designed transformer is of comparatively low impedance, as it consists of a few turns of heavy wire. In consequence of this, an excessively heavy current would flow through such a coil with a train on the track circuit, if some current limiting device were not connected in series between the rails and the track secondary coil; otherwise, the coil would be practically short circuited and burned out if a train stood on the track circuit for any length of time and in addition a lot of power would be wasted. Such current limiting devices, consisting of either a simple resistance tube or an impedance coil, are called *track resistances* or *track impedances*, as the case may be.

Fig. 135. Track Circuit Resistance.

In addition to their function in limiting the short circuit current with a train on the track circuit, track resistances and impedances have an important influence on the phase relation between track and local currents in two-element relays. Track resistances, such as the one shown in Fig. 135, consist of a few turns of coarse wire wound on an insulating tube and are practically non-inductive, so that when connected between the transformer and the track they do not alter the phase relation of the current flowing into the track circuit with refer-

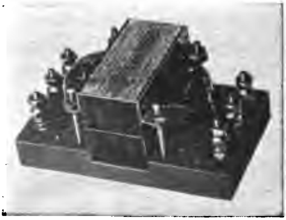


Fig. 136. Track Circuit Impedance.

ence to the voltage. Track impedances (Fig. 136) consist of a coil of wire wound around a laminated iron core and are consequently highly inductive, so that when connected between the transformer and the track the current is caused to lag considerably with reference to the voltage. In the case of two element relays, such as the galvanometer or the induction motor (polyphase), proper phase relations between track and local currents must be obtained before the relays will operate economically, and the correct selection of resistance or impedance between the transformer and the track is therefore an important matter.

2. Selection Between Resistance and Impedance for Track Circuits Using Vane Relays. The production of torque in the single element vane relay depends simply on the intensity of the current flowing through the winding and in this case, therefore, the question of phase relations does not arise. In the interest of power economy it is, however, advisable to use an impedance between the transformer and the track wherever possible, most commercial impedances having a power factor varying between 0.1 and 0.3, in which case the voltage drop through the impedance is practically wattless. On steam road track circuits, impedance Fig. 137 is generally used, and on some double rail electric road track circuits, Figs. 138, 139 or 140, depending on the current taken by the impedance bonds.

On all single rail track circuits where either D. C. or A. C. propulsion is employed, the use of an impedance is rarely possible, and instead, a resistance, like those shown in Figs. 142 and 143, must be employed as the iron core of an impedance would be saturated by the leakage propulsion current passing through the impedance coil, as explained in Chapter V; with a saturated iron core, the impedance would lose most of its self-inductive, or choking, effect, and, thus, an excessive current would be allowed to flow from the transformer to the track.

3. Selection Between Resistance and Impedance for Track Circuits Using Galvanometer Relays. The local coils of this relay consist of a large number turns of fine wire and are consequently highly inductive, having a power factor of approximately 0.4; the armature, on the other hand, consists of only a few turns of heavy wire and its self-inductance is negligible, the power factor being almost unity. The adjustment of the phase relation of the currents flowing in the two elements may be effected by inserting resistance between the transformer and the track, and also another resistance in series with the local, thereby bringing the armature and local currents in phase at a higher power factor, resulting in a considerable waste of heat energy in both resistances. Since the production of armature torque is simply a question of current, and not of power, the most economical adjustment will be obtained when the power factor of the complete armature and field circuits is as low as possible; therefore, power will be saved if, instead of the above resistances, the low power factor local is connected directly to the line and an impedance is inserted between the transformer and the track, thus causing the armature current to lag in phase with the local current. Due to the low power factor of the impedance, the voltage drop across it is nearly wattless.

On most steam road track circuits impedance Fig. 137 is therefore generally used, and on electric roads with double rail track circuits and impedance bonds (where, since the bonds act as a shunt, but little propulsion current flows through the transformer circuit) impedances Figs. 137, 138. 139 or 140 may be used, these being always provided with an air gap, not only to secure adjustment of the impedance value, but also to keep the core from being saturated by such propulsion current as may flow. The magnitude of the ballast leakage resistance in both steam and electric road track circuits, and the current taken by the impedance bonds in the latter case, have a very important influence on the question of phase relations, however, and the final decision as to whether resistance or impedance should be used between the transformer and the track can only be made after laying out a vector diagram covering the actual conditions in point; this matter is fully discussed in Chapter XIII.

4. Selection Between Resistance and Impedance for Track Circuits Using Polyphase Relays. Unlike the galvanometer relay, the polyphase relay works most economically with the track and local currents in quadrature, as explained in Chapter IV; the local and track coils are of the same size, they are both wound in an iron core and their power factors are, consequently, equal and low, about 0.65. It becomes necessary, therefore, to secure phase displacement by artificial means and for this purpose in steam road work, a small resistance housed inside the relay is generally connected in series with the local coils, so that the power factor of this element becomes as nearly unity as possible. Impedance Fig. 137, having a power factor of about 0.2, is then connected between the transformer and the track, and this, working in connection with the impedance of the rails themselves, causes the current in the track element of the realy to lag approximately 90 degrees behind the local current.

On electric roads, however, due to the comparatively large A. C. current taken by the bonds, and even on some steam road track circuits with excessively large ballast leakage, it becomes most economical to connect a small reactance in series with the local element of the relay (housed inside the relay case), and a resistance Fig. 142 or 143 between the transformer and the track; then the local current lags behind the current in the track element, giving the phase displacement necessary for the production of a rotating field. It is not necessary that the phase difference be a full 90 degrees, and in fact this is rarely attained, but the nearer it is to 90 degrees the better from the standpoint of power economy. Before deciding to use either resistance or reactance, however, all the factors, such as ballast, weight and bonding or rail, current taken by impedance bond, etc., should be taken into consideration and a vector diagram laid out as explained in Chapter XIII.

TRACK IMPEDANCE FOR STEAM OR A. C. ELECTRIC ROADS.

1. Where Used. This impedance (Fig. 137) is designed primarily for use on steam roads. It is not of sufficient capacity for D. C. electric roads, but where the current taken by the impedance bonds is not too heavy it may be used on double rail track circuits on A. C. electric roads.

2. Description. It consists of a form wound coil, impregnated for protection against moisture, assembled in a laminated iron core, divided into two separate parts, the lower half of the core being fixed to a japanned wooden base and the upper half being adjustable.

3. Characteristics. The coil is provided with six taps, and the impedance in circuit may thus be adjusted over a considerable range as shown in the following table, which covers a few standard windings. A further adjustment of the

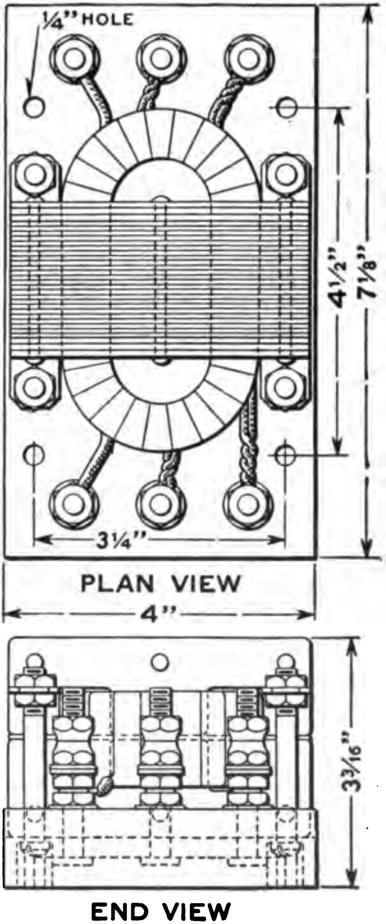


Fig. 137. Track Impedance for Steam or A. C. Electric Roads.

impedance value may be secured by varying the air gap between the top and bottom halves of the core, the air gap being increased to decrease the impedance, and vice versa. The maximum volts, amperes and impedance values tabulated below are for the whole coil in series; when the lower taps are used, the coil will stand greater currents than those given.

Fig.	Max. Amperes Constant Load	Max. Volts	Frequency	Impedance		Air Gap
				Max.	Min.	
1	6	18	25	3.0	0.5	0.012″
2	6	42	60	7.1	1.3	0.012″
3	6	10	25	1.6	0.3	0.035″
4	6	22	60	3.6	0.6	0.035″
5	8	10	25	1.3	0.3	0.012″
6	7	22	60	3.1	0.8	0.012″
7	10	7	25	0.7	0.2	0.035″
8	7	11	60	1.6	0.4	0.035″
9	3	35	25	11.7	2.2	0.012″

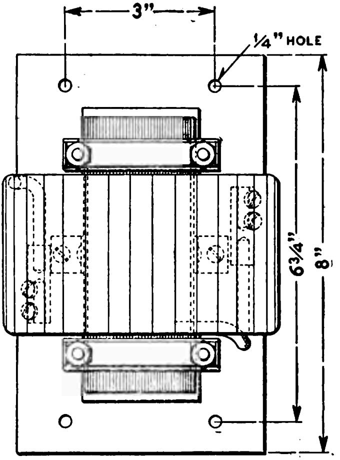
TRACK IMPEDANCE FOR ELECTRIC ROADS.

(Type A)

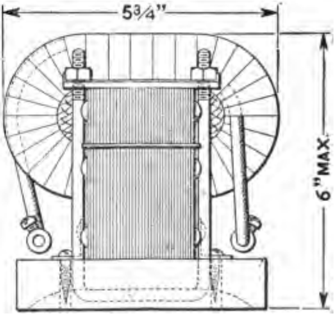
1. Where Used. This impedance (Fig. 138) is primarily designed for use on double rail D. C. electric road track circuits. It cannot be used where two abutting track circuits are fed from the same transformer secondary. For this latter service, the impedance described in Fig. 140 should be employed.

2. Description. It consists of a form wound coil of heavy copper impregnated to protect it against moisture, assembled into a laminated core divided into two parts, the lower half of the core being fixed to a japanned wooden base and the upper half being adjustable.

3. Characteristics. The maximum volts, amperes and impedance values are tabulated below; the impedance may be varied over a wide range by adjusting the air gap, the latter being increased to decrease the impedance, and vice versa.



PLAN VIEW



END VIEW

Fig. 138. Track Impedance for D. C. or A. C. Electric Roads. Type A.

Fig.	Max. Amperes Constant Load	Max. Volts	Frequency	Impedance	
				Max.	Min.
1	70	9	25	1.1	0.1
2	60	21	60	2.8	0.21
3	20	28	25	11.0	1.0
4	30	35	60	8.0	0.6
5	25	20	25	6.25	0.8
6	30	35	60	5.6	0.62

TRACK IMPEDANCE FOR D. C. OR A. C. ELECTRIC ROADS. (Type "B")

1. Where used. This impedance (Fig. 139) is primarily intended for use on double rail track circuits on either steam or electric roads, its capacity being somewhat less than that of the impedance shown in Fig. 138; it cannot be used where two abutting track circuits are fed from the same track transformer secondary. For this latter service use the impedance illustrated in Fig. 140.

2. Description. It is an enlarged form of the steam road impedance shown in Fig. 137, being, however, provided with a porcelain base.

3. Characteristics. The maximum volts, amperes and impedance (at full load) are tabulated below: The impedance may be varied over a wide range by adjusting the air gap.

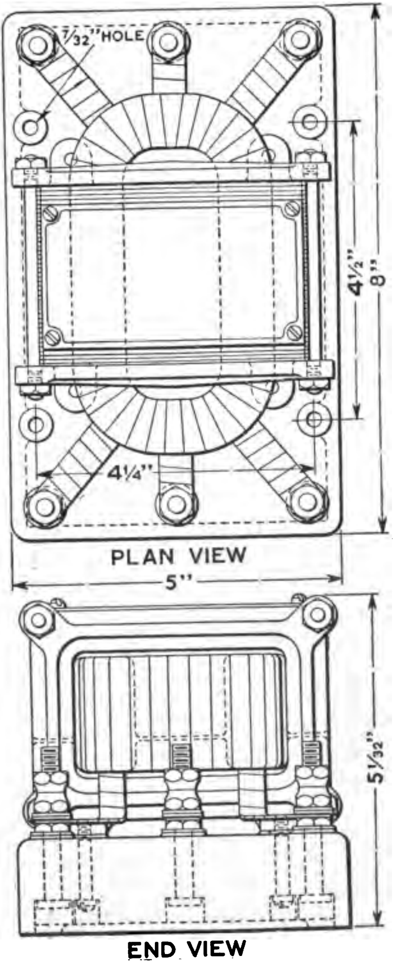


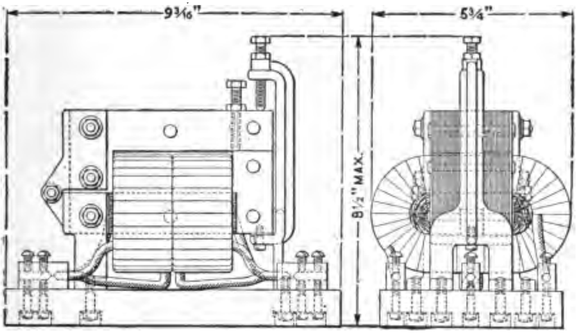
Fig. 139. Track Impedance for D. C. or A. C. Electric Roads. Type B.

Max. Amperes Constant Load.	Max. Volts	Frequency	Impedance	
			Max.	Min.
25	26	60	1.0	0.08

TRACK IMPEDANCE FOR ELECTRIC ROADS

(Type C.)

1. Where used. This impedance, like that shown in Figs. 138 and 139, is intended for use on double rail electric road track circuits, but is provided with two separate coils, one being connected into each track circuit from the transformer, this arrangement being used to prevent interference between abutting track circuits when two such tracks are fed at their meeting point from the same transformer secondary; this impedance is, therefore, intended only for such a double track fed layout.



SIDE VIEW

END VIEW

Fig. 140.

2. Construction. The general construction is the same as that described in connection with Fig. 138, with the above exception; in the present case, however, the coils are provided with taps and the air gap adjustment is made by means of a screw.

3. Characteristics. The maximum volts, amperes and impedance values are given in the table below; the impedance may be varied over a wide range, first by means of the taps on the coils, and secondly by adjustment of the air gap.

Fig.	Max. Amperes Constant Load	Max. Volts	Frequency	Impedance	
				Max.	Min.
1	60	12	25	1.0	0.2
2	30	30	25	4.3	1.0
3	50	28	60	2.25	0.45
4	40	18	25	2.25	0.45

RELAY SHIELDING IMPEDANCE COIL FOR D. C. ELECTRIC ROAD SINGLE RAIL TRACK CIRCUITS.

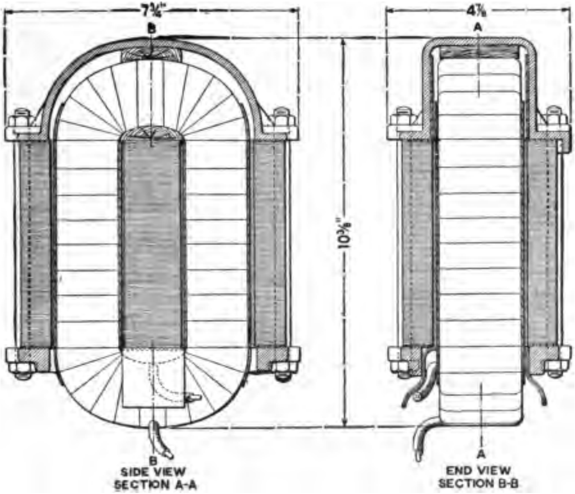


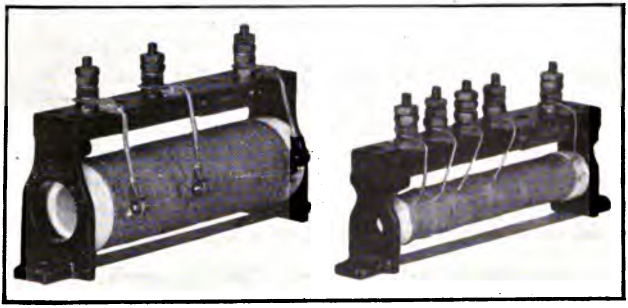
Fig. 141.

1. **Where Used.** This impedance coil is to be connected across the track terminals of relays (usually of the vane type), used on single rail D. C. electric road track circuits, in those cases where the D. C. propulsion drop in the return rail may be so great as would cause an excessive D. C. current to pass through the relay, were the above impedance not connected across the terminals to shunt out the direct current; in this connection, see the discussion of single rail track circuits in Chapter V.

2. **Description.** The coil consists of a few turns of heavy copper wound around a laminated iron core, the latter being of the open magnetic circuit type to guard against saturation. It is often supported and housed as shown in Fig. 3, Chapter I.

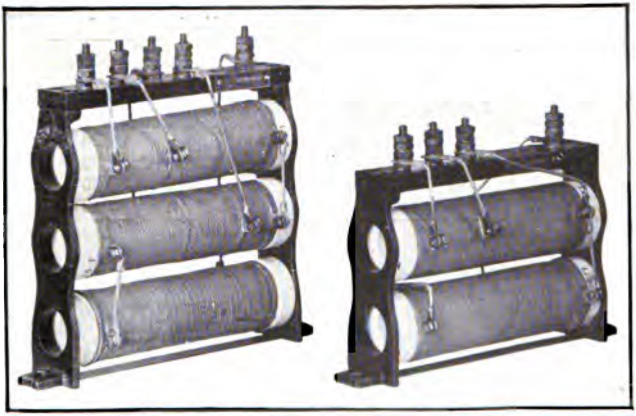
3. **Characteristics.** Its current carrying capacity and impedance are given below.

Fig.	Max. Amperes Constant Load	Frequency	Impedance	Air Gap
1	40	60	9.3	0.125″
2	40	25	4.0	0.125″



SU101A. SU201A.

Fig. 142. SU-Track Resistance Tubes.



SU103A. SU102A.

Fig. 143. SU-Track Resistance Tubes.

TRACK RESISTANCES FOR STEAM OR ELECTRIC ROADS.

1. **Where Used.** The resistance tubes shown in Figs. 142 and 143 are for use on steam or electric road track circuits. Which size should be selected depends on the current to be carried and the resistance required, these quantities depending on the length of track circuit, ballast leakage, current taken by impedance bonds, etc.; a track circuit calculation, as described in Chapter XIII, will show what the value of the resistance between the transformer and the track should be as well as its necessary current carrying capacity.

2. **Description and Capacity.** The units consist of one or more wire wound asbestos tubes provided with porcelain heads and supported on an iron frame; they are therefore fireproof. Six terminals can be furnished but four are generally sufficient. Within the watt ratings ($I^2 R$) given below, they can be provided with any winding required.

SIZES AND RATINGS SU RESISTANCE TUBES

Size	Overall Dimensions			Continuous Rating-Watts
	Length	Height	Depth	
SU 201 A	8″	3 ¾″	1 ½″	26
SU 101 A	9 $\frac{13}{16}$″	4 ¾″	2″	80
SU 102 A	9 $\frac{13}{16}$″	7″	2″	160
SU 103 A	9 $\frac{13}{16}$″	9 ¼″	2″	240

TRACK RESISTANCE FOR D. C. ELECTRIC ROADS.

1. Function and Characteristics. This resistance is intended for use in single rail track circuit work on D. C. electric roads using very heavy propulsion currents and long blocks, in which case the resistance may be used between the transformer and the track, the relay and the track, or in both places. It is designed to be suspended on the bolts projecting beyond the grids, as shown in the above drawing; see Fig. 3, Chapter I, for an example of its housing.

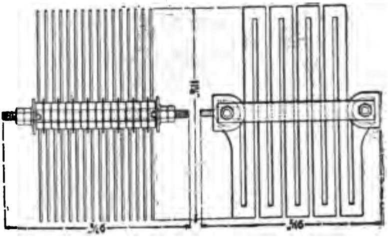


Fig. 144.

It consists of a number of grids cast out of a special grade of iron, these grids being connected in series to make a total resistance of one ohm; it may also be insulated into two sections of one-half ohm each. The normal current carrying capacity either way is 20 amperes, but the resistance will stand momentary overloads of some 20 times normal current.

CHAPTER VIII

SIGNALS.

(Part I)

SEMAPHORE SIGNALS.

CHAPTER VIII
SIGNALS.
(Part I)

Semaphore Signals.

Looking at the matter from a mechanical standpoint, alternating current signal mechanisms resemble direct current mechanisms in all important respects. It is in the electrical portions—the motor and the holding device—that the characteristic differences are found. As a matter of fact, most of the better known types of signal mechanism now on the market are constructed so as to be easily convertible from direct current operation to alternating current operation through a simple interchange of motors and slots. As all alternating current signal mechanisms employ either induction or commutator motors as prime movers, and either tractive magnet or induction slots as holding clear devices, these characteristic elements deserve a thorough preliminary study.

ALTERNATING CURRENT MOTORS.

Induction Motor.

1. Elements. In its electrical behavior, the induction motor is the exact electro-magnetic equivalent of an ordinary transformer with a considerable amount of magnetic leakage between primary and secondary coils. It consists of two elements: first, the *stator*, which is a stationary outer ring or shell of laminated iron, slotted on its inside face to receive the primary windings, and, second, the *rotor*, which is a cylindrical laminated iron core or drum, slotted on its outside face to take the secondary winding, and rotating within the stator

Fig. 145. Elements of the Induction Motor.

bore, the motor shaft being keyed to the spider which carries the assembled rotor laminations and their winding. At the right of Fig. 145 will be seen a laminated stator core for a signal motor, slotted and ready to receive the primary winding; the completed stator, with the end connections of its windings insulated and taped, is shown at the left of the photograph. The rotor with the secondary winding is illustrated in the center of the photograph, with a rotor lamination immediately to its left resting against the finished stator; in this case, as in all induction motors for signal work, the secondary winding consists simply of heavy copper or brass rods, driven through the rotor slots and connected electrically at both front and rear ends by thick copper or brass end plates, the joints between the bars and end plates being carefully soldered to minimize resistance; rotors of this construction are known as *squirrel cage rotors.* Power is fed into the primary winding from the external circuit and the rotor is caused to turn, as will presently be explained, by the heavy currents induced in the rotor bars by the rotating magnetic field set up by the primary winding carried on the stator core. *The rotor winding is in no way connected to the external circuit*; it carries no commutator, brushes or slip rings. In fact, the induction motor is simply a transformer with a short circuited secondary, this secondary being free to move.

2. Theory of the Induction Motor. The operation of the induction motor depends upon the fact that, when a magnetic field is dragged across a conductor, currents are induced in that conductor, which themselves give rise to a secondary field of such a direction as to oppose the movement of the generating magnetic field. In 1834, Lenz summed up the matter by stating that "in all cases of electro-magnetic induction the induced currents have such a direction that their reaction tends to stop the motion which produces them." This very important physical theorem can be demonstrated experimentally, as explained in Chapter IV, by the apparatus shown in Fig. 65, where a metal disc D is dragged into rotation by the permanent magnet P, moved by hand circularly around the periphery of the disc in a clockwise direction, as indicated by the arrow, the disc following the magnet because of the reaction between the field of the permanent magnet and the secondary field produced by the currents induced in the disc by the primary field of the permanent magnet. Lenz's Law above quoted states that the reaction between two such fields tends to stop the motion which produces them; therefore the currents induced in the disc tend to hold the permanent magnet back, but, as the latter is being moved forward forcibly by hand, the disc is itself dragged around. The disc corresponds exactly to the rotor of an induction motor, and the rotating field of the permanent magnet corresponds to the rotating field produced by the induction motor stator.

In the induction motor, the primary, or stator, winding is grouped around the stator core in two or more independent sets of coils, wound progressively in slots around the core, and energized by two or more separate currents considerably out of phase with each other. In the two-phase induction motor, the currents in its two separate sets of stator coils are 90 degrees out of phase, while in the three-phase motor, the currents in its three sets of coils are 120 degrees out of phase with each other, as regards the production of such polyphase currents; it is obviously, possible, by placing on the armature of the ordinary alternator, two or three sets of coils, one angularly ahead of the other, to obtain respectively two or three alternating currents of equal frequency and strength, but differing in phase by any desired degree. When the stator coils of an induction motor are progressively energized by such currents, a rotating field is produced, which drags the rotor around with it, just as in the case of the disc illustrated in Fig. 65, and for exactly the same reason.

3. Production of Rotating Field in the Induction Motor. Most induction motors for signals operate on the two-phase principle, and it is now proposed to explain just how the rotating magnetic field is produced. One-half the stator winding (one phase) of a two-phase four-pole induction motor is shown in full lines B in Fig. 146, the other half A, exactly like B, being omitted for the sake of clearness. In this figure, the straight radial lines represent the conductors which lie in the slots of the stator, and the curved lines represent the connections around the outside of the stator core joining the slot inductors. The complete stator winding is arranged in two distinct circuits; one of these circuits includes all the conductors marked A, and this circuit receives current from one phase of a two-phase system, the other circuit, including all the conductors marked B, receiving current from the other phase of the two-phase system. The terminals of the B circuit are shown at tt'. The conductors which constitute one circuit are so connected that the current flows in *opposite directions* in adjacent groups of conductors, as indicated by the arrows.

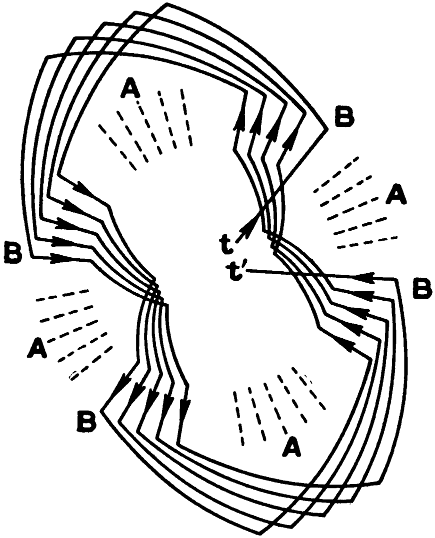


Fig. 146. Half the Stator Winding for a 2-Phase, 4-Pole Induction Motor.

The above windings A and B, assembled on the stator core, are shown in Fig. 147, the small circles representing the conductors in section, conductors carrying down-flowing currents being marked with crosses (+), those carrying up-flowing currents with dots, and those no current at all being left blank. The action of currents in these bands, or groups, of conductors is to produce magnetic flux along the dotted lines in the direction of the arrows according to the Corkscrew Rule, which, it will be recalled, states that, if the direction of current flowing in a conductor corresponds to the forward movement of a corkscrew, then the circular flux lines about the conductor due to the current, turn about the conductor in the same direction as the corkscrew turns to go forward.

Suppose, now, that two currents, A and B, separated by a phase angle of 90 degrees, as shown in Fig. 148, flow, respectively, through windings A and B, in Fig. 147, these latter being connected to the circuit, so that the current in coil A leads that in coil B, as indicated by the direction marks within the circles representing the stator conductors. At (a) in Fig. 147 is shown the state of affairs when the current in conductor group A is a maximum and the current in group B is zero, corresponding to point 0 of Fig. 148, the dotted lines in Fig 147 indicating the direction of the magnetic flux, determined by the Corkscrew Rule above mentioned; this flux enters the rotor from the stator at the points marked N, and leaves the rotor at the points marked S. At (b), one-eighth of a cycle, or 45 degrees later, the current in the B set of conductor has increased, and the current in the A conductors has decreased to the same value, so that equal currents flow in the A and B conductors, as will be evident from the wave heights at the end of the first eight of a cycle in Fig. 148; note that the points N and S have now moved over one-sixteenth of the circumference of the stator

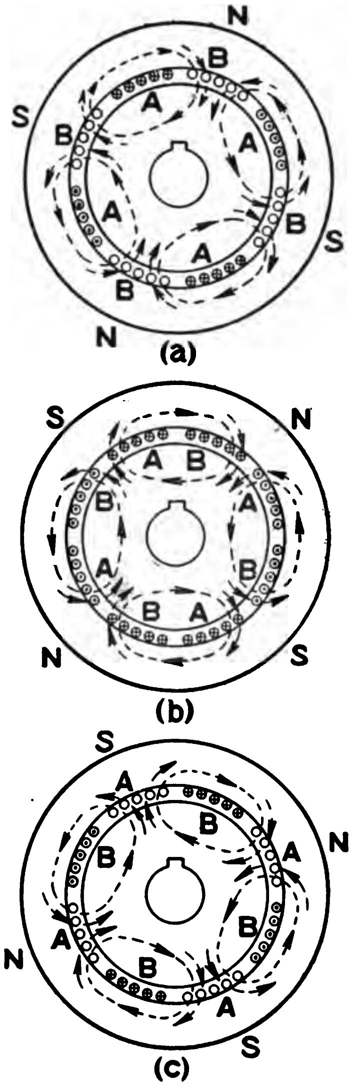


Fig. 147. Production of a Rotating Magnetic Field.

ring, from the positions they occupied in (a). Still, one-eighth of a cycle later, as at (c) the current in B conductors has reached the maximum value, and the current in the A conductors has fallen to zero; the points N and S have again advanced over one-sixteenth of the circumference of the stator ring.

The above rotation of the points N and S shows that the magnetic field is continuously revolving, the points (and the field) making one complete revolution while the alternating currents supplied to the stator windings are passing through two cycles. In general:

$$n = \frac{2f}{p} \tag{1}$$

where n is the number of revolutions per second of the stator magnetism, p is the number of poles, N and S, and f is the frequency of the alternating current supplied to the stator windings.

4. Speed, Slip and Torque. If n is taken to represent the revolutions per second of the magnetic field and n^1 the revolutions per second of the rotor, then, when $n = n^1$, the rotor and the magnetic field are turning at the same speed and the rotor would be said to be running in *synchronism.* Under such circumstances, the relative motion between rotor and magnetic field is zero; consequently no electromotive force is induced in the rotor conductors and no current flows, so that no torque is exerted by the field on the rotor. The velocity of the rotor in an induction motor can therefore never equal the velocity of the rotating magnetic field, since there must be relative motion between the rotor and the magnetic field to induce currents in the rotor to produce torque. Even when the motor is running light, its speed cannot be synchronous. When load is thrown on, the speed of the rotor will immediately fall, the difference $(n - n^1)$ of the speeds of the field and the rotor will

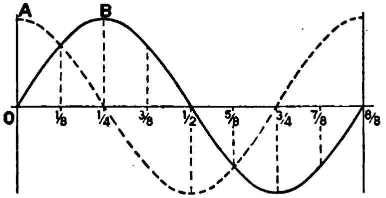


Fig. 148. Two Currents in Quadrature.

increase, and, therefore, the electromotive force induced in the rotor conductors, the currents in the conductors, and the torque with which the field drags the rotor, will all increase, tending to bring the rotor up to speed again. It is to be remembered that the rotor is simply the short-circuited secondary of a transformer, and that, consequently, as explained in Chapter VI, the secondary or rotor currents flow in such a direction as to decrease the impedance of the primary, thus permitting more current to flow into the primary or stator from the mains as the load on the rotor increases. However, the fact that this secondary, or rotor, field is in opposition to the stator field results in some of the stator flux being forced back, so that it does not link with the rotor conductors, but shunts out, instead, through the air gap between the rotor and stator; this leakage flux links only with the stator and gives rise to a counter voltage in the stator to prevent the stator current rising to correspond with the increase of load on the rotor. If the whole of the primary flux were to link with the rotor conductors, the torque would increase in exact proportion to $(n - n')$, but, as a matter of fact, a larger and larger fraction of the primary flux leaks around through the air gap as the rotor is loaded, and, consequently, the torque increases more slowly as $(n - n')$ increases.

As load is taken on by a motor, the rotor speed, therefore, decreases in nearly direct proportion to the load, from nearly synchronous speed at no load to about 92 per cent. in small motors at full load. The difference in speed $(n - n')$, expressed as a percentage of synchronous speed, is called the *slip* of the motor. When an induction motor is overloaded, it draws excessive current from the supply mains, and its torque increases up to a certain value of the slip; when loaded up to this limit, the machine is unstable, and a slight additional load will cause a great drop in speed.

5. Induction Motor at Starting.

At the moment the motor is connected to the mains, and when its speed is zero, the relative speed of the rotor and the rotating magnetic field is maximum. It is at this time, therefore, that the voltage induced in the rotor conductors is greatest, and, in the case of large motors, where the rotor conductors are bars of heavy copper, enormous currents would be induced in the rotor which would result in the motor being burned up, if some means were not provided to limit the rotor current, either by temporarily inserting resistance in the rotor circuit, or by impressing a smaller voltage on the stator during starting. In small motors, such as used in signal work, such devices are not necessary, for the reason that, due to the comparatively large air gap used, the primary leakage flux is considerable; as previously explained, this flux links only with the primary, whose impedance is thus prevented from falling below a certain safe value, with the result that excessive currents do not flow through either the stator or the rotor.

In this connection it is interesting to note that, due to the primary leakage flux and the consequent presence of reactance in the primary, or stator, circuit, the stator current lags behind the impressed stator voltage, so that all induction motors have, consequently, a low power factor, particularly at starting.

In Chapter VI, dealing with transformers, it was explained that, when the secondary of a transformer is open-circuited, a certain current, known as the exciting current, flows into the primary to magnetize the core and to supply no-load copper and iron losses. Naturally, if there is an air gap in the core, the exciting current will be larger than would be the case with a solid core. In the case of the induction motor, there is a similar exciting current, which will be comparatively large, due to the necessity of providing a safe air gap between rotor and stator, and, in signal motors, this exciting current constitutes a large part of the total current; in fact, it will generally be found that the full load current differs little from the no load current or the starting current.

6. Split-Phase Motors. The above discussion has been worked out on the basis of a pure two-phase motor—one having two separate primary circuits fed from two sets of mains whose voltages differ in phase by 90 degrees. Were a signal system to be equipped with straight two-phase signal motors, three transmission wires would be required(one wire acting as a common for the two phases), and, in many cases, this would be objectionable on account of cost. As a single-phase transmission with two wires is used in most cases, it becomes necessary to provide some means to divide the single-phase current into two components separated by a proper phase angle, if induction motors are to be employed; the current flowing in the mains must be split up into two components sufficiently out of phase with each other, so that, when they are fed into the windings of a two-phase motor, the required rotating magnetic field will be produced.

Fortunately, this can be done, for, when a single-phase current divides between two branches of a circuit where the ratio of resistance to reactance is different in the two branches, a phase-difference results between the branch currents. For, example, referring to Fig. 149, M represents a two-phase induction motor, with its windings A and B connected, respectively, in series with resistance R and reactance X, these external elements and the stator windings A and B being, therefore, connected in multiple series across the single-phase signal mains as shown. The stator windings themselves generally have a low inherent power factor, and their currents would naturally lag considerably behind the voltage, as the windings are carried on an iron stator core and are, therefore, highly inductive. In the left hand circuit, however, the resistance R is introduced to bring the current more nearly in phase with the impressed voltage E, thus counterbalancing, in a way, the inductive effect of the stator winding A; on the other hand, the reactance X is introduced in the right hand circuit to help stator winding B to still further displace the current out of phase with the impressed voltage E. For example, if the total dead resistance in the left hand circuit is 75 ohms. while the inherent reactance of winding A is 25 ohms, then the power factor (cos θ) of the total left hand circuit is:

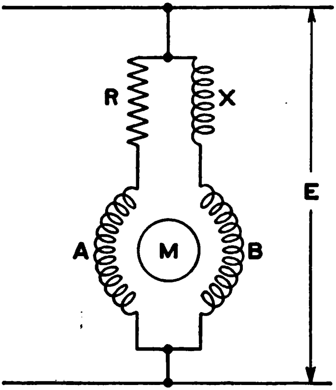


Fig. 149. Split-Phase Induction Motor.

$$\cos \theta_A = \frac{R}{\sqrt{R^2 + X^2}} = \frac{75}{\sqrt{75^2 + 25^2}} = \frac{75}{79} = 0.95 \qquad (2)$$

which corresponds to a lag angle θ of only 18 degrees. If the total resistance in the right hand circuit is 25 ohms and the reactance is 75 ohms, then the power factor of that circuit will be:

$$\text{Cos } \theta_B = \frac{R}{\sqrt{R^2 + X^2}} = \frac{25}{\sqrt{25^2 + 75^2}} = \frac{25}{79} = 0.31 \qquad (3)$$

which corresponds to a lag angle θ of 70 degrees. Finally, therefore, the effective *difference* in phase between the currents in stator coils A and B is 71° - 18° = 53°, so that the motor actually runs as a two-phase motor, with 53° instead of the ideal 90° phase displacement.

In many cases, the reactance X in series with stator winding B, Fig. 149, is alone used without the resistance R in series with the A winding; at other times, the reactance X in series with the B winding may be omitted and a resistance used in series with winding A instead. In all such instances it will be found that the designer has managed to secure adequate phase splitting with one external element (either resistance or reactance) only, the natural or inherent power factor of the other element being considered about right without external aid.

It is not necessary that the two components be separated by the full 90° displacement, for a rotating magnet field can be obtained by means of any two alternating currents, whatever their phase angle, although the speed of the field may not be absolutely uniform, and its intensity will not be so great as would be the case with a pure quadrature relationship. As a matter of fact, the intensity of the resultant field will be found equal to the maximum value of either of the two equal components multiplied by the sine of their phase angle. To secure a given torque, each of the currents in a split-phase motor will, therefore, have to be greater than those required for a pure two-phase motor whose currents are in quadrature; in the example given above, where the currents in a split-phase motor are separated by a phase angle of 53° it will be found that these currents will each have to be approximately 25 per cent. greater than those required with a full 90° displacement.

7. Split-phase versus Pure Two-phase or Three-phase Motors. The split-phase motors just described are, of course, not ideal from a purely theoretical standpoint. They are, however, very simple and reliable, and can be operated from single-phase mains involving only two-line wires for the transmission system; for these reasons, they have generally been adopted for signal operation, except where polyphase currents are available. As will be explained in the next chapter, it is sometimes more economical to transmit power for the signal system by a three-phase system requiring three-line wires; in this case, of course, there is no necessity of using split-phase motors, and they should not be employed in view of the greater current they take.

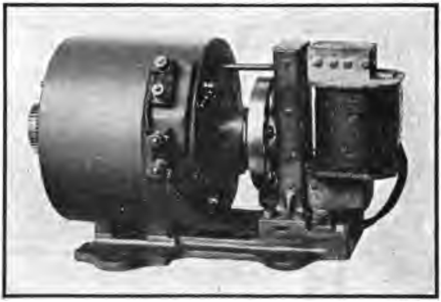


Fig. 150. Induction Signal Motor.

8. Construction of Induction Motors. A common design of split-phase induction motor for the operation of signals is illustrated in Fig. 150, where the iron case, or shell, housing the stator and rotor is seen at the left of the photograph, and the phase-splitting device, serving also as a brake, at the right. It will be seen that this brake coil is wound around a vertical laminated core, pivoted at the bottom; this highly inductive coil is connected in series with the inductance or lagging phase winding of the stator, so that, consequently, the current in that winding lags greatly behind the current in the other, or resistance, winding which is connected directly across the feeding mains. Normally, when no current is flowing through the motor windings, the brake drops by gravity to the position shown in Fig. 150, but the moment the motor circuit is closed by the signal control relay, current flows through the brake coil, and it picks up, closing t air gap at the top and pulling the brake pad at the same time away from the bottom of the brake wheel, the brake pad being carried by an extension on the bottom of the core on which the brake coil is wound. When the motor circuit is opened, the brake coil is de-energized, the brake core falls away, and the pad comes in contact with the brake wheel so as to prevent the motor drifting. This element, therefore, serves the double function of phase-splitter and brake. A sectional side view of this motor is shown in Fig. 151.

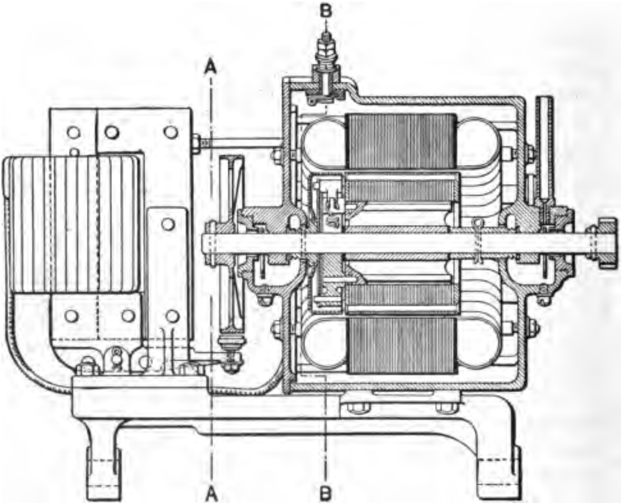


Fig. 151. Cross Section of Induction Signal Motor Shown in Fig. 150.

When this motor, and others of similar design, is operated as a split-phase motor on 60 cycles, the heavy secondary reaction at starting is liable to make the starting torque rather small, unless one is willing to put considerable power into the motor at that time; in order to avoid this, the rotor is often connected to its shaft through a simple centrifugal clutch, which allows the rotor to get up speed and cut down the secondary reaction before the motor takes on its load. With this in view one of the end plates of the rotor is provided with two short steel studs placed diametrically opposite, each carrying a short centrifuge arm, the outer, or shoe end which engages with a pressed steel shell, or drum, pinned to the rotor shaft; when the rotor speeds up at starting, it spins free on the shaft for the first few revolutions. Thus, even though the starting torque is small, the motor finally will carry its load with a very moderate amount of power.

COMMUTATOR MOTORS.

9. Elements. The alternating current commutator motors used for the operation of signals are, without exception, of the series type, and, in their construction and electrical characteristics, they are, in many ways, similar to the direct current series motors so familiar to every signal man. The elements of the alternating current series commutator motor are, first, the laminated field core with its energizing coils, and, second, a wire wound armature carrying a commutator, the armature and field being connected in series through the commutator and its brushes.

10. Theory of the A. C. Series Motor. Since a direct current series motor, such as is generally used for the operation of D. C. signals, does not reverse its direction of rotation when the current is simultaneously reversed in its field and armature windings, it might be expected to run when supplied with an alternating current. As a matter of fact, this is the case when the field and armature cores are well laminated to avoid excessive eddy currents, and the electric and magnetic circuits are so designed as to keep the self-inductive reactance within reasonable limits, for it must be remembered that the flow of alternating current through the field and armature windings gives rise to induced voltages in these elements, purely aside from the counter-electromotive forced induced in the armature conductors by their rotation through the field.

In the case of the D. C. series motor, it is common to make the fields strong to prevent skewing of the field flux, with resultant poor commutation, while the armature is made magnetically weak for the same purpose, and also in order to reduce the self-inductance of the coils under commutation to a minimum. In the A. C. series motor, on the contrary, the field is made magnetically weak to reduce its self-inductance to a minimum and to prevent too great a voltage being induced in the armature, with resultant sparking. To secure adequate torque, the armature is made magnetically strong.

The greatest difficulty which has been encountered in the design of A. C. series motors has resided in the unavoidable voltage produced in the rotating armature coils at the moment they are under and are short-circuited by the brushes, this voltage being due to the cyclic variation in the field magnetism. At the instant when the field flux is a maximum, no current is induced in the short-circuited armature coils, due to its change, but the coils enter the condition of short-circuit bearing maximum line current; and, when the field flux is zero a maximum current is induced in the short-circuited armature coil, but the line current is zero. The short circuited coils being, with respect to the field windings, in effect, transformer secondaries of very low resistance, the short circuit currents become very large. When a brush passes form one commutator segment to the next, as the armature rotates, the electromotive force is short-circuited through the brush which completes the connection between segments. The current through this short circuit is likely to be of large volume and produces an excessive heating of the brush, the segment and the coil. Moreover, and what is of greater importance, the rupture of this heavy current produces destructive arcing at the brushes, which roughens and spoils the surface of the commutator.

11. Construction of the A. C. Series Motor. The motor illustrated in Fig. 152 illustrates the general construc-

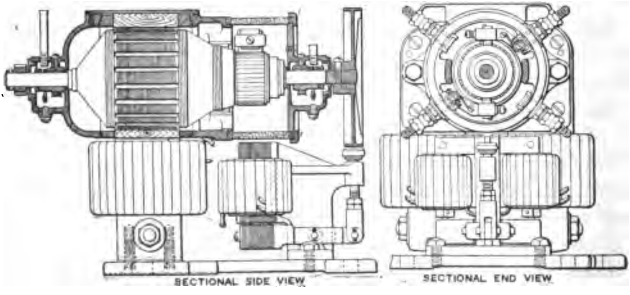


Fig. 152. A. C. Series Commutator Signal Motor.

tion of motors of this type, it being evident, from this drawing, that, in appearance, the A. C. series motor is almost exactly like the D. C. series motor. In Fig. 152, a brake coil connected in multiple with the armature and field windings, actuates a brake mechanism, whereby, when the motor circuit is opened, a leather pad carried by the brake armature comes into contact with a wheel pinned to the motor shaft, thus preventing the motor from overrunning or drifting.

12. Application of A. C. Series Motors. Series motors at one time were rather favored by some engineers because of attractive power economy; the A. C. series motor consumes, possibly, not more than 60 per cent. of the power of a single-phase induction motor of equal output. When carefully designed, series motors work out fairly well. The sparking at the brushes and the roughening of the commutator, mentioned above, are not very serious matters in the case of a signal where the motor is not forced to rotate backward when the signal is traveling from *proceed* to *stop*, but would be intolerable in the case of a drift backward spindle type mechanism. A. C. series motors have, occasionally, been used with signals of this latter type, but have not proven satisfactory, because the roughening of the commutator, due to sparking, sometimes seriously retards the backward movement of the mechanism from *proceed* to *stop*, simply because considerable friction is introduced at the place where it does the most harm—the commutator which travels at the highest speed.

13. Comparison between Induction and Series Motors. Without question, the induction motor is the simplest and most easily maintained of alternating current motors. It is free from commutators and brushes, and all the troubles which are inherent with such devices when used to break heavy alternating currents at a high voltage. The ability of the squirrel cage induction motor to withstand rough treatment and heavy overloads is proverbial. Well-designed induction motors for signal operation can even be "blocked," or held stationary indefinitely with full voltage across their windings, without injury, whereas, under similar circumstances, a series motor would burn up.

From the signal engineer's standpoint, the chief objection to the series wound motor is the commutator. This is especially true with signals so designed that a motor rotor rotates while the signal arm is changed from *proceed* to the *stop* indication. The friction of the brushes upon the commutator requires a large extra counterweight on the spectacle casting. This not only means extra energy for carrying the extra weight, but also means unnecessary wear to the mechanism; first, on account of the inertia to be overcome in starting the signal from the *stop* to the *proceed* indication, and second, on account of the wear of the mechanism due to the momentum of the motor rotor, which accelerates very rapidly with the downward movement of the spectacle casting in carrying extra heavy weight. Brushes require constant attention, and, in the case of a broken brush, or poor contact, a signal failure results. Also, sparking of the commutator tends toward carbonization, which necessitates careful watching and special attention to the insulation between the segments of the commutator. With the induction motor, all of this and kindred troubles are eliminated.

As regards the matter of relative power economy, a representative type of series motor takes 165 watts against 270 watts for an inductive motor. Now, if there were four trains per hour passing a signal for 24 hours each day, and it required four seconds to clear the signal, then the series motor would consume 6,424 watt-hours per year, while the induction motor would take 10,512 watt-hours. The difference, 4,088 watt-hours per year, at two cents per kilowatt hour, would make a difference in the cost of current for clearing each signal 8.2 cents per year. This gain in economy would hardly seem to justify the use of the series motor, except in special cases. The real cost for energy for the operation of a signal is not the cost of clearing the signal, but the cost of the energy to hold the signal at the *proceed* indication; this amount would, of course, be constant, regardless of the type of motor used.

It is in its influence on the size of the transmission line that the series motor is most attractive. Due to the low current it requires, as compared with the induction motor, the size of the transmission wire may be made smaller for the series motor than for the induction motor. The size of the transmission wires is regulated by the maximum current they have to carry, and, of course, this maximum condition arises every time all the signals have to be cleared at once, as would happen, for example, after some momentary interruption at the power house. In practically all cases, however, the temporary drop in the transmission caused by a system of induction motors all running at once may be compensated for by raising the voltage at the power house for a few seconds until the signals have latched up and their motors have stopped.

HOLDING DEVICES.

14. Kinds. Briefly, slots or holding devices for alternating current signals may be divided into two classes: (a) Tractive Magnets with shading bands, and (b) Induction Slots.

15. Tractive Magnets. If a laminated iron magnet core, say of the horseshoe pattern as illustrated in Fig. 153, is magnetized by an alternating current flowing in the coils wound around the core, then a magnetic flux in phase with the current will, naturally, be set up in the iron core. As the current in the coils rises and falls, so will the flux rise and fall correspondingly and in such a manner that, when the current passes through the zero point of the alternating current sine wave, so, also, will the flux pass through zero. When the flux is zero, the pull, or tractive, effort on the armature opposite the poles is also zero. Consequently, the pull of such a magnet is pulsating and the armature rattles back and forth against the pole faces with a humming noise.

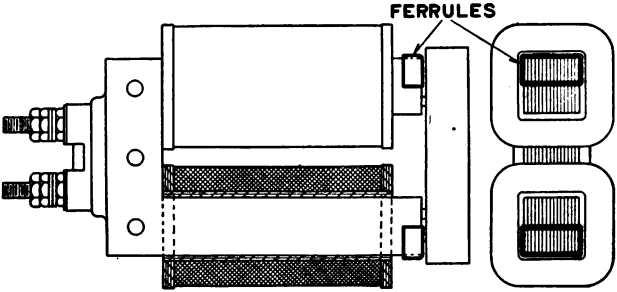


Fig. 153. Tractive Type Slot Magnet.

If, now, a pair of heavy copper ferrules, or shading bands are set into the pole faces so that half of each pole end is surrounded by a band, as shown by the heavy black lines in Fig. 153, then currents will be set up in the shading bands by the alternating magnetic flux; necessarily, the currents in these shading bands will lag just 90° behind the flux, because it is when the rate of change of the main flux is greatest (when the main flux is passing through zero) that the induced currents are the greatest. The currents induced in the copper shading bands exert a counter magnetizing force acting in a direction to reduce the increase in lines leading through the shading coil. Thus, the flux increases rapidly over the "unshaded" portion of the pole, while that in the shaded portion is retarded and lags behind the main flux. Or, again, the currents induced in the shading coils may themselves be considered as the seat of a secondary magnetic field, which is zero when the main flux is maximum, and is maximum when the main flux is zero. It is, therefore, apparent that some flux is always passing from pole pieces to the armature, and, in that way, a continuous tractive effort, or pull, is maintained. Slot magnets of this type are used in signals of the Style "B" and the Style "S" types.

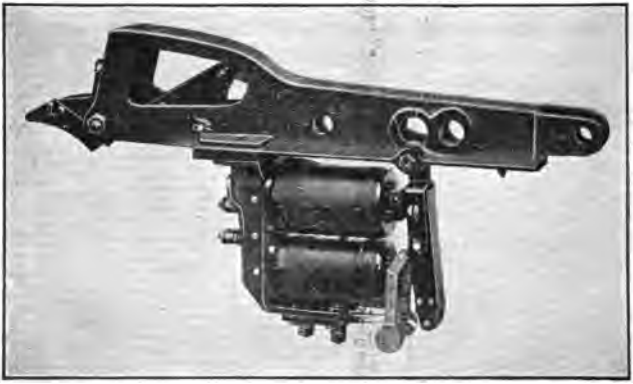


Fig. 154. Slot Arm Provided with Slot Contact.

In many cases, such a slot magnet as the above may conveniently be used also, as a line relay when equipped with the proper contacts. For example, where line control for distant signals is used, a line relay usually has to be provided at the controlled signal to close the distant motor and slot circuits. The design shown in Fig. 154 illustrates how such a line relay may be dispensed with. The distant slot armature carries at its lower end a small insulating block supporting a carbon roller about $\frac{5}{8}''$ in diameter in such a manner that, when the slot magnet is energized from the line and the armature is pulled forward, it closes the circuit between the Y-shaped ends of the two contact springs supported on insulations carried at the bottom of the slot magnet core frame; the terminal posts for these contact springs are seen didirectly under the slot magnet in Fig. 154. When the signal indicates *stop* and the slot arm is down, the pair of swinging brass counterweights immediately at the left of the armature hold the armature away from the magnet poles, so that the contact is held open. This device is called a slot contact; it takes the place of an ordinary line relay in controlling the motor circuit of the slot arm and signal in question.

16. Induction Slots. Holding devices of this kind, working on the induction principle, consist of a primary, or stator, element and a secondary, or rotor element. They are mainly used at present on spindle type top post signals of the T-2 type hereinafter described. Their theory of operation will be readily grasped from a study of Fig. 155, which shows an eight pole laminated stator H carrying 8 coils, C one over each pole, and which, when energized,

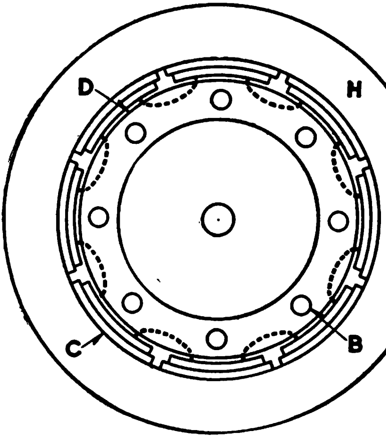


Fig. 155. Induction Slot.

give rise to fixed magnetic fields flowing between poles in the direction of the dotted lines. The rotor D is also laminated and carries 8 copper bars B arranged symmetrically about the rotor, these bars being soldered into massive end plates, just as in an induction motor. Furthermore, rotor D is pinned to the motor shaft so that, when prevented from rotating, the semaphore shaft, attached to the motor shaft through a train of gears, is in turn held locked, and in this manner the signal may be held in the proceed position after it has once been cleared by the motor. As long as there is no torque on the shaft, the bars of the slot rotor D (when the stator is energized) will rest directly under the middle of the pole faces of the stator core, but, when the signal is cleared and load comes on the slot rotor D through the motor shaft, then bars B come within the field of the stator windings, with the result that currents are induced in the slot rotor bars; these secondary currents, of course, flow in such a direction that the field which they give rise to reacts on the main stator field in such a direction as to thrust the rotor bars back out of the field into which the torque of the motor shaft had forced them; this is in accordance with Lenz's Law stating that in all cases of electro-magnetic induction, the induced currents have such a direction that their reaction tends to stop the motion which produces them. In fact, the rotor bars will be forced just far enough within the stator field to have just enough current induced in them to balance the torque brought on them by the motor shaft.

Induction slots are very simple and strong in their construction, require little maintenance, and are not liable to be stuck by congealed moisture or gummy oil, since there are no surfaces to come in contact, the slot rotor D simply rotating in the bore of the stator, the two being separated by a liberal air gap.

SIGNAL LIGHTING.

17. Lamp Bodies. Lamp bodies for electric lighting for signals are generally much simpler than those for oil lighting, as the top draft or ventilating feature of the oil lamp and the oil font are, of course, unnecessary in electric lighting; some of the commercial types of lamp body for electric lighting consist simply of a cylindrical sheet iron casing provided at the top with a sheet iron cap, the incandescent bulb being supported on the inside of the lamp body by a wooden or porcelain block carrying pony sockets. Another well known type of lamp, somewhat more accessible tham that previously described, consists of two light iron castings, as shown in Fig 156, one fitting on top of the other, the lower one carrying the terminal block and lamp sockets.

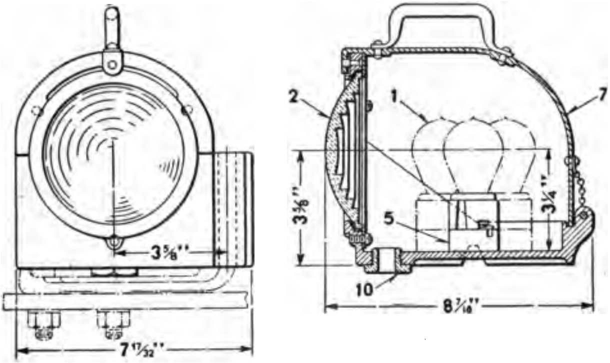


Fig. 156. Semaphore Lamp for Signal Lighting.

18. Carbon versus Tungsten Lamps. In the early days of electric lighting for signals, carbon lamps were generally used, but, due to the low economy of the carbon lamp, it has now been generally replaced by the lamp with a tungsten filament; for example, a 2 C. P. 110 volt carbon lamp requires about 14 watts, whereas the tungsten lamp takes only 2½ watts; it is not surprising, therefore, that the carbon lamp has been superceded by the tungsten lamp in signal lighting, as elsewhere. The economy of the tungsten lamp results from the fact that the metal filament can be worked at a very high temperature, and consequently, the filaments are rather small in cross section as compared with the carbon lamps; in fact, the filament of a 2 C. P. tungsten lamp for 110 volt work would be too fragile to be serviceable, although carbon lamps can be obtained for almost any voltage. In order t secure a strong, sturdy filament, most tungsten lamps used for signal lighting are made for a normal voltage of 10 or 12.

19. Number and Candle Power of Lamps. In most cases, two incandescent lamps are used in each lamp body, so that their lives will overlap, thus insuring that one lamp will be always burning; it is, of course, highly important to keep at least one light always burning to maintain the indication. Some very careful work has recently been done with tungsten lamps, however, and at present the life of the tungsten lamp can be predicted with considerable certainty within 2 per cent. of its actual performance. It is the general practice to use two 2 C. P. lamps back of each lens, although two 1 C. P. lamps would give sufficient light for good indication, if a 1 C. P. tungsten lamp were commercial, which, however, is not the case, as the filament would be too small and fragile.

20. Life of Lamps. Lamp manufacturers generally guarantee a life of at least 1000 hours for tungsten lamps, but, in actual practive, it is generally found that the life of the lamp will be much longer than is indicated by the manufacturers' guarantee; as a matter of fact, most tungsten lamps will have a life varying between 1700 and 3000 hours, if burned at full normal voltage.

However, it is a well known fact that the life of a lamp is enormously increased if the lamp is burned considerably below normal voltage, and, consequently it is the general practice to burn 12 volt signal lamps at 10 volts; at this voltage plenty of light is secured, and it is not unusual for a lamp to burn from eight months to a year.

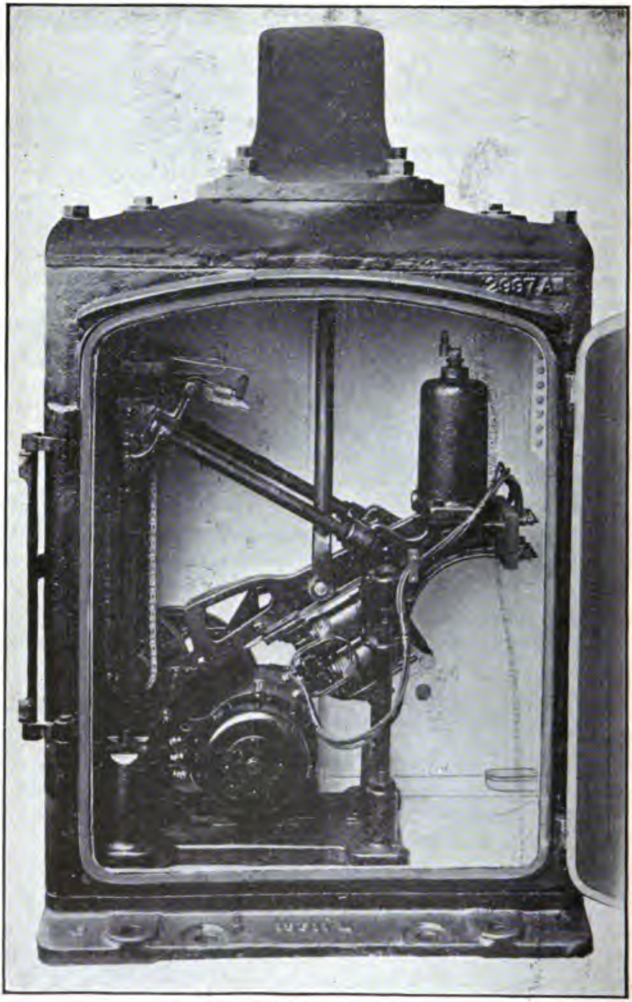


Fig. 157. Style "B" Two-Position A. C. Signal Mechanism in Case.

THE STYLE B SIGNAL

1. Description. The style B signal is, without doubt, the best known signal in America, there being some 60,000 of them, A. C. and D. C., in service. A detailed description is, therefore, unnecessary for American readers, but for the information of foreign engineers, it will perhaps not be out of place to state that the machanism consists of a motor, located at the lower left hand corner of the front view shown in Fig. 158, driving through a train of gears a vertical chain carried at top and bottom by sprocket wheels, as illustrated at the extreme left of the front view. The chain, turning in a counter-clockwise direction, carries two projecting roller studs, evenly spaced along its length, one of which as it travels upward, engages a forked head projecting from the slot arm, to which latter the up and down rod of the signal is attached, the slot arm being the member extending downward diagonally from right to left. The slot arm carries the slot magnet or holding device, which, when energized, holds locked through a simple system of levers, the forked head carried at the extreme left. When the chain roller engages this forked head, the slot arm

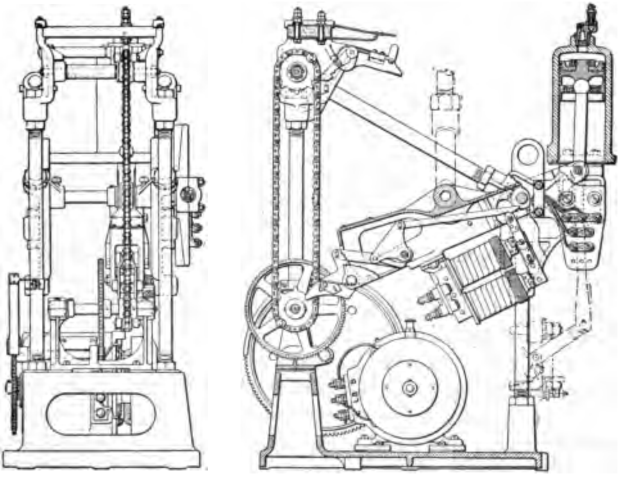


Fig. 158. Cross Section Style "B" Two-Position A. C. Signal Mechanism.

is lifted upward, turning on a shaft at its right hand end. As the slot arm is lifted, the up and down rod rises with it, and the motion continues until the signal is cleared and the chain roller, arriving at the end of its travel, passes out from under the forked head, leaving the latter to rest on a pair of hooks, or fingers, which slip under it at the end of its stroke. Meanwhile, the head of the slot arm has pushed open the circuit breaker shown at the upper laft hand corner of the mechanism, thus automatically opening the motor circuit; immediately the current is interrupted, the motor is quickly brought to rest by the brake shown in Fig. 150; this half revolution of the chain brings the second roller around below the bottom chain sprocket ready to lift the slot arm the next time the signal is to be cleared; it will be evident that, were the motor not promptly stopped, the roller would overtravel and the chain would have to make another half revolution before the next chain roller were in the engaging position.

When the signal control relay opens and the slot magnet is thereby de-energized, the slot armature is immediately thrust away from the poles due to the thrust transmitted from the up and down rod through the slot arm levers, the armature thus unlatching or unlocking the forked head; this latter is not rigidly attached to the slot arm, but is pivoted thereon, so that due to the heavy downward thrust of the up and down rod attached to the semaphore, the forked head turns upward about its pivot, slips off the hooks on which it hung, and the whole slot arm drops instantaneously by gravity down to the position indicated in Fig. 158. To prevent the mechanism being jarred or injured by this downward drop of the slot arm, the latter actuates a piston working inside the cylinder shown at the upper right hand corner of the cut, the compression of air in the cylinder on the up-stroke of the piston serving to ease the downward movement of the slot arm; to regulate the degree of compression, the buffer cylinder is provided at the top with an adjustable escape valve or vent.

It is to be noted that the backward movement of the signal from *proceed* to *stop* is in no way retarded, except by the compression of air in the buffer. There is no compression until the slot arm has unlatched and has started to drop downward; in practice, it is found that the slot arm drops immediately through about three-quarters of its stroke before compression becomes effective. The Style B mechanism, therefore, differs radically in principle from spindle type top mast mechanisms, where the motor acts more or less as a buffer, and has to be turned backward at a rapid rate when the signal is returning from *proceed* towards *stop*. The proverbial safety of the Style B signal is directly due to the fact that the backward movement of the signal from *proceed* to *stop* is absolutely free and unrestricted; there can be no false clear failures resulting from dirt clogging the motor air gap, as the motor is entirely disconnected during the backward stroke.

2. **Motor and Slot.** The Style "B" A. C. signal may be provided with either an induction motor or a seies commutator motor; for reasons previously explained, the induction motor is recommended and the mechanisms illustrated in Fig. 157 and 158 are so equipped. The slot is of the tractive magnet type with shading bands, as described in connection with Fig. 153. The motor and slot can be wound for any commercial voltage or frequency, single or polyphase, the standard voltage being 110 and the frequencies 25 and 60.

3. **Three-position Signal.** The mechanism shown in Fig. 158 has but one slot arm and is designed to operate a one-arm two-position semaphore through either 60° or 90° in either the upper or the lower quadrant. Where home and distant signals are to be operated on the same mast, the mechanism is simply provided with two independent slot arms, one for the home blade and the other for the distant, one motor serving for both blades as the two are never cleared simultaneously. In the three-position signal (Fig. 159) two slot arms are likewise used, the up-and down rod being provided at the lower end with a small rotating pinion meshing between two vertical toothed racks projecting upward between guides from the slot arms. Each slot arm lifts a rack and when the front slot arm reaches the top of its stroke, its rack has carried the pinion to lift the up and down rod through half its total travel, thus bringing the semaphore to the 45°, or caution position; when the back arm slot lifts, it completes the upward stroke of the up-and-down rod, so that the signal indicates 90°, or full proceed.

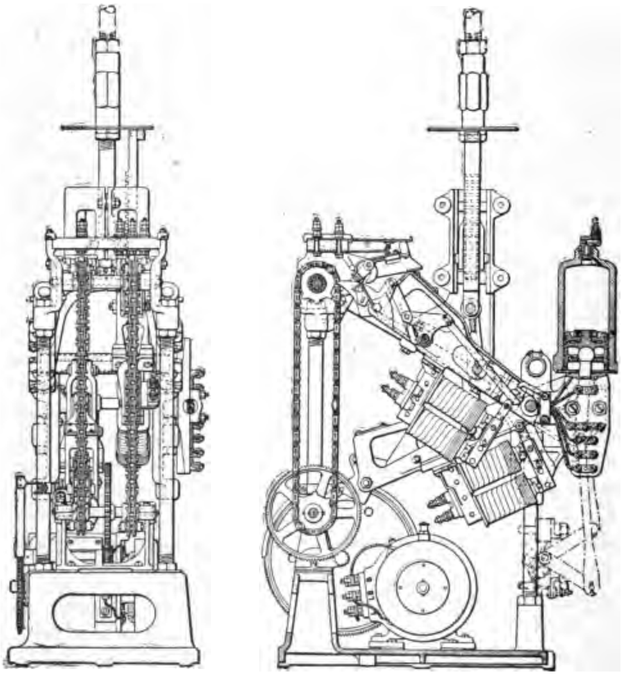


Fig. 159. Style "B" Three-Position A. C. Signal Mechanism.

4. Circuits. The complete circuit diagram for the Style "B" signal, working in either three positions or as a home and distant signal, is covered by Fig. 160, the circuit breakers at the left (those carried on the insulating base at the upper left hand corner of the mechanism in Fig. 159 and operated by the slot arm) being shown in positions corresponding to the *stop* indication of the signal blade, both slot arms A and B being shown. When slot arm A is cleared it opens at the top of its stroke, circuit breaker 1 and closes circuit breakers 2 and 3, so that when the 90° control circuit is complete the motor will clear slot arm B through circuit breaker 5. When the signal is controlled directly by a three-position track relay it must be remembered that when the relay shifts from one position

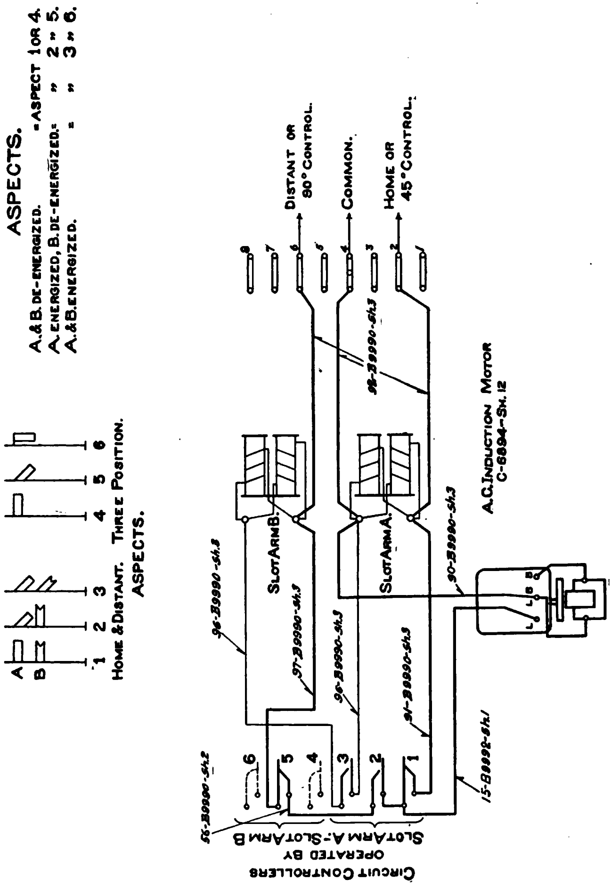


Fig. 160. Circuits for Home and Distant or Three-Position Style "B" A. A. C. Signal.

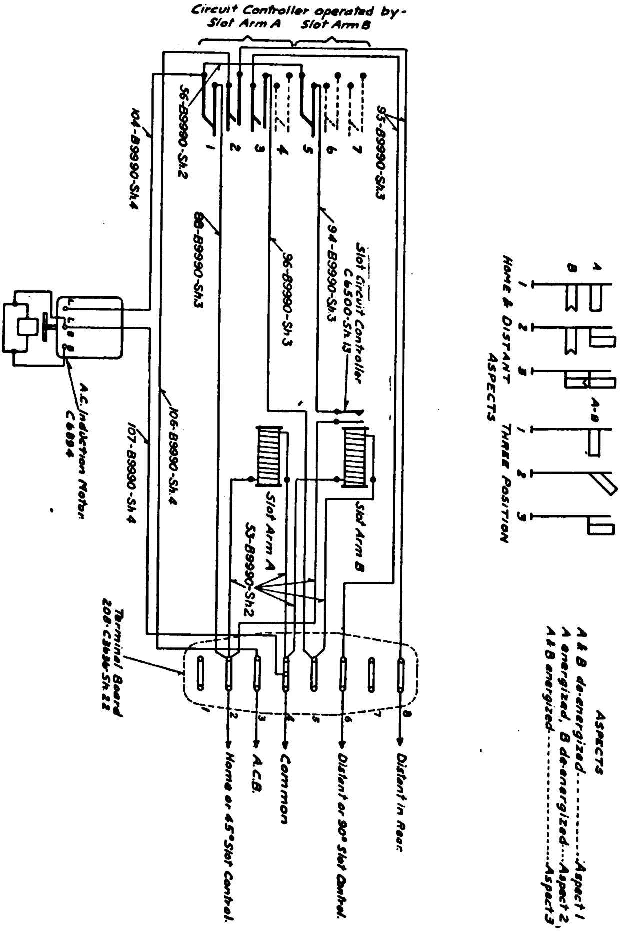


Fig. 161. Circuits for Home and Distant or Three-Position Style "B" A. C. Signal with Slot Contact on Distant Arm.

to the other, the control circuit is momentarily interrupted, and in order to prevent the *caution* slot from "kicking off," it is customary to feed the latter direct from the transformer over the points of a slow acting relay, the relay itself being controlled from a 45° contact of the three-position track relay. The slow acting relay may be either of the vane type or of the polyphase type; the polyphase is naturally slow acting on account of its geared movement and the vane can be made slow acting by adjusting its contacts so that they will not open until the vane has fallen nearly to the bottom of its stroke. Thus while the slow acting relay is de-energized during the reversal of polarity of the track relays, the signal circuit is kept closed. It is obvious, of course, that a slow acting relay is not necessary when the signal is controlled by separate two-position track and line relays, such as would be used in a line control circuit for the clear or distant indication.

Where line control for the clear or distant indication is employed the slot contact device illustrated in Fig. 154 and described on page 258 of this chapter may conveniently be used, as it eliminates the necessity of a line relay. Fig. 161 illustrates this application, clear or distant slot arm B acting as a line relay to close the slot contact immediately to its left to control the motor circuit. Slot contacts of this type have seen a very extensive application and their dependability has been thoroughly proved.

ELECTRICAL CHARACTERISTICS OF STYLE "B" A. C. SIGNALS.

Signal	Frequency	Voltage		Induction Motor (Single-Phase)		Slot		Clearing time Sec.
		Normal	Minimum	Amps	Watts	Amps	Watts	
2 pos. 60°	25	110	90	2.1	120	0.32	11	8
"	60	110	90	2.3	130	0.45	15	8
3 pos. 90°	25	110	90	2.2	125	0.64	22*	11
"	60	110	90	2.4	135	0.90	30*	11

*Total with both slot arms energized.

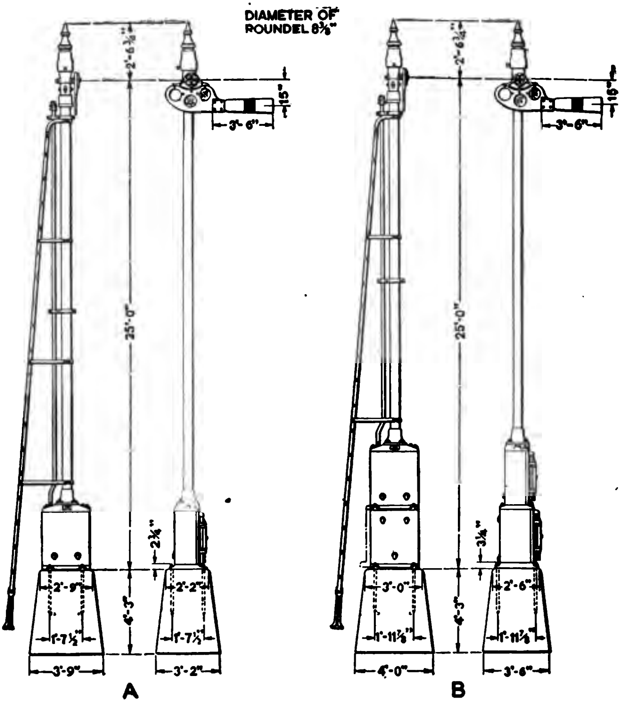


Fig. 161b. One Arm Style "B" Three-Position Upper Quadrant Ground Post Signals. The Signal at the Right is Provided with a Double Case, the Lower Half of which May be Used for Housing Track Transformers, Impedances ors Extra Relays.

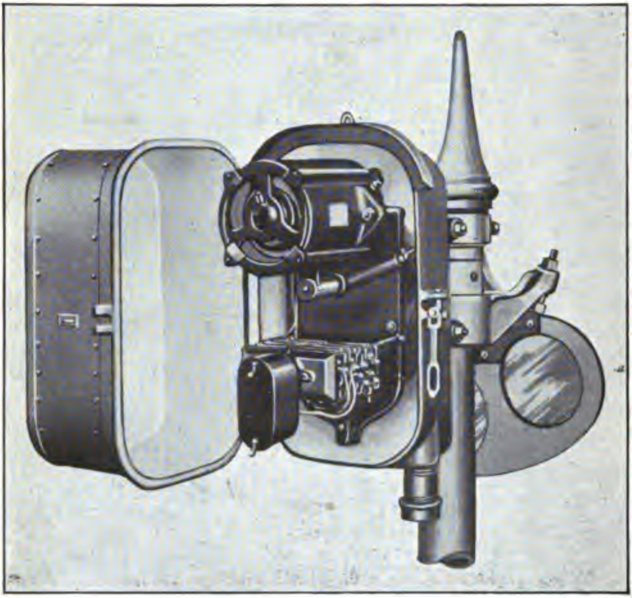


Fig. 164. Style "T-2" A. C. Signal.

THE STYLE T-2 SIGNAL.

1. Description. This signal is of the spindle or top mast type, the motor, located at the top of the mechanism, as shown in Fig. 164, driving the semaphore shaft directly through a train of light but strong drop forged oil-tempered gears running on roller bearings, the motor itself running on ball bearings. The motor and slot, or holding, device are both housed in the same cylindrical iron case illustrated in the photograph. The circuit controller, projecting outward from the bottom of the mechanism, consists of two porcelain

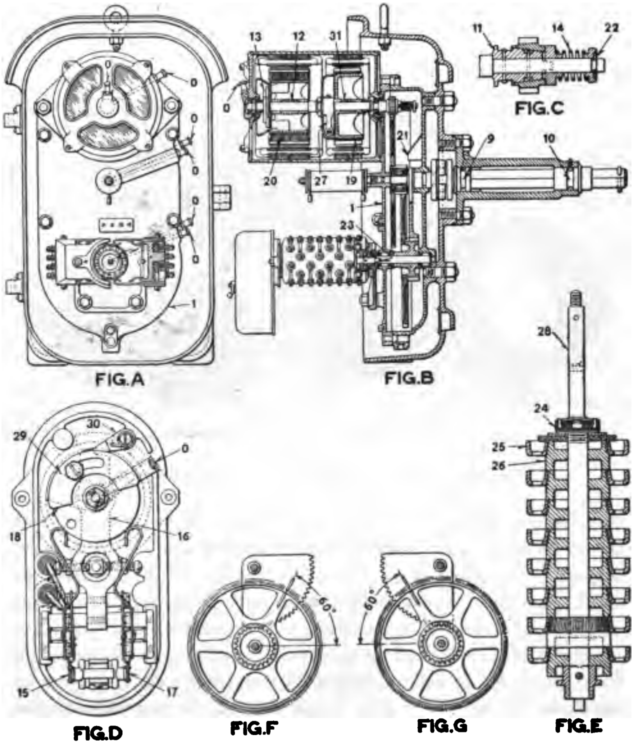


Fig. 165. Cross Section of "T-2" A. C. Three-Position Signal Mechanism.

blocks carrying contact fingers extending inwardly and rubbing on circular brass segments, insulated from each other by moulded bushings and carried on the circuit controller shaft. These details will, perhaps, be more easily understood after an inspection of Fig. 165.

2. Motor and Slot. The motor and slot are both of the induction type; a full explanation of the principle on which the latter works will be found in connection with Fig. 155, from which it will be noted that the slot rotor is locked magnetically and prevented from rotating by currents induced in its conductors by the slot stator when the latter is energized by the control relay. The detail parts of the motor and slot are illustrated in Fig. 166, where 39 and 40 are the slot and motor stators, and 19 and 20 are the slot and motor rotors, respectively, (carried on the same shaft); 60 is the case, or shell, housing the above elements, and 41 is the front plate closing the case and containing at its center a ball bearing, in which the front end of the motor and slot shaft runs; the front plate 41, it will be noted, is provided with transparent windows 42, permitting an inspection of the parts inside the case.

Fig. 166. Motor and Slot Parts of "T-2" Signal.

The assembled motor and slot are clearly shown at the top of Fig. 165, 19 and 20 being, respectively, the slot and motor

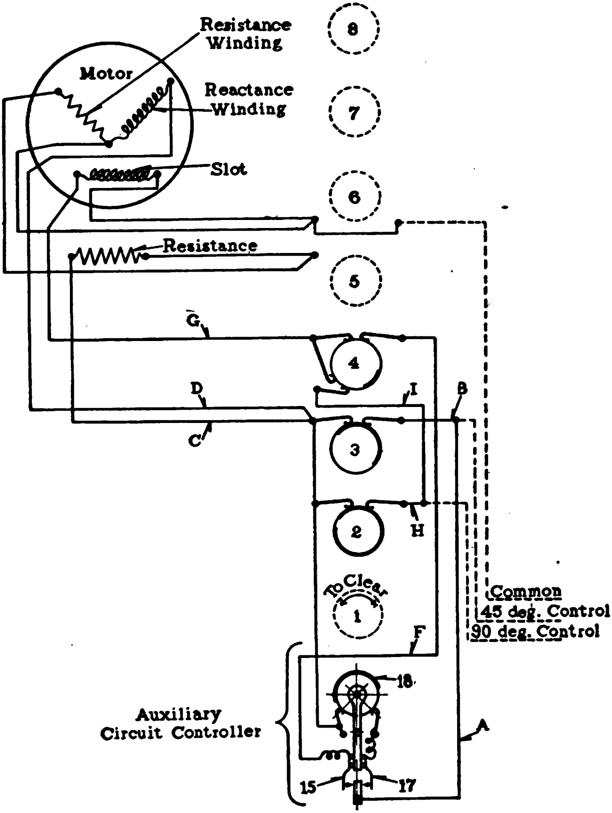


Fig. 167. Wiring Diagram for "T-2" Three-Position A. C. Signal.

rotors, as before. The motor rotor drives the shaft through a toothed ratchet 13 on the clearing stroke, but when the semaphore is traveling backward toward *stop*, the motor rotor is disengaged from the shaft through the ratchet, and, when the blade reaches the *stop* position, the rotor spins free on the shaft, thus relieving the mechanism from the shock of absorbing its momentum. The motor can be wound for either single or polyphase operation; when required to run single-phase, phase splitting is accomplished through the insertion of resistance in one of the windings, this resistance consisting of a fireproof spool wound with bare wire and located immediately under the motor in Fig. 165; the conductors of the other winding are laid in peculiarly formed slots in the stator core, so that the inductive reactance of this winding is extremely high. Thus, even though, for safety's sake, a large air gap is provided between stator and rotor, excellent phase splitting permits of low power input, considering the size of the air gap used.

3. **Circuits.** The circuit arrangement for a three-position signal controlled off a single-phase circuit by a three-position relay, is shown in Fig. 167.

Contact segment 2 controls the motor circuit for the *proceed* position, and segment 3 controls the circuit for the *caution* position. Segment 4 controls the slot circuit. An auxiliary cuit controller attached to the outward end of the regular circircuit controller shaft, as shown in Fig. 165, is used to produce a retarding torque through the motor when the semaphore arm is returning from the *proceed* to the *caution* position and thus assist in bringing the rotor of the slot to a stop so as to enable it to hold at *caution*. This controller, (D, Fig. 165), consists of a contact segment 18, and a vertical arm 16, which carry two movable contact fingers 15 and 17, at the lower end. This arm has a limited horizontal motion between two stop screws, which enables the circuit to be closed at 15, in one direction, and at 17, in the other direction. By a friction drive, contact 15, is held closed when the semaphore arm is being moved toward the *proceed* position.

When energy is supplied to the 45 degree control wire, it passes to the motor through contact segment 3, and wires C D. The circuit of wire C includes the resistance coil for phase splitting. The motor winding connected with this coil is known as the resistance winding. The winding of the motor connected to wire D is known as the reactance winding. The windings connected to wires C and D make connection to common.

The holding circuit in the *caution* position is through wire A, contact 15, wire F, contact segment 4, and wire G, through the slot winding to common. When the 90 degree control circuit is energized, the motor circuit is completed through wire H, and contact segment 2, in the manner described above. The holding circuit in the proceed position is through wire I, contact segment 4, and wire G, to the slot coil.

When the semaphore arm is returning from the proceed to the caution position, the auxiliary circuit controller is brought into play. In this case contact 15 is opened and contact 17 is closed, and the circuit to the motor from the 45 degree control wire is completed through the contact fingers bearing against contact segment 18. Segment 18 has an adjustment between the positions corresponding to 42 degrees and 52 degrees of the stroke of the semaphore arm and is arranged to close the circuit of the motor when the caution position is reached, in a manner tending to produce rotation in a direction to move the semaphore arm towards the proceed position again. This has the effect of stopping the mechanism and the first movement of the mechanism tending to drive the semaphore arm towards the *proceed* position opens the motor circuit at 17, and closes the slot circuit from the 45 degree wire at 15, thus enabling the slot to hold in this position. The mechanism wiring for a two-position signal is somewhat simpler, contact segments being necessary only to open the motor circuit and close the slot circuit. No auxiliary circuit controller for buffing is needed for the two-position signal, because, naturally, the return movement of the semaphore arm does not have to be slowed up so that the slot may hold at *caution*. Due to the mass inertia of the moving parts no slow acting relay is required to bridge over the interval during the reversal of the three-position control relay.

4. Characteristics of Style T-2 A. C. Signals. As this signal is of the drift-backward type, especial care has been taken in its design to eliminate in every possible way the element of friction, so that the semaphore will be perfectly free to drop from the *proceed* toward the *stop* position. Hence:

(a) The gears travel on roller bearings;

(b) The motor runs on ball bearings;

(c) The motor is of the induction type and is, therefore, free from commutator friction, which would have to be contended with if an A. C. series motor were used.

(d) The slot is also of the induction type and is free from any contacting surfaces or latching devices; its rotor, like the motor rotor, turns in a large air gap and is locked or held only by the currents induced in it, over this air gap, by the stator magnetic flux.

ELECTRICAL CHARACTERISTICS OF STYLE "T2" SIGNALS.

Signal	Frequency	Voltage		Induction Motor (Single-Phase)		Slot		Clearing time Sec.
		Normal	Minimum	Amps	Watts	Amps	Watts	
3 pos. 90°	25	110	92	2.3	197	0.44	13	10
3 pos. 90°	60	110	92	3.3	230	0.72	13	9.5

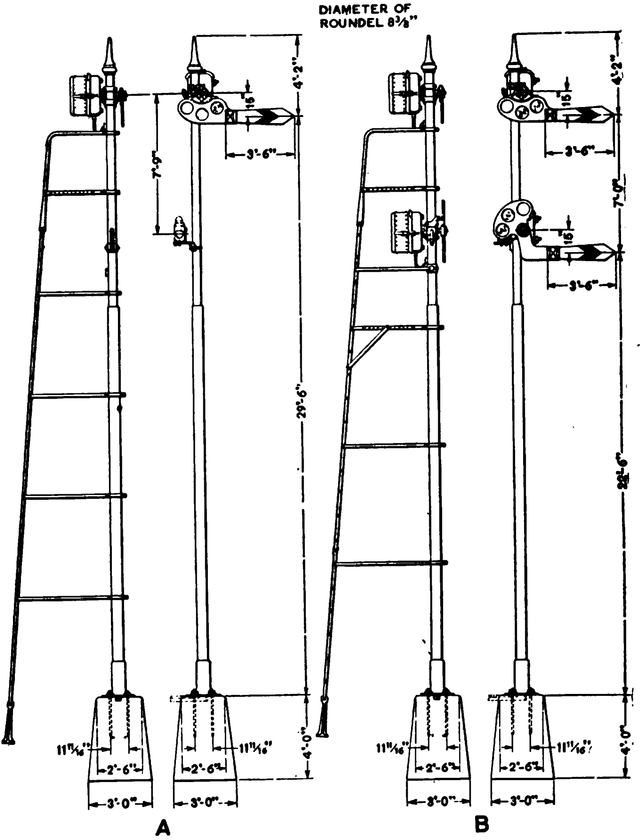


Fig. 167b. One Arm and Two Arm Upper Quadrant Three-Position "T-2" Top Mast Signals.

SIGNALS.

Part II.

Light Signals.

1. Application. Light signals for day and night indication have been employed for a number of years in the subways of New York, Boston and Philadelphia, and out in the open on the Brooklyn Bridge, Williamsburg Bridge, and the Pennsylvania Terminal area in New York. More recently they have seen a much broader application on the interurban electric roads. Their first and greatest advantage is, perhaps, their comparatively low cost, and, next, their simplicity due to their freedom from all moving mechanical and electrical parts. The indication, especially the red *stop*, will almost equal the semaphore, considering the oftentimes poor background of the latter, and in the dusk should be superior. The important indication, the red *stop*, is the most pronounced, and by proper hooding of the lens, can be made effective in the face of sunlight, which obviously will strike the lens only when the sun is low on the horizon and its rays are consequently weak. By the use of a well designed lens, properly hooded from the sunlight and well illuminated by incandescent lamps of adequate candle-power, the light signal can be made perfectly satisfactory for high speed service.

2. Hoods and Backgrounds. The hood above mentioned is generally a deep sheet iron cap; when seen from the distance, an illuminated lens, so hooded, has the appearance of being set in a dark well. A further contrast is secured by providing the case enclosing the lenses with a flat sheet iron background, this extending in a vertical plane at right angles to the track from the sides of the signal case. If the signal could always be located so that it would gave a dark background, such as that afforded by trees or a hill, the shield just described would probably not be required, but, when the signal is set up against the sky, the shield provides the necessary contrasting background. Practically all light signals for outdoor service are, therefore, equipped with both hoods and backgrounds, as will be evident from the photographs in the following pages.

3. Types. Light signals may be divided into the following classes:

I—Light signals for outdoor service:
  (A) Color light signals giving indication by colored lenses.
  (B) Position or beam light signals giving indication by the illumination of one or more rows of uncolored lenses spaced angularly to represent the successive positions of a corresponding semaphore.

II—Light signals for subway service:
  (A) Color light signals giving indication by colored lenses.

COLOR SIGNALS—OUTDOOR SERVICE.

MODEL 12 LIGHT SIGNAL.

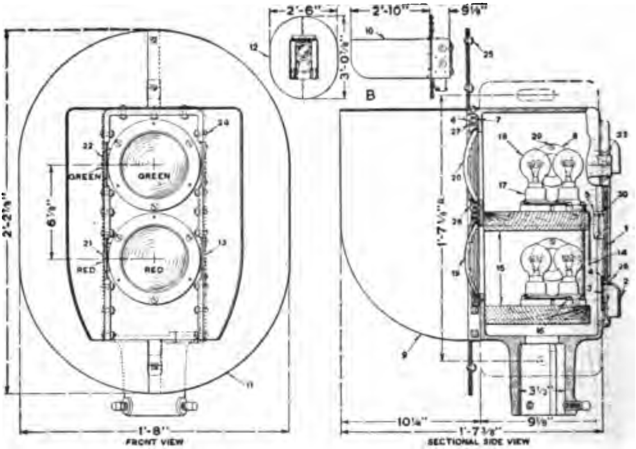


Fig. 168.

1. Range and Application. The above signal is provided with one green and one red lens, each $5\frac{3}{8}''$ in diameter, intended to indicate *proceed* and *stop*, respectively. Under the worst conditions, with the sunlight shining directly on the lenses, the indication is effective up to approximately 1500 feet; at other times of the day, when the conditions for visibility are more favorable, the above limit is increased about 50 per cent. This signal is the simplest of the light signals, and is intended primarily for use as an intermediate signal on interurban roads, where the block lengths do not require greater range of visibility than above given.

2. Lenses and Lamps. The lenses are of the Fresnel optical pattern. Each lens is ordinarily illuminated with two 20 watt 110 volt tungsten lamps connected in multiple.

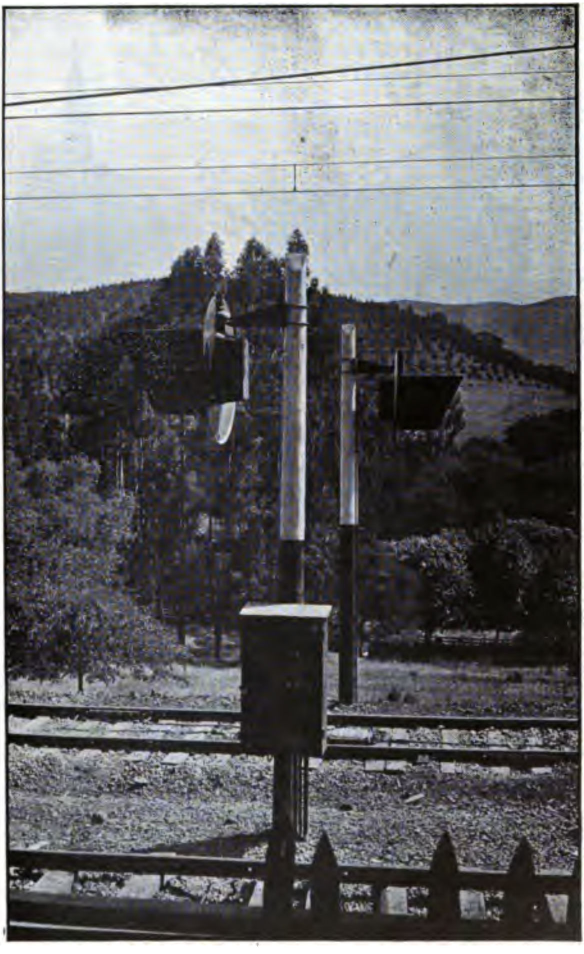


Fig. 169. Model 13 Light Signals, Oakland, Antioch and Eastern R. R.

COLOR SIGNALS—OUTDOOR SERVICE.
MODEL 13 LIGHT SIGNALS.

1. Construction. The signal shown in Fig. 170 is provided with two colored lenses, each $8\frac{3}{8}''$ in diameter, it may also be equipped with three lenses (red, green and yellow) when required for three-position work. The case is suspended from the mast by means of the bracket shown in the photograph, the attachment between the case and bracket being made by means of a knuckle or universal joint, so that the signal can be easily focused towards any part of the track; this adjustment is often of great convenience, especially in the case of signalling on curves. The lenses, lamps and terminal boards may easily be gotten at through the two hand holes whose covers are visible in the side view; the lamp bases are adjustable, so that the lamps can be easily focused with the lenses. All small metal parts are sherardized and the larger parts are well painted to guard against rusting.

Fig. 170.

2. Range and Application. Under the worst conditions, with sunlight shining directly on the lenses, the indication of this signal is effective up to approximately 2000 feet; at other times of the day, when the conditions for visibility are better, the above limit is increased about 50 per cent. This signal is often used for indications on long blocks on high speed interurban electric roads.

3. Lenses and Lamps. The lenses of the doublet pattern (a combination of two special lenses), by means of which a considerable angle of divergence, or spread, of the light rays is secured; this makes the signal indication more effective on curves than would be the case with simple lens. Each lens is illuminated by two 25 watt 110 volt tungsten lamps connected in multiple.

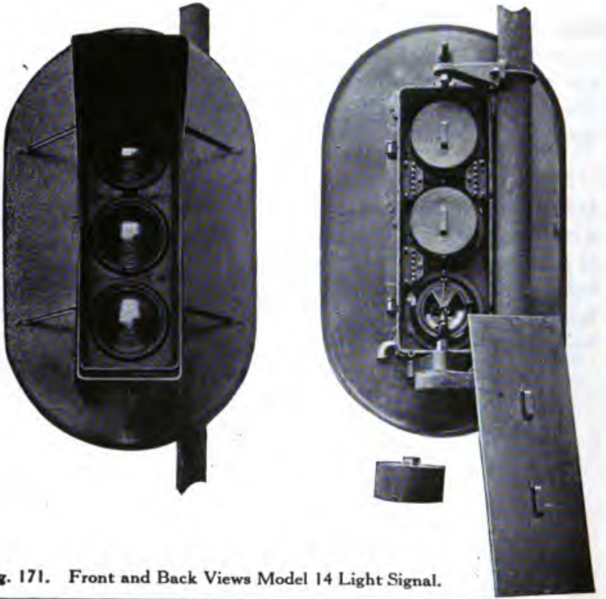


Fig. 171. Front and Back Views Model 14 Light Signal.

Fig. 171a. Model 14 Light Signals in Service on the New York, New Haven & Hartford R. R.

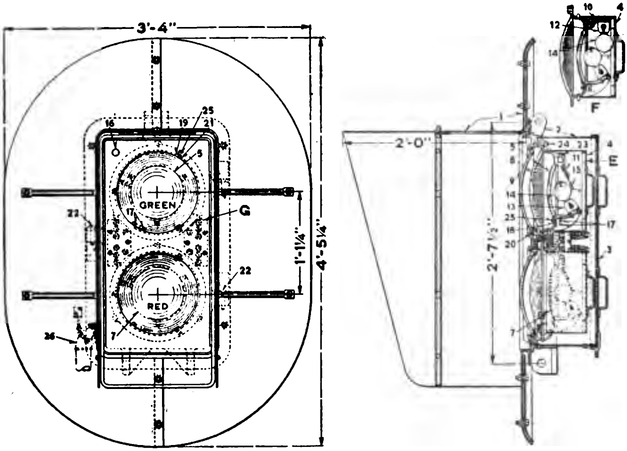
COLOR SIGNALS—OUTDOOR SERVICE.
MODEL 14 LIGHT SIGNALS.

1. Construction. The signal shown in Fig. 171 is built on the unit basis, each lamp body, complete with its lens and lamps, being separately mounted on the cast iron front plate, to which is also attached the sheet iron shield, or background. The signal may, therefore, be easily equipped with either two or three lens units to fit it for two-position or three-position work; in the two-position signal, red and green lenses are employed to give the usual *stop* and *proceed* indications, and to these a distinctive deep yellow or amber lens is added when a three-position signal is required. For a three-position signal the lenses may be arranged either vertically, as in Fig. 172a, or they may be placed in triangular fashion as illustrated in Fig. 172b, since but one lens is illuminated at a time. The lamps, lenses and terminal boards are easily gotten at by removing the sheet steel cover plate whose hand grips are shown at the right of the side view.

2. Range and Application. Under the very worst conditions, with the sunlight shining directly on the lenses, the indication is effective on a tangent up to approximately 2500 feet: at other times of the day, when the conditions for visibility are better, the above limit is increased by about 50 per cent. This signal has, therefore, a longer range than any of the other light signals previously described, and is, therefore, well fitted for use either on high speed electric or steam roads, and it has already been successfully applied to this latter exacting service.

3. Lenses and Lamps. The lenses of the model 14 light signal are $10\frac{1}{2}''$ in diameter. They are specially designed for high efficiency long range work. Where curves are to be signaled, a deflecting prism screen is provided, which, acting in conjunction with the main lens, serves to deflect or spread the light rays around the curve; on tangent track, this prismatic screen is, of course, not required.

When marker lights are not used, two lamps are provided back of each lens, the filament of one being located directly at the focal point, and the other being suspended from the top of the lamp body so that the center of its filament is somewhat above the optical axis of the lens and between the lens and its focus. This latter lamp is often called a "pilot" lamp; due to the location of its filament above the optical axis of the lens, its rays are projected diagonally downward toward the track, and this insures a distinct short range indication, useful in interlocking limits where marker lights are not generally used. In order to increase the efficiency of the lens and lamp combination, the filament of the lamp is concentrated in the form of a small helix, so that, when the filament is placed exactly at the focus of the lens, as in the case of the lower or main lamp, practically all the rays are projected directly through the focus. This concentration results in a strong beam of light, visible at a great distance. For the sake of uniformity, the main and pilot lamps are made alike. These lamps have tungsten filaments, and each lamp takes 20 watts at 6 volts. In order to increase their life, the lamps are generally burned at 5½ volts, it being a well known fact that the life of a lamp can be greatly extended by burning it below normal voltage.



FRONT VIEW

SECTIONAL SIDE VIEW

Fig. 172a. Two-Position Model 14 Light Signal With Lenses Arranged Vertically.

When marker lights are used, as is nowadays frequently the se in automatic block work, it is customary to use but one lamp equipped with a reflector back of each main signal lens; as it is not difficult to predict quite accurately the life of the lamp so that it may be removed before it burns out; if it burns out prematurely the marker light indicates the presence of a signal and in the absence of the signal indication the engineman must stop. Such a marker light (see Fig. 156) is attached to the mast a short distance below the signal and is equipped with one 8 c. p. lamp burning constantly.

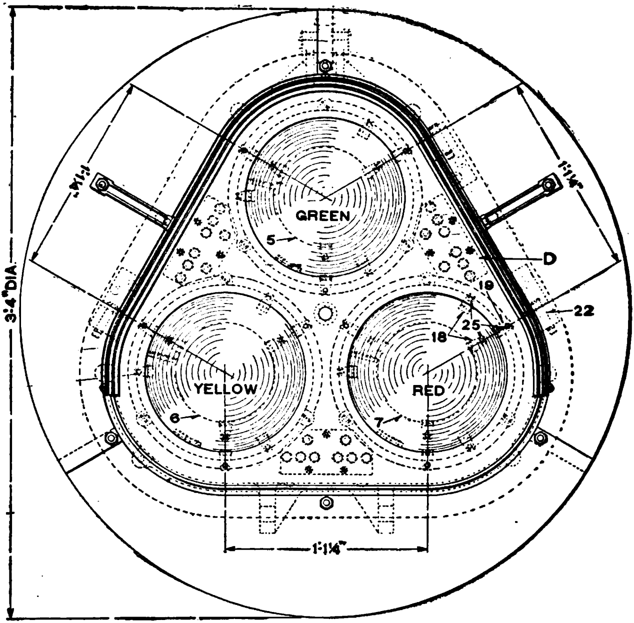


Fig. 172b. Three-Position Model 14 Light Signal With Lenses Placed Triangularly.

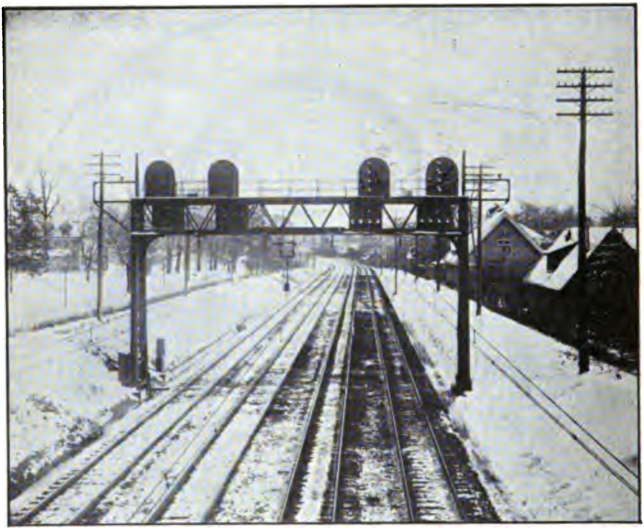


Fig. 173. Beam Light Signals in Service on the Pennsylvania R. R.

POSITION OR BEAM.
LIGHT SIGNAL.

1. General Description. The beam or position light signal is the joint invention of Mr. A. H. Rudd, Signal Engineer of the Pennsylvania Railroad and Dr. William Churchill of the Corning Glass Works. It consists of a number of light units, or lamp bodies, Fig. 174, assembled on a pipe frame work in various combinations, as shown in A, B and D, of Fig. 175. In all arrangements, the same light unit is used, this being usually called the "lamp," and the lamps are spaced about 18'' center to center. The lamp consists of an aluminum casting provided with a universal joint for clamping it to the pipe frame work, shown in Fig. 174.

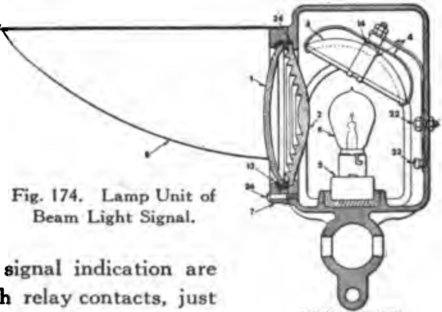


Fig. 174. Lamp Unit of Beam Light Signal.

All lamps are the same color. Signal indications are given by position only. The arms supporting the lamps are stationary, but the proper lamps for any signal indication are selected through relay contacts, just as the lamps on an electric sign are selected through the circuit controller. Referring to Fig. 175, combination A represents a three-position signal. When the four lights in the horisontal row are illuminated, the signal indicates *stop*; similarly, a 45 degree aspect means *caution*, and a vertical row of lights means *proceed*, just as in the case of a right hand upper quadrant semaphore. The central light burns continuously, as it is common to every indication. Combination B represents a two-position 0–90 signal; D represents a two-position 0-45 degree signal. In Fig. 176 will be found the complete code of indications, or aspects, the usual semaphore indications being given in the left hand column and the corresponding position light signal aspects in the next column to the right, the meaning of the various aspects, as translated by the engineman, being given in the column at the extreme right. The three bottom aspects are those used in automatic block work, the others above being provided for use in interlocking limits; it will be observed that they are all arranged on the basis of the well known "speed signaling" scheme. Of course, for an ordinary three-position signal, the simple three-beam combination shown at A, Fig. 175, would alone be required.

2. Lenses and Lamps. A 5⅜'' inverted toric lens 2, Fig. 174, is equipped with a "no glare" cover glass; this glass has a yellowish tinge which renders the light more distinct and less liable to be confused with reflections from surrounding objects. At the focus of the lens is placed a 12-volt 5-watt concentrated filament tungsten lamp, the filament being about ¼'' long and disposed horizontally and at right angles to the optical axis. A hood 8, Fig 174, is provided to shield the lens from the direct rays of the sun. In order to secure a good short range indication, a glass mirror reflector 3, Fig. 174, is mounted above the lamp in such a position as to cast light downward toward the base of the signal. This effect is further aided by the so-called "toric" lens.

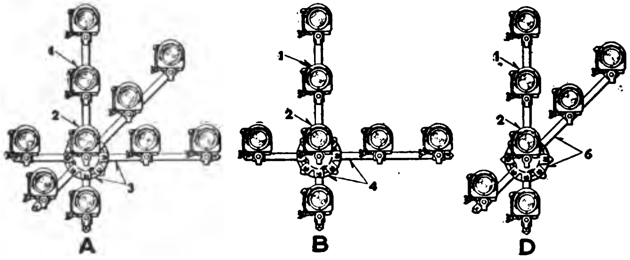


Fig. 175. A Few of the Possible Combinations Obtainable with the Beam Light Signal.

3. Range. Although the beam candle-power of the position light signal lamp is much less than that of the Model 14 light signal previously described, the transmission factor of the lenses is greater, due to the absence of color, so that the range of the position signal lamp is practically equal to that of the Model 14 light signal; i. e., 2500 to 4000 feet, depending upon the sunlight and weather conditions.

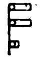
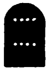
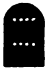
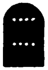
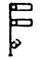
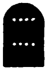
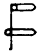
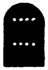
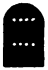
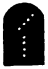
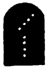
ASPECTS			
	SEMAPHORE	LIGHTS DAY & NIGHT	MEANING
			STOP
			PROCEED PREPARED TO STOP AT NEXT SIGNAL
			PROCEED PREPARED TO PASS NEXT SIGNAL AT MEDIUM SPEED
			PROCEED
			PROCEED AT MEDIUM SPEED PREPARED TO STOP AT NEXT SIGNAL
			PROCEED AT MEDIUM SPEED
			PROCEED AT LOW SPEED PREPARED TO STOP TRACK MAY BE OCCUPIED OR NEXT SIGNAL AT STOP
			PROCEED AT LOW SPEED
			STOP THEN PROCEED - RULE 504
			PROCEED PREPARED TO STOP AT NEXT SIGNAL
			PROCEED PREPARED TO PASS NEXT SIGNAL AT MEDIUM SPEED
			PROCEED

Fig. 176. Beam Light Signal Aspects and Their Meaning.

COLOR LIGHT SIGNALS FOR SUBWAY AND TUNNEL WORK.

1. Description. In general, color signals for use in subways or tunnels do not require such large lenses, nor so much candle-power back of their lenses, as similar signals for service out of doors, for the obvious reason that sunlight does not have to be contended with. On account of this, light signals for underground work are very simple in construction. This will be evident from an inspection of Fig. 177, illustrating the home and distant signals used in the Hudson and Manhattan tunnels in New York. Here the signals are of the unit type, two units being placed one above the other, as shown at the right of the photograph; each circular cast iron case is divided vertically into two light proof compartments, each provided with a simple optical lens. The top, or home, signal, is provided with red and green lenses, and the bottom or distant, signal with red and yellow lenses.

Fig. 177. Light Signals, Hudson and Manhattan Tubes.

Another form of tunnel signal is illustrated in Fig. 178, this being a drawing of one of the light signals recently installed in the Boylston Street Subway of the Boston Elevated Railroad; the signal is of the three-position type, having three lenses, red, yellow and green, housed in a simple sheet iron case, each lens being illuminated by two 4 C. P. 55 volt tungsten lamps. The track side of the signal is provided with hinged sheet iron doors, which allow easy access to the lamps, lenses, etc. The signal shows up very brightly in the dark tunnel, and, as in the case of the similar signal shown in Fig.

177, the indication is visible over much greater distance than the permissible block length as dictated by traffic conditions.

Fig. 179 illustrates the light signals used in the Pennsylvania terminal area in New York, the same general type of signal being used for automatic work in the tubes under the Hudson River, as in interlocking limits out of doors; the signals for the latter service were, of course, provided with lamps of greater candle power, and also with hoods to shield them from sunlight, as illustrated in the photograph. The interlocking signals are provided with five lenses, the three upper ones fulfilling the function of a three-position high speed signal, and the two lower ones that of a two-position low speed route or "calling on" signal.

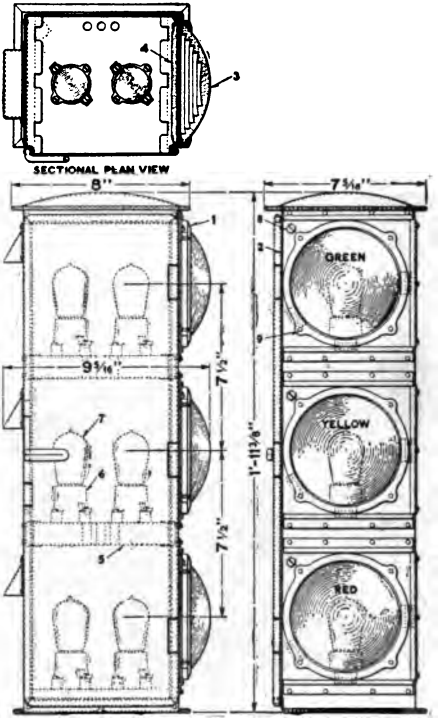


Fig. 178. Three Light Tunnel Signal.

Fig. 179. Light Signals in the Pennsylvania Terminal Area New York City.

CHAPTER IX.

TRANSMISSION SYSTEMS
AND
POWER HOUSE EQUIPMENT.

CHAPTER IX.

TRANSMISSION SYSTEMS AND POWER HOUSE EQUIPMENT.

General Considerations. One of the most attractive features of the alternating current system of signaling is the practicability of transmitting power economically over long distances from one central power house. This is in line with the modern Central Station idea—the unified supply of power for a district from one central station where power can be generated economically and efficiently by large units. Of course an A. C. transmission along the right of way need not be restricted to supplying power to signals. It may be, and in many cases is, employed as a joint power supply for signals, station lighting, mercury arc rectifiers, motor driven pumps, and a score of other utilities which soon appear once cheap power is available. The generating-transmission system has therefore contributed important commercial advantages—economy and utility—to alternating current signaling.

Ultimately, the success of any signaling system depends primarily upon its reliability, and in the A. C. system the power supply is an important link in the chain, for on its integrity depends the continuity of service without which the most perfect signals and relays are useless. In the power house, this involves either a dependable commercial power supply, in addition to the main generating equipment, or else duplicate apparatus. The transmission line, if aerial, must be strong enough to withstand, with a good margin of safety, all sleet and wind strains to which it is liable to be subjected, and, if underground, the wires must be well insulated and carefully laid to guard against the necessity of ripping the line up in case defects develop after installation. Care in design and construction of the generating apparatus and transmission will avoid traffic delays due to interruptions in the power supply.

Next comes the question of first cost and operating economy. Obviously, through the use of a heavy copper transmission, the power losses may be reduced to any desired quantity, but a point is finally reached where the interest on the money invested in extra copper exceeds the money saved in power losses through the use of that extra copper. The subject resolves itself into a judicious balancing of first cost against losses. So many local conditions demand special consideration that each case must be treated on its own merits. In such matters there is plenty of room for individual skill and good judgment.

In order to secure reliability and high operating economy with a moderate first cost, the power transmission system must, therefore, be thoroughly studied, and in this connection, the signalman will do well to be very careful in adopting any formula or rules given in the standard text-books on high tension transmission, for while the same fundamental principles underlie the design of all transmissions, the problem of carrying, say, 50 K. V. A. over 25 miles for a signal system is radically different from that of transmitting 20,000 K. V. A. for the supply of a city 100 miles away. It is, therefore, the object of this chapter to discuss the more important technical and practical considerations governing the design of transmission systems and power equipment adapted to meet the rather peculiar requirements characterizing alternating current signal systems.

THE TRANSMISSION.

Voltage and Line Wire Size.

1. Voltage. Given a transmission of stated length and the amount of power to be delivered, the first question which arises is that of the voltage at which power is to be transmitted; we will first determine what part the voltage plays in the calculations.

If the line and load are operating on unity power factor (current and voltage in phase) the power delivered to the line may be expressed in watts as $W = I\ E$, where E is the initial voltage impressed on the transmission and I the current. In most cases, however, the current and voltage will be considerably out of phase on account of the fact that the track circuit apparatus and the induction motors operating the signals are of a highly inductive character; the power factor of the load at the power house will, therefore, in the case of most signal systems, be in the neighborhood of 0.6 to 0.7, in which case the power delivered to the line will be expressed as $W = I\,E \cos \Theta$, where $\cos \Theta$ is the power factor, or in other words, the cosine of the lag angle between the current I and the voltage E.

A given amount of power W can therefore be delivered to the line either at low voltage and a correspondingly higher current, or at high voltage and a small current, the product of current and voltage (volt-amperes) being the same in either case. It becomes immediately evident that the employment of a high voltage is desirable, as only a small current need be carried by the transmission, for then small line wires may be employed, involving only a relatively small investment in copper. High transmission voltage is therefore the secret of low first cost of the transmission line.

Let us see what this means. Take, for example, the problem of delivering at the end of a 30 mile single-phase line 50 kilo-watts net power at unity power factor after a 10 per cent loss in transmission. At the power house 55 K. W. must be fed into the line, the loss, of course, being 5 K. W. Table I below illustrates the enormous saving in money effected through the use of high transmission voltages, the first column indicating the trial voltages employed, the second column the corresponding currents, and the third, fourth and fifth columns, the size, weight and cost of copper for each case, the cost of the copper being taken at 16c per pound. In calculating the table, the various

TABLE I.

Showing the decreasing cost of copper with increasing line voltages for a 30 mile single-phase transmission delivering 50 K. W. after 10 per cent line loss, neglecting inductance and skin effect.

Voltage	Current	Copper.		
		Diam. Line Wire	Total Weight	Cost
220 volts	250 amps.	6.55 in.	20,300 tons	$6,500,000
1100 "	50 "	1.31 "	812 "	260,000
2200 "	25 "	0.655 "	203 "	65,000
4400 "	12.5 "	0.3275 "	50.75 "	16,250
11000 "	5 "	0.131 "	8.12 "	2,600

currents were found, of course, by dividing the initial power, 55 kilowatts (55000 watts), by the corresponding voltages, after which the resistance R of the line may be solved for, the 10 per cent. loss (5000 watts, constant in each case) being simply I^2 R of which R is the only unknown quantity. R once determined for the given length of wire (60 miles for the two wires of a single phase transmission), the size and weight of the corresponding copper can be looked up in the wire tables at the back of this book.

The following simple rules, illustrated by the above table, are easily memorized and will often prove handy.

1. The energy loss varies with the square of the current. Halving the current divides the absolute loss by four, and the percentage loss by two, since the total power is proportional to the current, the e.m.f. being fixed.

2. With a fixed percentage loss, doubling the working voltage will divide the amount of copper required by four, since the current for a given amount of power will be reduced by one-half, while the actual volts lost will be doubled in maintaining the fixed percentage.

3. The amount of copper required for transmitting a given amount of power a given distance, at a fixed efficiency, will vary inversely as the square of the voltage.

4. If the length of the transmission is doubled, the area of the conductor must be doubled also; consequently, since the length is doubled, the weight of copper will be increased four times. Hence, for the same energy transmitted at the same per cent. efficiency, and the same voltage, the total weight of copper will be increased directly as the square of the distance. By increasing the voltage in direct proportion to the distance, the weight of copper required for a given percentage loss will be made a constant quantity independent of the distance.

2. Choice of Voltage. Generally speaking, therefore, the higher the pressure the less the transmission will cost with a given line loss. In view of the economy in copper secured through the employment of high transmission voltages, the question immediately arises as to what is the limit in voltage. The answer lies in the fact that the higher one goes in voltage the greater becomes the general strain on the insulation of the line and the apparatus connected to it; in other words, as the voltage mounts, it becomes more difficult and expensive to insulate the transformers, and at the same time the other line auxiliaries—insulators, lighting arresters, fuse cutouts, etc., become more costly.

Given, then, the length of the line and the power to be transmitted, what voltage and what line wire size will give us the most economical arrangement with a reasonable loss in the transmission While, on account of the variable factors entering into the calculation, no general rule or formula can be laid down, the process of selection is considerably simplified on account of certain limits within which it is advisable to work. These limits are as follows:

1. The commercial voltages for which transformers and other transmission apparatus are generally built are 2200, 3300, 4400, 6600 and 11,000; it is not advisable to select a mongrel voltage. Voltages of under 2200 are rarely used in signal work as most commercial transformers, lightning arresters, transformer fuse cutouts, etc., are built to stand at least that voltage, and nothing will be gained as far as they are concerned in going to 1100 volts or lower, while for given line loss the line wire size would have to be greater. On the other hand, before going above 2200 volts with given line loss, the saving in copper thus effected must more than compensate for the additional cost of the transformers and line auxiliaries.

2. The allowable percentage loss on the line must next be decided on, for the efficiency of the transmission may be made as high as you please, depending on how much money you are willing to invest in copper. In signal work it is customary to allow a 10 per cent. voltage loss in the line with all signals clear.

$$\text{Per cent. voltage loss} = \frac{E_0 - E_1}{E_1}$$

where E_0 = volts at generator end and E_1 = volts at load end.

After the voltage and line wire size have been determined on, the voltage drop with all signals clearing at once (as occurs after an interruption in the power supply) should be calculated; if the line drop is excessive the signals at the end of the transmission farthest away from the power house may not receive sufficient voltage to clear them. Depending on the type of signal used and the relative power taken by the track circuits, which is of course constant, the percentage voltage loss with all signals clearing will run from 15 per cent. to 20 per cent. If the line wire size calculated to give a 10 per cent. loss with all signals clear is found to give too low a voltage at the far end of the line with all signals clearing simultaneously, then a larger conductor must be employed. The signal manufacturer will furnish data covering the normal and minimum voltages on which his signals will work and the difference between the two will, of course, indicate the permissible variation in voltage loss; data of this character is given in Chapter VIII.

3. The line wire must be of a commercial gauge; for example, the calculations will generally indicate a conductor falling midway between two standard sizes; it would not pay to have a special wire drawn, and therefore the nearest *larger* size conductor as given in the wire table should be employed.

4. Regardless of electrical calculations, the wire must be strong enough mechanically to bear up not only under its own weight, but also under any additional wind or sleet load to which it may be subjected. Under no circumstances should the wires of an aerial transmission be smaller than No. 10 B. & S. solid copper or No. 12 B. & S. copper clad.

The selection of voltage and line wire size for a transmission system of minimum first cost and proper line loss characteristics resolves itself into a cut and try process; but, keeping the above limitations in mind, the designer cannot go very far astray. He should start out with a trial voltage of 2200 and then compute the total cost of the corresponding line with its transformers and other auxiliaries. The next calculation, made on the basis of 3300 volts, will indicate whether money can be saved through the employment of a higher voltage, and this process should be continued until the most economical combination of line wire size and voltage is discovered, all the calculations, of course, being based on the same percentage voltage loss.

3. Voltages and Line Wire Sizes Frequently Used in Signal Work. Naturally, the voltage and line wire size for any given system will depend entirely upon the extent of the system, but, in the case of many signal systems, 2200 volts will be found satisfactory, and in order to avoid the extra cost for lightning arresters, fuse cut-outs and transformers, 2200 volt transmissions have become common for lines of a moderate length of, say, 25 miles. On this basis, a stretch of signaling twice as long would double the transmission load, and with the same size line wire as for 2200 volts, a 4400 volt transmission would give the same percentage line drop over fifty miles. The author has in mind a typical stretch of fifty miles of double track on a steam road, where a 4400 volt, 60 cycle, single phase transmission, with No. 4 copper gave the very moderate drop of 8 per cent. with all signals clear, and 15 per cent. with all clearing at once, the transmission, in addition, carrying a station lighting load. In another case, one involving the transmission of signal and station lighting load for a 150 mile stretch of double track steam road, trial calculations showed that a single phase transmission at 11000 volts with No. 6 copper clad wires would be the most economical. No general rule for such calculations can be laid down, however. Each case must be considered on its individual merits.

CHOICE OF FREQUENCY.

4. Twenty-Five vs. Sixty Cycles. Coming now to the matter of frequency, we may choose either of the commercial frequencies, 25 or 60 cycles. From the viewpoint of power economy, 25 cycles has somewhat of an advantage, because, in the first place, the reactance drop in the transmission is less on 25 cycles than on 60, as will presently be explained. In addition to this, a 25 cycle track circuit of given length will require less power than one operating on 60 cycles, because the drop in the rails, and, consequently, the volts at the track transformer, are less with the lower frequency. The same statements apply also to the power for the signals.

Aside from such technical considerations, however, other practical considerations must be taken into account. In all cases, it is advisable to have an auxiliary power supply to fall back on, if the power house fails, and almost invariably the frequency of the commercial sources of power available in towns along the right-of-way will be found to be 60 cycles, as 25 cycles is not satisfactory for lighting purposes, on account of the "flicker" of the lamps due to the low frequency.

This fact is of great importance in choosing the frequency of a signal system for steam roads; in the case of electric roads, of course, it is not of much importance, for, if the A. C. power fails, then the rotaries are tied up and cars cannot run anyway. It must be kept in mind, in making up cost estimates, that 25 cycle transformers and power apparatus cost more than 60 cycle apparatus, which, of course, is an item in favor of a 60 cycle system.

In settling the matter of frequency, therefore, the amounts of power required on 25 and 60 cycles, auxiliary commercial supply, and relative cost of apparatus, must be considered. Except in rare instances, the difference between the amounts of power at 25 or 60 cycles will not be of great consequence; the author has in mind a typical case on a steam road where the power for a double signal location with two one-mile track circuits, totalled 330 V. A., 162 watts on 25 cycles, as against 407 V. A., 159 watts on 60 cycles, although with other types of apparatus, and other conditions, the difference might well have been much greater, and thus have made the case for 25 cycles stronger. The reader is referred to an excellent article on this subject, written by Mr. J. E. Saunders, and published in the 1913 Proceedings of the R. S. A., covering the selection of frequency under a particular set of conditions.

PRACTICAL CALCULATIONS.

5. Resistance, Reactance and Impedance Drops. Thus far in the discussion, for the sake of simplicity, the drop in the line has been calculated as a purely *resistance drop*—I R—but, actually, due to the inductive effect of the current flowing in the wire, there is a *reactive drop*, the square root of the sum of the squares of the two (or what is the same thing, the product of the current into the total impedance of the line), constituting the *impedance drop*. The numerical difference between the initial impressed voltage and the receiver voltage at the end of the line is called simply the *line drop*. The impedance drop is not the same as the line drop, as will presently be shown.

As is well known, when a current traverses a coil of wire lines of magnetic force spring out from the coils, and in doing so, cut the coils and induce a voltage therein in opposition to the impressed voltage. Now, self-induction will result even if the wire is not coiled, for, as the lines of force spring circularly outward from the theoretical center of the wire, just as happens when a stone is thrown into a pond, the body of the wire is itself cut by the expanding circular lines of force, and a counter voltage is induced in the wire, thus increasing the apparent drop. This is just what happens in the case of transmission wires, the inductive effect being more marked, of course, as the diameter of the wire increases. The spacing of the wires has, however, an important bearing on the self-induction of the transmission, for, taking, as an example, the two parallel wires of a single-phase line, the currents in the wires are flowing in opposite directions, going and coming; due to this fact, the circular expanding lines of magnetic force are of opposite direction, according to the Corkscrew Rule, stating that, if the inward motion of the corkscrew represents the direction of the current in the wire, then the direction of its circular motion represents the direction in which the magnetic lines of force are traveling, and, if the two wires are very close to each other, the magnetic fields will almost neutralize each other, and the reactive effect will practically disappear. As the wires are spread farther and farther apart, the magnetic fields of the two wires become separated, and some of the lines linked with one wire do not cut the other, in which case the neutralizing effect above described becomes of less and less consequence, with the result that, finally, the self-induction of each wire has to be reckoned with. The coefficient of self-induction in millihenrys for *one* conductor of an overhead transmission line one mile long is given by the formula:

$$\text{Millihenrys} = 0.741 \times \log_{10} \left(2.568 \frac{D}{d}\right) \qquad (1)$$

Where D is the distance between centers of the outward and return conductors and d is the diameter of one conductor, these measurements being expressed in inches. This formula applies to a conductor of any non-magnetic material, such as copper or aluminum but not to steel wires or wires with a steel core.

Table II calculated from the above formula gives at various spacings the self-inductance of solid non-magnetic wires

TABLE II.

SELF INDUCTANCE OF SOLID NON-MAGNETIC WIRES*

Millihenries per MILE of each wire of a single-phase or of a symmetrical three-phase line

Size of wire, cir. mils. or A.W.G.	Diam. of wire, inches	Inches between wires, center to center							
		1	3	6	9	12	18	24	30
1,000,000	1 0000	0.3036	0.6572	0.8803	1.011	1.103	1.234	1.327	1.398
750,000	0.8660	0.3499	0.7035	0.9266	1.057	1.150	1.280	1.373	1.445
500,000	0.7071	0.4152	0.7688	0.9919	1.122	1.215	1.346	1.438	1.510
350,000	0.5916	0.4726	0.8262	1.049	1.180	1.272	1.403	1.496	1.567
250,000	0.5000	0.5267	0.8803	1.103	1.234	1.327	1.457	1.550	1.622
0000	0.4600	0.5536	0.9072	1.130	1.261	1.353	1.484	1.577	1.648
000	0.4096	0.5909	0.9445	1.168	1.298	1.391	1.521	1.614	1.686
00	0.3648	0.6282	0.9818	1.205	1.335	1.428	1.559	1.651	1.723
0	0.3249	0.6654	1.019	1.242	1.373	1.465	1.596	1.688	1.760
1	0.2893	0.7029	1.057	1.280	1.410	1.503	1.633	1.726	1.798
2	0.2576	0.7402	1.094	1.317	1.447	1.540	1.671	1.763	1.835
4	0.2043	0.8148	1.168	1.392	1.522	1.615	1.745	1.838	1.910
6	0.1620	0.8894	1.243	1.466	1.597	1.689	1.820	1.912	1.984
8	0.1285	0.9641	1.318	1 541	1.671	1.764	1.894	1.987	2.059
10	0.1019	1.039	1.392	1.615	1.746	1.839	1.969	2.062	2.134
12	0.08081	1.113	1.467	1.690	1.821	1.913	2.044	2.136	2.208
14	0.06408	1.188	1.542	1.765	1.895	1.988	2.118	2.211	2.283
16	0.05082	1.263	1.616	1.839	1.970	2.062	2.193	2.286	2.357

Size of wire, cir. mils. or A.W.G.	Feet between wires, center to center								
	3	4	5	6	8	10	15	20	25
1,000,000	1.457	1.550	1.622	1.680	1.773	1.845	1.975	2.068	2.140
750,000	1.503	1.596	1.668	1.726	1.819	1.891	2.021	2.114	2.186
500,000	1.569	1.661	1.733	1.792	1.884	1.956	2.087	2.179	2.251
350,000	1.626	1.719	1.791	1.849	1.942	2.014	2.144	2.237	2.309
250,000	1.680	1.773	1.845	1.903	1.996	2.068	2.198	2.291	2.363
0000	1.707	1.800	1.872	1.930	2.023	2.095	2.225	2.318	2.390
000	1.744	1.837	1.909	1.967	2.060	2.132	2.262	2.355	2.427
00	1.782	1.874	1.946	2.005	2.097	2.169	2.300	2.392	2.464
0	1.819	1.911	1.983	2.042	2.135	2.206	2.337	2.430	2.501
1	1.856	1.949	2.021	2.079	2.172	2.244	2.374	2.467	2.539
2	1.894	1.986	2.058	2.117	2.209	2.281	2.412	2.504	2.576
4	1.968	2.061	2.133	2.191	2.284	2.356	2.486	2.579	2.651
6	2.043	2.135	2.207	2.266	2.359	2.430	2.561	2.654	2.725
8	2.118	2.210	2.282	2.341	2.433	2.505	2.636	2.728	2.800
10	2.192	2.285	2.357	2.415	2.508	2.580	2.710	2.803	2.875
12	2.267	2.359	2.431	2.490	2.582	2.654	2.785	2.877	2.949
14	2.341	2.434	2.506	2.565	2.657	2.729	2.860	2.952	3.024
16	2.416	2.509	2.581	2.639	2.732	2.804	2.934	3.027	3.099

* The inductances given in this table also apply, with a practically negligible error, to ordinary stranded wires of the *same cross-section.*

TABLE III.

25-CYCLE REACTANCE OF SOLID NON-MAGNETIC WIRES*

Ohms per MILE of each wire of a single-phase or of a symmetrical three-phase line

Size of wire, cir. mils. or A.W.G.	Diam. of wire, inches	Inches between wires, center to center							
		1	3	6	9	12	18	24	30
1,000,000	1.0000	0.04770	0.1032	0.1383	0.1588	0.1733	0.1939	0.2085	0.2196
750,000	0.8660	0.05497	0.1105	0.1456	0.1661	0.1807	0.2011	0.2157	0.2270
500,000	0.7071	0.06523	0.1208	0.1558	0.1763	0.1909	0.2115	0.2259	0.2372
350,000	0.5916	0.07425	0.1298	0.1648	0.1854	0.1998	0.2204	0.2350	0.2462
250,000	0.5000	0.08274	0.1383	0.1733	0.1939	0.2085	0.2289	0.2435	0.2548
0000	0.4600	0.08697	0.1425	0.1775	0.1981	0.2126	0.2331	0.2477	0.2589
000	0.4096	0.09283	0.1484	0.1835	0.2039	0.2185	0.2389	0.2536	0.2649
00	0.3648	0.09869	0.1542	0.1893	0.2097	0.2243	0.2449	0.2594	0.2707
0	0.3249	0.1045	0.1601	0.1951	0.2157	0.2302	0.2507	0.2652	0.2765
1	0.2893	0.1101	0.1661	0.2011	0.2215	0.2361	0.2565	0.2712	0.2825
2	0.2576	0.1163	0.1719	0.2069	0.2273	0.2419	0.2625	0.2770	0.2883
4	0.2043	0.1280	0.1835	0.2187	0.2391	0.2537	0.2741	0.2887	0.3001
6	0.1620	0.1397	0.1953	0.2303	0.2509	0.2653	0.2859	0.3004	0.3117
8	0.1285	0.1515	0.2071	0.2421	0.2625	0.2771	0.2975	0.3122	0.3235
10	0.1019	0.1632	0.2187	0.2537	0.2743	0.2889	0.3093	0.3239	0.3353
12	0.08081	0.1749	0.2305	0.2655	0.2861	0.3005	0.3211	0.3356	0.3469
14	0.06408	0.1866	0.2422	0.2773	0.2977	0.3123	0.3327	0.3473	0.3587
16	0.05082	0.1984	0.2539	0.2889	0.3095	0.3239	0.3445	0.3591	0.3703

Size of wire, cir. mils. or A.W.G.	Feet between wires, center to center								
	3	4	5	6	8	10	15	20	25
1,000,000	0.2289	0.2435	0.2548	0.2639	0.2785	0.2898	0.3103	0.3249	0.3362
750,000	0.2361	0.2507	0.2620	0.2712	0.2858	0.2971	0.3175	0.3321	0.3434
500 000	0.2465	0.2609	0.2723	0.2815	0.2960	0.3073	0.3279	0.3423	0.3536
350,000	0.2554	0.2701	0.2814	0.2905	0.3051	0.3164	0.3368	0.3514	0.3627
250,000	0.2639	0.2785	0.2898	0.2990	0.3136	0.3249	0.3453	0.3599	0.3712
0000	0.2682	0.2828	0.2941	0.3032	0.3178	0.3291	0.3495	0.3642	0.3755
000	0.2740	0.2886	0.2999	0.3090	0.3236	0.3349	0.3554	0.3700	0.3813
00	0.2800	0.2944	0.3057	0.3150	0.3294	0.3407	0.3613	0.3758	0.3871
0	0.2858	0.3002	0.3115	0.3208	0.3354	0.3466	0.3671	0.3818	0.3929
1	0.2916	0.3062	0.3175	0.3266	0.3412	0.3525	0.3730	0.3876	0.3989
2	0.2975	0.3120	0.3233	0.3326	0.3470	0.3583	0.3789	0.3934	0.4047
4	0.3092	0.3238	0.3351	0.3442	0.3588	0.3701	0.3906	0.4052	0.4165
6	0.3210	0.3354	0.3467	0.3560	0.3706	0.3818	0.4023	0.4169	0.4281
8	0.3327	0.3472	0.3585	0.3678	0.3822	0.3935	0.4141	0.4286	0.4399
10	0.3444	0.3590	0.3703	0.3794	0.3940	0.4053	0.4257	0.4404	0.4517
12	0.3561	0.3706	0.3819	0.3912	0.4056	0.4169	0.4375	0.4520	0.4633
14	0.3678	0.3824	0.3937	0.4030	0.4174	0.4287	0.4493	0.4638	0.4751
16	0.3796	0.3942	0.4055	0.4146	0.4292	0.4405	0.4609	0.4755	0.4869

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* The reactances given in this table also apply, with a practically negligible error, to ordinary stranded wires of the *same cross-section*.

TABLE IV.

60-CYCLE REACTANCE OF SOLID NON-MAGNETIC WIRES*

Ohms per MILE of each wire of a single-phase or of a symmetrical three-phase line

Size of wire, cir. mils. or A.W.G.	Diam. of wire, inches	Inches between wires, center to center							
		1	3	6	9	12	18	24	30
1,000,000	1.0000	0.1145	0.2478	0.3319	0.3811	0.4158	0.4652	0.5003	0.5270
750,000	0.8660	0.1319	0.2652	0.3493	0.3985	0.4336	0.4826	0.5176	0.5448
500,000	0.7071	0.1565	0.2898	0.3739	0.4230	0.4581	0.5074	0.5421	0.5693
350,000	0.5916	0.1782	0.3115	0.3955	0.4449	0.4795	0.5289	0.5640	0.5908
250,000	0.5000	0.1986	0.3319	0.4158	0.4652	0.5003	0.5493	0.5844	0.6115
0000	0.4600	0.2087	0.3420	0.4260	0.4754	0.5101	0.5595	0.5945	0.6213
000	0.4096	0.2228	0.3561	0.4403	0.4893	0.5244	0.5734	0.6085	0.6356
00	0.3648	0.2368	0.3701	0.4543	0.5033	0.5384	0.5877	0.6224	0.6496
0	0.3249	0.2509	0.3842	0.4682	0.5176	0.5523	0.6017	0.6364	0.6635
1	0.2893	0.2650	0.3985	0.4826	0.5316	0.5666	0.6156	0.6507	0.6778
2	0.2576	0.2791	0.4124	0.4965	0.5455	0.5806	0.6300	0.6647	0.6918
4	0.2043	0.3072	0.4403	0.5248	0.5738	0.6089	0.6579	0.6929	0.7201
6	0.1620	0.3353	0.4686	0.5527	0.6021	0.6368	0.6861	0.7208	0.7480
8	0.1285	0.3635	0.4969	0.5810	0.6300	0.6650	0.7140	0.7491	0.7762
10	0.1019	0.3917	0.5248	0.6089	0.6582	0.6933	0.7423	0.7774	0.8045
12	0.08081	0.4196	0.5531	0.6371	0.6865	0.7212	0.7706	0.8053	0.8324
14	0.06408	0.4479	0.5813	0.6654	0.7144	0.7495	0.7985	0.8335	0.8607
16	0.05082	0.4762	0.6092	0.6933	0.7427	0.7774	0.8268	0.8618	0.8886

Size of wire, cir. mils. or A.W.G.	Feet between wires, center to center								
	3	4	5	6	8	10	15	20	25
1,000,000	0.5493	0.5844	0.6115	0.6334	0.6684	0.6956	0.7446	0.7796	0.8068
750,000	0.5666	0.6017	0.6288	0.6507	0.6858	0.7129	0.7619	0.7970	0.8241
500,000	0.5915	0.6262	0.6533	0.6756	0.7103	0.7374	0.7868	0.8215	0.8486
350,000	0.6130	0.6481	0.6752	0.6971	0.7321	0.7593	0.8083	0.8433	0.8705
250,000	0.6334	0.6684	0.6956	0.7174	0.7525	0.7796	0.8286	0.8637	0.8909
0000	0.6435	0.6786	0.7057	0.7276	0.7627	0.7898	0.8388	0.8739	0.9010
000	0.6575	0.6925	0.7196	0.7416	0.7766	0.8038	0.8528	0.8878	0.9150
00	0.6718	0.7065	0.7336	0.7559	0.7906	0.8177	0.8671	0.9018	0.9289
0	0.6858	0.7204	0.7476	0.7698	0.8049	0.8317	0.8810	0.9161	0.9429
1	0.6997	0.7348	0.7619	0.7838	0.8188	0.8460	0.8950	0.9301	0.9572
2	0.7140	0.7487	0.7759	0.7981	0.8328	0.8599	0.9093	0.9440	0.9712
4	0.7419	0.7770	0.8041	0.8260	0.8611	0.8882	0.9372	0.9723	0.9994
6	0.7702	0.8049	0.8320	0.8543	0.8893	0.9161	0.9655	1.001	1.027
8	0.7985	0.8332	0.8603	0.8826	0.9172	0.9444	0.9938	1.028	1.056
10	0.8264	0.8614	0.8886	0.9105	0.9455	0.9727	1.022	1.057	1.084
12	0.8547	0.8893	0.9165	0.9387	0.9734	1.001	1.050	1.085	1.112
14	0.8826	0.9176	0.9448	0.9670	1.002	1.029	1.078	1.113	1.140
16	0.9108	0.9459	0.9730	0.9949	1.030	1.057	1.106	1.141	1.168

* The reactances given in this table also apply, with a practically negligible error, to ordinary stranded wires of the *same cross-section*.

in millihenrys per mile of each wire of a single-phase or of a symmetrical three-phase line; the total self-inductance of the two conductors of a single-phase line is of course twice that of a single conductor, and in a three-phase line the total self-inductance is $\sqrt{3}$ times as great as that of one of the three conductors of which it is composed. Table III is the corresponding reactance at 25 cycles and is derived from Table II by the formula $X = Lp$, where X is the reactance in ohms, L is the self-inductance in henrys and $p = 2\pi n$, where n is the frequency in cycles per second. Table IV covers the reactance at 60 cycles. Self-inductances and reactances for other wire spacings and frequencies can be easily calculated from equation (1) above and the formula $X = Lp$. Table V shows the resistance, reactance and impedance $(Z = \sqrt{R^2 + X^2})$ of copper clad wire of 40 per cent. conductivity; the reactance and impedance of this latter wire are naturally much greater than the similar functions of non-magnetic wires, such as copper or aluminum.

TABLE V.
Resistance, Reactance and Impedance
40% Copper Clad Wire.
All Values for One Mile Single Wire.
Current 5 Amperes.

Size	Spacing	D.C.Res. 1 Mile	25 Cycles			60 Cycles		
			A.C. Res.	Ind. React.	Imp.	A.C. Res.	Ind. React.	Imp.
No. 6	12″	4.86	4.92	.316	4.93	4.92	.771	4.98
No. 6	18″	4.86	4.92	.343	4.93	4.92	.822	4.99
No. 6	24″	4.86	4.92	.369	4.93	4.92	.873	5.00
No. 8	12″	9.15	9.18	.348	9.19	9.18	.882	9.23
No. 8	18″	9.15	9.18	.375	9.19	9.18	.919	9.23
No. 8	24″	9.15	9.18	.390	9.19	9.18	.956	9.23
No. 10	12″	12.03	12.09	.296	12.10	12.09	.750	12.11
No. 10	18″	12.03	12.09	.317	12.10	12.09	.792	12.11
No. 10	24″	12.03	12.09	.338	12.10	12.09	.833	12.11
No. 12	12″	19.73	19.73	.296	19.75	19.73	.728	19.77
No. 12	18″	19.73	19.73	.317	19.75	19.73	.778	19.77
No. 12	24″	19.73	19.73	.338	19.75	19.73	.828	19.77
No. 14	12″	29.20	29.20	.264	29.20	29.20	.685	29.20
No. 14	18″	29.20	29.20	.295	29.20	29.20	.752	29.20
No. 14	24″	29.20	29.20	.317	29.20	29.20	.818	29.20

6. Calculation of Line Drop. Let the line OI in Fig. 180 represent the current flowing through the transmission line and the receiving circuit; let E_1 represent the voltage at the load at the end of the line and Θ, the phase difference between

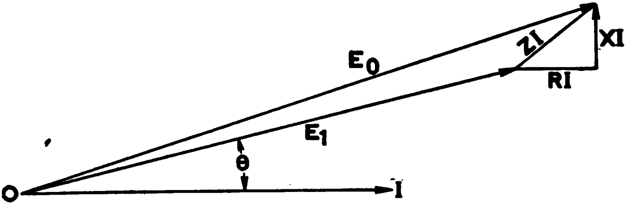


Fig. 180. Elementary Vector Diagram of Transmission Line.

E_1 and I, depending on the power factor of the load. If R is the total resistance and X the total reactance of the transmission line, E_0 the voltage of the generator, will be the vectorial sum of the receiver voltage E_1, and the impedance drop ZI, which latter is of course the vectorial sum of the resistance drop RI and the reactance drop XI. The resistance drop RI is laid off parallel to OI, as it is in phase with the current; the reactance drop XI is laid off perpendicular to the current vector OI, as the reactance drop is 90° out of phase with the current. The *numerical* difference between E_0 and E_1 is the line drop, as would be indicated by the difference between simultaneous voltmeter readings taken at the generating and receiving ends of the line. It will be seen, therefore, that the line drop is not the same as the impedance drop ZI; the line drop depends not only on the impedance drop, but also upon the phase relation between the generator and receiver voltages.

7. **Calculation for Wire Size.** Given the line drop suppose it is desired to determine the wire size for a single-phase transmission of stated length and wire spacing, to deliver a prescribed amount of power P at a prescribed voltage E_1 and frequency to a receiving circuit of power factor $\cos\ \Theta$. As in the previous case, the generator voltage E_0 is the numerical sum of the receiver voltage E_1 and the line drop. The power P to be delivered is $P \text{ watts} = E_1\ I \cos\ \Theta$, from which the load current I can be determined, E_1 and $\cos\ \Theta$ being stated. Referring now to Fig. 181, which covers the problem vectorially, the component of E_1 in phase with the cur-

rent I is $E_1 \cos \theta$, and the corresponding reactance component is $E_1 \sin \theta$ at right angles to the current. By

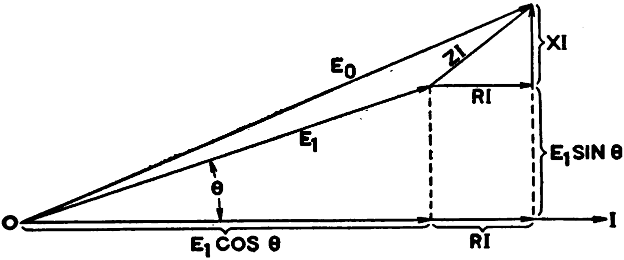


Fig. 181. Initial Voltage Impressed on Transmission Line Divided Into Its Components.

treating the problem first as a direct current proposition, an approximate resistance R_1 of the line is found from the relation IR_1 = line drop. From this trial resistance and the known length of line, the approximate size of the wire may be found from the wire tables in the back of the book; the wire size thus determined may with ample accuracy be used to find the corresponding line reactance, at the given frequency, from Tables III, IV, or V, for even if the calculations finally show that the reactance drop is such as to require the next larger size of wire, the difference in reactance will be negligible.

The component of E_0 parallel to I is $(E_1 \cos \theta + RI)$ where R is the true resistance of the line to be solved for, and the component of E_0 perpendicular to I is $(E_1 \sin \theta + XI)$. The diagram shows that:

$$E_0^2 = (E_1 \cos \theta + RI)^2 + (E_1 \sin \theta + XI)^2 \qquad (2)$$

$$\text{and } RI = \sqrt{E_0^2 - (E_1 \sin \theta + XI)^2} - E_1 \cos. \theta \qquad (3)$$

$$R = \frac{\sqrt{E_0^2 - (E_1 \sin \theta + XI)^2} - E_1 \cos. \theta}{I} \qquad (4)$$

and from this latter equation (4), the true line resistance R may be found, and, in turn, the corresponding size of wire from the wire tables as previously described.

8. Example of Signal Transmission Calculation. Let us take as a concrete case the design of a transmission for a short stretch of single track electric interurban road 15 miles long, the power at 25 cycles for the various signal functions being summarized below on the basis of apparatus meeting R.S.A. specifications. The track circuits, one per block, are to be center fed and there will consequently be two relays per track circuit. Semaphore signals will be used at both ends of each block for each direction of traffic and similarly two light signals will be used in each block as intermediates, one for each direction. This example may therefore be considered as fairly representative as it covers most of the combinations usually met with.

Functions	No.	Power per Unit		Total V.A.	P.F.	Watts	R.F.	React. V.A.
		Volts	Amps					
Track Circuit 5300′ long	1	4.1	10	41	.50	21	.87	36
Track Circuit 15000′ long	1	10.75	16.8	180	.54	98	.84	152
Track Circuit 17000′ long	3	13.0	19.0	741	.55	408	.83	615
Track Relay locals	10	110	0.33	363	.70	254	.71	258
Line Relays	10	110	0.12	132	.52	69	.86	114
Signal Slot Coils	10	110	0.33	363	.50	182	.87	316
Light signals	10	110	0.50	....	1.0	550	....	....
Sema. & switch Lamps	19	110	0.26	....	1.0	533	....	....
Station Lamps	32	110	0.55	....	1.0	1936	....	....
LineTransformer Losses { Iron	6	......	.....	260	0.3	78	.96	250
Copper	6	......	.....	....	1.0	114	....	....
Track Transformer Losses { Iron	5	......	.....	875	0.2	175	.98	858
Copper	5	......	.....	....	1.0	36	....	....
Total load, all signals clear	....	......	.....	5157	.864	4454	.504	2599
Signal Motors, all clearing	10	110	1.9	2090	.53	1108	.85	1776
Total load, all signals clearing	....	......	.....	7076	.79	5562	.62	4375

The headings of the above columns are self-explanatory, excepting perhaps those of the last two. The next to the last column is headed R. F., meaning *Reactance Factor*, which is simply sin θ and when multiplied into the voltamperes V. A. in column five, gives the wattless power in the last column, headed *Reactance Voltamperes*, just in the same manner as the product of the power factor (P. F. = cos θ) in column six, by the voltamperes in column five gives the true power in watts in column seven; complete tables of cosines with their corresponding sines will be found in the back of the book. In determining the total power for the system it is not permissible to add up directly the figures in the voltampere column, because of the widely differing power factors; hence the voltamperes for the individual functions are split up into watts and reactance voltamperes, so that a direct addition may be made, the total voltamperes being simply the square root of the sum of the squares of the watts and reactance voltamperes. Knowing the total voltamperes and total watts, the power factor for the entire load can then be found, this P. F. being the ratio of total watts to total voltamperes.

As regards the track circuit power given opposite the first three items, this can be calculated, if not already known, by the method described in Chapter XIII. The power data for the track relays, line relays, signal sets, etc., will be furnished by the manufacturer; representative information of this kind will be found in the corresponding chapters in this book. Likewise, data covering the transformer losses will be furnished by the manufacturer; however, if the transformers are available for test, the iron loss (constant at all loads) can readily be determined by measuring with a wattmeter the primary input with the secondary open circuited and then deducting the corresponding primary copper loss, this being simply $I^2 R$, I representing the primary no load current and R the primary resistance, determined by a D. C. Ohm's Law measurement. The secondary resistance may likewise be found and thus the total copper loss in both primary and secondary at the given load can readily be computed, the iron loss remaining constant. For a full discussion of these characteristics of transformers see Chapter VI.

Proceeding now to the transmission design proper, it is first apparent that the signal load is distributed fairly evenly all along the line, instead of being concentrated at the extreme end as in the ideal cases thus far considered. With a signal transmission the line current is heaviest near the power house because that part of the line carries practically the entire load, the current in the line falling off gradually as one proceeds from the power house. With such an even distribution as this, it is perfectly allowable to consider the entire load as being concentrated at the middle of the line, this being the point of average current and voltage. So that, although the transmission in the present case is actually 15 miles long from the power house to the extreme end of the line, the calculations should be made on the basis of the total load being concentrated at the end of a line $7\frac{1}{2}$ miles long, the two wires for this distance having a combined length of 15 miles, or 79,000 feet. It will easily be found after a few trial calculations, as previously outlined, that, on the basis of 10 per cent. voltage line loss with the signals clear, a 2200 volt tiansmission would seem quite feasible; this means 2000 volts at the load since

$$\text{Percent line loss} = \frac{E_0 - E_1}{E_1}$$

where E_0 = volts at generator end and E_1 = volts at load end and the calculations will, therefore, be made on this basis. Referring now to equations (2), (3) and (4) above, and Fig. 181, we have:

E_1 = 2000 volts at the load signals clear
P = 4454 watts at the load signals clear
Cos θ = 0.864 P. F. at the load signals clear
E_0 = 2200 volts with line drop = 200 volts (10 per cent. of 2000).
Frequency = 25 cycles
Distance = 7.5 miles (79,000 ft. total line wire)
Wire spacing = 12 inches

From the fact that

$$P \text{ watts} = I E_1 \cos\theta$$
$$4454 = 1 \times 2000 \times 0.864$$
$$I = \frac{4454}{2000 \times 0.864} = 2.58 \text{ amperes line current}$$

Solving for the trial resistance R_1, knowing the line drop (200 volts):

$$IR_1 = 200$$
$$2.58\ R_1 = 200$$
$$R_1 = 77.5 \text{ ohms}$$

This figure of 77.5 ohms is to cover a total of fifteen miles (79,000 feet) of wire, and, from the wire table, will be found to correspond closely to No. 10 B. & S. Copper wire, whose reactance X per mile on 25 cycles, with wires spaced 12 inches on centers, is 0.2889 ohm, or a total of 4.3 ohms for 15 miles, as given in Table III. Now:

$E_1 \cos\theta = 2000 \times 0.864 = 1728$ volts

and $E_1 \sin\theta + XI = (2000 \times 0.504) + (4.3 \times 2.58) = 1019$ volts

From equation (4) above

$$R = \frac{\sqrt{E_0^2 - (E_1 \sin\theta + XI)^2} - E_1 \cos\theta}{I}$$

of which all the quantities are now known, and the true resistance R of the 79,000 feet of wire is discovered to be 86 ohms; this corresponds to a solid copper wire size between No. 10 and No. 11 B. & S., and therefore No. 10, the nearest larger size should be chosen.

To determine the total power delivered to the line at the generator end, this being the sum of P and the line losses, proceed as follows: The quantity $(E_1 \sin\theta + XI)$, equal to 1019 volts, represents the wattless volts delivered to the line at the power house. The quantity $(E_1 \cos\theta + RI)$, equal to 1931 volts (for No. 10 copper) represents the power volts delivered to the line. The sum

$$E_0 = \sqrt{(E_1 \sin\theta + XI)^2 + (E_1 \cos\theta + RI)^2},$$

equal to 2183 volts, is the total volts E_0 at the generator. The power factor of the power house load is the ratio of the power volts to the total volts E_0 and, in the present case, is 1931 divided by 2183 or 0.884. The line current, as solved for above, was found to be 2.58 amperes and with an initial voltage of $E_0 = 2183$ fed to the line, the load at the power house becomes simply $2.58 \times 2183 = 5.63$ K. V. A. or 4.98 K. W. at 0.88 P. F. It is to be noted that due to the employment of No. 10 line wire, which is a little larger than theoretically necessary, the required voltage at the generator end of the line is only 2183 volts instead of 2200 volts as originally assumed; the percentage line loss is therefore decreased to 9.2 per cent.

Knowing the current and the load voltage with all signals clear, the corresponding generator voltage E_0 could also have been found by considering the load as an impedance of Z_L ohms whose components X_L and R_L could have been determined, knowing the power and reactance factors of the load; knowing the line impedance and the load impedance, the total impedance Z_0 of the line and load combined could have been found, and from this the impressed generator voltage would have been $E_0 = IZ_0$ where I is the line current of 2.58 amps.

To illustrate this method, let us determine the total power at the generator and the percentage line drop with all signals clearing simultaneously. In our power summary we figured that with 110 volts on the line transformer secondaries the power required at the load with all signals clear would be 5157 V. A. at 0.86 P. F. and with 2000 volts at the load the generator voltage E_0 would be 2183 volts; similarly we calculated that with 110 volts on the signal motors (2000 volts at the load) the power at the load with all signals clearing would be 7076 V. A. at 0.79 power factor and 0.62 reactance factor, the corresponding line current at this voltage being

$$I = \frac{7076}{2000} = 3.54 \text{ amps.}$$

The equivalent impedance of this load would be

$$Z_L = \frac{E}{I} = \frac{2000}{3.54} = 565 \text{ ohms}$$

Now from the power summary $\cos\theta = 0.79$ and $\sin\theta = 0.62$, and referring to equations (13) to (20) in Chapter II

$$\text{Cos } \theta = \frac{R_L}{\sqrt{R_L^2 + X_L^2}} = \frac{R_L}{Z_L} = 0.79$$

$$\text{Sin } \theta = \frac{X_L}{\sqrt{R_L^2 + X_L^2}} = \frac{X_L}{Z_L} = 0.62$$

Where R_L, X_L and Z_L are respectively the equivalent resistance reactance and impedance of the "all clearing" signal load.

$$\therefore R_L = 0.79 \times Z_L = 0.79 \times 565 = 446 \text{ ohms}$$

$$\therefore X_L = 0.62 \times Z_L = 0.62 \times 565 = 350 \text{ ohms}$$

Now we found in calculating the line that its resistance *r* is 79 ohms and its reactance *x* is 4.3 ohms; hence, representing the total resistance, reactance and impedance of the combined line and load, acting as one circuit, as R_0, X_0 and Z_0 respectively,

$$R_0 = R_L + r = 446 + 79 = 525 \text{ ohms}$$

$$X_0 = X_L + x = 350 + 4.3 = 354.3 \text{ ohms}$$

$$Z_0 = \sqrt{R_0^2 + X_0^2} = \sqrt{(525)^2 + (354.3)^2}$$

$$= 633 \text{ ohms}$$

and since the impressed generator voltage $E^0 = 2183$

$$I_0 = \frac{E_0}{Z_0} = \frac{2183}{633} = 3.45 \text{ amps.}$$

and the total load at the power house becomes

$$E_0 I_0 = 2183 \times 3.45 = 7.53 \text{ K. V. A.}$$

The power factor of the combined line and load is

$$\cos\,\theta = \frac{R_0}{Z_0} = \frac{525}{633} = 0.83$$

and the total load at the generator in kilowatts is

$$7.53 \times 0.83 = 6.25 \text{ K. W.}$$

With a load current of $I_0 = 3.45$ amperes as above determined, the volts at the load E_L is

$$E_L = I_0 Z_L = 3.45 \times 565 = 1949 \text{ volts}$$

$$\text{Percentage line loss} = \frac{2183-1949}{1949} = 12 \text{ per cent.}$$

Therefore, if the secondaries of the line transformers give 110 volts with a primary "all clear" voltage of 2000, when all signals are clearing the transformer secondary voltage will fall to $\frac{1949}{2000} \times 110 = 107.2$ volts; the signals immediately in the vicinity of the power house would of course be supplied with a higher voltage than this since the line drop is small near the power house, increasing to its maximum of 12 per cent. at the end of the line farthest from the power house.

The power generating apparatus and main step up transformer in the power house must, of course, be of sufficient capacity to handle the maximum "all clearing load"; due however to the short duration of this maximum load the power apparatus will in most cases be satisfactory if rated at 75 per cent. of the "all clearing" K. V. A., provided, naturally, that the regulation of the generator and the transformer is not excessively poor. In the present instance the nearest appropriate commercial size of transformer will be found from the list on page 205 to be 7.5 K. V. A.

SINGLE PHASE VERSUS POLYPHASE TRANSMISSION.

9. Single-Phase Systems. The system we have thus far discussed, that shown in Fig. 182 (a), is known as Single Phase Transmission and it is the simplest of all transmissions. Summarized its characteristics are as follows:

1. Two line wires the length of the system.
2. Power delivered $W = E_1 I$ on non-inductive load.
   or $W = E_1 I \cos \theta$ on inductive load.
   where E_1 = load voltage and θ is the phase angle between I the load current and E_1.
3. Power lost in transmission $= 2I^2r$ where r is the resistance of each line conductor.
4. But one simple transformer is required at each signal location.

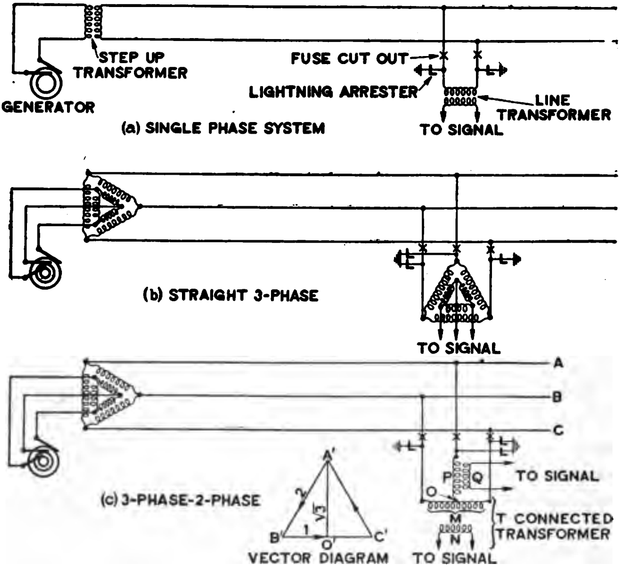
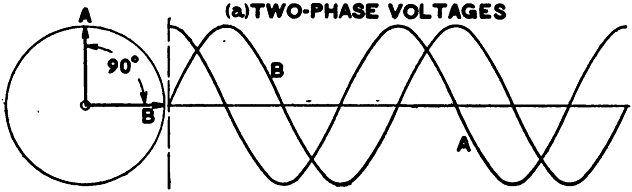


Fig. 182. Diagrams of Three Principal Transmission Systems Used in Signal Work.

10. Polyphase Systems. A polyphase power transmission may with advantage be employed in those cases in A. C. signaling where the system is an extensive one and power has to be transmitted over a distance of, say, 100 miles or over from one central power station; here, with a given amount of power to be transmitted over a stated distance at a given voltage and percentage line loss, a polyphase power transmission will require less line copper, and will, furthermore, lend itself readily to the economical use of induction signal motors, as described in chapter VIII.

The generation of polyphase currents is a very simple matter, the object in view being the production of two or more currents differing in phase by some convenient amount, usually 90 degrees or 120 degrees. To obtain two currents 90 degrees apart, as in a two-phase system, it is only necessary to provide the armature of the alternator with two separate windings placed in the slots 90 electrical degrees apart, so that when the voltage generated in one winding is a maximum, the voltage in the other coil is zero, as indicated in (a) Fig. 183. To obtain three voltages 120 degrees apart for a three-phase system, three separate windings are employed, spaced and connected to give voltages as shown in (b) Fig. 183.


(a)TWO-PHASE VOLTAGES

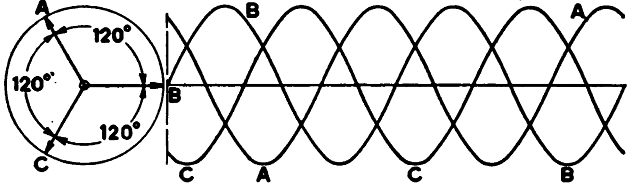
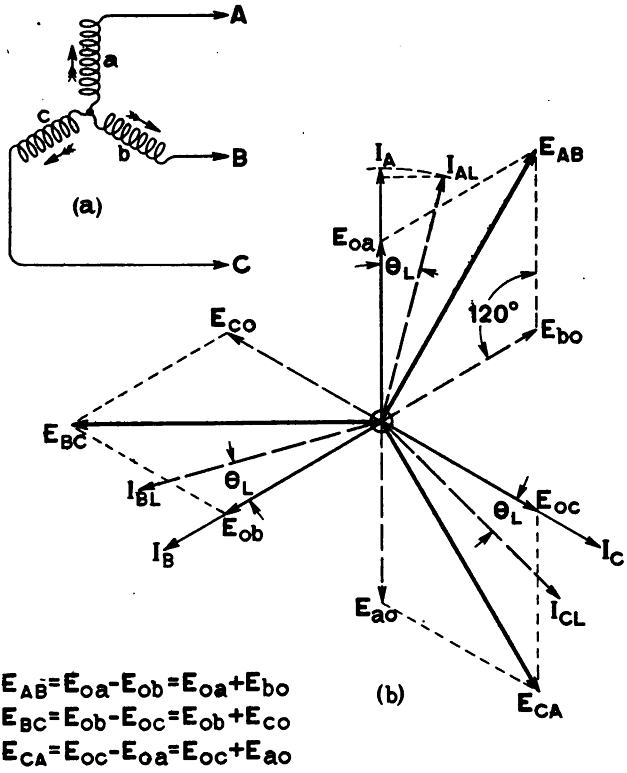
(b)THREE-PHASE VOLTAGES


Fig. 183. Wave Traces of Two-Phase and Three-Phase Voltages.

With a three-phase arrangement as described, it is usual to connect the armature windings so that only three transmission wires will be required, this resulting in increased copper economy, as will presently be shown. The two most general methods of connecting the three windings are known as the *star* connection Fig. 184, and the *delta* or *mesh* connection, shown in Fig. 185.

11. **Three-Phase Star.** In the star connection, each of the three armature windings is brought to a common junction point, the *neutral*, and the three remaining ends are connected to the outgoing wires by slip rings carried on the armature shaft. The three lines A, B and C, in (a) Fig. 184, then serve, in turn, as the outgoing and incoming return circuit, the maximum current shifting in regular rotation from one to the others, as shown in (b) Fig. 183. The same voltage, say 1000 volts, is generated in each of the coils *a*, *b* and



$$E_{AB}=E_{oa}-E_{ob}=E_{oa}+E_{bo}$$
$$E_{BC}=E_{ob}-E_{oc}=E_{ob}+E_{co}$$
$$E_{CA}=E_{oc}-E_{oa}=E_{oc}+E_{ao}$$

Fig. 184. Vector Diagram of Currents and Voltages in Three-Phase Star System.

c, Fig. 184, but these voltages are 120 degrees apart, so that while the voltage between neutral point *o* and each of the lines A, B and C will be 1000 volts, the voltage across A and B, B and C, and C and A, will be the vectorial sum of the equal voltages induced in the two coils across which each pair of mains is connected. Due to the shifting direction of the voltages generated in the three coils, their vectors must be added with proper attention to their algebraic sign, the notation of the diagram at the right of Fig. 184 being such that when the voltage generated in coil *a* tends to send a current outward from *o* along *a* that voltage is designated as E_{oa}. Now, when the voltages in coils *a* and *b* are to be combined vectorially, it must be noted that they are acting in opposite directions from the neutral point *o*, so that they really have to be subtracted; in other words, if voltages E_{oa} and E_{ob} are to be added with due attention to their sign, E_{ob} must be extended backwards on itself, so that it can be added to E_{oa}, according to the usual parallelogram of forces, in which event the resultant voltage across the mains becomes.

$$\begin{aligned} E_{AB} &= E_{oa} - E_{ob} = E_{oa} + E_{bo} \\ E_{BC} &= E_{ob} - E_{oc} = E_{ob} + E_{co} \\ E_{CA} &= E_{oc} - E_{oa} = E_{oc} + E_{ao} \end{aligned}$$

In magnitude, these resultant voltages are simply the long side of a 120° triangle and are, therefore, $\sqrt{3} = 1.732$ times the length of either of the short legs composed by the coil voltage vectors. We started out with the assumption that each coil voltage was 1000 volts; the voltage across any two the mains is, therefore, $\sqrt{3} \times 1000$ volts = 1,732 volts.

On a non-inductive load the currents flowing in each of the coils *a*, *b* and *c* are, of course, in phase with the coil voltages and since the current in each main flows right out of the coil to which it is connected, it follows that the currents I_A, I_B and I_C in the mains are in phase with their respective coil voltage E_{oa}, E_{ob} and E_{oc}, as shown. On a highly inductive load such as met with in signal work, the current lags behind the voltage and if the phases are equally loaded, the line currents I_{AL}, I_{BL} and I_{CL} will lag θ degrees behind their respective coil voltages, θ being the angle of the lag of the load. In this case, the power delivered by one coil is one-third the total power W.

$$W = 3 I_{AL} \times \cos\theta \times E_{oa}$$

$$\text{but } E_{oa} = \frac{E_{AB}}{\sqrt{3}}$$

$$\therefore W = 3 I_{AL} \times \cos\theta \times \frac{E_{AB}}{\sqrt{3}}$$

$$\text{and since } \frac{E_{AB}}{\sqrt{3}} = \frac{\sqrt{3}\,E_{AB}}{\sqrt{3} \times \sqrt{3}} = \frac{\sqrt{3}\,E_{AB}}{3}$$

$$W = \sqrt{3}\,E_{AB}\,I_{AL}\cos\theta$$

$$\therefore W = \sqrt{3}\,E\,I\,\cos\theta$$

where E and I are the line voltages and currents, respectively.

12. **Three-Phase Delta.** With the more common Delta, or Mesh connection Fig. 185, the six terminals of the three generator windings are connected two and two, the junction points of the windings being connected to the outgoing lines. Here, each coil generates the full voltage between the pair of mains to which it is connected, but the current in any line, as B, is the vectorial sum of the currents in the coils *c* and *b*, differing in phase by 120 degrees, just as the voltages between the mains with a star connection is made up of the vectorial sum of the two coil voltages. The current in B is, therefore, $\sqrt{3}$ times the current in coils *c* or *b*, and so on for the other lines A and C. In the delta connection, therefore, we deal with resultant currents, just as in the star connection we deal with resultant voltages. Here, again, on a balanced non-inductive load, coil *c* would deliver one-third of the total power to the system; the total power would, therefore, be:

$$W = 3 I_{oo} \times E_{AB}$$

$$\text{but } I_{oo} = \frac{I_B}{\sqrt{3}}$$

$$\text{and } \frac{I_B}{\sqrt{3}} \times \frac{\sqrt{3}}{\sqrt{3}} = \frac{\sqrt{3}\,I_B}{3}$$

$$\therefore W = \sqrt{3}\,E_{AB}\,I_B$$

$$\text{and, in general, } W = \sqrt{3}\,E\,I$$

where E and I are the line voltages and currents, respectively. On an inductive load, I_{oo} lags by θ degrees behind the line voltage, and, therefore, the component of the coil current in phase with the voltage becomes I_{OCL} cos θ

$$\text{and } W = \sqrt{3}\ EI \cos\theta.$$

The delta connection is generally employed in signal work, especially in connecting transformer coils, as shown in Fig. 182 (*b*), for the reason that if one of the transformer coils burns out the other two will handle the load, although the system will be unbalanced; with the star connection, one of the mains would be entirely dead if the transformer coil connected to it were burned out.

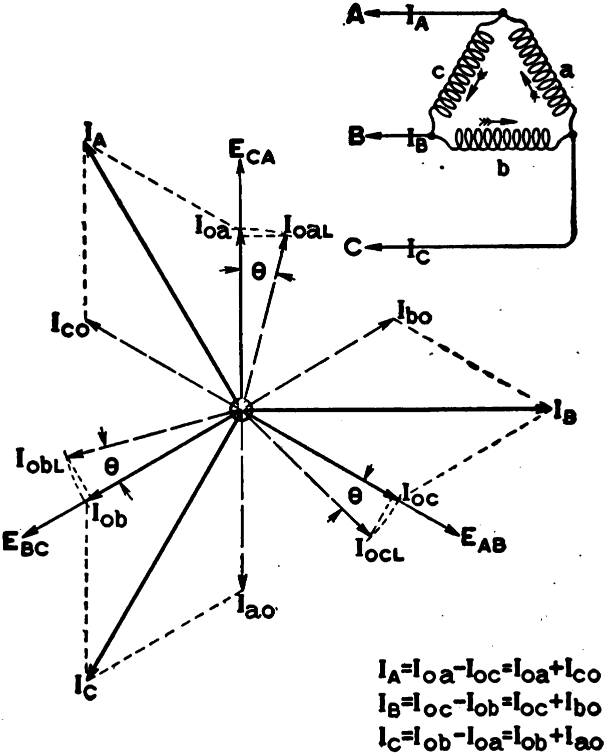


Fig. 185. Vector Diagram of Currents and Voltages in Three-Phase Del System.

13. Copper Economy of Three-Phase System. The three-phase transmission system has the remarkable property that only 75 per cent. as much copper is required to deliver a given amount of power with a stated transmission voltage, loss and distance, as in the single-phase system. Assume, for example, a three-phase system carrying a non-inductive load with E volts between mains, the current in each main being I, and the resistance per line wire R. Then, for a star connection, as we have seen, the voltage in each generator coil is $\frac{E}{\sqrt{3}}$, the current in each coil is I (the same as the line current), the power delivered to each branch by the coil to which it is connected is $\frac{EI}{\sqrt{3}}$, or $\frac{\sqrt{3}\,EI}{3}$, and, since there are three branches, the total power delivered to the system is $3\frac{\sqrt{3}\,EI}{3}$, or $\sqrt{3}\,EI$. Similarly, with the delta connection, the stated voltage across the mains being E as before, the coil current, as previously shown, is $\frac{I}{\sqrt{3}}$, where I is the line current, and hence, the power delivered by each coil to the circuit is $\frac{EI}{\sqrt{3}}$, or $\frac{\sqrt{3}\,EI,}{3}$ the total power delivered by the three coils to the system being $\frac{3\sqrt{3}\,EI}{3}$, or $\sqrt{3}\,EI$, as with the star connection.

The loss in each line, with either star or delta connection, is obviously $I^2 R$, I being the current line, this latter quantity being the same in all cases. Then the total line loss will be $3\,I^2 R$, since there are three wires. Now, let the same amount of power, $\sqrt{3}\,EI$, be transmitted by a single-phase system at a transmission voltage of E volts. The current will, evidently, have to be $I\sqrt{3}$. Let R_1 be the resistance of each of the single-phase wires, such that the total line loss will be $3\,I^2 R$, as with the three-phase system. The resistance of the com-
te single-phase circuit will be $2\,R_1$, and the total loss with
3 amperes flowing will be $(I\sqrt{3})^2 x\ 2\,R_1 = 6\,I^2 R_1$. But

since it is stipulated that the loss single-phase shall equal the loss three-phase,

$$6 I^2 R_1 = 3 I^2 R$$

$$\therefore R_1 = \frac{R}{2}$$

that is, the resistance of each of the single phase wires will be just one-half of the resistance of each of the three-phase wires. The cross-section of each single-phase wire will, then, be twice the cross-section of each three-phase wire. If the weight of each of the three-phase wires is W, the total weight for the three-phase line will be 3 W, while the total weight of the two single-phase mains of double cross-section will, evidently, be 4 W for the same length of transmission. Hence, the three-phase system requires only 75 per cent as much copper as the single-phase system.

14. Relative Advantages of Single and Three-Phase Systems. The copper economy of the three-phase trans-system makes it very attractive, and it is now coming into use in signal work where power has to be transmitted, say, a distance of fifty miles or over, and particularly where there is a considerable station lighting load in addition to the signal load; for short lines, the calculations will often indicate a wire size too small for mechanical strength, in which case, of course, a single-phase transmission ought to be used, as the third wire for the three-phase system would be an absolute loss.

Referring to (b) Fig. 182, showing a straight three-phase delta system, the step-up in transformation at the power house may be effected by three ordinary single-phase transformers, with their primaries (inside the triangle) and their secondaries (outside the triangle) connected as shown; or, again, a special three-phase transformer may be used, its core having three legs, on each of which a primary and its secondary may be threaded. The same statements apply to the step-down transformers required at the signal locations along the line. From this, it will be seen that the use of a straight three-phase system has the drawback that at each location either three single-phase transformers are required or one special three-phase one. This fact also complicates matters, in that extra fuse cut-outs are required for disconnecting the transforming apparatus from the line. The amount of extra apparatus required in the way of transformers, fuse cut-outs and lightning arresters is a serious drawback to the straight-three-phase system, but, on long lines, or where there is considerable load to be carried, it will generally be found that a three-phase transmission is the cheapest, particularly if some scheme can be found whereby the number of transformers at each signal location can be cut down.

PHASE TRANSFORMATION.

15. Three-Phase to Two-Phase; Scott "T" Connection. In addition to representing the voltages in a three-phase system by three radiating vectors 120° apart, as shown in Figs. 184 and 185, it is perfectly feasible to represent these voltages by the sides of an equilateral triangle $A_1B_1C,_1$ shown at (c) in Fig. 182, providing the direction of the voltages is properly indicated by arrows as shown; this triangle diagram corresponds exactly to those with the radiating vectors shown in Figs. 184 and 185, for if the vectors in triangle A_1, B_1 C_1 of (c) Fig. 182 are projected in the direction of the arrows from any single vertex, representing the origin of Figs. 184 or 185, it will be found that three radiating vectors 120° apart are the result.

Suppose, now, that we connect two transformers to a set of three-phase mains, as shown in (c) Fig. 182, where one terminal O is of one primary P is connected to the middle point of the other primary M, and, furthermore, let us provide primary P with $\frac{\sqrt{3}}{2}$ times as many turns as M. Since M is connected across mains B and C, its voltage is represented by vector B_1C_1 in the diagram at the left of Fig. 182 (c), and, since one terminal *O* of primary P is joined to the middle point of coil M, one end of the vector representing the voltage across P can logically be placed at O_1. As regards the placing of the other end of this latter vector, it must be remembered that we intentionally provided P with $\frac{\sqrt{3}}{2}$ times as many turns as M, or, what is the same thing, $\sqrt{3}$ times the turns in each half of M; we are, therefore, justified in placing the outer end of the vector representing the voltage of P at A^1, since the long leg O^1A^1 of the 60° triangle $O^1A^1B^1$ is $\sqrt{3}$ times the short leg O^1B^1. Finally, then, the three-phase vectors A^1B^1, B^1C^1 and C^1A^1, which we originally started out with, are now resolved into the three component vectors B^1O^1, O^1C^1 and O^1A^1, the original vector A^1B^1, for example, being the resultant of B^1O^1 and O^1A^1.

It is to be noted from the diagram that O^1A^1 is separated by 90° degrees from B^1O^1 and O^1C^1, and for this reason, the voltages induced in the corresponding secondaries Q and N are 90° out of phase. These two transformers in Fig. 182 (c) therefore deliver pure two-phase currents from their secondaries, Q and N, and we are thus permitted to use two-phase induction motors which, on account of their freedom from artificial phase splitting devices, such as have to be used in single-phase induction motors, are much more economical than the latter. The track circuit apparatus and the signal slots and lights are, of course, single-phase devices, and, in feeding them, they should be divided up between secondaries Q and N so as to balance the load on the primaries. This ingenious scheme was invented by C. F. Scott, and is, hence, known as the Scott or "T" connection. It provides a means whereby we may take advantage of the copper saving effected by a three-phase transmission, while still requiring only two transformers at each signal location.

16. Three-Phase to Single-Phase. Another scheme whereby the number of transformers at signal locations may be cut down, where a three-phase transmission is used, consists in dividing the transmission into three equal lengths, feeding all signals on the first section from single-phase transformers connected to one phase, the signals on the second section from the second phase, and the signals on the remaining stretch from the third phase, thus approximately balancing the load. With this arrangement, the only disadvantage is that single-phase motors must of course be used, and if they are of the induction type they will not be so economical as polyphase motors. However, the extreme simplicity of the scheme in the way of apparatus makes it of great merit and it will probably see extensive use on long lines, particularly if the balancing of the load between phases can be improved by a well distributed station lighting component or other such power load.

PRACTICAL CONSIDERATIONS.

The Line.

17. Aerial Line Materials. Either copper or aluminum may be used, but it is probably safe to assert that, apart from the question of cost, the high conductivity combined with the great strength and elasticity of hard drawn copper, give this material an advantage over all others for use on high tension transmissions. The relative properties of copper and aluminum are given in the Table VI below:

TABLE VI.

Stranded Aluminum and Solid Hard Drawn Copper Compared. The commercial sizes of stranded aluminum cables made by the Aluminum Company of America are not even circular mil and B. & S. sizes, but are of such cross section as to give the same conductivity as even circular mil and B. & S. sizes of copper cables of 97 per cent. conductivity. The resistances below given for copper apply to hard drawn line wire whose conductivity is somewhat less than that of ordinary soft drawn copper wire.

Size B.&S.	ALUMINUM 61% Conductivity				COPPER 97% Conductivity			
	Diam. In.	Area Cir. Mils.	Ohms per 1,000 ft.	Lbs. per 1,000 ft.	Diam. In.	Area Cir. Mils.	Ohms per 1,000 ft.	Lbs. per 1,000 ft.
0000	0.66	336,420	.05068	307.7	0.460	211,600	.05048	640.5
000	0.59	266,800	.0639	244.0	0.4096	167,800	.06365	508.0
00	0.53	211,950	.0806	193.5	0.3648	133,100	.08027	402.8
0	0.47	167,800	.1017	153.5	0.3249	105,500	.01012	319.5
1	0.42	133,220	.1281	121.7	0.2893	83,690	.1276	253.3
2	0.37	105,530	.1616	96.5	0.2576	66,370	.1610	200.9
3	0.33	83,640	.2037	76.5	0.2294	52,630	.2029	159.3
4	0.30	66,370	.2569	60.7	0.2043	41,740	.2560	126.4
5	0.26	52,630	.3239	48.2	0.1819	33,100	.3227	100.2
6	0.23	41,740	.4085	38.2	0.1620	26,250	.4070	79.46
7	....	....	......	.....	0.1443	20,816	.5131	63.02
8	....	....	......	.....	0.1285	16,509	.6470	49.98
9	....	....	......	.....	0.1144	13,094	.8160	39.64
10	....	....	......	.....	0.1019	10,381	1.029	31.43

The conductivity of hard drawn aluminum wire is between 60 per cent. and 61½ per cent. of pure copper. The weight of an aluminum conductor is about 49 per cent of that of a copper conductor of equal resistance, and is about 73 per cent. as strong, in safe working stress, as the equivalent copper wire. Comparing aluminum of 61 per cent conductivity with copper of 97 per cent. conductivity, the diameter of the equivalent aluminum conductor would be 1.28 times the diameter of the copper wire. The average breaking stress of hard drawn aluminum is between 23,000 and 30,000 pounds per square inch, depending on size and hardness; for copper, the average breaking stress varies from 50,000 to 62,000 pounds per square inch. The average maximum working stresses for aluminum and copper are generally placed as 13,000 and 28,000 pounds per square inch, respectively. Aluminum cannot be soldered, and, where taps have to be made, a bolted or clamped construction must be resorted to; in cases of splices in the line, a special double aluminum sleeve for twisting the two conductors is employed. Finally, for equal conductance, aluminum is cheaper than copper, the price being held, by those in control of the market, about 10 per cent. less than copper; on account of this artificial cost, the scrap value of aluminum is very questionable, whereas copper may be considered as a fair investment, its scrap value being high.

Aluminum line wire for transmissions had best always be stranded, as a cable composed of a number of small wires is stronger than an equivalent solid wire. Due to its low tensile strength aluminum cannot well be used in the smaller wire sizes, but in sizes corresponding to conductivities of No. 6 B. & S. copper, it can be stranded and oftentimes provided with a steel core, so that it will be sufficiently strong and still cheaper than copper.

18. Stringing, Pole Spacing and Wire Spacing. The most important point in the design of aerial lines is to obtain a strong construction, so that the line will stand up under the severest weather conditions. This means, especially that the wire must be large enough, mechanically, to have a good factor of safety; *smaller wires than No. 10 hard drawn copper or No. 12 copper clad should never be used.* In stringing the wire, one need merely make the span tight enough to aver risk of the wires swinging together. Any tighter stringing is a concession to appearance, and may lead to a break during a severe storm, particularly during cold weather, when the wire contracts. Deflections of 2 per cent. or three per pent. at normal temperatures are none too great for most situations. Depending on the size and kind of wire used, the poles should be spaced from 150 feet to 200 feet apart, the former figure being generally employed on those signal transmissions where hard drawn copper is used. On account of its lesser weight for equal conductivity, aluminum wire will allow of a greater pole spacing than copper, particularly if the aluminum is stranded and provided with a steel core; for example, on one long signal transmission which the author has in mind, a No. 4 B. & S. stranded aluminum steel core cable is used, and, in this case, the poles were spaced 200 feet apart.

For 2200 volt work, the wires should never be spaced less than 12", and preferably 15" or 18", to avoid their swinging together in a high wind and with loose stringing. For 4400 volts, a 24"-28" spacing is considered good practice.

19. Underground Lines. Here the line is generally laid in creosoted trunking buried about two and one-half feet below the surface of the ground, the wires being, of course, pitched in; Fig. 186 illustrates a construction of this kind. First, a layer of pitch about ⅞" thick is poured into the trunking as an insulating bed, after which the wires are laid and finally pitched in. The wires ought to be laid close together (there is a double wall of rubber insulation between them), for this provides for a good layer of pitch between the sides of the trunking and wires. In the construc-

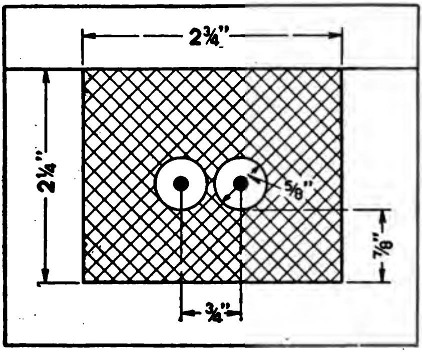


Fig. 186. Conduit for 3300 Volt Single Phase Underground Transmission.

tion shown in Fig. 186, the wires were of No. 4 stranded copper, extra heavily insulated and carried the entire power at 3300 volts for a twenty mile stretch of double track signaling with considerable margin in conductivity. The conduit was laid in 2000-foot lengths and connections made in concrete junction boxes by Dossert connectors. The secret of successful construction of this kind lies in careful installation.

20. Sectionalizing. In order to avoid traffic delays due to breakdowns in the line, the latter ought to be divided into sections and sectionalizing switches (usually oil immersed and hung at the top of the pole) installed at the junction points, so that the section in trouble may be cut out for repairs, the line in the meantime, being fed from both ends up to the dead section; with this provision, only those signals fed by the dead section will be out of service. If the line is a very important one, sectionalizing switches may be installed at each signal location; otherwise, every five miles to eight miles.

Fig. 187. Porcelain Fuse Cut-Out for 2200 Volt Lines.

21. Fuse Cut-outs. It is often necessary to temporarily disconnect a line transformer from the transmission, and it is furthermore advisable to protect the line from a short-circuit in case the primary coils of the transformer should themselves become short-circuited, due to an insulation breakdown following a lightning discharge, for example. For this purpose, a fuse cutout, Fig. 187 for 2200 volt work, or Fig. 188 for voltages higher than 2200, is inserted in each primary lead wire, the fuse cutouts being attached to the cross-arm on either side of the transformer, on the pole. The 2200 volt cutout Fig. 187 consists of a porcelain block at the left of the photograph, into which the plug in the middle is slipped, being held there by a spring catch released by a twist of the plug. The plug carries a long fuse wire connected to brass terminals, which close the circuit when the plug is inserted in its holder, as shown at the right of the figure. The plug is a solid block of glazed porcelain, so that there is no chance of one being shocked when it is desired to disconnect the transformer from the line. The cutout shown in Fig. 188 is spoken of as the "expulsion type," and is intended for voltages over 2200; it consists of a long fuse carried in a vertical fibre tube, the sudden expansion of the air in the tube, due to heating when the fuse blows, being utilized to blow out the arc. The fuse is removed from its holder by simply pulling the door of the box open as shown in the photograph. The wooden box carrying the fuse is to

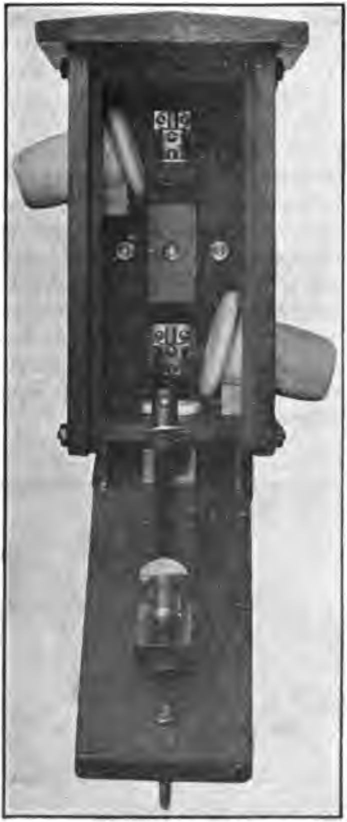


Fig. 188. Expulsion Fuse Cut-Out for Lines over 2200 Volts.

be nailed to the cross-arm near the transformer; one fuse should be provided for each primary lead.

22. Lightning Protection Along the Transmission. It is customary to install lightning arresters on the line at each transformer location, one lightning arrester being provided for each primary lead of the transformer to be protected. For line voltages up to 2200, the well known Compression Chamber Multigap arrester Fig. 189, may be used, this arrester consisting simply of a series of short spark gaps in series with a resistance rod, all slipped into a porcelain tube as shown at the right of Fig. 189. As will be evident from this latter cross section, the spark gaps occur between a number of button shaped units; these units are made of a special non-arcing zinc alloy. In the 2200 volt arrester illustrated there are eight gaps. Briefly, the action is as follows:

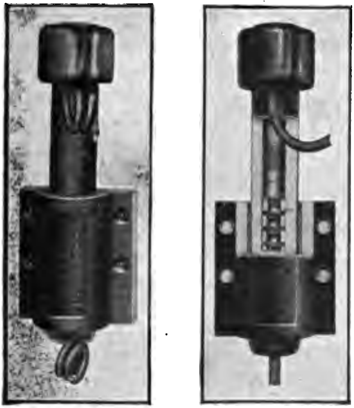


Fig. 189 Compression Chamber Lightning Arrester Assembled Complete and in Section.

When excess potential on the line, due to lightning or similar causes, reaches a value high enough to cause the row of air gaps to break down, a flow of current occurs through the arrester to ground, relieving the line of the dangerous potential. Immediately after this current has passed, the line current, due to the fact that a path has been established through the air gaps, begins to flow through the arrester. The first flow of current has, however, generated zinc vapor which has, although in a lesser degree, the same quality as mercury vapor, namely, that of rectification of the electric current, or allowing the current to flow only in one direction. Hence the line current following the discharge flows only until the voltage wave reverses, in other words, until the end of the half cycle, whereupon it is prevented from reversing by the rectifying action of these gases.

It will be noticed in Fig. 189 that the zinc alloy electrodes with the small porcelain separators make a small closed chamber. During a discharge the gases formed by the arc are held within these chambers, become slightly compressed and assist in extinguishing the arc by partially smothering it. This feature gives the arrester its name. An arrester is required for each primary lead of the transformer to be protected and the arresters may conveniently be placed on the same cross-arm as the transformer, one on either side in the case of single-phase lines.

For lines of higher voltages, the so-called Graded Shunt arrester, Fig. 190, is considered standard. This latter arrester is similar to the Compression Chamber type previously described, but, in addition, is provided with two or more carbon rods of high resistance connected in shunt across a number of gaps between the cylinders, so that minor static disturbances on the line may find ground through the carbon rods, with one or two gaps in series, but without having to leap the whole series of spark gaps; heavy discharges of high potential, on the other hand, will force their way across the whole series of gaps. The arrester is housed in a wooden box and is to be attached, one for each primary transformer lead, to the cross-arm supporting the transformer.

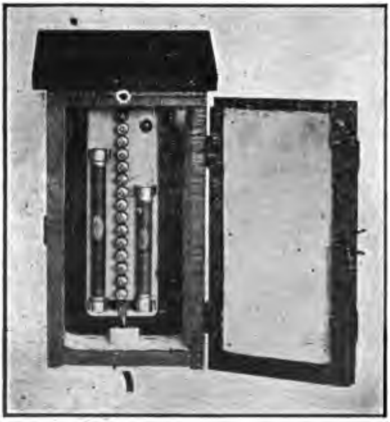


Fig. 190. Graded Shunt Multigap Lightning Arrester.

A good ground for the arresters above described is formed by a 1" galvanized iron rod or pipe about 8 ft. long driven into the ground. The lead between the arrester and ground should be as straight as is possible to make it, without kinks or bends.

23. Insulators. As moisture condenses on the inside surfaces of glass insulators more readily than is the case with porcelain, and, as the latter, moreover, is capable of withstanding sudden strains better than glass, most insulators for high tension lines are made of porcelain.

Fig. 191. Main Power House Switchboard Handling Duplicate Generating Sets, Step-up Transformers and Two Sets of Outgoing Mains.

POWER EQUIPMENT.

24. Elements. The apparatus in the power house consists of the engines, generators, switchboard equipment, and main lightning arresters. Continuity of service is of prime importance, and therefore, duplicate apparatus ought to be installed, unless some reliable source of commercial power is available.

25. Switchboard Equipment. Fig. 191 is a photograph of a standard switchboard providing switching facilities for duplicate engine driven generators feeding duplicate step-up transformers, supplying power to two sets of outgoing high voltage mains working single-phase. A simplified wiring scheme of this board is shown in Fig. 192. The board consists of three panels, the two panels at the left being duplicates, one for each generator and transformer set, while the remaining right hand panel controls the two sets of outgoing mains. At the top of each generator panel is the Tirril regulator connected by a local circuit (not shown, to simplify diagram) to the generator field, and automatically regulating the generator voltage, so that the latter will be constant. Below the Tirril regulator is the ammeter A, Fig. 192, indicating the cur-

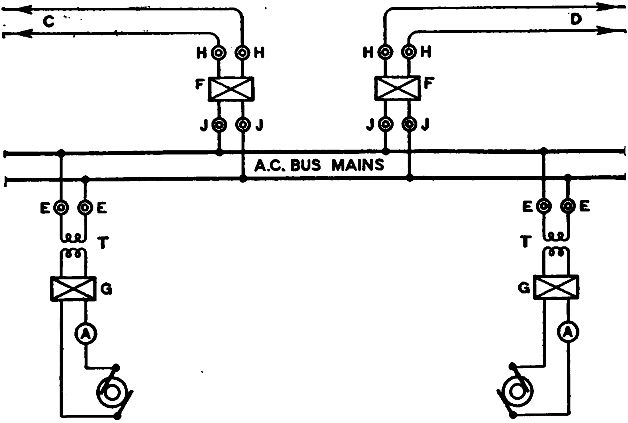


Fig. 192. Schematic Circuit Diagram for Main Switchboard Shown in Fig. 191.

rent output of the generator, and, on either side of the ammeter, are the plug switches E, by means of which the main step-up transformer T may be disconnected from the busbars after the oil switch G has been opened; the plug switches themselves are only intended for opening the circuit when it is once dead. The handle for the generator field rheostat is next below the ammeter, and still farther down, at the bottom of the board, is the handle of the oil switch G for opening the generator circuit.

In transferring the load from one generator to the other in case of shut down, the incoming generator, which is to take up the load, must first be brought up to voltage and in phase with the generator carrying the load before the incoming machine may be connected to the busses. This operation is called *synchronizing*, and a synchronizing meter at the top of a small swinging panel, at the extreme upper left of the switchboard, indicates when the incoming machine is up to speed, the needle pointing to "Fast" or "Slow", depending upon the speed of the incoming machine. Below the synchroscope are the synchronizing lamps, which are dark when the machines are exactly in phase. The voltage and frequency of the incoming machine are indicated, respectively, by the voltmeter at the bottom of the swinging panel and the frequency meter directly above it.

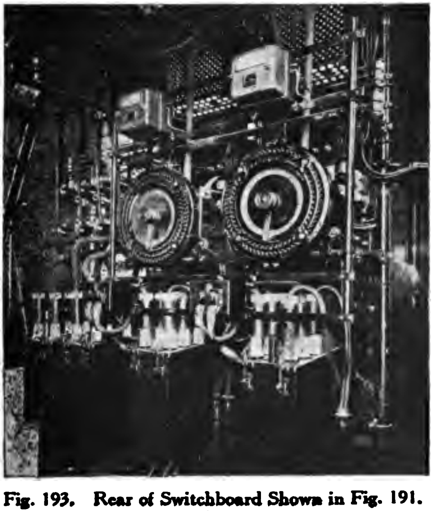


Fig. 193. Rear of Switchboard Shown in Fig. 191.

The outgoing mains are controlled from the large panel at the right of the board, at the bottom of which are the oil switches F, in Fig. 192, provided with an overload trip coil to open the circuit in case of a short. Above these oil switches are the plug switches J and H; by means of these switches J, either or both of the outgoing lines may be disconnected from the busses; by means of the switches H, the lines can be isolated entirely, thus protecting the oil switches F. If the local power plant goes out of service, line D can be fed from line C by opening plug switches E and feeding D from C through H, F and J, across the busses. At the top of the outgoing feeder panel is a recording voltmeter drawing a curve of the actual line voltage during the day, and on either side of this meter are a set of ground detector lamps for the two wires of each set of outgoing mains. The back of the board is shown in Fig. 193, the oil switches being plainly evident at the bottom. Above the field rheostats are watt-hour meters measuring the energy for each pair of feeders.

Fig. 194. Interurban Road Switchboard.

26. Switchboard for Interurban Signaling Sub-Stations. The above switchboard is intended for steam road signaling where power has to be furnished by a local set of engines and generators. In the case of electric roads, however, A. C. power may be taken directly from the A. C. side of the rotaries in some convenient substation, and in such cases the switchboard layout is greatly simplified, as only duplicate step-up transformers and the necessary meters and switches are required. A simple board of this character is shown in Fig. 194, the corresponding wiring diagram being covered by Fig. 195. The board consists merely of a double-pole circuit breaker C with an overload trip coil E at the top of the board over which power is brought from the A. C. side of the sub-station rotaries to the middle of the double-pole double-throw hand switch B by means of which either of the step-up transformers T_1 or T_2 may be energized. When C opens it closes the circuit for bell W, by means of contacts made through the operation of bar D connected to C, and the substation attendant is thus audibly warned that the line is dead. The transformers T_1 and T_2 can be entirely disconnected from the line by plug switches P. The ammeter A indicates outgoing amperes; to avoid danger because of the high voltage used, the ammeter is not directly connected to the high tension mains, but is fed from the secondary of a current transformer of known ratio.

27. Lightning Arresters. Because of the value of the power plant apparatus and the paramount importance of protecting the station from a breakdown due to lightning, a very sensitive lightning arrester of good discharge capacity is required. For this purpose, an arrester of the Aluminum Electrolytic type is generally connected to the line at the power house, Graded Shunt, Compression Chamber or Multi-gap arresters being used at the signal locations along the line. The aluminum electrolytic arrester, shown in Fig. 196, consists of a number of aluminum cones piled closely one over the other with a slight air-gap between filled with an electrolyte.

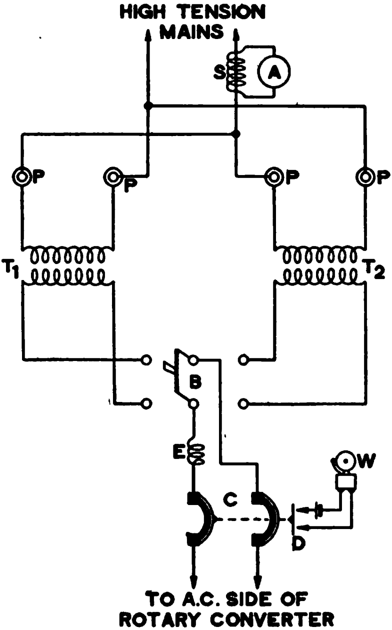


Fig. 195. Circuit Diagram of Interurban Road Switchboard.

A film of aluminum hydroxide is formed on the cones and about 325 volts is required to break down the film on each cone. Up this critical voltage, the cell allows only an exceedingly small current to pass, but when the critical voltage is passed, the flow of current is limited only by the ohmic resistance of the cell, which is very low. A close analogy to this action is found in the safety valve on a steam boiler, by which the steam is confined until the pressure rises above a certain value. With the Aluminum Electrolytic arrester but little current passes through the cell at normal voltages, but when the line is subjected to over-voltage, as in the case of lightning, the hydroxide film on the cone breaks down, and the counter action of the cell disappears so that the discharge passes freely to ground. As soon as the excess voltage disappears, the film re-asserts itself, and the cell acts once more as a closed safety valve. For high transmission voltages, a number of cones in series must be used to secure sufficient counter effect.

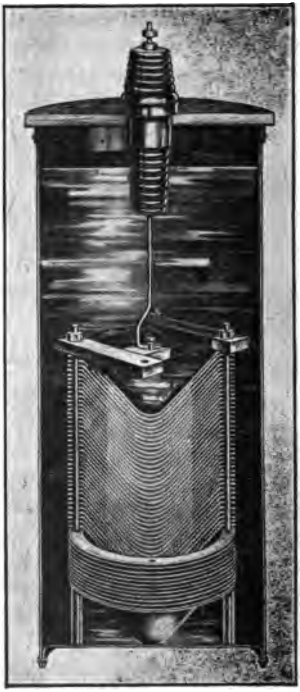


Fig. 196. Aluminum Electrolytic Lightning Arrester.

It is customary to insert a choke coil, consisting of a few turns of heavy hard drawn copper, wound in a spiral and mounted on a porcelain or other suitable base, between the aluminum lightning arrester and the power apparatus; due to the great impedance of the choke coil in the case of high frequency surges and lightning discharges, such surges and discharges are choked back on the line so that they do not reach the power apparatus, but escape over the lightning arresters.

CHAPTER X.

INTERURBAN ROAD SIGNALING.

Fig. 197. Three Position Signaling on a High Speed Double Track Interurban Road. New York State Railways.

CHAPTER X.

INTERURBAN ROAD SIGNALING.

General Requirements. During the past ten years, the interurban electric roads have been extended and developed to such a degree that at the present time they are to a considerable degree comparable to the steam roads as regards speed, weight of rolling equipment, and frequency of train movements. It has, consequently, become necessary to signal them, and alternating current track circuits and signals have come into general use. On double track lines this has presented no difficulties and, as a matter of fact, the signaling equipment of such roads is practically the same as on the steam roads and electric trunk lines. Three-position semaphore or light signals controlled by polarized track or line circuits are usually employed, and Fig. 197 will give the reader a good idea of the standard layout.

However, most of the interurban roads are single track lines and in signaling them new problems have been encountered. These problems arise chiefly from the fact that, while the signaling must be such as to prevent opposing moves through the block between two sidings, it must, in case of dense traffic, allow properly spaced following cars to proceed through the block at the same time. Obviously, these requirements will be met only by some scheme of signaling wherein the relative direction of the moving cars will be taken into account. To meet these exacting requirements with safety and to facilitate train movements, the scheme of automatic blocking known as the "T. D. B." system (Traffic Direction Block) has been devised and extensively adopted.

THE T. D. B. SYSTEM.

1. General Description. The signaling layout is illustrated in Fig. 198. Two cars are permitted between sidings, each in a separate block, and are protected head-on and rear by absolute signals. There is but one track circuit and four signals for each opposing block unit. The blocks for opposing cars do not coincide with the blocks for the following cars, and hence the following definitions will be useful.

Opposing Blocks: The section of track from one siding to the next siding; so called because a car at any point between sidings will block opposing cars at the next siding.

Following Block: One-half of the section of track from one siding to the next siding; so called because there are two blocks for following cars in one block for opposing cars.

Each opposing block, extending from siding to siding, is equipped with four signals, two of which are at the ends, or sidings, and two (one for each direction) are near the center of the block; these latter signals are known as intermediates. Each signal at a siding governs to the signal at the next siding in the case of opposing movements, but only to the next signal in the same direction of traffic in the case of following movements; whereas the intermediate signals govern to the next signal for the same direction of traffic—the signal at the siding.

Besides serving as automatic block signals for following moves, the intermediates, spaced at sufficient braking distance apart, provide perfect head-on protection in case two opposing cars should pass the signals at their respective ends of the block at exactly the same instant, as of course with no train in an opposing block the signals governing entrance thereto are both clear.

Another way of securing similar protection is to provide a short preliminary track circuit in advance of each opposing block, so that a car on this preliminary will throw the opposing signal at the next siding to danger, an opposing car being held at this latter siding until the first car has proceeded through the block. Thus, the control of the signal at one end of a block is extended past the signal at the opposite end of the block and into the adjoining block, so as to prevent the two opposing cars from entering the block simultaneously. Unfortunately the preliminary section is always near a siding, and as a result, a car standing within the limits of the preliminary may prevent an opposing car from entering the adjoining block, even though this block is clear and the car should be allowed to proceed.

The absence of preliminary track circuits and the use of intermediates, as illustrated in Fig. 198, makes opposing block (from siding to siding) a unit; this allows very flexible operation, as cars which are to meet may advance promptly to the sidings. Another advantage is that close headway is permitted for following cars, without complication of apparatus.

2. Operation of the System. Figs. 198 and 199 show the indications assumed by each signal as one or more cars proceed through the blocks.

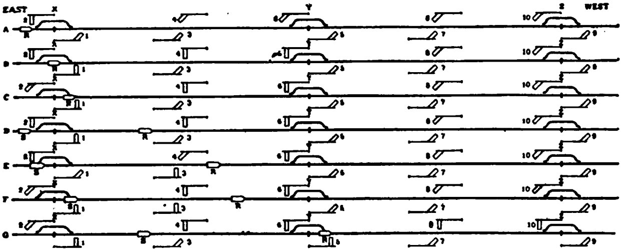


Fig. 198. Effect of Train Movements on Signal Indications in the T. D. B. System.

In Fig. 198 at A, a westbound car is approaching siding X, and opposing signal 2 is at stop.

At B the car is passing signal 1 setting it at stop. Signal 2 is held at stop until the car has passed. Opposing signals 4 and 6 are also set at stop.

At C there is no change except that signal 2 has cleared as the car has passed out of the block at the left.

At D the first car "R" has proceeded to signal 3, and a following car is approaching signal 1. Signal 1 is protecting the rear of car "R" and signals 4 and 6 protect it against opposing movements.

At E car "R", having passed signal 4, signal 1 has cleared up for car "S."

At F car "S" has entered the first following block, while car "R" is in the second following block. Opposing signals 4 and 6 still protect the cars against opposing movements, and signals 1 and 3 protect against following movements.

At G car "R" has entered the next opposing block while car "S" is following and both are protected rear and head-on.

The operation for east bound cars is similar.

At H, I, J, K, L, Fig. 199, are shown the positions of the cars and the indication of signals as a meet is made at siding Y. In this case one car heads in and backs out of the siding, although this particular method of making a meet is not necessary. It will be evident that either car can take the siding because all sidings are shown double-ended, and this system of signaling will permit either car to back in and head-out,

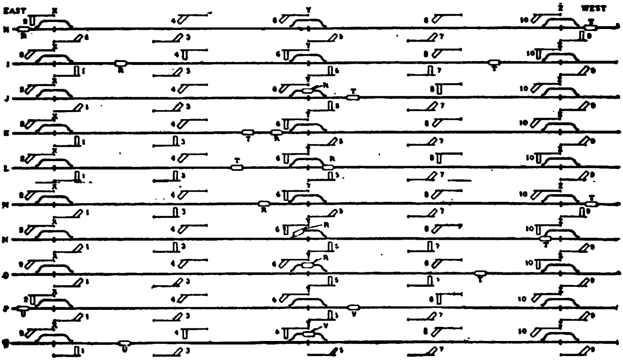



Fig. 199. The Position of Cars and the Indications of the Signals as a Meet Made at a Siding.

head-in and head-out, or head in and back out. With stub ended sidings and signals placed opposite the fouling or clearance point of the sidings, the cars would be protected equally well by the signals with this system, for a car on a siding does not affect any of the signals in any way.

It will be noted that cars between X and Y do not in any way affect the signals between Y and Z. This is shown at M, N, O, P, Q, Fig. 199. At M, car "R" does not affect the movement of car "T", which, we will assume is late. At N and O, car "R" is shown proceeding into the siding so as to clear opposing block X to Y for car "T." At P and Q, an east-bound car is taking siding without affecting the movement of a west-bound car "U."

These diagrams cover all usual car movements. Special movements of any kind are protected equally as well, as the broad principle of track circuit control insures that, when the track circuit, or block, is occupied, the signals will be in the stop position, and when the track circuit or block is unoccupied, the signals will be in the proceed position. No sequence of movements is required to secure complete protection. Therefore, cars may leave a block at any point, and the signals will assume the proceed position.

From the above description it will be evident that the system possesses the following advantages:

1. Each car is at all times protected in the rear as well as head-on by one, or sometimes two, stop signals.

2. When the block is unoccupied and a proceed signal is given, the car may proceed through the block at full speed. This is an important improvement over a circuit scheme whereby following cars are given a caution or permissive indication to proceed through the block at reduced speed; in this latter case, providing the train schedule is properly arranged, the preceding car will have gotten out of the block long before the following car has had time to proceed very far into it and hence the following car loses considerable time because it is compelled to run through the block at slow speed.

ENGINEERING DETAILS OF THE T. D. B. SYSTEM.

3. **Circuit Scheme.** The complete circuit layout for one block unit is shown in Fig. 200. The track circuits are of the double rail type described in Chapter V, both rails being used for the return of the propulsion current.

Each opposing block has one track circuit with two track relays T1 and T6, track transformer R supplying current at the center of the track circuit; it is through the employment of this center fed track circuit that traffic direction control is secured. Each track relay will be shunted by any car which may be on the track circuit between the track relay itself and the transformer feeding it. Both track relays will be shunted by a car within a short distance on each side of the transformer. There is, therefore, a territory on each side of the transformer within which a car will shunt both relays.

Referring to Fig. 200, signals 1 and 6 normally are controlled by both track relays or the entire section of track between them. Signal 3 is controlled over the points of line relay 3L by track relay T6, and signal 4 is controlled over the points of line relay 4L by track relay T1.

A westbound car entering the block XY at X will deenergize the track relay T1, and thereby set signals 1, 4 and 6 at stop. As signal 3 is controlled by the track relay T6, it will not be set at stop until the car reaches the point near the track transformer where it affects relay T6.

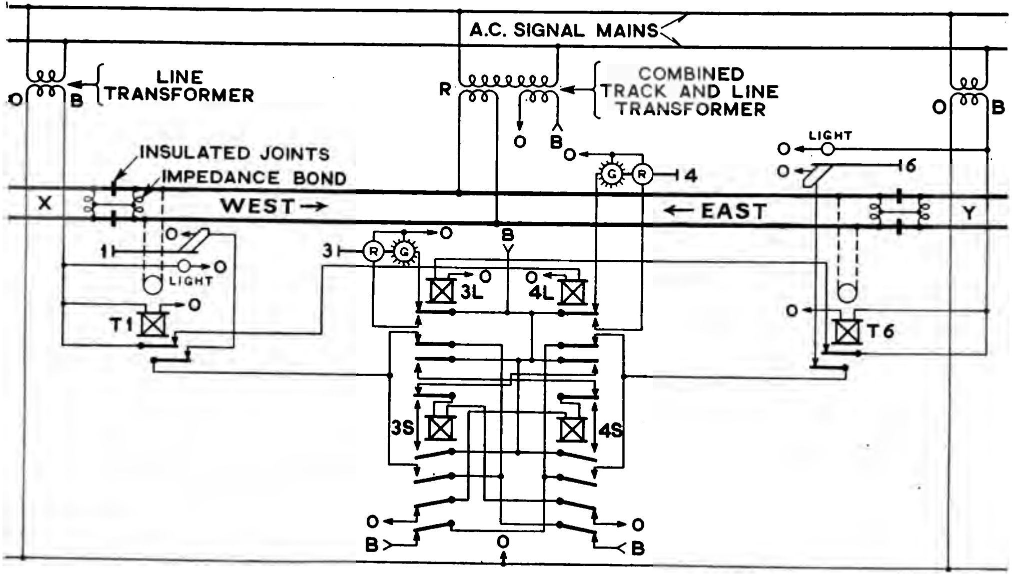


Fig. 200. Circuit Scheme for T. D. B. System.

The car, in de-energizing relays T1 and 4L, energizes stick relay 3S which is used to clear signal 1 after a car has passed signal 4. This stick relay cuts out the control of signal 1 from the track relay T6 and line relay 3L. As the car proceeds, passing signal 3, track relay T6 is de-energized, setting signal 3 at stop and still holding the other three signals at stop When the car passes signal 4, track relay T1 is again energized and signal 1 is cleared. Incidentally, signal 4 is cleared because track relay T1 is energized, but this has no effect on westbound movements. When the car has passed signal 6, all signals and relays again assume their normal positions un-

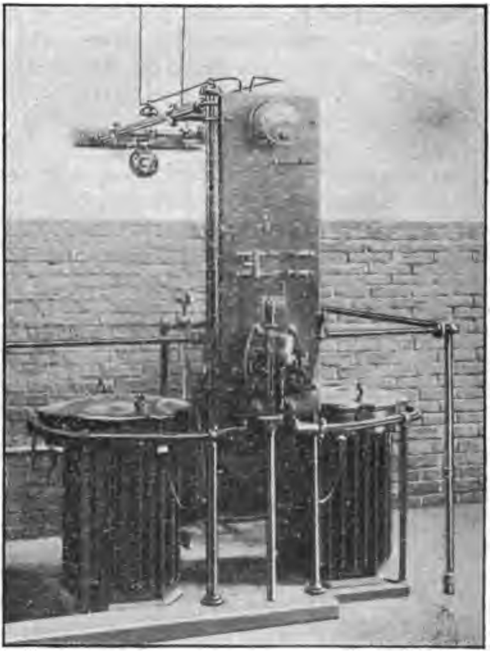


Fig. 201. Complete Power House Equipment for an Interurban Signal System.

less a second car has entered the block at signal 1 before the first car passed signal 6. The operation of east bound cars is similar.

Stick relay 3S is active only in connection with westbound movements; eastbound movements have no effect upon it. Therefore, an eastbound car will set signal 1 at stop when signal 6 is passed. Likewise stick relay 4S is used to limit the control of signal 6 in a similar manner for eastbound movements.

It will be noted that the circuits are so arranged that but one of the two stick relays 3S or 4S can be energized at any one time. Evidently, if a westbound car should pass signal 1 at the same time that an eastbound car passed signal 6, signals 3 and 4, being directly controlled by the track relays, would afford positive protection.

From the foregoing description the system may appear to require a certain sequence of car movements, but this is not the case. A westbound car could proceed past signal 1 and afterward back out of this block instead of proceeding through, and all apparatus would again become normal when the car had left the block. The same would happen if an eastbound car should enter at signal 6, and then back out. The arrangement of circuits in conjunction with a standard relay so that it will be active for one direction of traffic only is not novel, not does it involve complication of apparatus or circuits.

4. Types of Signals Used. Either semaphore or light signals may be used throughout, but semaphore signals are more generally employed at sidings for the following reasons:

First. They provide indications which can be clearly seen while making movements into and out of sidings; therefore,

Second. They render unnecessary the use of switch indicators at adjacent switches.

Third. They are of the same general type and give the same indications as signals which have been standard in steam road practice for many years.

Fourth. They have a much greater advertising value, for their operation may be easily observed by passengers and the general public.

5. Power House Equipment. The signal system is generally fed from 2200 volt single-phase mains receiving power from a step-up transformer located in a convenient power house or sub-station. Duplicate step-up transformers are always provided to guard against a tie-up in case of lightning trouble. The necessary switching is accomplished by means of a simple switchboard such at that illustrated in Fig.

Fig. 202. Style "B" Signals on the Chicago, Lake Shore & South Bend Ry.

201, which photograph also shows the duplicate transformers above mentioned. The reader is referred to Figs. 194 and 195 (Chapter IX) and the explanation given in connection therewith for a full description and circuits for a standard switchboard for use in connection with interurban signaling.

6. Examples. The following concrete examples of installations made on the roads listed below will perhaps serve to better illustrate the T. D. B. system:

	Miles.	Blocks.
Chicago, Lake Shore & South Bend Ry....	55	20
Indianapolis, Columbus & Southern Tract. Co.	22	13
Chicago, South Bend & Northern Indiana Ry.	9.5	5
Louisville & Northern Ry. & Lighting Co.....	3.5	2
Ohio Electric Railway......................	4.2	2
Scranton & Binghampton Railroad...........	16.1	19
Kansas City Clay Co. & St. Joseph Ry........	70.1	25

In this table the blocks constitute the territory from siding to siding.

Fig. 203. Model 13 Light Signal Scranton and Binghamton Ry.

On these lines the semaphore signals are of the Style B type, electrically lighted, two-position, working in the upper left hand quadrant, as shown in Fig. 202. They are equipped with induction motors and the mechanisms are at the bottom of the posts. On the Chicago, Lake Shore & Southern Bend, and the Chicago, South Bend & Northern Indiana, all signals are semaphores. On the other roads light signals are used as intermediates. These light signals are of the Model 13 type (Fig. 203), equipped with two 8'' lenses each. They carry hoods to screen the lenses from sunlight and backgrounds to increase the visibility. Behind each lens are two

25 watt 16 C. P. tungsten lamps. See Chapter VIII, Part II, for a full discussion of the various types of light signals and their application.

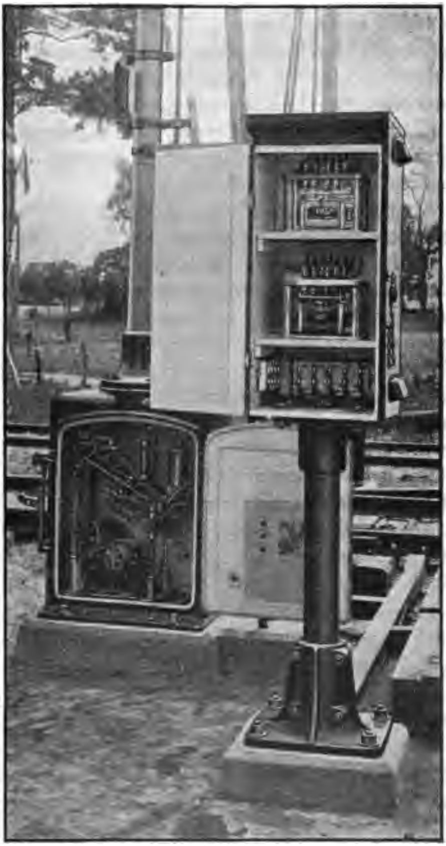


Fig. 204. Galvanometer Track Relays and Style "B" Signal. Washington, Baltimore and Annapolis Ry.

Each block—siding to siding—has but one track circuiwith a track relay at each end. Current is supplied by transformers at the center of each block. Galvanometer track relays (see Chapter IV.) are used on the six D. C. propulsion roads, and centrifugal frequency relays on the Chicago, Lake Shore & South Bend, which operates on alternating propulsion current at 6600 volts, 25 cycles. The semaphore signals are directly controlled by the track relays, whereas the light signals on the Indianapolis, Columbus & Southern Traction, Louisville & Northern Railway & Lightning, Scranton & Binghamton, Kansas City, Clay County & St. Joseph, and the Ohio Electric, require line relays which operate on 110 volt circuits controlled by the track relays.

All signal apparatus is designed for 60 cycle operation, except on the Scranton & Binghamton, the Ohio Electric Railway and the Kansas City, Clay County & St. Joseph, where 25 cycle current is used. The signal slot coils are controlled by line wire circuits through the track relay contacts, whereas the signal motor circuits receive their current from transformers at the sidings. They are on purely local circuits. Transformers with two secondaries, one for the track circuits and one to deliver 110 volts, supply current at the center of the block for the track and to line and intermediate signal circuits. Other transformers with one 110 volt secondary each, placed at the turnouts, supply current for the siding semaphore signals and line circuits. These transformers are provided with taps as required, and all receive current from the 2200 volts A. C. mains.

The Indianapolis, Columbus & Southern Traction, the Chicago, South Bend & Northern Indiana, the Louisville & Northern Railway & Lighting, the Scranton & Binghamton, the Ohio Electric and the Kansas City, Clay County & St. Joseph are D. C. propulsion roads. On the first six the potential is 600 volts, on the last 1,200, and the impedance bonds have a capacity of 500 amperes per rail. The impedance bonds on the Chicago, Lake Shore & South Bend, where alternating current at 6600 volts is used, have a capacity of 200 amperes per rail. Circuit controllers connected to the switch points require the switches to be set for the main line before the signals at the sidings can assume the clear position. All relay boxes are of iron, mounted either on separate iron posts or on the semaphore signal cases.

Fig. 205. Three Position Model 13 Light Signals. Pacific Electric Ry.

CHAPTER XI.

TYPE "F" A. C. ELECTRIC INTERLOCKING.

Fig. 206. Type "F" A. C. Interlocking Machine, N. Y., N. H. & H. R. R. Pawtucket, R. I.

CHAPTER XI

TYPE "F" A. C. INTERLOCKING.

1. General. Considering the high degree of perfection which alternating current motors and other devices have reached, not only in signal work but also in the industrial field, there seems to be no reason why such apparatus should not with advantage be employed in an interlocking system. Already in many interlockings within A. C. automatic territory, the track circuits and such signals as are automatic or semi-automatic in character are frequently arranged for operation on alternating current in order to maintain the continuity of the block system. It is only a logical step to operate the signals likewise. Wherever there is a reliable source of alternating current power available, an A. C. electric interlocking will possess the following advantages:

1. The power equipment is greatly simplified since the storage batteries, rectifier, and accompanying switchboard generally used in D. C. electric interlockings are eliminated in favor of a simple transformer, low in first cost and requiring no maintenance.
2. The efficiency of the transformer will run between 96 per cent. and 97 per cent. In a D. C. electric interlocking the storage battery will return only from 40 per cent. to 60 per cent. of the energy put into it; if a rectifier is used for charging a further loss of energy occurs in the rectifier itself whose efficiency is 75 per cent.
3. In point of safety and economy the alternating current track circuit is unequaled as it is free from foreign direct current influences. Such track circuits, used for detector locking and the semi-automatic control of signals, become immediately available in an A. C. electric interlocking system.

Such are the apparent advantages of any A. C. electric interlocking. The type "F" system, the invention of Mr. W. F. Follett, Assistant Engineer of Signals of the N. Y., N. H. & H. R. R., and assigned to this company, possesses certain other important advantages, however, which make it particularly attractive in safe, economical and reliable operation on either alternating or direct current, and the reader who is interested in the details of the D. C. interlocking is respectfully referred to our Bulletin No 71. The system is based on one simple principle, viz., the feeding of all functions from a pair of bus mains extending the length of the interlocking, power being admitted from the mains to each function over the contacts of a local relay controlled from the machine in the tower; the bus mains correspond to the main air line in the well-known electro-pneumatic interlocking system, and the control relays to the valve magnets. Naturally this results in an enormous saving in copper since the control wires for the local relays need only be large enough to stand up mechanically, whereas if the functions were fed directly from the tower, each set of wires would have to be large enough to carry the entire operating current. Further advantages in simplicity and safety are secured through an ingenious indication scheme which will presently be described.

2. **Elements of the System.** The type "F" alternating current interlocking consists of:

(a) A transformer, generally in duplicate, for stepping down from the transmission voltage to 110 volts for the interlocking bus-mains; the source of power may be of any voltage or frequency.

(b) Two bus-mains for delivering current to the signals, switches, etc., to be operated.

(c) The interlocking machine for the centralized control of the local relays placed at each function to be operated.

(d) Motor operated switch and lock movements for moving and locking the switches.

(e) Motor operated signals for governing train movements over the tracks after the switches have been lined up.

(f) Auxiliary devices, such as tower indicators, time releases, etc., now so generally used in interlocking work.

MAIN TRANSFORMER.

3. **Size and Location.** The size of the main transformer for feeding the bus-mains will naturally depend on the number of functions to be operated. In calculating the size, however, it is well to remember that the load constituted by the switch

and signal motors is only momentary in character and any well-designed oil-cooled transformer is capable of withstanding a 75 per cent. overload for the few seconds taken for switch or signal motor operation. As examples, the writer has in mind two type "F" A. C. interlockings of the following sizes:

Interlocking A.

10 levers for 13 switches, 2 M. P. frogs and 3 derails.
15 levers for 20 signals.
25 working levers.
10 spare spaces.
35 lever machine.

Interlocking B.

9 levers for 16 switches and 2 derails.
15 levers for 26 signals.
24 working levers.
5 spare spaces.
29 lever machine.

For each of the above layouts a 7½ K. V. A. transformer was found adequate, and the cost of the combined power for both of them, including track circuits for semi-automatic control and detector locking, as well as that for the operation of 15 top arm automatic blades on interlocked signals, ran about $1.75 per day at the rate of 2½ cents per kilowatt-hour.

4. Location of Main Transformer. The transformer ought to be located at the load center, or "center of gravity" so to speak, of the bus-mains; this is the point on either side of which the sums of the products of the current taken by each function times the distance of the function from the load center are equal. In the case of switch movements, the current will be about 6.0 amperes per point, and the signal motors will take between 2.2 and 3.5 amperes, depending on the type of mechanism employed. Maximum copper economy in the mains is secured when the transformer is so located, as will be evident after a moment's reflection; for example, if the transformer were placed considerably to the right of the load center, the mains to the left would have to be correspondingly larger if the drop were to be kept within the proper limits.

THE INTERLOCKING MACHINE.

5. Parts and their Functions. The type "F" interlocking machine illustrated in Figs. 206, 207 and 208, is a development of the well-known electro-pneumatic machine. It consists of miniature levers conveniently arranged in a common frame and adapted to the operation of a bank of mechanical locking, but of diminutive design. Each lever in the machine also operates the necessary electric contacts, and attached to each lever are one or more electric locks.

The *mechanical locking* is provided for preventing the operation of levers which, if moved, would conflict in function with one or more other levers.

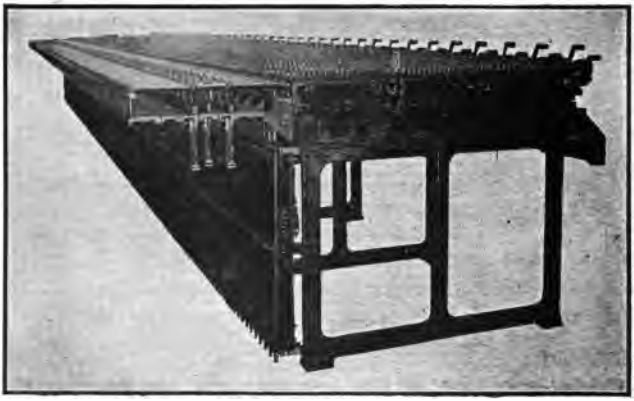


Fig. 207. Rear View of 169 Lever Type "F" Interlocking Machine With Case Removed.

The lever *contacts* control electric currents for the operation of the local relays at switches and signals, and are also used for opening and closing different circuits as required by the many combinations of lever positions.

The *electric locks* are provided for restraining lever operation according to conditions remote from the machine when these are adverse to their safe operation, such as preventing final movement of levers until the operated unit has responded to the initial lever movement and preventing the initial movement of switch levers by train action where detector track circuits are used instead of mechanical detector bars.

It is the custom in the type "F" system to operate from a single switch lever all of the switches upon the ground which it is permissible so to operate without restricting simultaneous traffic movements, and irrespective of the loads thus produced upon any lever. In the case of signal levers, it is the custom to operate all signals which under all circumstances govern routes conflicting with each other; thus many signals leading from individual tracks to a common point and diverging from the common point are handled from the same lever.

The form of lever used and the manner of its operation were adopted years ago to obtain, effectively, the concentration of many levers within the smallest space practicable. This form was adopted to insure that the operation of many switches and signals from a central point might be effected without frequent shifting of position by levermen during lever manipulation and without extravagance in the dimensions of the structure containing the machine. The general testimony of levermen is that with side throw levers as used in the Type "F" machine, a less number of men are required per trick than would be the case with a machine where the levers must be pulled directly outward, for if an attempt is made to throw levers of this latter type from the side, binding due to side friction results; hence the leverman must shift his position each time so that he may be directly in front of the lever to be pulled. Type "F" levers on the contrary may be thrown from any position within the leverman's reach.

Due to this form of lever construction, a large machine may often be operated by a single leverman while its location conveniently within the track system involves no serious encroachment upon space usually much needed for track purposes. The device is self-contained and suitably encased in a wood or metal case provided with detachable panels, each provided with means for locking the machine against access by other than authorized persons.

The type "F" machine is a development of the well-known electro-pneumatic machine, and few, if any, devices in existence to-day that were designed for the safe and reliable control of a multiplicity of contacts embrace that degree of concentration, security of construction, current carrying capacity, insulation and electrical separation of current carrying

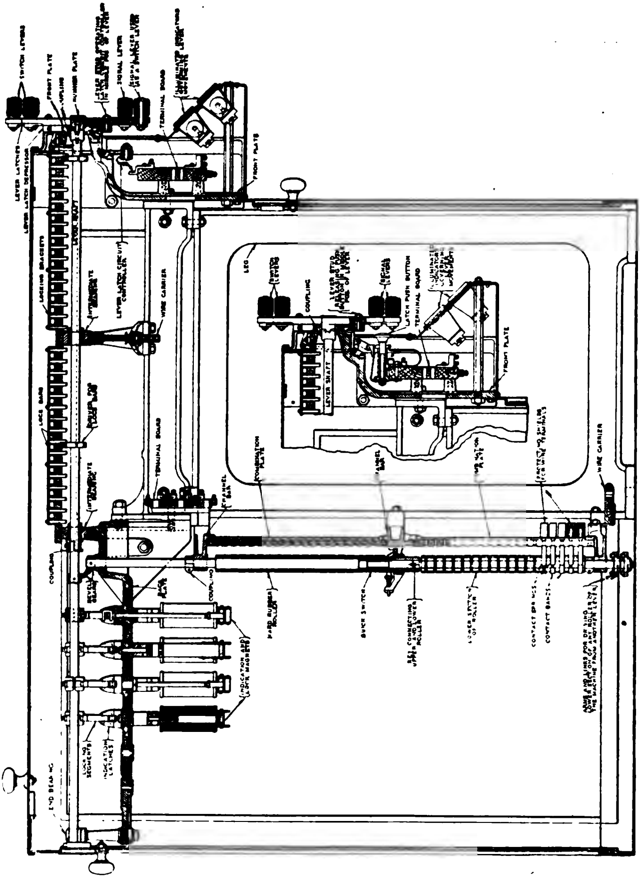


Fig. 208. Sectional Side View Type "F" Interlocking Machine.

parts with that degree of accessibility and ease of inspection that are conspicuous features of the electrical equipment of the type "F" machine. Thirty years of development have not only permitted the embodiment within this machine of these characteristics, but have also made possible the machine's application to the operation of track layouts of extreme magnitude, and the direction of traffic of the most congested nature, without the slightest modifications of its structure or resort to substitute appliances for meeting the intricacies of special control and operation that such applications frequently have to provide for,

6. Lever Movements. The complete operation and locking of a switch (from either of its two positions) is effected in this system, as in all power interlocking systems, by a partial (preliminary) movement of its lever, the complete (final) movement of the lever being impossible until the proper response of the switch to the preliminary lever movement occurs. Two systems of circuits are employed for these purposes; one for effecting switch *operation,* and one for releasing the lever thereafter for its final movement, the latter involving what is known as the *indication* system. The complete operation of a signal from stop to proceed is effected by a continuous complete lever movement, but its operation from proceed to stop necessitates two movements of the lever; a preliminary movement for interrupting the power supply to the signal, and a final movement that can be made only when the signal, so deprived of power, returns fully to the stop position. The operation of switches and signals thus involves the opening and closing of electric contacts during lever movement and at definite points in the lever's throw. The control of lever movement by switch and signal position

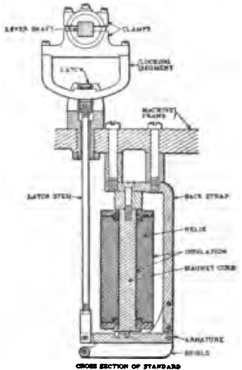


Fig. 209. Diagram of Lock Magnet and its Segment.

(which also embraces this contact control) necessitates the use of electric locks (Fig. 209) upon the machine which permit or prevent lever operations according to the energized or de-energized state of their magnets. Control of these locks is not restricted solely to switch and signal operation, train action being also at times a factor in it.

Fig. 210a represents the several positions occupied by a switch lever at important times during the operation of a switch from Normal to Reverse and from Reverse to Normal. It also shows the formation of the quadrant secured to the front of the machine frame and that of the lever latch carried by the lever, as these are designed to restrict lever movements under certain conditions. It also illustrates means for forcing the lever-latch into engagement with the quadrant at midstroke; a means provided that this quadrant and not the segments

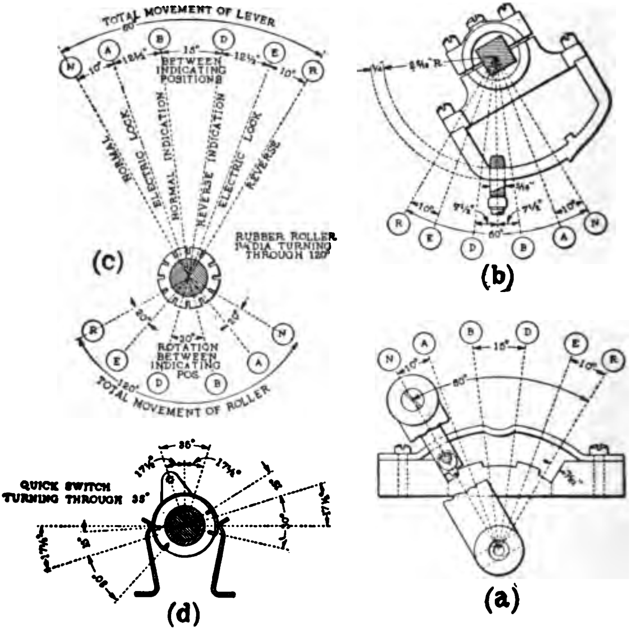


Fig. 210. Diagram Illustrating the Operation of Switch Levers.

of the electric locks will receive the impact of the lever's arrested movement, thus insuring entire freedom of action of the latches of the electric locks when these are to be elevated to release the segment, for final lever movement after the indication is received. Incorporated also in this figure, but only in a vague way shown, is a stud or pin which co-acts with the latch to open and to maintain open a set of contacts under certain positions of the latch and the lever; this circuit controller, and its operation jointly by the lever and the latch; will be described in connection with the automatic locking of switch levers by train action through the medium of the electric locks, employed primarily for switch indications. Fig. 210b represents one of the two segments and latches of a switch lever that are employed jointly for switch indication and detector circuit locking. Fig. 210c shows diagrammatically the

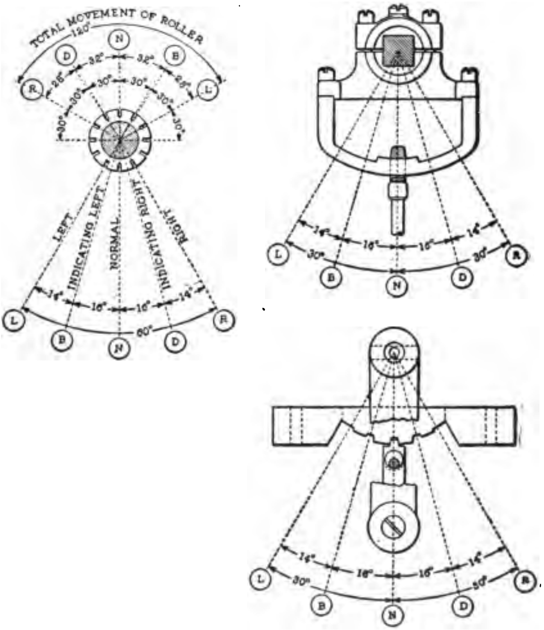


Fig. 211. Diagram Illustrating the Operation of Signal Levers.

several positions occupied by a switch lever, as already referred to, and the angle of rotation that lever movements impart to the contact rollers of the machine during lever operation. These rollers move at double the speed of the levers and, hence, their total angular movement is double that of the levers, or 120 degrees. Fig. 210d shows a section of the hard rubber roller that, while mounted concentrically upon and operated by the roller shaft, is not continuously movable with the shaft, but is restrained from following it during preliminary lever movements by a spring actuated toggle and until the final movement of the lever occurs after the indication has been received. This device is embraced in the indicating system and is known as the "quick switch."

Fig. 211 shows like characteristics of the Type "F" signal lever. Fig. 212 shows, in perspective, the actual design and relations of the various features of the switch lever, while Fig. 213 shows in like manner those of Type "F" signal lever. Fig. 214 shows a fragmental view of the insulated plate which carries the contacting system of the machine. This drawing also illustrates certain features of construction peculiar to the rubber rollers, quick switches, and contacting devices that will be referred to elsewhere.

7. **Checks on Lever Movements.** In describing the operation of the levers of the type "F" machine, the effects of lever movements upon switch and signal position, and the effect of switch, signal and train operation upon lever manipulation, it is assumed that the function of the mechanical locking of the machine is fully understood to be: first, the release of one lever for operation only after another has been fully operated; and, second, the locking of one lever against operation by movement of another lever before movements of the other have advanced sufficiently to affect those conditions which prevailed before an attempt to move it was made. No detailed description of this feature of the machine will be given, because the type of locking used is well understood and its efficiency and durability are well known to everyone at all familiar with mechanical interlocking practice. In the method of driving the bars of this locking from the levers in the type "F" machine, a departure from the practice employed in mechanical interlocking machines was made, however; this

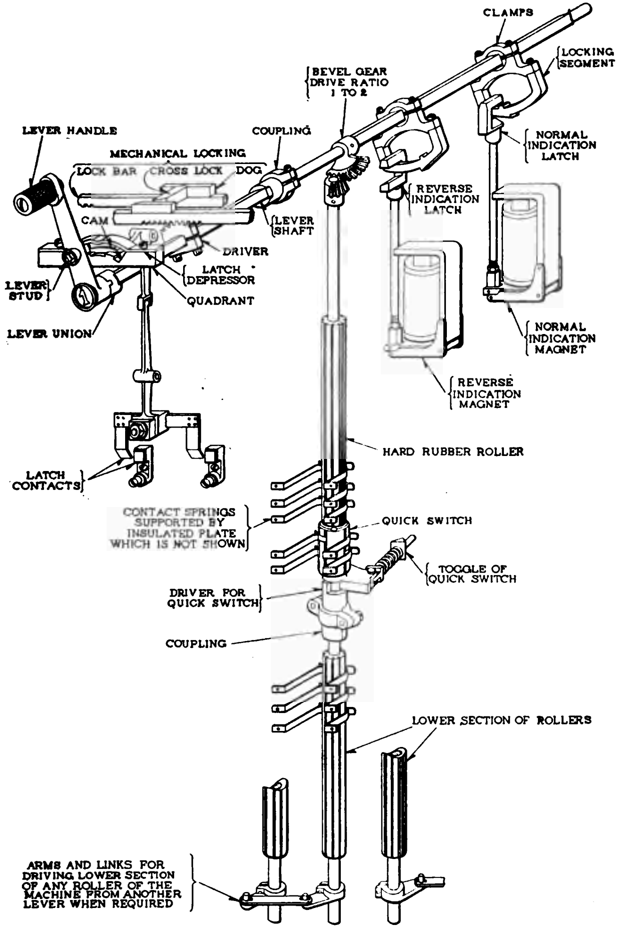


Fig. 212 Perspective Diagram of Switch Lever Complete.

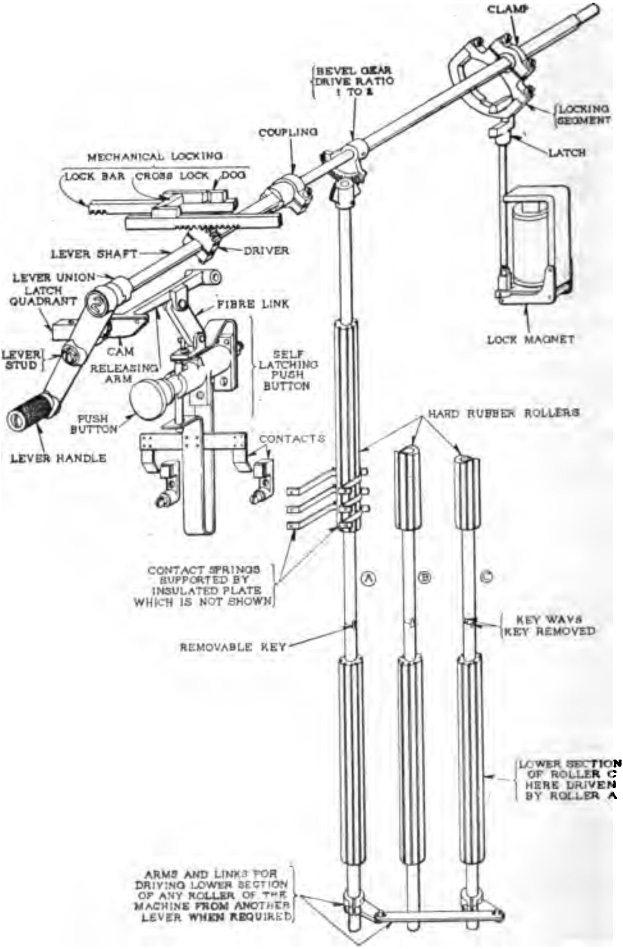


Fig. 213. Perspective Diagram of Signal Lever Complete.

embraced not only a much more direct and a simpler driving mechanism than that there used, but it involved the operation of the locking during lever movements, and not preliminary to lever movements, as in its operation from the catch rods of mechanical machines. This method was employed both because of its great simplicity and because in power interlocking practice, levers are necessarily moved through a considerable part of their stroke before their movement is influential in causing switch or signal action. This fact completely removes from all power interlocking machines that need for a preliminary operation of the mechanical locking that arose in mechanical interlocking through the fact that a change of switch and of signal position is there simultaneous and continuous with lever operation. There is, however, another feature embracing the locking of levers (both electrically and mechanically) that is involved in the concentration of this feature of the catch-rod's function within the lever itself, which should be made clear before the foregoing statement can be accepted as in all respects true. The movement of the switch lever, Fig. 210a, to position D is the first act necessary to operate the switch. This movement is possible only when the switch lever is unrestrained by both the mechanical and the electric locking of the machine. Ordinarily, the mechanical locking prevents any appreciable movement of the lever from position N when restraining the lever's movement. When the mechanical locking of one lever by another, however, is dependent upon the positions assumed at the time by many other levers (as is often necessary) it is impracticable to lock the lever so securely as to prevent a slight movement of it being made when mechanically locked. In consequence of this, it is of importance that the electric locks should be so designed as to engage the lever in any position which it may occupy while restrained from effective movements by the mechanical locking. To this end, the electric lock, while preventing effective lever movements, still permits of a partial movement of the lever from either of its extreme positions (from N to A or from R to E). This partial movement is without influence upon the system of contacts operated by the lever and hence may be totally ignored as an element essential to switch operation—its function being simply to provide after the effective operation of each lever has occurred, a further excess movement to permit, by that excess, the mechanical and the electric locking of the lever in a wholly safe manner and without resorting to the complication peculiar to preliminary locking.

Preliminary locking by lever catch-rods is indispensable to safe lever operation and control only when the lever itself is not given this excess of stroke, or when this excess of stroke is not employed exclusively for the function assigned, in mechanical interlocking practice, to lever catch-rods. When levers are given this extra throw, the catch-rod or lever-latch becomes simply a means for restraining the lever in one or the other of its extreme positions against inadvertent operation at times when lever operation is unrestrained by the locking. Those positions of the switch lever represented by lines A and E, Fig. 210, may, therefore, be regarded as corresponding with what would be the extreme positions of the lever were the catch-rods employed for preliminary locking purposes, as in mechanical interlocking practice, and were the electric locks applied to the catch-rods and not to the levers. The line D represents the position to which the lever is moved continuously from N, to effect the change of switch position. Beyond this position the lever cannot be moved until the switch, in response to the lever movement, completes its operation and thereby energizes that one of the indication magnets which, through its depressed latch, restricted the lever's movement at position D. Line B represents the indicating position of the lever upon its return operation from R to restore the switch to its original (normal) position, in which position it is restrained by the other indication magnet until that magnet is energized by the responding switch.

8. **Contact System.** While it is customary to arrange the switch levers so that these project upwards from their shafts, and to arrange the signal levers so that they project downwards, this is entirely an arbitrary matter. In practically all installations the number of switch levers required exceeds the number of signal levers required—largely by reason of that dual capacity of signal levers just referred to—and it not infrequently happens that switch levers are substituted for signal levers in such cases. It, furthermore, sometimes occurs that the requirements of certain levers in the way of

contact equipment, exceed the capacities of the two sectionalized rubber rollers ofeach lever that this equipment embraces. It invariably happens, also, in such cases that a single section only of other levers is more than ample for meeting their needs in this respect. To give to the former levers the desired capacities, the lower sections of the rollers of the latter are disengaged from their upper sections and connected by links to the overburdened rollers of the former levers so as to operate with them. In this way, an almost unlimited capacity for circuit control is assured each lever of the machine, and where unusual conditions assign to the lever the control of many circuits, no complications of design or resort to special equipment to meet its need is involved.

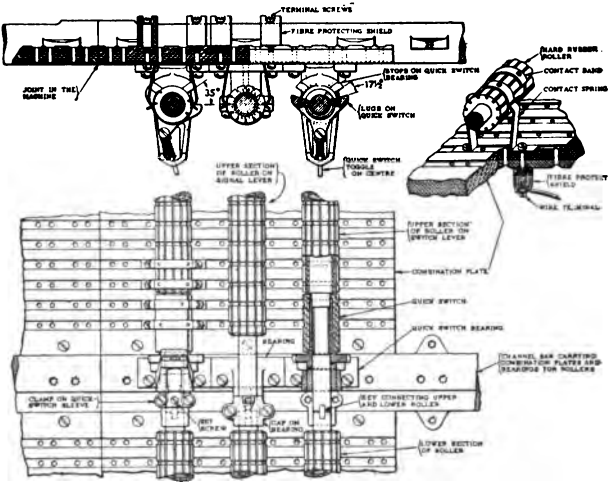


Fig. 214. Section of Combination Plate, Rollers and Contacts.

The vertical arrangement of the rollers has two distinct advantages; first, in permitting of their operation through an angle of 120 degrees—or double the angular throw of the levers; and second, a concentration of the elements of the machine in the interest of the floor space occupied. The 120 degree operation of rollers is of especial value in obtaining, by means of rollers of small diameter, a wide separation of contacts and a close definition of contact control with respect to lever positions, thus insuring permanency of adjustments and entire freedom from extreme care and delicacy in producing it originally and maintaining it afterwards. The panels or "plates" which support the contacting system of this machine are of special moulded insulated material so formed and secured to the machine frame as to prevent distortion due to temperature or humidity changes. To these plates the contacting springs are secured by substantial brass screws which pass entirely through them and into square brass nuts of liberal lengths by which the screw and spring are thoroughly secured. These nuts, being square and set into vertical grooves, cut in the rear of the plate, are non-turning, while the contact springs lying in similar grooves cut in the front of the plate are likewise held against turning by a single screw through each. The nut by which the screw is secured is of extra length where wire connection to a contact spring is to be made, and that portion of the nut which extends beyond the screw is equipped with a second screw and washer for securing the external wire connection. Over the terminal posts thus formed, a tube of insulating material is placed; the external wire connection being in a notch cut in the outer end of this tube, and when the wire is secured to the post by the screw a very simple and effective means of retaining the tube is thus obtained and a highly satisfactory protection afforded the terminals of the machine against accidental crosses or grounds during inspection, etc.; see Fig. 214.

The vertical mounting of the rubber roller might involve some risk of badly fitted contact bands thereon slipping out of position with serious consequences were means not employed for preventing it. To prevent this occurrence, grooves are turned in the rollers, and the contact bands being placed immediately over them are held against movement longitudinally upon the roller by several lugs or projections that are deflected into the groove after the band is applied. The ends of the bands are turned at right angles and inserted in two of the severally radially cut slots in the face of the rollers to secure their rotation at all times with the roller. These bands vary in length and in their positions on the rollers to meet the requirements of the circuit including them, the matter of lever positions. An electrical separation of

⅜" is obtained between contacting members, terminal posts, magnets, the frame of the machine throughout its construction complying fully with R. S. A. specifications in this respect and adapting the machine to safe operation with any working e. m. f. from 12 to 250 volts. The 3000 volt A. C. insulation test required by the R. S. A. is an important feature of the machine's construction, and a 5000 volt test is entirely practicable where required, without mechanical modification of any sort. The electro-magnets used for locking and indicating purposes are of the solenoid type and remain upon open circuit practically 90 per cent. of the time.

9. **Auxiliary Devices.** The front plate of the machine is constructed to recede from the place in which the levers operate and thus to form a compartment under the levers for the housing of the various lamps and contacting devices (see Fig. 208) that are frequently made a feature of lever manipulation in this system. The lamps serve as indicators and inform the operator when a lever may or may not be used. The usual contacting mechanism that is contained in this compartment has several functions; first, the control of switch lever locks by the catch-rods of the levers so as normally to retain the locks upon open circuit, as a matter of current economy solely; and, second, the retention of these locks positively separated, during lever movements between indicating positions from any possible supply of current energy to them save through the proper channels of the indicating system alone. Upon the efficiency of this provision hinges to some extent the desirability of the adaptation of the indicating magnets (alternatively) to the duty of detector circuit locking. The highly efficient and substantial manner of operating this contacting device jointly by both the catch-rod and the lever, and the joint control of the automatic lock circuit by this device, and by certain roller contacts of the machine that, because of the 120 degree angle of roller operation, are simple and certain of action, leaves no room for doubt as to the wisdom of utilizing the indicating magnets for detector circuit locking also. The third function of this equipment embraces, behind each signal lever, when desired, a "latching" push-button, the action of which, when depressed, is to operate a "calling-on" arm when the usual signal does not respond

to the lever's movement by reason of semi-automatic control of the signal and the presence of a train upon the track it governs. The depression of the button, in such cases, mechanically latches it depressed, and, in consequence, the circuit of the calling-on arm is closed until the latch is released. This release occurs by the partial restoration of the signal lever to normal; i. e., its movement to interrupt the circuit of the signal and thus to cause it to assume the stop position and, thereby, the lever's release for final movement to normal, as in ordinary signal operation.

SWITCH OPERATION.

10. Operating Mechanism. Switches in the type "F" interlocking, as in all well designed interlockings, are unlocked, operated, and again locked by one continuous operation of the prime mover, in this case a motor housed in the switch operating mechanism. This device is termed a Switch and Lock Movement, the general design of which is illustrated in Figs. 215, 216 and 217.

Motor. The motor shown at the rear of the case in Fig. 216 works on exactly the same principle and has many of the characteristics of the ordinary series motor used in D. C. signal operation, which it will be remembered does not change its direction of rotation when the current through both field and armature is reversed simultaneously; hence, any D. C. series motor will develop a unidirectional torque when connected across A. C. mains. However, if a D. C. motor is to be thus used, its field and armature coils must be well laminated in order to avoid heavy eddy current losses. Furthermore, due to the cyclic variation of the alternating field flux an e. m. f. will be induced in each armature coil over and above the counter e. m. f. of rotation, and as the commutator segments connected to the terminals of the coil pass under the brushes, a heavy short circuit current will flow and destructive sparking will result unless some provision is made in design to avoid it. The course followed in the present case is to make the field magnetization weak so that only a very small alternating e. m. f. is induced in the armature, the latter being made of correspondingly stronger magnetization to secure the necessary torque. As in the case of the D. C. series

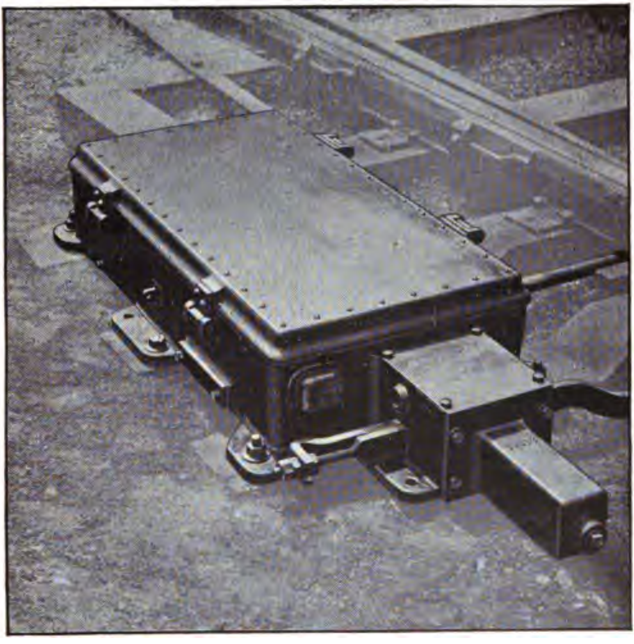


Fig. 215. Model 13 A. C. Electric Switch Movement.

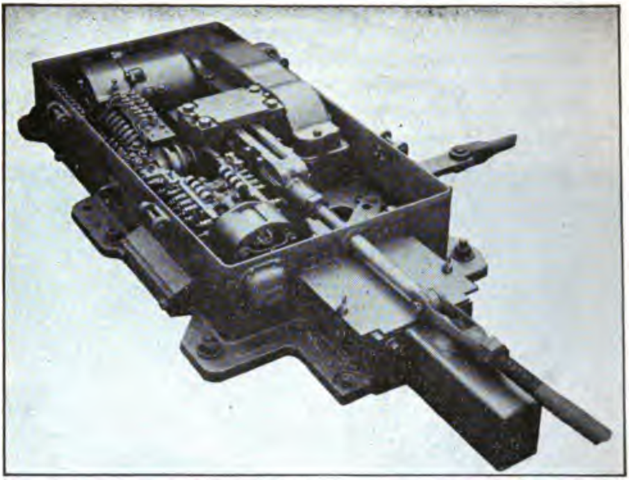


Fig. 216. Model 13 A. C. Electric Switch Movement. All Covers Removed

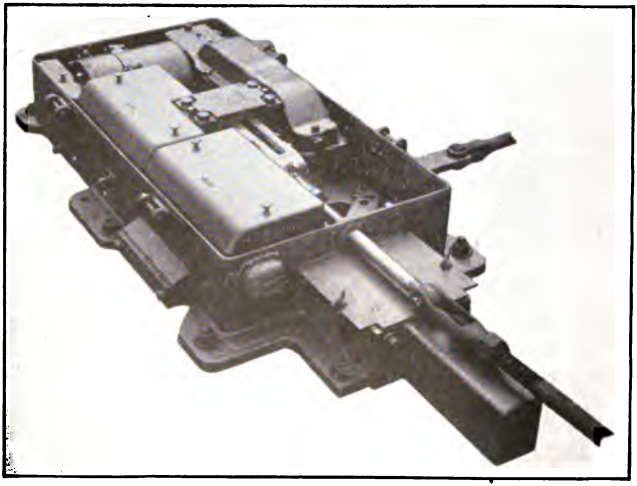


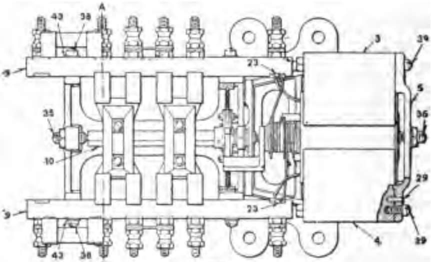
Fig. 217. Model 13 A. C. Electric Switch Movement With Individual Covers Over Operating Parts.

motor, however, this armature flux exerts a demagnetizing action on the main field flux, and as the latter has to be made weak to avoid sparkling, it is necessary to employ a so-called compensating winding to balance the armature reaction. This compensating winding, clearly shown in Fig. 219 is distributed in slots in the field core and is short-circuited on itself in such a manner that the current induced in it by the main field sets up a magnetization practically neutralizing that component of the armature magnetization which opposes the main field. Such a motor is known as a Compensated Series motor.

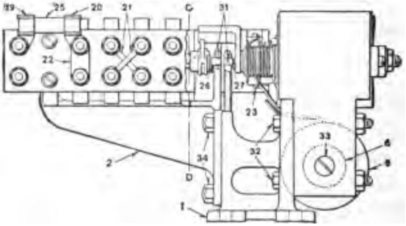
The armature is reversed to throw the switch points from one position to the other by reversing the direction of the current in the main field coil relative to that flowing in the armature, this latter element remaining fixed. The motor is designed to unlock, throw over and again lock the switch points in 2.5 seconds. Furthermore, like the D. C. series motor, the A. C. compensated series motor here described has an enormous overload capacity since, as it slows down as load increases as would occur if the switch points were frozen or blocked with snow, the armature counter e. m. f. falls off, more current flows, and the torque increases correspondingly.

Gear Train and Slide Bar. The motor carries at its right hand end in Fig. 216 a pinion, which, through the medium of a simple cone friction clutch, drives the gear train housed at the right of the motor in the above photograph. The last pinion of the gear train engages with a heavy toothed rack milled into the slide bar which, riding on substantial anti-friction guides, carries a stud engaging an alligator jaw or escapement crank connected directly to the switch operating rod projecting sidewise to the right of the case in Fig. 216. The operating rod is shown connected in Fig. 215, as is also the lock rod, this being the rod nearest the observer; the lock rod may be made adjustable or solid as may be required, but in all cases the whole locking arrangement may be easily gotten at or inspected since the cover of the shallow lock box can be removed in a few seconds. Where a detector bar is required, an operating rod, projecting longitudinally out of the case in Fig. 216, is provided.

Switch Circuit Controller. This device, illustrated at the extreme lower left hand corner of Fig. 216, and in detail in Fig. 218, is the polarized control relay, operated from the machine in the tower, over whose contacts the direction of current flowing in the main field of the switch motor is reversed to throw the switch points one way or the other as required. The controller is very simple in construction, consisting of a bipolar laminated field magnet carrying a coil the direction of current through which is controlled from the switch lever in the interlocking machine. In the bore of the field magnet swings a shuttle or armature whose extended shaft carries the movable contacts shown in Fig. 218; projecting out from the front of the motor frame to the left are two blocks of moulded insulation to which are attached flexible contact springs and their terminals. The armature is permanently connected to the bus-mains and is hence of constant polarity in relation to the field; when the switch lever in the tower is reversed, it reverses the polarity



PLAN VIEW



SECTIONAL SIDE VIEW

Fig. 218. Polarized Switch Circuit Controllers.

of the field in relation to the armature, and the latter immediately shifts, the contacts which it carries then reversing the motor. The armature torque is made intentionally large to insure good contact pressure and its shaft is provided with a simple toggle spring device which latches the contacts closed against train vibration, and they remain firmly closed until the armature is again reversed. Both elements of the switch circuit controller are thus continuously energized but the actual power taken in watts is very small due to the highly inductive character of the windings; in other words, the device operates on an extremely low power factor.

Indication Circuit Controller and Transformer. This controller, whose terminals and contact springs are seen immediately next the motor in Fig. 216, consists of a cast iron frame carrying a contact operating shaft driven from a cam connected direct to the main gear train. To the top of the frame is attached a block of moulded insulation supporting stationary contact springs and their terminals. One set of these springs serves to open the motor circuit after the switch has been thrown and locked, as will be evident from a study of the circuits shown in Fig. 219.

The controller is, however, provided with a set of pole-changer springs and between it and the switch circuit controller previously described is a small transformer, whose primary is directly attached to the bus-mains. The secondary of this transformer feeds current at 110 volts over the pole-changer contacts of the indication circuit controller acting as a pole-changer to a three-position relay of the polyphase type (Fig. 221) as described in Chapter IV; one set of contacts of this relay energize the normal indication magnet on the switch lever and the other set control the reverse indication magnet. The pole-changing contacts of the indication circuit controller are so designed that when the switch is in transit or is not fully locked at normal or reverse, the two wires leading to the three-position indication relay in the tower will be short-circuited and the relay will hence not only be de-energized but will be absolutely short-circuited. The protection against crosses and false indications, secured not only by this short circuiting feature, but more especially by the polarized character of the indication system, and its entire

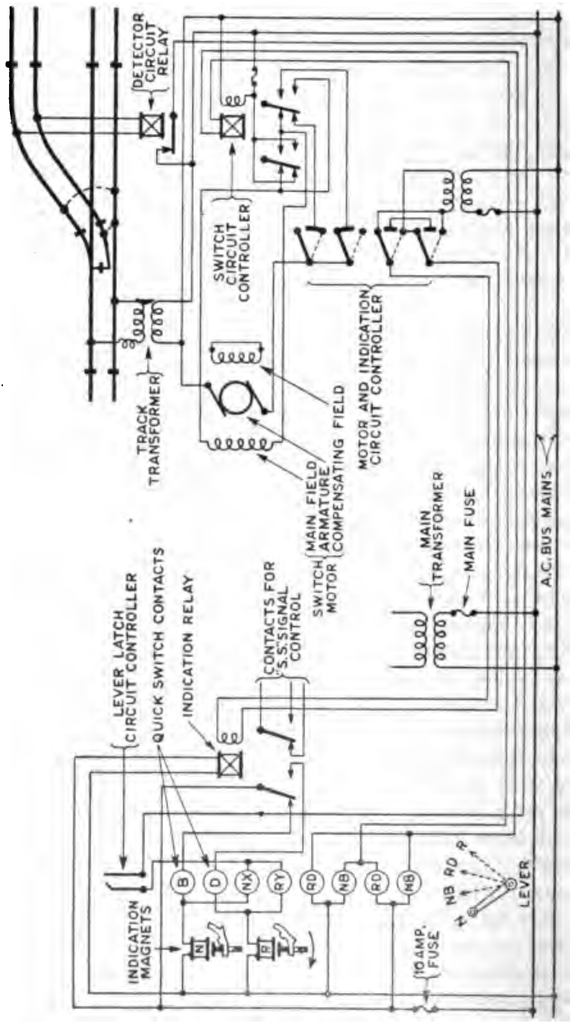


Fig. 219. Complete Operating and Indication Circuits for a Single Switch.

isolation from the bus-mains, will be more evident from a study of the circuits in Fig. 219.

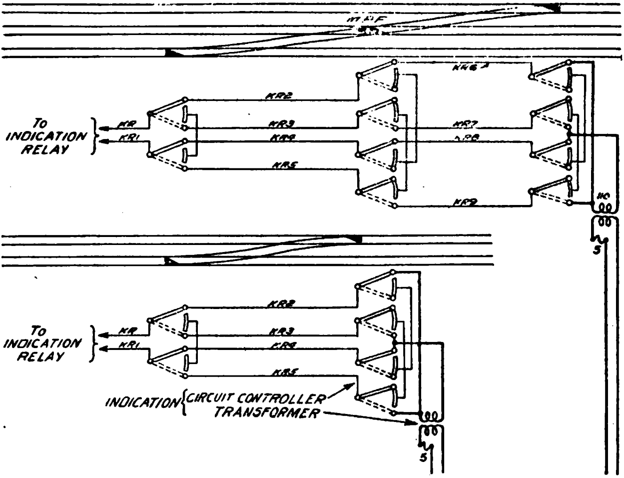


Fig. 220. Indication Circuits for a Crossover and for a Set of Movable Point Frogs.

11. Circuits for Switch Operation and Indication. Referring to Fig. 219, the significance of whose lever contact symbols is given on page 512, it will be noted that the switch lever is shown in the full normal position at which time the two lever contacts NB, serving as pole-changers, are made, thus energizing the field of the polarized switch circuit controller for the normal position of the switch, the motor circuit having been opened on the contacts of the motor circuit controller following the normal movement of the switch. To reverse the switch, the lever is moved slightly to the right, thus closing the lever latch contact illustrated at the top, and if there is no train on the electric detector circuit and the detector track relay is consequently picked up, the normal indication magnet will be energized over the points of the detector track relay and contact NX on the lever, thus freeing the normal locking segment; it will therefore be seen in this case the indication magnet N acts as a track circuit lock for if the track is occupied, magnet N cannot be picked up, with the result that the normal indication latch shown in Fig. 210 engages the normal locking segment and prevents further movement of the lever. Assuming then that the track is unoccupied and that indication magnet N can be picked up, the lever is then free to be moved to close the contacts RD which, acting as pole-changing contacts, as previously explained, reverse the current in the field of the switch circuit controller, thus feeding current into the switch motor for the unlocking, reversing, and relocking of the switch points; when the switch is fully reversed and relocked, the motor circuit controller opens the motor circuit and the motor stops. It is here to be observed that *the wires leading from the lever contacts to the switch circuit controller are entirely iso-*

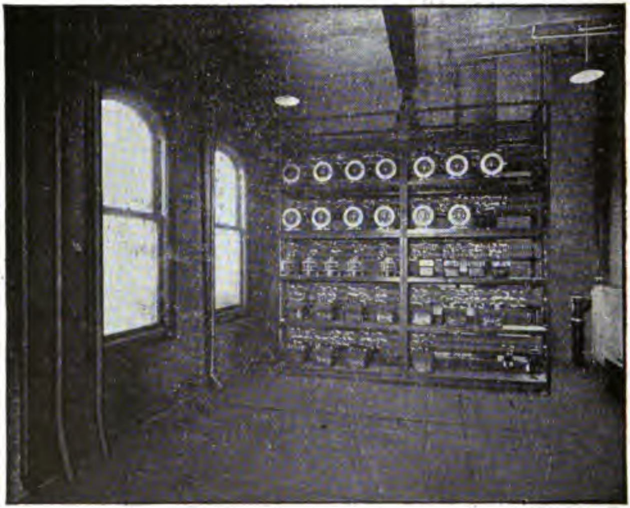


Fig. 221. Polyphase Indication Relays. These Together with the Machine Shown In Fig. 206 Constitute the Entire Tower Equipment For a Type "F" Interlocking at Pawtucket, R. I., on the New Haven Railroad.

lated from the bus-mains. No common return whatever is used and hence a false movement of the switch could only result through a double cross of the bus-mains with the switch operating wires; furthermore. this double cross would have to be of the required polarity.

It will be observed from Fig. 210 and 219 that the movement of the switch lever to the right after closing the pole changer contacts RD is stopped by the reverse indication segment and latch. After the switch is completely reversed and relocked, however, the indication circuit controller reverses the indication relay in the tower, thus energizing the reverse indication magnet R over contact D and lifting the reverse indication latch away from the upward projecting shoulder on the reverse indication segment. The lever may then be moved to full reverse, releasing the mechanical locking and permitting the corresponding signal to be cleared over its lever. When the lever is moved from the reverse to normal, the same cycle of operation is gone through, the reverse indication magnet R being first energized over the lever latch and contact RX (providing of course the detector track relay is picked up), thus releasing the lever to close pole-changer contacts NB to throw the switch circuit controller to the corresponding normal position; after the switch points are thrown normal and relocked, the indication circuit controller reverses the indication relay to energize the normal indication magnet N over lever contact B as shown in Fig. 219.

It will be noted that the lower periphery of the normal and reverse magnet indication segments shown in Figs. 210 and 219 are provided with a projecting shoulder; the purpose of this shoulder is to cause the armature of the corresponding indication magnet to be forced open mechanically after each lever stroke, thus introducing a positive safeguard against the armature being stuck closed. The actual latching of each magnet is accomplished through the medium of the shoulder projecting from the top periphery of the indication segment. When detector bars are used instead of detector circuits the lever latch contact is omitted and the indication segments are so cut that the lever may be immediately moved as far as the indication position, being restrained there of course until the switch is thrown and locked and the indication received over the points of the polarized indication relay and the lever contact B or D, as the case may be.

The complete operating and indication circuits for a single switch, are covered by Fig. 219; for a cross-over, the lever contacts, etc., in the tower are identical, the two switch controllers for their respective switch mechanisms at the points being simply connected in multiple to the two control wires ordinarily used for a single switch. The indication circuit controllers are wired as shown in Fig. 220, and feed current to the signal indication relay in the tower exactly as in the case of the single switch.

12. "SS" Control of Signals. It will be observed from Fig. 219 that normally a current flow is maintained through two contacts of the switch indication circuit controller in one direction, and through two of its other contacts in the opposite direction when the switch is reversed. This current, through two isolated conductors which extend to the polarized indication relay at the interlocking machine, maintains a normally active state of that relay to retain closed certain contacts and to retain open certain other contacts. Upon full reversal of the switch and lock movement, a reversal of the flow of current is produced by reason of the changed relations then occurring between the contacting members of the indication circuit controller. The polarized relay is thus caused to reverse its influence upon its contacts and hence close those contacts that formerly were open and open those that were formerly closed. The contacts of the relay thus repeat the two positions of the switch and lock movement, and are therefore employed for controlling not only the normal and reverse indication magnet of switch levers during switch operation by simple local circuits, but may also be used as shown in Fig. 219 as a means wholly within the interlocking tower to obtain a very simple and effective control of the current supply to every signal of the system by actual positions of each and every switch over which it governs. This method is designated as the "SS" control, and is obtained without recourse to any facing point circuit controllers or additional conductors or devices external to the tower which are necessary to other methods.

Obviously, this joint control of the indication magnets and that of the current supply to signals is not to be supported upon the grounds of this simplicity alone. Inherent in the method are elements of safety that insure immunity from faulty operations arising from any causes whatever that make it superior to any methods heretofore embraced in any power interlocking for like purposes. Naturally, the relay should be energized only when the switch is in one or the other of its two extreme positions and securely locked there. To insure that during the unlocked condition of the switch (and during its operation) the relay will be energized with certainty, the indication circuit controller interrupts the current supply to both indicating wires, and it also forms a shunt or short-circuit between them of very low resistance as an added safeguard.

By this method both indicating wires are maintained at the same (zero) potential until the switch is positively locked in one position or the other—the direction of current flow in them being distinctive for each switch position and hence positive in its selection of the indication magnet or signal released by it. The method is equally positive in its application to a single switch, crossover or to any number of switches operated by a single lever.

It will be observed from Fig. 212, that upon the assumption that a signal lever has been operated to permit a train to move over the switch, the switch lever shown is mechanically locked in the position it assumes, and this secures the lever, the switch circuit controller, the switch, the indicating circuits and the polarized indicating relay in the following respective conditions; the lever normal; the switch circuit controller normally energized; the switch held and mechanically locked in the normal position; the two indicating wires maintained at different potentials of a given polarity; the polarized indicating relay energized to close its normal contact; a circuit employing one of the closed normal "SS" contacts on the indication relay over which is carried the current supply to those contacts actuated by signal levers that primarily operate the one or more signals that govern train movements over the switch.

Obviously, under these conditions the switch lever cannot be moved until the signal lever is placed normal and the signal is in the stop position. The operation of the switch therefore by its lever compels a prior act of the signal lever which withdraws or withholds train rights over the switch. The operation of the switch by other means than its lever, as by the malicious or accidental manipulation of its operating mechanism, will be first accompanied by an interruption of the electric energy in the indicating wires and then a shunting of these wires against influence from foreign sources. This produces a de-energization of the indicating relay, the effect of which is to cause it immediately to cut off the electrical energy, through its contacts, by which each signal governing movements over the switch is controlled, and thereby to place at stop any such signal as may at the time be in the proceed position, or, should all of them be in the stop position at the time, prevent the operation to proceed of any such signal. In other words, the improper operation of a switch in this manner establishes the same condition of the indicating relay, as is established by failure of it to operate properly by its lever, and maintains that condition until the lever and switch are made again to coincide fully in position. When in ordinary operation the switch assumes a reversed position by virtue of a partial reversal of its lever, the indicating relay becomes again energized, but by current of a reversed polarity from that existing when the switch and lever were normal. The effect of this is to shift the polar contacts of the relay to establish current through the reverse indication magnet and the closed contacts of the quick switch, and thus to release the lever for final movement to its full reversed position. This final movement causes action of the quick switch again to open the circuit of the reverse indication magnet, and so to connect the normal indication magnet with the normal contacts of the indicating relay as to prepare that magnet for its next indicating function.

13. Detector Track Circuit Locking. The control of the indication magnets by the quick switch in this manner involves the use of but one magnet at a time for indicating purposes, and hence, leaves at all times one of the magnets free for other duties if desired. It is this fact that prompted the alternative use of each indication magnet for detector circuit switch lever locking by trains, and to render this effective two contacts, NX and RX, Fig. 219, operated by the switch lever are employed, (sometimes designated as "X" and "Y" contacts), for the purpose of throwing, alternatively, the indicating magnets into circuit with the contacts of a track relay that embraces the switch rails in its control. In this way, trains entering upon the switch cause that one of the indicating magnets that was last used for switch indicating purposes to remain upon open circuit and therefore to prevent initial movements of the lever, until the train has passed clear of the switch, The locking circuit thus formed also passes through a contact that is acted upon jointly by both the catch-rod and the lever—a contact closed as the catch-rod is elevated to energize the lock, if the track is unoccupied, and which is opened again by the lever during its movements between its positions of engagement by the locks. This is done by the latch to economize in current energy when the lever is at rest in either the normal or the reversed position, and by the lever absolutely to disconnect both magnets from any possible current influence save that peculiar to the indicating system, as soon as the lever moves beyond the influence of the automatic track circuit control of levers and into that entirely separate field of control that embraces only the switch indicating system.

14. Cross Protection. Because of the vitally important functions performed by the indication system in the type "F" electric interlocking, i. e., first, the coincidence in position of switch and lever before final lever movement can be made, and second the continuous and active control of signals by switch position thereafter, every precaution that could be consistently taken to insure reliability of action under all probable conditions has been taken in its arrangement. The separation of the indication circuit of each switch from electric contact with any part of any other circuit between the switch and the interlocking machine, was the first step; the use of individual circuits so arranged for each switch or set of switches operated by a single lever was the second step; the use of a current of one polarity for indicating one position of the switch, and the use of a current of an opposite polarity for indicating the other position of the switch, and means for shunting or short-circuiting the two indicating mains at the switch until the switch is properly locked in one or the other of its two positions, constitute the third provision; the fourth provision embraces the use of the polarized indicating relay at the interlocking machine so adapted as to control jointly the current supply to both the indicating magnets of a switch lever and to each and all signals governing traffic over the switch or switches operated by the lever.

15. Switch and Lock Movement Layouts. Model 13 switch and lock movements may be applied to the operation of switches of every character and rail section. Variations in character are exemplified by four commonly encountered types: Derails, Simple Turn-Outs, Slip-Switches, and Movable Frogs. The first two of these types involve no special consideration in their operation by switch and lock movements, the mechanisn shown in Fig. 215 serving the purpose. The operation of movable point frogs, however, involves conditions analogous to the operation of two single switches, the theoretical points of which coincide in position, and the leads of which extend in opposite directions. Switch and lock movements adapted to movable frog operation, hence, must operate and lock two sets of points. The points of each set, furthermore, must move simultaneously, and in opposite directions by independent connections, and they must also be equipped with independent lock rods for insuring the direct and individual locking of each set. With M. P. frogs it is therefore customary to operate one set of points from a single switch movement (Fig. 215) and the other set from an external switch and lock movement driven from the above motor movement and consisting of the usual crank, operating rod and lock rod, carried on a base plate bolted to the single switch movement and housed in a small cast iron box; this arrangement is really equivalent to a single long slide bar equipped with two switch driving cranks and rods and a double set of lock rods with their locking blocks.

When movable frogs are a part of a slip switch layout the frogs are operated simultaneously with one end of the slip switch, one set of frog points and the slip end each being provided with a switch and lock movement driven in tandem from the motor mechanism Fig. 215 located at and operating the other end of frog points. The remaining slip end must of course be driven independently from a motor mechanism, Fig. 215; it is, therefore, the custom in type "F" interlocking to adapt a single motor to the operation of three switch and lock movements in tandem in the case of slip switches with M. P. frogs. Such an arrangement calls for electric contacts only on the slip end mechanism for controlling the switch indicating system, since the mechanism (being the one most remote from the driving motor) can assume correct positions in response to lever movements only in case the frog mechanisms have also assumed such positions.

In the operation of slip ends individually (independently of the frogs, as is sometimes done) and in the operations of single switches and derailing devices, a single switch and lock movement complete is employed.

16. Detector Bars. When detector bars are required they are operated by the first part of the mechanisms movement, which although employed primarily for unlocking the switch is also employed for the elevation of the bar above rail level. A train standing upon or moving over a switch obviously prevents the elevation of the bar, and hence the unlocking and movement of the switch under trains. During that part of the slide bar stroke that affects switch operation, the detector bar remains motionless in its elevated position, and during the final movement to lock the shifted switch the bar is depressed to its former position below rail level. The bar is operated from the rod extending lengthwise out of the case in Fig. 216.

Since detector bars constitute the chief loads to be met by the switch motors of power interlockings their elimination, upon the score of power economy and operating speed is desirable. Since modern practice embraces, in power interlocking, the automatic locking and releasing of switches through the medium of detector circuits and sectional route locking by train action in a manner that precludes the possibility of switch levers being operated while trains are approaching or passing over interlocked switches, the value of the detector bar in this service is confined solely to cases where improper or irregular lever movements are resorted to—as during blockades, wrecks, or like derangements. For these reasons detector bars are not regarded as an essential feature of power interlocking and the cost of their application and maintenance usually exceeds the value of the protection they afford in this field.

SIGNAL OPERATION.

17. **Signal Mechanism.** All types of A. C. signal mechanisms as described in Chapter VIII are equally well adapted for use in type "F" interlocking. In the case of the Style B signal a motor current contact is attached to the slot armature and normally holds the motor circuit open as explained in connection with Figs. 154 and 161, Chapter VIII; the slot coils are directly energized from the signal lever contact and when so energized draw the armature up to the slot magnet poles, closing the motor circuit to drive the signals to one of the proceed positions. The slot and armature thus perform the dual duty of holding the signal clear and act as a line relay, thus economizing in first cost, power and space The Style "S" three-position signal may likewise be provided with a slot contact for its caution position but not for its full proceed position, since there is but one slot armature and it remains closed with the signal in the caution position; a vane type line relay (Chapter IV) is therefore generally used to control the 90° or proceed position. The Style T-2 signal cannot, of course, be provided with a slot contact and in this case a two-position or a three-position line relay as may be required, are employed, these relays being controlled directly from the signal lever in the tower. In most cases a two-position line relay will be sufficient, as the proceed or 90° indicator is generally secured from the signal in advance. The reader is referred to the wiring diagrams, Figs. 161, 163 and 167 for further information.

18. **Signal Control.** Since no special devices are required for signals in Type "F" interlocking, the control circuits are extremely simple and are plainly shown in all their phases in Figs. 222 and 223. It will be seen that they are very similar to those used in the electro-pneumatic interlocking system except that the negative or return wire for a signal or group of signals on one side of a signal lever is carried back to the machine and over a contact on the signal lever roller. *This provides a separate return, without connection to*

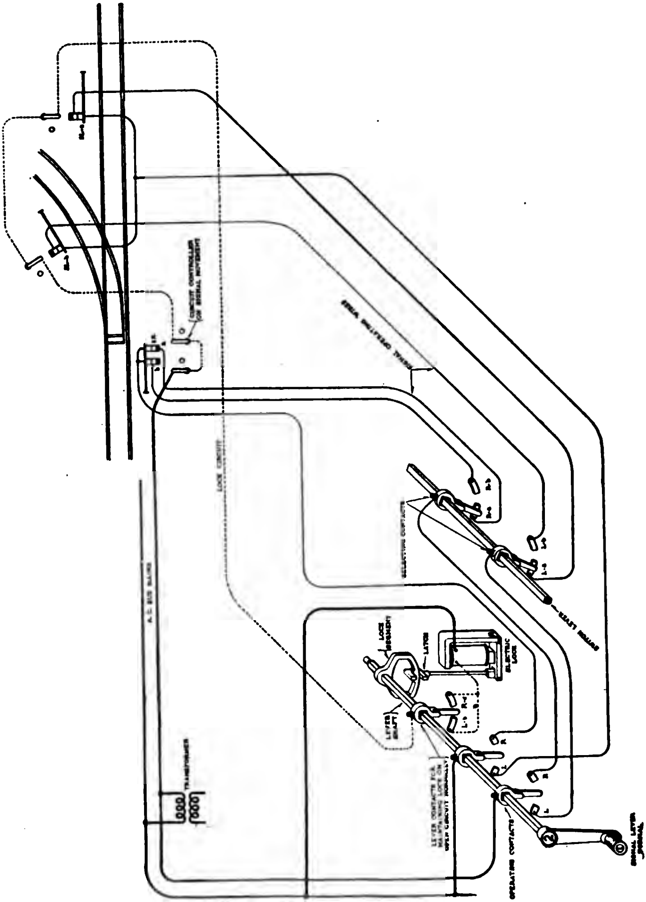


Fig. 222. Complete Signal Control and Indication Circuits—Lever and Signals Normal.

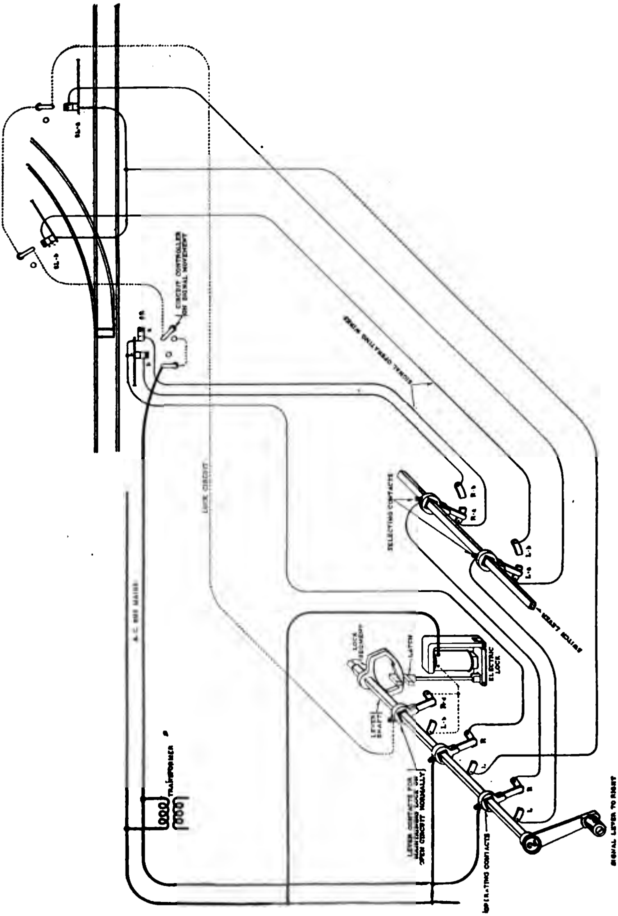


Fig. 223. Complete Signal Control and Indication Circuits—Lever and One Signal Reversed.

either of the bus-mains, just as in the case of the control for switches; this arrangement renders harmless a cross on either of the signal control wires.

Where two or more signals are operated from a single lever in Type "F" interlocking, each signal is made to interrupt a common circuit including the electric lock on the lever, so that all of the signals must be returned to the stop position before the signal lever may be put normal and another route set up. The perspective diagrams, Figs. 222 and 223, illustrate this control of the lock circuit and also the manner of selecting a number of signals, by switch position, for operation by a single lever. The control of signals in this manner is made of two-fold value because of the double function of signal levers obtained by their operation to their right (from the central position) for routes of a given direction over a given point, and to the left for routes of a reverse direction which conflict with the first mentioned routes. The semi-automatic control of a group of signals thus operated is possible for a single track circuit, frequently, and by means of a single contact relay. These features are important in their influence to concentrate the control of many functions within comparatively simple and hence trustworthy instruments, and are of especial value in route locking and in the control generally of signals and lever locks by train action.

19. Route Locking. In order to illustrate the basic principles upon which sectional route locking is arranged and, at the same time, to show its relation to other prospective features of Type "F" interlocking, the diagram, Fig. 224, is presented. The track layout is of the simplest form necessary to the purpose, the two switches therein serving quite as well as a greater number of switches in a more complicated track plan to illustrate the automatic locking of all switches in a given route and the individual release of each after the passage of the train beyond the fouling limits embraced in the two track leads of each. These two switches serve also to illustrate the principle of selecting signals by switch position, when a number of signals are operable from a single lever. It will be observed from the plan that the rails of each switch are included within separate track circuits, and that these circuits embrace both leads as far as their fouling points, and

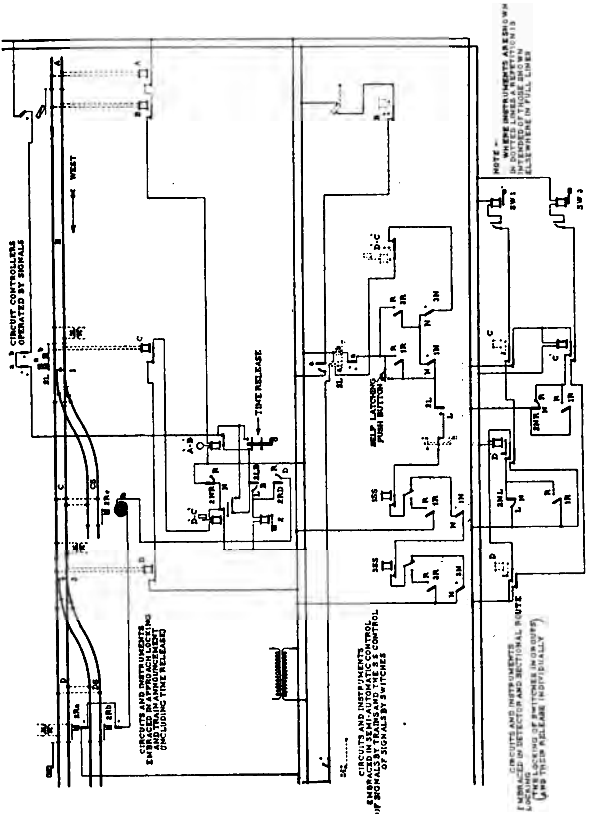


Fig. 224. Sectional Route Locking Circuits.

extend in each direction to the signals governing the movements over these two switches. A track circuit also extends from the signal which primarily governs the first switch to the preceding signal, usually called the "distant" signal. A fourth section also extends from this distant signal to a point preceding it 3,000 feet or more. These sections are designated on the plan by the letters D, C, B and A. The switches are designated by the numerals 1 and 3, corresponding with the numbers of the two levers assigned to their operation. The signals are all operated by lever No. 2; the three eastbound signals being operated by the lever thrown to the right and the two arms of the westbound signal by the lever thrown to the left—this being possible because each of these signals conflict with each other signal under all circumstances.

The operation of signal 2L-a for a westbound train requires that switches 1 and 3 be set and locked as shown, before lever 2 may be moved to operate the signal. The operation of lever 2 to the left through the mechanical locking of the machine locks levers 1 and 3 normal, and hence the switches 1 and 3 for the route governed by the signal so long as lever 2 remains moved from its normal position.

It will be evident, therefore, that even though signal 2L-a be restored to the stop position by the partial return of the signal lever toward normal, the switches of the route still remain mechanically locked. It is evident, too, that whether lever 2 is retained out of its normal (central) position by choice or by compulsion, the switches remain locked with equal security.

20. Approach Locking. The return of signal 2L-a to normal, ordinarily, releases the lever for its restoration to normal; where route locking is in vogue, this release of the lever by the signal's return is made dependent upon an added condition. This condition is that a train has not, previous to the signal's return, entered upon the track circuits A or B. If the train has so entered, its approach is automatically announced to the operator by annunciator A′-B′, and the electric lock of lever 2 is retained upon open circuit during the train's presence upon either of the sections. Before the annunciator A′-B′ can be re-energized to release the lock 2, the train must have left sections A and B completely. If its leaving was by permission of signal 2L, the train naturally entered upon section C before it left section B. This act causes, through relay C, the indicator D′-C′ to become de-energized before the annunciator A′-B′ becomes re-energized and releases the lock of lever 2 whereby that lever becomes free to be put normal and the mechanical release of switches 1 and 3 becomes possible. The release of lever 2 by indicator D′-C′ when this indicator is de-energized has another important function. If a second train enters section A-B before lever 2 is restored (this lever having been thrown to clear signal 2L for a previous train), indicator D′-C′ will not pick up, being a "stick" indicator. The release circuit, through a back contact of indicator D′-C′, will remain closed and allow the leverman to restore lever 2 although the lock circuit of lever 2 is open through indicator A′-B′. The signal lever may also be restored while a train is in section A-B by the use of a time release, the operation of which is described in a subsequent paragraph. Should lever 2 be restored to normal after a train has accepted signal 2L, the release mechanically, of levers 1 and 3 that follows is without danger, because the entrance of the train upon section C (that necessarily preceded this event) caused, through relay C, the interruption of the electric lock circuit of lever 1, and through stick relay C′, the interruption of the electric lock circuit of lever 3, thus effectually retaining these levers still locked against operation, but by direct electric means peculiar to each.

21. Switch Locking. While switch levers are thus locked automatically in groups by train action upon the first switch of the group, their release must occur not in like manner by the exit of the train from the last switch of the group, but each lever must be released individually as the train passes over its switch and clear of the fouling limits of the switch leads. The movement of the train westward off of section C and into section D causes relay C and stick relay C′ to become re-energized and the electric lock of lever 1 released. Before this occurs, however, relay D has been de-energized, by the entrance of the train upon section D in its movement from section C, and hence the circuit of lock 3 is continued open at relay D, notwithstanding its closure at relay C′, and lever 3 still remains locked until the train passes entirely clear of section D and until relay D becomes thereby re-energized.

It will be observed that stick relay D′ is not operated with relay D, for were this done, the lock circuit of lever 1 would be opened thereby and the release of switch 1, which is desirable, would not follow the train's exit from section C. The action of the train on section D, and the consequent de-energization of relay D, would not open the circuit of relay D′ because of a "by-pass" formed by lever 2 when that lever is not in a position for governing eastbound traffic. This by-pass bridges the open contact of relay D and prevents the action of relay D for westbound traffic; when lever 2 is thrown to the right, however, for signaling eastbound traffic, the train's action upon section D operates not only relay D, but also the relay D′, thereby opening the lock circuits of both levers 1 and 3. Upon passing on to section C, relay C only is de-energized and not relay C′, as when the westbound train entered section C from section B. Relay C′ is thus retained in an energized state by virtue of a by-pass formed by lever 2 when that lever is in any position other than that employed for eastbound traffic, and hence when the train moves from section D into section C, the re-energization of relay D closes the lock circuit of lever 3 and releases switch 3 for possible operation. This would not occur did not the relay C′ remain energized, through the by-pass referred to. The lock circuit of lever 1 is necessarily opened by relay C before the exit of the train from section D into section C fully occurs, so that after the occurrence, when both relay D and relay D′ are energized, the circuit of lock 1 remains open at relay C and until the train passes clear of section C, whereupon switch 1 may be moved if desired.

It will also be observed that when switch 1 is reversed, a by-pass is established on stick relay D′ which causes this relay to remain energized regardless of the condition of track relay D. The purpose of this by-pass is as follows: With switch 1 reversed and a westbound train having not yet cleared section D, if signal 2R-c were cleared for a second train to move from siding CS to the main line, stick relay D′ would open if it were not for this by-pass and switch 1 would be locked and remain locked as long as the first train stood on section D, thus preventing all movements of traffic over switch 1 in its normal position. A similar by-pass acts on stick relay C′ and prevents switch 3 from being locked while a train is passing into siding CS after having accepted signal 2L-b. This latter feature is not very important with this particular layout, but with a more complicated arrangement of tracks and switches it is essential to prevent the tying up of several parallel train movements under the conditions cited.

22. Approach Detector and Section Locking. That feature of automatic lever locking by trains, which is peculiar to the action of trains prior to their entrance upon the switches of the interlocking, is generally referred to as approach locking, and embraces also the automatic announcement of trains. That feature which involves the action of lever locks by train movement over the switches of the interlocking, is generally termed detector locking and sectional route locking. The latter feature embraces, besides the automatic locking and releasing of switch levers, the semi-automatic control of signals by trains through the medium of track circuits common to both.

23. Calling-on Arm. In the diagram, Fig. 224, the circuits peculiar to the operation and control of the two westbound signal arms only are shown in the interest of simplicity. The top arm only is under automatic control by trains (through the indicator D′-C′), since the lower arm is here assigned to movements into either one of the two sidings whether these be occupied already or not, and also to the main track D, only in case that track is already occupied, and the top arm is hence restrained against operation by indicator D′-C′, for such train movements. The use of the lower arm in this capacity is as shown not possible by lever action alone but demands in addition the operation of a push button which is mounted behind the signal lever so that its operation is convenient only when the lever is moved from normal—a movement that must necessarily precede the effective use of the button for clearing the "calling-on" arm. This button, when depressed, closes a pair of contacts in the signal circuits that are effective to clear the calling-on arm providing the high speed signal above it is in the stop position, and providing also that the signal lever 2 is moved to the left.

24. Time Releases. The current supply to both arms is also drawn through contacts of a device known as a "time release," Fig. 236, Chapter XII and already referred to in in a general way. This is done in order to insure that the first act of its operation will be to open the signal circuit and thus prevent any possible operation of the signals until the device has been again returned to its original position. The operation of the time release to unlock electrically during emergencies a lever properly held locked by train action, requires first, a distinct action by the leverman, and second, that a sufficient period of time must elapse, following this action, to insure that the train, which is locking this lever, has either stopped or is traveling at a reduced speed, before the lever is restored to its normal position. It is also to compel the restoration of the time release to its normal position after each operation (before signals can be again operated for traffic movement under them) that signal circuits are thus controlled by contacts on the time release. The current supply to both signals is further drawn through contacts of other devices than the indicator D′-C′ and the time release. In order to insure that a misplaced switch, wrongfully set from any cause out of coincidence with the new position of its operating lever, and to insure also that a lever which from any cause assumes a position at variance with that of the switch it operated, may effectually prevent the display at such times of any signal giving proceed rights over the switch, this current supply is also drawn through the contacts of the switch indicating relay and through corresponding contacts operated by the switch levers.

25. Laying Out Plant. In adapting the Type "F" interlocking system to the requirements of any particular track and signal lay out, the first step is to group the switches for operation by the least number of levers possible, numbering the switches to correspond with the levers assigned to their operation. The second step is to group in like manner the signals for operation by the least possible number of levers, numbering the signals to correspond with the levers assigned to their operation. The switches and signals being thus designated clearly by the number of their operating levers and the size of the machine being thereby established, the mechanical locking of one lever by another or by others is next worked out, as in mechanical interlocking practice. This constitutes the third step in the development of an interlocking. The mechanical locking of Type "F" machines is greatly simplified, as compared with that which would be required of a purely mechanical machine adapted to the same track and signal layout, by reason of the much greater capacity per lever of the former and the consequent reduced number of levers it requires.

26. Track Circuits and Electric Locking. The fourth step consists in subdividing the track layout into track sections in such a manner, that, as far as is practicable, the rails of each pair of diverging, converging or intersecting tracks shall comprise a separate section throughout that portion of each wherein each fouls the other. Track sections are also formed of rails of tracks lying between the sections referred to, and these track sections are primarily for the automatic locking and releasing of switch levers by trains (in lieu of detector bars), but are also utilized for the semi-automatic control of signals by trains, where this practice is employed. The fifth step consists of laying out the detailed circuits for the control of signals, approach locking of signals, detector and sectional route locking of switches, etc., according to the requirements as described in these paragraphs.

27. Locking Between Towers. The first requisite of a safe method of preventing the simultaneous entrance of trains from opposite directions onto a piece of common track is the interlocking of the two signal levers by which movements to such a track are governed. When both levers are comprised in a single machine (both signals embraced in the same interlocking) this interlocking is done mechanically and in a very simple way well understood. When, however, the levers constitute elements of two separate machines (the signals embraced in two different interlockings), the locking is not practicable by purely mechanical means and is accomplished electrically. Usually, more than one signal governs train movements for each interlocking over a "gauntlet" track. To obtain the simplest circuits and the least number of instruments, contacts, etc., for the protection sought in such cases, an independent lever in each interlocking is employed as a "master" lever and it is to those levers that the electric locking is applied—these levers (through the mechanical locking of the machine) being locked by each signal lever of the machine giving train rights over the gauntlet track. In the assumed case, shown in the diagram, Fig. 225, Lever 1L of Tower "B" and lever 1R of Tower "A" are the master levers while 2L and 4L are the actual signal levers of Tower "B" and 2R and 4R are those of Tower "A."

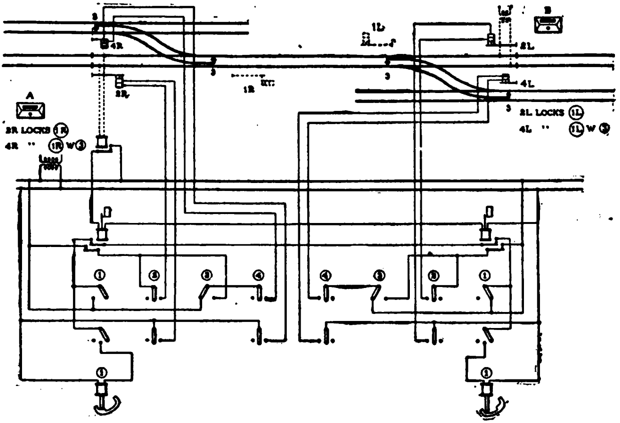


Fig. 225. Check Locking Between Towers.

Between the signals of the two towers a track circuit is formed that controls directly an indicator in each tower. The indicator informs the operator at each station of the entrance and exit of trains from the track sections lying between them. They also serve as means for the direct semi-automatic control of the signals of each tower by trains. Primarily, however, these indicators are employed for the control of the electric locks of levers 1R and 1L by train action upon the gauntlet track. The direction of traffic over the track is established by joint action of both towermen in placing their respective "master" levers in proper predetermined positions. While both towermen must thus co-operate to establish conditions essential to any given direction of traffic, each operator has full power to control the signal indications of his own apparatus—granting or prohibiting train movement to the gauntlet track at will after consent of the opposing tower has been obtained. In this control, however, he is restrained from either intentionally or accidentally granting to his neighbor the right to use the gauntlet track until it is wholly unoccupied by trains, and until all signals governing movements to it are at stop, and their operating levers are n the normal position. With these conditions prevailing, that one only of the master levers which granted permission for traffic movements from the tower remains free to be operated at will. Upon the reversal of this lever a similar lever in the opposing tower is electrically unlocked and is then free to be shifted to release mechanically those signals at that tower by which a like unrestricted use of the gauntlet track is reserved to train movements to and from it under the signals of that lever exclusively.

Thus the gauntlet being unoccupied, and each towerman being made aware of this by his indicator, A may desire to move a train under signal 2R to B. This he can do under the conditions prevailing, because signal lever 2R is free to be moved when master lever 1R is thrown to the right as shown. This action of lever 2R, however, operates the signal only upon condition that the current supply to the signal is not interrupted by either or both of the tower indicators. A train acting upon the authority of signal 2R operates that signal automatically to stop through the medium of the track circuit and the tower indicators controlled therefrom, and simultaneously retains the locks of levers 1R and 1L upon open circuit until it passes completely from the track circuit.

While levers 1R and 1L may at any time be placed in their central position, that one at A (lever 1R) may be moved only to the extreme left at all times, while that one at B (lever 1L) may be moved only to the extreme right at all times. The application of the electric locks to these levers by train action restrains but one of the master levers against full reversal. For the direction of traffic shown in the diagram lever 1L, Tower "B," is so restrained, while for traffic in the opposite direction lever 1R, Tower "A," is likewise restrained.

When the train has passed clear of the gauntlet track section both indicators give evidence of the fact and the master levers may then be operated to change the direction of traffic.

Reversal of 1R locks mechanically signals 2R and 4R against operation while reversal of 1L releases signals 2L and 4L for operation. A westbound train now acting upon authority of signal 2L or 4L de-energizes both indicators and retains both electric locks upon open circuit as before. Now, however, it is lever 1R that is restricted against full operation in reverse by the train until the latter has passed clear of the gauntlet section—thus automatically holding traffic over the gauntlet to conform with its own direction.

28. Complete Circuits for an Example Plant. Fig. 226 shows a complete small interlocking plant together with track circuits for the control of the various features of the system. Figs. 227 and 228 show the complete controlling and electric locking circuits for this plant. These features have already been described in detail and are typical of standard practice.

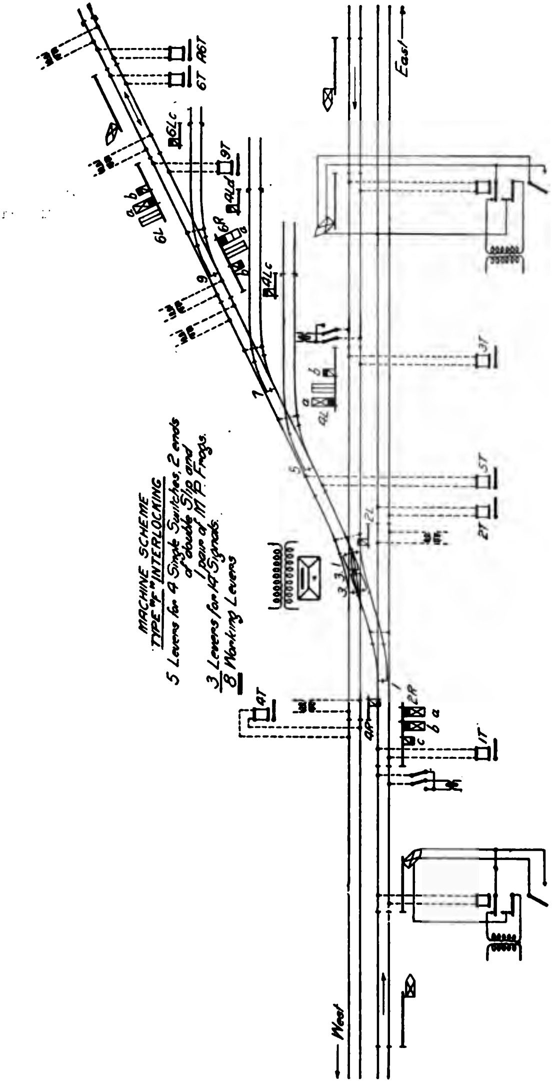


Fig. 226. Complete Layout fo Small Type "F" Interlocking Plant.

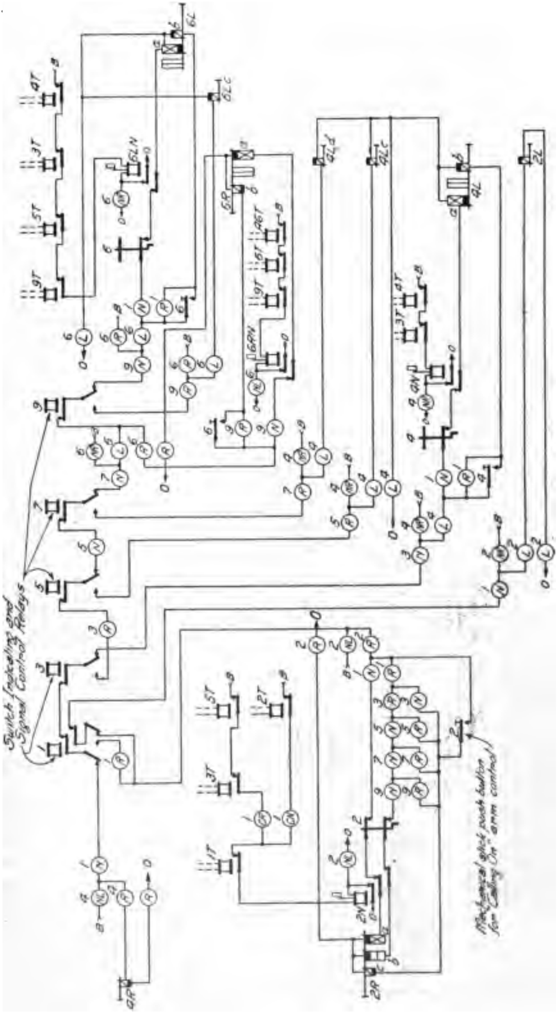


Fig. 227. Signal Control Circuits for Plant Shown in Fig. 226.

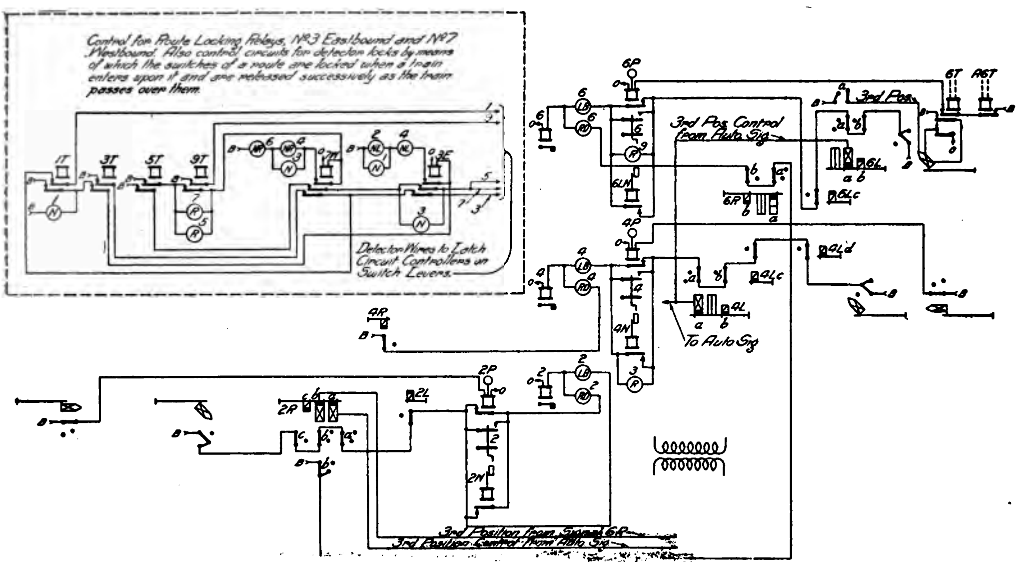


Fig. 228. Control Circuits for Third Position of Signals and for Electric Locking for Plant Shown in Fig. 226.

CHAPTER XII.

AUXILIARY APPARATUS USED IN A. C. SIGNALING.

CHAPTER XII.

AUXILIARY APPARATUS USED IN A. C. SIGNAL SYSTEMS.

A. C. SWITCH INDICATOR.

"Z" Armature Type.

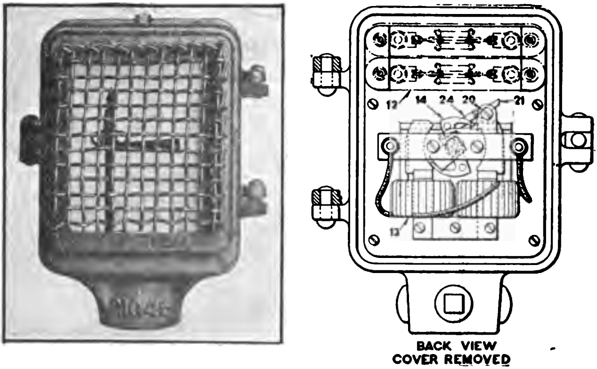


Fig. 229.

POWER REQUIRED.

Normal Voltage	Frequency	Minimum Voltage	Amps.	Watts.
110	60	85	0.24	3.0
110	25	85	0.12	2.0

A. C. SWITCH INDICATOR.
"Z" ARMATURE TYPE.

The operating movement of the switch indicator, illustrated on the preceding page, consists of a laminated bi-polar field. in the bore of which turns a laminated "Z" armature 14, in the right hand (back) view; when the field coils are energized, the magnetic lines of force tend to shorten their path, and, in so doing, cause the "Z" to turn in a clockwise direction, when viewed from the back of the case, until its middle leg is in a horizontal position, when, of course, the magnetic path for the lines of force is the shortest from one pole of the field magnet to the other, and the turning movement of the "Z" ceases. A large air gap is provided for the Z to swing in, and the entire mechanism (blade and all) is mounted on a quickly removable plate, painted white on the front to form a background for the indicator blade.

The case may be provided with either a plain glass front or a wire shield may be provided to protect the glass against breakage, as illustrated in the photograph. By the employmentof the proper cranks, the "Z" armature can be made to swing the indicator blade in the upper or lower quadrant through any required angle. Space is provided in the case above the operating movement for either two Spark Gap lightning arresters, (Fig. 235) as shown, or for two front and two back relay contacts, easily operable from the armature through the addition of a connecting crank.

A. C. TOWER INDICATOR.
"Z" ARMATURE TYPE.

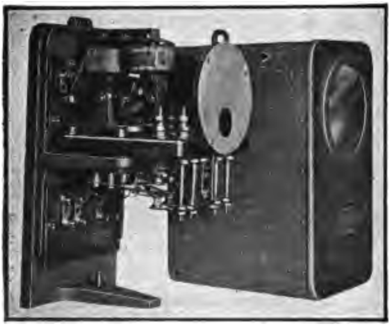


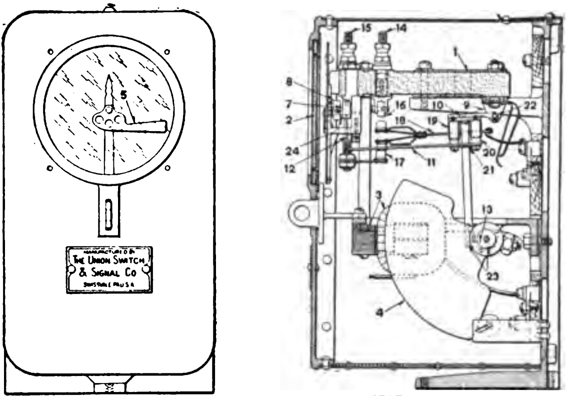
Fig. 230.

The operating movement of the above indicator, it will be noted, is of the "Z" type previously described in connection with the "Z" type switch indicator; in the present case the bar carrying the contact fingers is operated from the "Z" by a vertical link attached at its upper end to a crank on the armature shaft, the semaphore blade, or disc, being operated by a small up-and-down rod attached at its bottom end to a finger carried by the contact bar. The instrument illustrated above is built for four front and four back high voltage contacts; a wider instrument of similar design carrying eight front and eight back contacts, or any combination thereof, can also be furnished.

POWER REQUIRED.

Normal Voltage	Contacts	Frequency	Minimum Voltage	Amps.	Watts.
110	4	60	85	0.24	3.0
110	4	25	85	0.12	2.0
110	8	60	80	0.32	4.0
110	8	25	80	0.17	3.0

A. C. TOWER INDICATOR
VANE TYPE.



FRONT VIEW

SECTIONAL SIDE VIEW

Fig. 231.

This indicator is provided with a movement exactly similar to that used in the well known vane relay, and is, therefore, immune to direct current. The instrument can be supplied with any number of contacts up to four front and four back, and with either a semaphore or disc indication.

POWER REQUIRED.

Normal Voltage	Contacts	Frequency	Minimum Volts	Amps.	Watts.
110	4	60	90	0.25	14
110	4	25	90	0.12	7

UNIVERSAL SWITCH CIRCUIT CONTROLLER.

Fig. 232.

This controller may be equipped with two-position contacts to suit it for controlling line circuits or shunting A. C. steam road track circuits, or three-position contacts may be provided to adapt the box for selective purposes at turnouts. With either arrangement, five independent sets of contacts can be furnished.

The side of the box is cut out in the above photograph to illustrate how a very accurate and permanent adjustment may easily be made; the segments pinned to the shaft carry pinions, each of which mesh in a rack cut on the inner face of its segment, the pinions themselves actuating cams which operate the contacts. An accurate micrometer adjustment is thus secured. The trunking leads into the cap, or cover, shown bolted to the left side of the box, this cover being transferable from one side of the box to the other, as the switch layout may require.

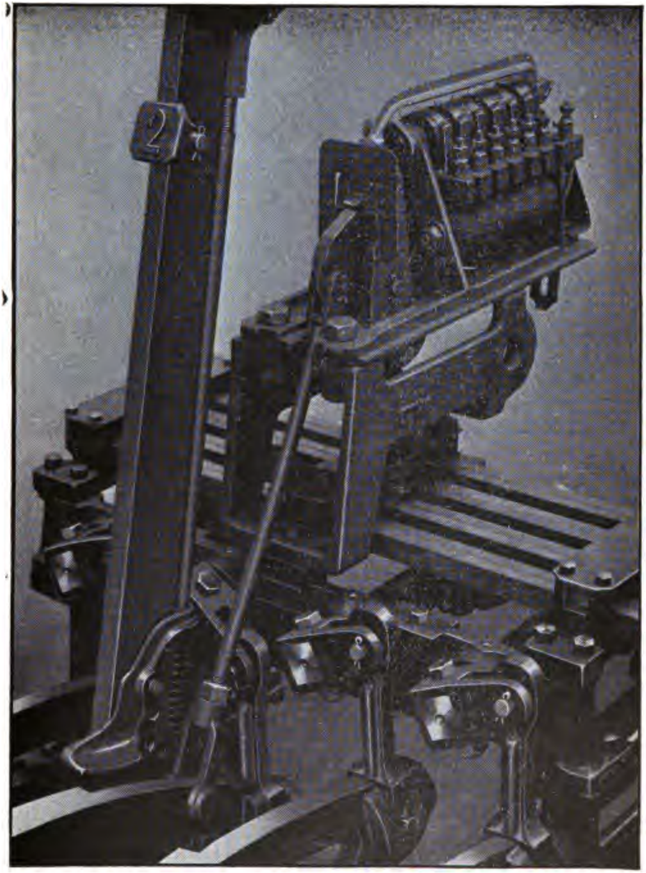


Fig. 233a. Model 12 Electric Lock Applied to S. & F. Machine.

MODEL 12.

A. C. ELECTRIC LOCK.

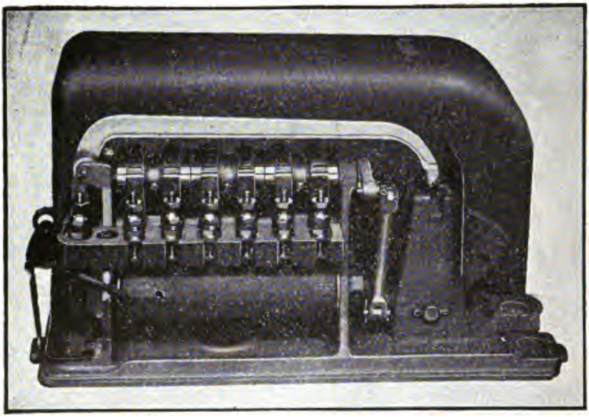


Fig. 233b.

The above lock is applicable to mechanical interlocking machines of the horizontal or vertical locking types. Its operating movement consists of an armature actuated by a horseshoe electro-magnet, whose poles are equipped with shading bands exactly similar to those used on tractive type slot magnets described in connection with Fig. 153, Chapter VIII. The lock is designed for six independent circuits.

The lock is energized only for an instant while the indication is being taken; the amount of power used is hence of little consequence and it has not been consideaed advisable to complicate the design to secure a more economical but less simple mechanism.

POWER REQUIRED.

Frequency	Normal Voltage	Minimum Voltage	Amps.	Watts.
60	110	84	85.0	72
25	110	84	30.0	23

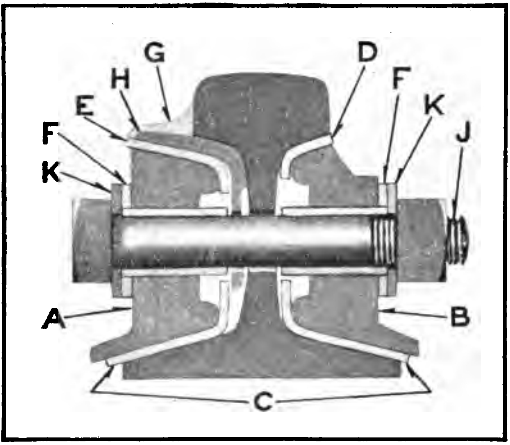


Fig. 234. Model 14 Keystone Insulated Rail Joint.

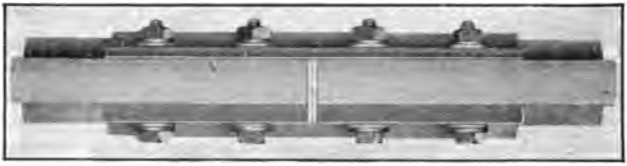


Fig. 234a. Model 14 Keystone Insulated Rail Joint.

Parts	Number of parts for one Joint	
	4 Hole	6 Hole
A Outside splice bar................	1	1
B Gauge side splice bar.............	1	1
C Bottom fibre plates...............	2	2
D Bakelized fabric plate............	1	1
E Top fibre plate...................	1	1
F Fibre bushings....................	8	12
G Fibre end post....................	2	2
H Filler............................	2	2
J Steel heat treated bolt with nut....	4	6
K Steel washer......................	8	12

KEYSTONE INSULATED RAIL JOINT.

1. Construction. The Keystone joint has come into very general use where great mechanical and electrical strength, combined with durability, are required. Heavy rolled steel splice bars and fillers, illustrated in the cross section in Fig. 234, provide as much resistance to both vertical and horizontal stresses as is found in the best designs of non-insulated joints; thus, the danger of failure under moving trains due to the breakage of the rail through bolt holes is minimized to the utmost and a smooth riding track is assured. The bolts furnished with the joint are subjected to a special heat treatment whereby their strength is increased 40 per cent. above that of ordinary bolts. Due to this great increase in strength, the bolts will not "draw" and, besides eliminating the necessity of frequently tightening the nuts, the joint is always held tight, this naturally preventing the insulations from being chafed and worn.

All insulations, except a strip under the rail head, are of the best quality of fibre obtainable and, due to the conformation of the fillers and angle bars, the load is evenly distributed over the entire contact area of the fibre; the unit surface load on the fibre is, therefore, comparatively small, so that the insulations are long-lived. Under the rail head, on the gauge side of the joint, where the load is the greatest, is placed a strip of insulation known as Bakalized Canvas; this material consists of compressed built-up layers of close woven canvas impregnated under heat with Bakalite, a heat and absolutely moisture proof synthetic compound possessing great insulating value. Bakalized canvas will, therefore, not crack, as it is built up from a more or less flexible fabric base, and, in addition, it is moisture and heat proof. Keystone joints equipped as above have, in many cases, stood up two years under heavy traffic without requiring any insulation renewals or other attention whatever.

2. Instructions for Applying Keystone Joints.

First:—The rail end should be square and free from fins or projections. Rails with sawed ends only should be used with insulated joints. Sharp projections should be carefully chipped off at all places where they come in contact with fibre parts.

Any ordinary tie plates which may be on the ties supporting the rail ends must be removed. If a tie plate is required, the insulating type of plate on U. S. & S. Catalogue Plate M-1 is recommended.

Second:—Assemble outside half of joint with fillers, bolts, bushings, and top fibre plate, put bottom fibre plate in position on rail, and apply parts, care being taken to see that the turned up portion of the bottom fibre plate is between filler and splice bar.

Third:—Insert end posts between rail ends. Rail end should press firmly against end post.

Fourth:—Put bottom fibre plate in position on gauge side of rail, slide gauge side splice bar over projecting bolts, insert bushings, put on steel washers and nuts, and pull joint up part way. The bakalized fabric plate can then be either dropped into place from top or slid in at end of joint to suit convenience, and joint tightened up.

Final Adjustments.

1st. After assembling, tighten nuts uniformly beginning at middle of joint.

2d. Sledge splice bars on both sides of rail, and tighten nuts again.

3rd. Tap bolt heads lightly with spike maul and tighten nuts again.

4th. Tamp the joint ties up to rails.

5th. Tighten nuts again in three or four days and again in ten days.

The fibre washers and tubes should not be separated, but should be applied as a unit. If separated, the ends of the tubes will probably be battered to such an extent in driving them over the bolts that the washers will not pass over them, with the result that when the nuts are screwed up, the pressure will come on the ends of the tubes instead of against the splice bars. A short piece of pipe, used as a set to drive the bushings into position will prevent damage to either tubes or washers.

Particular attention is called to the importance of bringing the ties up to support the rail end at the insulated joint. No rail joint, whether insulated or not, can be expected to stand the strain of keeping the rail ends in surface indefinitely if the ties underneath it give no support.

SPARK-GAP LIGHTNING ARRESTERS.

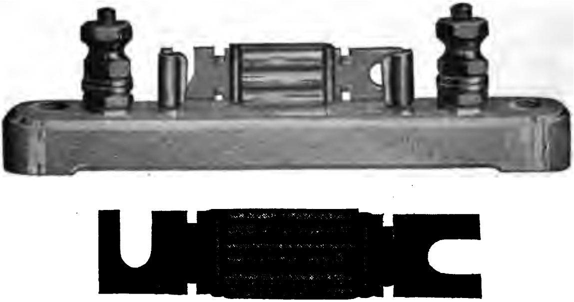


Fig. 235.

The working unit of this arrester, illustrated in the bottom view above, consists of a short sheet mica plate, provided at either end with terminal lugs and projecting ears, which support between them glass tubes, into each of which are slipped two ordinary pins spaced with a $\frac{1}{32}''$ air gap between them; the pins and tubes are carried in a clip which is easily removed when it is necessary to renew the pins after their points have been burned off by lightning discharges. The arrester, shown on its porcelain support with terminals, in the top view, is thus provided with six multiple air gaps, and is very sensitive, discharging to ground at a voltage well below the potential which the insulation in ordinary signal apparatus is built to withstand. Many thousands of these arresters are in service, and it has been proved that, while lightning discharges may burn the pin points completely off, the pins will never fuse together. The points may be easily inspected for separation through the glass, and can be quickly renewed at a few cents cost. On ordinary line circuits, one terminal of the arrester is connected to ground and the other to the line to be protected. In the case of track and line relays, it is, however, a customary practice to connect the lightning arrester directly across the relay, the idea being that, due to the enormous impedance of the latter on a high frequency lightning discharge, the lightning is choked out of the relay and is shunted across the spark-gap before the potential can rise to a serious value.

CLOCK WORK TIME RELEASE.

Fig. 236.

The function of this instrument is clearly described on page 409. The maximum time interval which can be secured is four minutes, and the design is such that the interval can be varied to any time between that amount and zero by the adjustment of stops contained within the instrument.

As will be noted from the photographs, a graduated dial and clock hand are provided so as to indicate at all times the length of time which has elapsed since releasing the knob. Provision is made in the instrument for the control of four independent circuits, two at the zero or extreme right hand position of the pointer, and two at whatever time it may be set for. The turning of the knob to the right winds up the clock mechanism a sufficient amount to always bring the pointer back to the time desired after the knob has been released.

The instrument is made in two forms; one in which the pointer stands normally at whatever time interval it is desired to secure, and the other in which the knob and pointer are latched at zero. In the former type the operator merely turns the knob to zero and releases it, permitting the clock work to restore it to the time desired. In the second type, the operator, after turning the knob to zero, gives a small movement to the left to release the latch, when it will automatically return to the time desired. In neither type, however, is the operator able, by turning the knob to the left, to vary the time required to effect the release.

It will be noticed from the foregoing, that the second type of release equipped with a retaining pawl or latch can be used for the same purposes as the type without such an attachment, since the operator can, after turning his knob as far as it will go to the right, give it the slight left hand turn necessary to release the retaining pawl in practically one operation.

In addition to hand operation, this release can be operated by the lever of any type of interlocking machine by substituting an attachment in place of the knob and omitting the retaining latch entirely.

ELECTRICAL MEASURING INSTRUMENTS USEFUL IN A. C. SIGNAL WORK.

1. Measurements to be Made. In order to obtain accurate information as to whether the apparatus in an alternating current signal system is receiving the proper energization, the following measurements often have to be made:

I. Voltage Across—
  1. Motor, slot, line relay, and primary of track transformer.
  2. Local element of track relay.
  3. Track element of track relay.
  4. Rails opposite track transformer.
  5. Track transformer secondary.

II. Current Fed to—
  1. Motor and slot.
  2. Track from track transformer secondary.

2. Instruments Required. Considerable care should be exercised in the selection of meters, particularly as regards scale and resistance, as otherwise the deflections may not be easily read, and, furthermore, may not indicate accurately the quantities under measurement, if the meter is such as to alter the circuit conditions when it is connected in. These points have been given due attention in the preparation of the following list, which covers meters having characteristics suiting them to the measurements outlined in the preceding paragraph. For lack of space, only three standard makes of instruments are referred to, although there are, of course, many others which will meet the requirements.

I. Voltmeters.

Where very accurate readings are required, as in the case of field investigations carried out directly from the signal engineer's or supervisor's office, a meter of the Weston Model 341 type (Weston Electrical Instrument Co., Waverly Park, N. J.), or the General Electric P-3 type (General Electric Co., Schenectady, N. Y.), will be found useful. These instruments should be provided with a 7.5^v-30^v double scale and a five multiplier for the 30 volt scale, so that voltages of 0-7.5^v, 0-30^v and 0-150^v can be measured. The 0-150 volt scale serves for the measurement of the voltage across the motors slots, line relays, and track transformer primaries, the normal potential across their terminals being usually 110 volts. The 0-30^v scale can be used to measure the voltage across the secondary of the track transformer (when over 7.5 volts), the voltage at the rails opposite the track transformer, and, finally, the voltage across the local coil of the track relay in those cases where this element is wound for low voltage operation; otherwise the 150 volt scale can be used for this latter measurement. The 7.5^v scale can be used for measuring the voltage at the transformer end of the track circuit (when under 7.5 volts) and also the voltage across the track terminals of the track relay in all cases except where polyphase relays are used on steam or electric roads; the track element voltage of these relays is so small (0.6 volt or less) that they cannot be read accurately on the 7.5 scale, the lowest scale marking thereon being generally one volt. The power taken by the track element is so small in comparison with that taken by the meter that were the latter provided with a low reading scale, the corresponding winding would have such a low resistance that the insertion of the meter across the relay would cause a relatively large drop in the rails of the track circuit; thus the voltage indicated by the meter would be considerably below that existing across the relay before the meter was connected in circuit. For such work, a special high resistance voltmeter is required, and one of these, the Weston Model 330, is shown in Fig. 237; it is provided with four scales, reading 0-1, 0-5 0-10 volts, and 150 volts, and has a resistance of 20 ohms per volt, whereas the Weston

Fig. 237. Weston Model 330 Portable High Resistance A. C. Voltmeter.

Model 341 and General Electric P-3 meters previously mentioned have resistances of about 12 ohms per volt.

For the use of maintainers, either the General Electric Type P-8 (Fig. 238) voltmeter, or the Weston Model 155, will be found satisfactory. These instruments are less expensive and less accurate than the Model 341 previously described, but should be provided with the same scales and multiplier; they however cannot be used for measuring the voltage across the track terminals of polyphase track relays, for when provided with the low reading scale, their internal resistance would be so low as to alter the circuit conditions immediately the instrument were connected in. For this service, only an instrument of the Weston Model 330 type, or one of equal resistance, will give satisfactory readings.

Fig. 238. General Electric Type P-8 Portable A. C. Voltmeter.

II. Ammeters.

The full set of voltage readings secured as described above will generally give sufficient information as to whether proper energy is being delivered to the signal apparatus, and, in most cases, current readings may be dispensed with. However, it is occasionally necessary to measure the amount of current flowing in a signal motor or slot, particularly if it is suspected that some of their coils are short-circuited, in which event an ammeter would quickly indicate that they were taking excessive current. Occasionally, it is desired to measure the current fed into the track from the track transformer secondary. For steam road work, an ammeter fo the Weston Model 155 type, or the General Electric Type P, will be found satisfactory. These instruments should be provided with a 0-1 ampere scale, so that they will give a fair reading on the motor current (2-3.5 amps.), the slot current (about 0.5 amp.), and the current fed into the track by the transformer, the value of which may run from a very small current up to 10 amperes, depending on the length of track circuit, ballast leakage, and type of relay. On electric roads with impedance bonds, the above meters may require auxiliary current transformers when the current fed into the track is to be measured, as this may run as high as 50 amperes in the case of long track circuits equipped with impedance bonds of heavy current carrying capacity and relatively low impedance.

III. Combination Meters.

A convenient combination meter for field service is manufactured by the Roller Smith Co., of Bethlehem, Pa., this meter being provided with the following scales:

Amperes	0–3, 0–12, 0–60.
Volts	0–6, 0–30, 0–120, 0–240

This instrument is free to a very considerable degree from the influence of direct current, and it thus becomes available for use in making alternating current and voltage measurements on D. C. electric road track circuits, where direct current and alternating current are flowing simultaneously through the circuits to be measured.

All the instruments described above will indicate on both direct and alternating currents; if these instruments were used in making measurements on single rail electric road track circuits, in which there is a considerable D C. propulsion drop, the reading will be higher than it ought to be, as it will be the result of the steady direct current superimposed on the alternating current wave.

As far as the writer knows the Roller Smith instrument here referred to, is the only one which can be used for work of this character; it will give approximately accurate results, although it is not absolutely free from the influence of direct current. Of course, the Weston and G. E. instruments will give absolutely accurate results, provided the direct current can be cut off while the A. C. readings are being made.

IV. Phase Meters.

It will be remembered from the discussion given in Chapter IV that the highest efficiency of track circuits equipped with two-element relays results only when the currents in the track and local coils of the track relay are in proper phase relationship. In order to secure highest track circuit efficiency it therefore becomes necessary to occasionally make phase readings, and the instrument shown in Fig. 239 is designed for this purpose. The instrument itself is provided with two windings one of which is to be connected to the track element of the relay and the other to the local of the relay, the dial of the meter being graduated to show the phase relationship of the track and local voltages; knowing the power factor of each element of the relay it is then a simple matter to determine the phase relationship of the currents as it is the currents and not the voltages which determine the efficiency of the relay. The instrument could be designed to indicate currents instead of voltages, but it would not be of sufficiently high internal resistance and might consequently effect the track circuit conditions immediately it were connected in. The phase meter here shown can be utilized in connection with relays either of the gavlanometer or of the polyphase type. It is manufactured by the U. S. & S. Co.

Fig. 239. Phase Meter.

CHAPTER XIII.

TRACK CIRCUIT CALCULATIONS.

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1. General. The proper calculation of the track circuit is of prime importance in the design of an alternating current signal system as it enables the engineer to select that type of track circuit apparatus which will operate most economically under the particular set of conditions in question. Furthermore, aside from the matter of economy, maximum safety of the track circuit can only be guaranteed by proper track circuit adjustments as dictated by the calculations. The process of calculation is not at all difficult and the simple formulae and diagrams here presented should enable the reader to make a full analysis of any type of circuit operating under any conditions he may encounter.

2. Resistance, Reactance and Impedance of Rails. The track circuit is in reality a small single-phase transmission system whose two line wires are represented by the rails, and whose load is represented by the relay at the end of the track circuit. Like the line wires of the transmission, the rails possess impedance (Z) composed of resistance (R) and reactance (X); the effective resistance of a steel rail is, however, from three to five times the actual resistance to direct current, due to the fact that the flow of alternating current in the magnetic material of which the rail is composed, sets up a magnetic field producing a counter e. m. f. in the body of the rail itself, forcing the current to the outer surface or skin of the rail, rendering thereby but a fraction of the cross-sectional area available for conducting current. This is known as the "skin effect," and is present in a greater or less degree in all conductors carrying alternating currents.

A further increase in the apparent resistance of the rails is introduced by their self-inductance, this depending on the spacing of the rails and their size, just as in the case of the two wires of a transmission. Since the rails are magnetic, however, their respective fields will be considerably more localized around each conductor than would be the case if non-magnetic conductors were in question, and hence, as explained in Chapter IX, the reactance of the rail circuit will

TABLE I.

IMPEDANCE OF BONDED RAILS TO SIGNAL CURRENTS IN OHMS PER 1000 FEET OF TRACK.

Weight of rail, lb. per yard	Bonding*	27.5-ft. rails				30-ft. rails				33-ft. rails			
		25~		60~		25~		60~		25~		60~	
		z	P.F.	z	P.F.	z	P.F.	z	P.F.	z	P.F.	z	P.F.
100	To capacity	0.10	0.40	0.25	0.40	0.10	0.40	0.25	0.40	0.10	0.40	0.25	0.40
	2 No. 6 copper	0.13	0.72	0.28	0.56	0.13	0.70	0.28	0.56	0.13	0.69	0.27	0.54
	1 No. 8 iron 1 No. 6 copper	0.17	0.83	0.30	0.65	0.16	0.82	0.30	0.63	0.15	0.79	0.29	0.62
	2 No. 6 c.c.—40%	0.19	0.87	0.32	0.69	0.19	0.86	0.32	0.69	0.17	0.84	0.31	0.68
	2 No. 6 c.c.—30%	0.25	0.91	0.36	0.75	0.22	0.91	0.35	0.74	0.20	0.88	0.34	0.73
	2 No. 8 iron	0.40	0.97	0.50	0.88	0.36	0.96	0.47	0.87	0.34	0.96	0.44	0.85
90	To capacity	0.10	0.43	0.26	0.43	0.10	0.43	0.26	0.43	0.10	0.43	0.26	0.43
	2 No. 6 copper	0.14	0.73	0.29	0.58	0.13	0.72	0.28	0.58	0.13	0.70	0.27	0.54
	1 No. 8 iron 1 No. 6 copper	0.17	0.83	0.31	0.67	0.16	0.82	0.31	0.64	0.16	0.80	0.29	0.62
	2 No. 6 c.c.—40%	0.19	0.87	0.33	0.71	0.19	0.87	0.33	0.70	0.17	0.84	0.31	0.68
	2 No. 6 c.c.—30%	0.23	0.91	0.36	0.76	0.26	0.91	0.36	0.76	0.20	0.89	0.34	0.73
	2 No. 8 iron	0.40	0.97	0.51	0.89	0.37	0.97	0.48	0.88	0.35	0.96	0.45	0.86
85	To capacity	0.10	0.46	0.26	0.46	0.10	0.46	0.26	0.46	0.10	0.46	0.26	0.46
	2 No. 6 copper	0.14	0.74	0.29	0.60	0.13	0.73	0.29	0.59	0.13	0.71	0.28	0.58
	1 No. 8 iron 1 No. 6 copper	0.17	0.84	0.32	0.68	0.17	0.83	0.31	0.67	0.16	0.81	0.30	0.65
	2 No. 6 c.c.—40%	0.19	0.88	0.33	0.72	0.19	0.87	0.33	0.69	0.18	0.85	0.32	0.70
	2 No. 6 c.c.—30%	0.23	0.91	0.37	0.77	0.23	0.91	0.36	0.77	0.21	0.89	0.35	0.76
	2 No. 8 iron	0.41	0.97	0.52	0.89	0.37	0.97	0.49	0.88	0.35	0.96	0.46	0.84
80	To capacity	0.11	0.48	0.26	0.48	0.10	0.48	0.26	0.48	0.11	0.48	0.26	0.48
	2 No. 6 copper	0.14	0.75	0.29	0.62	0.14	0.73	0.29	0.60	0.13	0.72	0.29	0.60
	1 No. 8 iron 1 No. 6 copper	0.17	0.84	0.32	0.69	0.17	0.84	0.31	0.68	0.16	0.82	0.31	0.67
	2 No. 6 c.c.—40%	0.20	0.88	0.34	0.73	0.20	0.88	0.34	0.73	0.18	0.85	0.33	0.71
	2 No. 6 c.c,—30%	0.23	0.91	0.38	0.78	0.23	0.91	0.37	0.78	0.21	0.89	0.36	0.76
	2 No. 8 iron	0.41	0.97	0.53	0.89	0.37	0.97	0.49	0.88	0.35	0.96	0.47	0.87
70	To capacity	0.11	0.52	0.27	0.52	0.11	0.52	0.27	0.52	0.11	0.52	0.27	0.52
	2 No. 6 copper	0.15	0.77	0.30	0.65	0.14	0.76	0.30	0.65	0.14	0.75	0.30	0.64
	1 No. 8 iron 1 No. 6 copper	0.18	0.86	0.33	0.72	0.17	0.85	0.33	0.71	0.17	0.82	0.32	0.70
	2 No. 6 c.c.—40%	0.20	0.89	0.36	0.75	0.20	0.89	0.35	0.75	0.18	0.86	0.34	0.74
	2 No. 6 c.c.—30%	0.24	0.92	0.39	0.80	0.24	0.92	0.38	0.81	0.22	0.90	0.37	0.78
	2 No. 8 iron	0.42	0.97	0.54	0.90	0.38	0.97	0.51	0.89	0.36	0.96	0.48	0.87

* c.c. = copper clad.

be much greater than would be indicated by the usual formulae and tables for non-magnetic conductors. The "skin effect" depends upon the permeability of the rails, which latter factor is a variable depending on the current density. Due to the presence of this variable, the magnitude of the skin effect is not susceptible to mathematical calculation. The permeability factor also obviously influences the magnitude of the self-inductance and in turn the reactance of the circuit.

Actual measurements have, therefore, had to be resorted to and Table No. I on the preceding page so determined gives the total impedance per 1000 feet of track (both rails including bond wires) under various conditions of bonding in common practice, and for values of current commonly used for relay energization; these tables have been in use for six or seven years and have been found to give results sufficiently accurate for all practical purposes. While the values shown apply especially to steam road conditions, they may also be safely used on electric road track circuit calculations, since the presence of propulsion current in the rails will only tend to decrease the permeability of the rails and in turn their effective resistance and impedance; hence the voltage at the relay may increase slightly with heavy propulsion currents flowing in the rails and any error introduced will be on the safe side. Table II shows separately the resistance of various kinds of bond wires as used in steam road work; on electric roads the rail is bonded to capacity, or nearly so, for propulsion current.

TABLE II.

RESISTANCE OF BONDS TO SIGNAL CURRENTS.

Ohms per 1000 feet of track.

Bonds per Joint	27.5 Ft. Rails	30 Ft. Rails	33 Ft. Rails	
2 No. 6 B&S Copper	0.057	0.052	0.048	Bonds 48 inches long no allowance is made for conductance of fish plates
1 No. 6 B&S Copper & 1 No. 8 BWG Iron	0.098	0.089	0.082	
2 No. 6 Copper clad 40%	0.124	0.112	0.103	
2 No. 6 Copper clad 30%	0.166	0.150	0.138	
2 No. 8 BWG iron	0.348	0.315	0.291	

3. Ballast, Leakage Resistance and Conductance. The resistance of the leakage path between rails in ohms per 1000 feet of track varies with the nature of the ballast, the condition of the ties, and the weather conditions. In connection with the calculations involving rail impedance as given in Tables I and II, the following values for resistance of ballast and ties may be used; they are given for ballast cleared away from the rails:

	Ohms per 1000 ft. of track
Wet Gravel	3
Dry Gravel	6
Wet Broken Stone	6
Dry Broken Stone	16

In making track circuit calculations, a leakage resistance of 6.0 ohms per thousand feet is very commonly used as representing the worst condition of well drained broken stone or rock ballast; two ohms per 1000 feet is a low wet weather value for track with gravel ballast. Poorly drained cinder ballast with old water-soaked ties will generally run as low as one ohm per thousand feet. In making the calculations the wet weather ballast leakage figure should be used as if the track transformer were designed and track circuit adjustments were made on the dry weather basis, the track relay might fail to pick up in wet weather. It is, however, advisable to make a check calculation on the dry weather basis in order to determine the variation in voltage on the track relay from the wet to the dry condition, as in the case of extremely long track circuits with poor ballast, the relay voltage in dry weather may be so high that special means may have to be employed to prevent the relay from being excessively energized. In track circuit calculations it is generally more convenient to represent the ballast leakage factor in terms of conductance rather than resistance; conductance (expressed in mhos) is the inverse of resistance (expressed in ohms), and thus a ballast leakage resistance of 6.0 ohms per thousand feet corresponds to a ballast conductance of $\frac{1}{6}$ mho per thousand feet.

4. Track Circuit Formulae and Their Derivation. Given the voltage e and the current i required at the track relay terminals, the length of the block, the rail impedance with its power factor, and the ballast leakage resistance, the problem which confronts us is the determination of the power to be fed into the track at the transformer end.

To begin with, due to the impedance drop in the rails caused by the relay current, the difference of potential between the rails increases from e at the relay end of the track circuit to some higher value E at the transformer end; thus, the ballast leakage current increases as we proceed from the relay to the transformer. The ballast leakage current itself produces a drop in the rails which again increases the voltage required at the transformer. The fact that the ballast conductance is distributed uniformly throughout the length of the track circuit rather complicates matters in that the current in the rails and the voltage across them from point to point changes with the varying magnitude of the ballast leakage current. In order to simplify matters, it is sometimes assumed that the ballast leak is concentrated at the center of the track circuit, but this is not strictly accurate; evidently the concentrated ballast leak is located nearer the transformer end of the track circuit than the relay end, for it is near the transformer end that the voltage is highest and the ballast leakage greatest. The correct determination of the ballast leak is therefore somewhat of an involved process. It can, however, be determined, and in fact this method is quite extensively used in England; the reader who is interested in this phase of the matter is referred to a very interesting and complete discussion given in the January, 1915, issue of the Railway Engineer of London.

It is evidently more accurate to consider the ballast conductance as uniformly distributed, and by means of the following simple formulae, originated by Mr. L. V. Lewis and first presented in the July, 1911, number of the Signal Engineer, the voltage E and the current I at the transformer end of the track circuit, as well as their phase relationship, can easily be calculated. These general equations are:

$$E = e \cosh \sqrt{ZG} + i \sqrt{\frac{Z}{G}} \sinh \sqrt{ZG} \qquad (1)$$

$$I = i \cosh \sqrt{ZG} + e \sqrt{\frac{G}{Z}} \sinh \sqrt{ZG} \qquad (2)$$

where e and i are the relay voltage and current respectively; Z is the total impedance of the rails of the track secured by multiplying the values in Table I by the length of the track circuit in thousands of feet, and G is the total ballast leakage conductance secured by multiplying the reciprocal of the ballast leakage resistance in ohms per thousand feet by the length of the track circuit in thousands of feet. The terms *cosh* and *sinh* (pronounced "cosh" and "shin") are the hyperbolic cosine and sine respectively of an imaginary or complex angle represented in this case by the quantity $\sqrt{ZG}$. These formulae may be reduced to workable form by expanding the functions into their corresponding infinite series beginning

$$\cosh x = 1 + \frac{x^2}{\underline{|2}} + \frac{x^4}{\underline{|4}} + \frac{x^6}{\underline{|6}} + \ldots \qquad (3)$$

$$\sinh x = x + \frac{x^8}{\underline{|3}} + \frac{x^5}{\underline{|5}} + \frac{x^7}{\underline{|7}} + \ldots \qquad (4)$$

where x represents the hyperbolic angle $\sqrt{ZG}$ and the sign $\underline{|\ \ }$ represents arithmetical multiplication; for example, $\underline{|3}$ is called "factorial three" and is equal 1 x 2 x 3 = 6; likewise, $\underline{|4} = 1 \times 2 \times 3 \times 4 = 24$. Hence

$$\cosh \sqrt{ZG} = 1 + \frac{ZG}{2} + \frac{(ZG)^2}{24} + \frac{(ZG)^8}{720} + \ldots \quad (5)$$

$$\sinh \sqrt{ZG} = \sqrt{ZG} + \frac{\sqrt{(ZG)^8}}{6} + \frac{\sqrt{(ZG)^5}}{120} + \ldots \quad (6)$$

Substituting the above values in equations (1) and (2)

$$E = \left(e + \frac{eZG}{2} + \frac{e(ZG)^2}{24} + \frac{e(ZG)^3}{720} + \right) + \left(i\sqrt{\frac{Z}{G}}\sqrt{ZG} + \frac{i\sqrt{\frac{Z}{G}}\sqrt{(ZG)^3}}{6} + \frac{i\sqrt{\frac{Z}{G}}\sqrt{(ZG)^5}}{120} + \right)$$

$$I = \left(i + \frac{iZG}{2} + \frac{i(ZG)^2}{24} + \frac{i(ZG)^3}{720} + \right) + \left(e\sqrt{\frac{G}{Z}}\sqrt{ZG} + \frac{e\sqrt{\frac{G}{Z}}\sqrt{(ZG)^3}}{6} + \frac{e\sqrt{\frac{G}{Z}}\sqrt{(ZG)^5}}{120} + \right) \quad (8$$

Reducing and rearranging the terms of equation (7) and (8)

$$E = e + Zi + \frac{Z}{2}Ge + \frac{Z}{3}\,\frac{G}{2}Zi + \frac{Z}{4}\,\frac{G}{3}\,\frac{Z}{2}Ge + \ldots \quad (9)$$

$$I = i + Ge + \frac{G}{2}Zi + \frac{G}{3}\,\frac{Z}{2}Ge + \frac{G}{4}\,\frac{Z}{3}\,\frac{G}{2}Zi + \ldots \quad (10)$$

The above equations may be carried out to any number of terms by carrying out the above process, noting that the first element of each term of equation (9) is Z, and of equation (10) G, each divided by 1, 2, 3, 4, etc., according to the number of the term in the infinite series, the remaining elements of the term under consideration being identical with the next preceding term in the other equation. Sufficient accuracy for all practical purposes will in most cases be secured by calculating only the first five terms of each series as above shown, the remaining terms being generally small enough in value to be disregarded.

Equations (9) and (10) may also be developed direct from Ohm's law, stating that $E = I\,Z$ and $I = E\,G$, and consideration of the matter on this basis will enable the reader to grasp fully their physical meaning. To begin with, the first two terms e and i of equations (9) and (10) are the relay voltage and current respectively and as such are known. Relay current i flowing through the rail impedance causes a drop $e_2 = Zi$ and likewise the relay voltage e impressed across the rails throughout the length of the track circuit produces a leakage current $i_2 = Ge$. Zi and Ge therefore constitute the second terms of their respective series. Obviously $e_2 = Zi$ (where i is constant) increases uniformly from the relay to the transformer and its average value is therefore $\frac{e_2}{2}$ and the corresponding ballast leakage current is $i_3 = \frac{e_2}{2}G = \frac{G}{2}\,Zi$; likewise, it may be shown that $e_3 = \frac{Z}{2}\,Ge$. These last quantities thus constitute the third term of the current and voltage series respectively.

The development of the next voltage term e_4 from i_3 presents some difficulty in that we have no reason for assuming that the average value of i_3 is $\frac{i_3}{2}$; as a matter of fact, it is not, since i_3 contains the product of the two factors G and Z, varying with the length of the track circuit, and hence increases with the square of the distance from the relay. It may be demonstrated by the calculus that in any equation of the form $y = x^n$ the average value of y between the limits of y, and o is $\frac{1}{(n+1)}$ of the maximum value of y Therefore, the average value of i_3 above is $\frac{i_3}{3}$ and the corresponding e. m. f. is $e_4 = \frac{Zi_3}{3} = \frac{Z}{3}\,\frac{G}{2}\,Zi$, and likewise

$i_4 = \frac{G}{3}\frac{Z}{2}$ Ge; these latter values form the fourth terms of the voltage and current series respectively, and the process may be carried out until equation (9) and (10) are entirely duplicated. It should be noted that any term in the current series is derived from the preceding term in the voltage series by multiplying by the conductance G, divided by 1, 2, 3, etc., depending on the number of the term, which is perfectly logical since it is that preceding voltage which causes the current in question to flow; conversely, any term in the voltage series is derived from the preceding term in the current series by multiplying it by Z, divided by 1, 2, 3, etc.

5. Comparison of Center Leak and Distributed Leak Methods. If the above terms are developed by the centre leak method, in which the entire ballast conductance is considered as being concentrated at the centre of the block, we find that

$$E = e + Zi + \frac{Z}{2}Ge + \frac{Z}{2}\ \frac{G}{2}Zi \qquad (11)$$

$$I = i + Ge + \frac{G}{2}Zi \qquad (12)$$

The first three terms of the above formulae are identical with the corresponding terms of equations (9) and (10) calculated on the distributed leak basis. The fourth term of equation (11) is however 50 per cent. greater in value than the corresponding term of equation (9). The center leak method will therefore, give sufficiently accurate results where the track circuit is short enough in length to permit all terms after the third being disregarded.

6. Application of Track Circuit Formulae; Examples. Let us apply formulae (9) and (10) to two of the usual track circuit arrangements, first, considering a galvanometer relay on a steam road, and, second, a polyphase relay on an electric road. Both of these relays are of the two-element type and one of them (the galvanometer) works most economically with the currents in its track and local elements in phase or nearly so, while the other (the polyphase) works best with its track and local currents in quadrature. These examples may therefore be considered as representative; calcula-

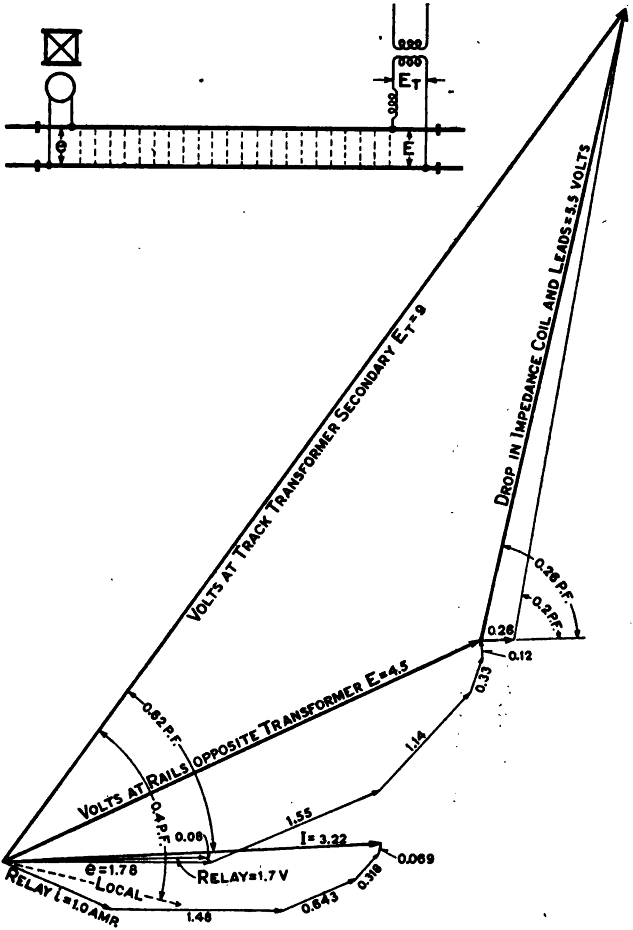

Fig. 240. Vector Diagram For a Track Circuit Equipped with a Galvanometer Relay.

tions for a track circuit employing a single element relay would of course be made in exactly the same manner, the calculation and diagram as used in the case of a two-element relay being simply discontinued after the track volts, amperes and power factor at the transformer are determined for the one winding used in the case of the single element instrument.

(a) **Galvanometer Relay:** See vector diagram Fig. 240.

Steam road 100 lb. rails, 33 feet long, bonded with 2-40 per cent. copper clad wires.

Track circuit 5,000 ft. long, end fed; ballast resistance 6.0 ohms per 1,000 feet.

Relay; track 1.7 V., 1.0 A., 0.9 P. F., on 60 cycles;
local 110 V. 0.3 A., 0.4 P. F., on 60 cycles.

Rail impedance $Z = 5 \times 0.31 = 1.55$ at 0.68 P. F. (See Table I).

Ballast conductance $G = 5 \times \frac{1}{6} = 0.83$ at 1.0 P. F.

Relay and transformer leads to track, 100 ft. No. 9 each set = 0.08 ohms.

Resistance drop in relay leads = $1.0 \times 0.08 = 0.08$ volts.

$E = 1.78 + 1.55 + 1.14 + 0.33 + 0.12 + \ldots\ldots$

$I = 1.0 + 1.48 + 0.643 + 0.318 + 0.069 + \ldots\ldots$

Volts at rails opposite relay = 1.78 obtained from Fig. 240; it is the vectorial sum of the relay voltage $e = 1.7$ and the lead drop 0.08 volts, the latter being in phase with and hence parallel with the current vector $i = 1.0$ drawn at an angle whose P. F. = 0.9 lagging behind the relay volts $e = 1.7$.

In plotting the various leakage currents and their corresponding drops in Fig 240 it will be remembered that each term in the voltage series is obtained by multiplication of the preceding terms in the current series by Z; the power factor of Z is 0.68 and hence each term of the voltage series is laid off at a lead angle whose P. F. $= \cos \theta = 0.68$ using the preceding term of the current series as a base line. The ballast conductance G is, of course, non-inductive and its P. F. = 1; hence each term in the current series is parallel with the preceding term in the voltage series which produces it.

Following the above method the final current at the transformer end of the track circuit will be found to be $I = 3.22$

amps; it is simply the vectorial sum of the relay current and the various ballast leakage currents laid off with due attention to phase relationship. Likewise the final voltage at the rails at the transformer end of the track circuit is E = 4.5 volts, for it is again the vectorial sum of the relay voltage and the various rail drops caused by the ballast leakage currents.

To prevent the flow of an injurious short circuit current flowing through the transformer secondary with a train in the block, it is necessary to insert some current limiting device between the transformer and the track and for this purpose we will select the impedance coil shown in Fig. 137, page 225, having a power factor of 0.2. The feed current of 3.22 amps. flowing through the leads between the transformer and the track gives a drop of 3.22 x .08 = 0.26 volts, laid off parallel to the current since the leads are non-inductive. As will presently be explained, enough impedance ought to be inserted between the transformer and the track to make the voltage at the transformer secondary about twice that at the rails. The impedance drop vector is laid off at a P. F. = 0.2 with the current and is made long enough so that the transformer secondary voltage will meet the impedance drop vector at a point where E_T = 2 x 4.5 = 9.0 volts.

The relay local current has a lag angle whose P. F. = 0.4, and hence it is laid off at a P. F. of 0.4 with the transformer secondary voltage E_T, for while the transformer which supplies E_T is not the same one as feeds the relay local, the transformer feeding the local is connected to the same transmission and hence its voltage is in phase with E_T.

The relay local current thus laid off will be found to be nearly in phase with the track element current. From Chapter IV it will be remembered that in the case of relays of the galvanometer type, maximum power economy is secured with the track and local elements in phase, and it was in order to secure this ideal relationship that an impedance coil was used between the transformer and the track; if a resistance having a unity power factor had been employed instead, the entire drop between the transformer and the track would have been in phase with the current vector I = 3.22 and the vector E_T would have been swung around in a clockwise direction through a large angle; the local current vector laid off the from at a P. F. = 0.4 would then have been away out of phase with the track current vector and hence the relay would not have operated economically since the voltage for the track at the relay would have had to be increased until that component of the track current in phase with the local current were equal to 1.0 ampere as we started off with.

Scaling the angle between the transformer voltage E_T and the current, we find it to be such that the cosine or P. F. = 0.62; hence, the total power with the block unoccupied is $E_T I \cos\theta = 9 \times 3.22 \times 0.62 = 18$ watts. With a train on the track circuit opposite the transformer, the current flowing will be equal to the transformer voltage E_T divided by the vectorial sum of the inserted impedance and the resistance of the transformer track leads. The drop in this part of the circuit as scaled from the diagrams is found to be 5.5 volts and this is due to a current I = 3.22 amps.; hence the combined value of the impedance and leads is $Z = \frac{E_T}{I} = \frac{5.5}{3.22} = 1.71$ ohms. With a train on the track circuit as above there will be only 1.71 ohms in series with the transformer secondary, and, neglecting the resistance of the wheels and axles of the train which is negligible, the short circuit current flowing will be $\frac{9.0}{1.71} = 5.26$ amperes, the corresponding power factor being 0.26 as scaled from the diagram, this being simply the power factor of the impedance and the resistance of the track leads in series. The total power with the block occupied is, therefore, $9 \times 5.26 \times 0.26 = 12.3$ watts. It is thus seen that the power with the block occupied is less than when the block is clear; this arises from the fact that the short circuit current with the block occupied is almost in quadrature with the transformer voltage due to the phase displacement produced by the impedance coil.

Polyphase Relay; see vector diagram Fig. 241.
Electric road, 70 lb. rails, 33 ft. long, bonded to capacity.
Double rail end fed track circuit, 8,000 ft. long.
Relay, track 0.15 V., 0.25 A., 0.65 P. F. on 25 cycles;
local 12 V., 0.20 A., 0.4 P. F. on 25 cycles.
Z on 25 cycles = $8 \times 0.11 = 0.88$ at 0.52 P. F.
$G = 8 \times \frac{1}{4} = 2$ mhos for ballast leakage of 4 per 1,000 ft.

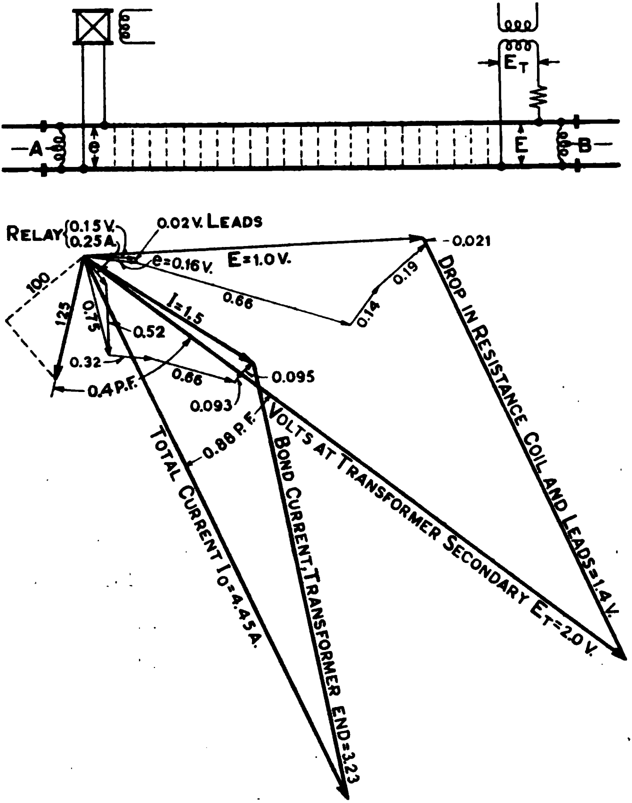

Fig. 241. Vector Diagram For a Track Circuit Equipped With a Polyphase Relay.

Impedance bonds, 500 amperes per rail with unbalancing capacity of 150 amp., impedance 0.31 ohms at 0.15 P. F.
Relay and transformer leads 100 ft. No. 9 wire = 0.08 ohms.
Drop in relay leads = 0.25 x 0.08 = 0.02 volts.
Volts opposite relay = 0.16 scaled from diagram.

Bond current at relay end $= \frac{0.16}{0.31} =$ 0.52 amps.

Total current at relay end = 0.75 amp. from diagram.

$E = 0.16 + 0.66 + 0.14 + 0.196 + 0.021 + 0.017$

$I = 0.75 + 0.32 + 0.66 + 0.093 + 0.095 + 0.008$

Referring to Fig. 241, the relay voltage 0.15 V. and the current 0.25 A. are laid off at a P. F. = 0.65 as before, and taking into account the drop in the leads of 0.02 V., laid off parallel to the relay current, the voltage at the relay end of the track circuit is found to be e = 0.16. At 0.16 volt the bond A takes 0.52 amps. and this current is laid off lagging at an angle corresponding to 0.15 P. F. with the track voltage *e*. The total current at the relay end of the track circuit is the vectorial sum of the relay current and the bond current and scales 0.75 amps. Applying equations (9) and (10) and laying off the various ballast leakage currents and voltages listed above in exactly the same way as in the case of the galvanometer relay diagram, Fig, 240, the current I = 1.5 A. and the voltage E = 1.0 V. is found at the transformer end of the block. The bond B at the transformer end of the block takes at 1.0 volt $\frac{1.0}{0.31} = 3.23$ amps. and this current is laid off at a P. F. = 0.15 with the corresponding voltage E and the total current fed into the track scales 4.45 A., being the vectorial sum of the bond current 3.23 A. and the track current I = 1.5 A.; employing a resistance between the transformer and the track, the corresponding drop is laid off in phase with and parallel with the total current and with a transformer voltage of twice the track voltage, the final voltage at the transformer secondary $E_T = 2.0$ is obtained. The drop in the leads and resistance scales 1.4 volts and the corresponding total resistance is $\frac{1.4}{4.45} = 0.315$ ohms.

On laying off the vector for the current in the local element of the relay at a P. F. = 0.4 with the transformer voltage E_T

it will be noted that the local current is considerably out of phase with the track element current, though not a full 90° for quadrature relationship as required for the most economical operation of the polyphase type as explained in Chapter IV. In fact, if we lay off a line at right angles to the track element current as shown at the left of the diagram, and project on it the local current, we find that only $\frac{100}{125}$ or 0.8 of the local current is in quadrature with the track current so that we must compensate for this imperfect phase displacement by increasing the transformer voltage accordingly, the current values for the two elements of the relay as given in the list above being based on a pure quadrature relationship. To make the quadrature component of the track current a full 0.25 A. which we started out with in laying out the diagram, we increase the transformer voltage in the proportion of $\frac{125}{100} \times 2 = 2.5$ volts; naturally, the total current fed into the track increases in corresponding ratio with the voltage, and, thence, the final feed current I is $\frac{125}{100} \times 4.45 = 5.56$ amps. The drop across the resistance and leads scaling 1.4 is likewise increased to $\frac{125}{100} \times 1.4 = 1.75$, and the corresponding value of the resistance is $\frac{1.75}{5.56} = .315$ ohms.

With the block clear the total power is $E_T\ I_O \cos = 2.5 \times 5.56 \times 0.88 = 12.2$ watts, the power factor of 0.88 being the cosine of the angle between I_O and E_T as scaled from the diagram. With a train on the circuit opposite the transformer, the maximum current is equal to the transformer volts divided by the total resistance between transformer and the track and is $\frac{2.5}{.315} = 7.94$ amps. at 1.0 P. F. since the resistance is non-inductive. The power with the block thus occupied is $2.5 \times 7.94 \times 1.0 = 19.8$ watts.

It will now be apparent why a resistance was employed between the transformer and the track, for if an impedance had been used instead, the local current vector would have been nearly in phase with the track current vector and the relay would hardly have picked up even with several times its normal current, simply due to the imperfect phase displacement;

7. The Train Shunt. In general, alternating current track relays have a much lower internal impedance than the ordinary track relays used in direct current practice; for example, the galvanometer relay which we considered in connection with Fig. 240 has an impedance of $Z = \frac{E}{I} = \frac{1.7}{1.0} =$ 1.7 ohms, while the polyphase relay discussed in connection with Fig. 241 has an impedance of $\frac{0.15}{0.25} =$ 0.6 ohms as compared to the resistance of 4.0 ohms of the standard direct current instruments. Since, with two circuits in parallel, as in the case of the track relay and the car wheels across the rails, the current in each circuit is inversely proportional to the resistance of that circuit, it follows that with a train shunt of given resistance the alternating current track relay will take a larger proportion of the current than would be the case with a direct current relay; hence the train shunt is not so effective in the former case.

The value of the train shunt in ohms is of course equal to the impedance of the axles added vectorially to the ohmic contact resistance between rails and car wheels. The impedance of the wheel and axle part of the shunt circuit is negligible, and hence the reactance factor in the circuit may also be neglected. It is also true that in the case of the heavy rolling stock employed in steam and electric trunk line service, the wheel-rail contact resistance may likewise be considered as insignificant. Table III below was compiled from a series of tests made on rails with a clean bearing surface in which a single pair of wheels and their axle was submitted to various loads. It will be noted that the total resistance of the shunt thus formed is practically independent of the loading; while the total shunt resistance is extremely low in all cases, it is to be noted that, as might be expected, the total apparent resistance increases with the frequency. Compared to any of these shunt resistances the impedance of the relays above given is so enormously high that the shunt may be considered as practically perfect.

TABLE III.

Contact Surface of Wheels and Rails Clean Metal.

Frequency Cycles	No. of Test	Total Lbs. Weight on Track	Amps. Axle Current	Volts Across Rails	Apparent Ohmic Res. Between Rails via Wheels and Axle
25	1	18,700	185	0.133	.0007
	2	23,052	175	0.13	.0007
	3	27,404	180	0.134	.0007
	4	36,108	180	0.14	.0008
60	1	18,700	112.5	0.12	.001*
	2	27,404	112.5	0.114	.001
	3	36,108	112.5	0.11	.00097
d.c.	1	18,700	55	.022	.0004
	2	27,404	56	.021	.00037
	3	36,108	55	.018	.00033

*Note—2′ 9″ of axle gave drop of .048 volts. From this point (on either side) to rail average drop 0.35 volts.

It is only when rusty or dirty rail surfaces are encountered that the resistance of the train shunt becomes significant and this statement applies equally well to direct current track circuits; every signal man is familiar with the occasional difficulties experienced on heavily sanded track. Table IV indicates what the surface contact resistance may amount to, the tests having been made on a four wheel truck loaded so that the total weight on the rails was 40,900 lbs.

TABLE IV.

	Clean Rails		Rusty Rails	
	25 Cycles	60 Cycles	25 Cycles	60 Cycles
Total amps. through axles	220	180	70	125
Volts across rails	0.232	0.1	0.82	0.37
Train shunt in ohms	0.00105	0.00055	0.0117	0.003

On steam and electric trunk lines where the rolling stock is generally heavy and the train movements are frequent enough to keep the rails clean, it may be safely assumed that the train shunt resistance is so extremely low as to be negligible. On some of the interurban trolley lines, however, where light single car trains are operated and movements are not frequent enough to keep the rails bright, the value of the train shunt must be taken into consideration; in such cases, it has been found to run much higher than the values in Table IV and since the relay ought to be shunted out to a point at least 50 per cent. below its minimum shunt point, it is often customary to make electric road track circuit shunt calculations with a train shunt value of 0.064 ohms. In those cases on electric roads where it is suspected that the train shunt may be of comparatively high resistance due to light rolling stock and rusty rails resulting from infrequent train service, it is therefore generally advisable to check the track circuit calculations as described below in order to be certain that the relay will be shunted open with a train in the block.

8. Methods of Controlling Track Circuit Sensitiveness. In the first place, the train shunt is least effective when the train is opposite the relay, for at that time the entire rail impedance will be in circuit between the train shunt and the track transformer with the result that the track feed current and the consequent drop in the resistance or impedance between the transformer and the track will be less than with the train opposite the transformer; then, since the voltage at the rails opposite the transformer is the vectorial difference between the transformer voltage and the drop in the resistance or reactance inserted between the transformer and the track, it follows that with the train opposite the relay, the voltage at the track opposite the transformer and in turn that opposite the relay will be greatest when the train is at the relay end of the track circuit. Since this latter is the worst condition encountered, calculations to improve the effectiveness of the track circuit should be made on this basis.

What we desire to do is to reduce to the lowest point possible the voltage at the relay with a train in the block, and it will be immediately apparent from the above discussion that we have in the impedance or resistance (as the case may be) inserted between the transformer and the track a very effective means of controlling the voltage at the rails opposite the transformer, since, as this voltage decreases so also will the voltage at the relay decrease. Hence, if we used an impedance or resistance of high value the short circuit current with a train on the block will cause a correspondingly heavy drop between the transformer and the track and as a result the track voltage opposite both transformer and relay will be low. It is customary to use sufficiently high impedance or resistance so that with the block clear the voltage at the track opposite the transformer will be about one-half that at the transformer secondary, and it was with the train shunt in mind that these values were employed in connection with Figs. 240 and 241; with such an adjustment the track voltage will generally fall to a perfectly safe figure when a train comes on the track circuit. Inserting impedance or resistance to give a transformer voltage greater than twice the track voltage will rarely be justified since after the relay is once shunted out with a large margin of safety any further increase in inserted impedance or resistance will only result in a useless waste of power.

With the aid of the vector diagrams shown in Figs. 240 and 241, it is not a difficult matter to ascertain whether the inserted impedance or resistance, determined on the basis of the transformer volts being twice the track volts with the block occupied, will insure the track relay being open with a train opposite it. It is assumed of course that all the track circuit constants are known, including the shunting point as well as the normal operating point of the relay. With a train shunt of given value across the rails at the relay, use the normal operating voltage of the relay plus the drop in the track leads as the first term *e* of equation (9), and considering the train shunt as an impedance bond of unity power factor, construct a diagram like Fig. 241, leaving the propulsion bonds out if a steam road track circuit is being investigated; in the case of an electric road circuit, the train shunt will simply constitute an extra bond at the relay end in multiple with the propulsion bond. The vector diagram thus obtained will of course indicate a transformer voltage considerably greater than what is actually existent as determined from the calculation with the block clear. Calling this hypothetical transformer voltage E_{TS} and the actual existent transformer voltage E_T, the volts *e* at the relay end of the block must be reduced in the proportion of $\frac{E_T}{E_{TS}}$; in turn the relay voltage and current will be decreased in like ratio and if with this reduction it is found that the relay current is below the shunting point of the instrument, the impedance or resistance chosen for the "block clear" condition may be considered as satisfactory. If the reduction is not sufficient, the impedance or resistance inserted between the transformer and the track will have to be arbitrarily increased until the calculations prove that the relay is effectively shunted.

9. Power Factor Triangle. In laying out vector track circuit diagrams such as those shown in Figs. 240 and 241, the value of the various angles are given by the calculations in terms of their cosines, these being the power factors of the corresponding angles. The phase spacing of vectors is, therefore, much more easily effected through the use of a triangle marked off in cosines, such as that shown in Fig. 242, than through the employment of a protractor indicating degrees, since in the latter case the angles corresponding to the cosine would have to be looked up in a table. A transparent triangle should be used as it is often necessary to use it upsidedown; the lines 0.1 to 0.7, as drawn from vertex A are laid oft with a protractor at angles with base line B C corresponding to cosines of 0.1 to 0.7 as given in the tables at the back of this book; the lines 0.8 to 0.99 as drawn from vertex B are laid off from base line B C likewise at angles corresponding to cosines of 0.8 to 0.99. Considerable care should be exercised in using the triangle at first, especially when reversing it, as otherwise one may be using the complement of the angle instead of the angle itself.

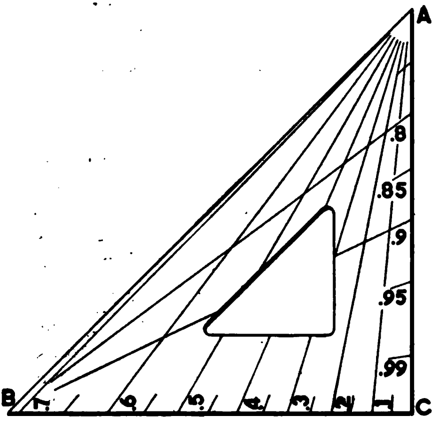

Fig. 242. Power Factor Triangle For Constructing Track Circuit Vector Diagrams.

CHAPTER XIV.

TABLES AND DATA

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WIRE AND SHEET METAL GAGES

1. Wire Gages; Kinds and Applications. Wires of a diameter less than $\frac{1}{2}$ inch are usually specified according to certain arbitrary scales called gages; the gage number of a solid wire refers to the cross section of the wire perpendicular to its length; the gage number of a stranded wire or cable refers to the total cross section of the wires composing it, regardless of the pitch of the spiraling. Wires larger than $\frac{1}{2}$ inch in diameter are generally described in terms of their cross sectional area in circular mils (abbreviated c. m.) a circular mil being the area of a circle 1 mil (0.001″) in diameter and the circular mil area of any wire is equal to its diameter in mils squared; thus a wire of 0.100″ diameter has a circular mil area of 10,000 c. m.

The principal gages and their uses are as follows:

Brown & Sharpe (B. & S.) or American Wire Gage (A. W. G.). This gage is the standard in this country for the designation of copper, aluminum and resistance alloy wires. The diameters of wires having successive numbers are in the ratio of $\sqrt[39]{92}$ or 1.1225 approximately.

A No. 10 B. & S. copper wire has the following approximate characteristics:

Ohms per 1000 feet	1
Area in c.m.	10,000
Weight in pounds per 1000 ft	32

A No. 10 B. & S. aluminum wire has the following approximate characteristics:

Ohms per 1000 feet	1.6
Area in c.m.	10,000
Weight in pounds per 1000 ft	9.5

Birmingham (B. W. G.) or Stubs Wire Gage. This gage is generally used for the designation of galvanized iron and steel wire; it is sometimes referred to as the Stubs' Gage, but must not be confused with Stubs' Steel Wire Gage.

United States Steel Wire Gage. This gage is frequently employed in this country for the designation of steel and iron wire—telephone and telegraph wires for example. It is also sometimes known as the "Washburn and Moen," "Roebling" and "American Steel & Wire Co." Gage.

British Standard Wire Gage. This gage, usually called the Standard Wire Gage (S. W. G.) also is known as the "New British Standard" (N. B. S.), the English Legal Standard, or Imperial Wire Gage; it is the legal standard in Great Britain for all wires.

London Gage. This gage is also sometimes known as the "Old" English Wire Gage and is frequently used in connection with brass wires.

Stubs Steel Wire Gage. This gage is sometimes used for designating drill rod sizes; the Brown and Sharp Twist Drill gage is however in most general use for this purpose. See Page 480.

Old English Wire Gage. This is occasionally used for designating brass wire.

2. **Sheet Metal Gages.**

Brown & Sharpe Gage. This gage, the same as the wire gage of the same name, is generally used in specifying the thickness of sheet copper, brass and German silver.

United States Standard Gage. This gage, standardized in this country by act of Congress, is quite generally used for the designation of sheet iron and steel.

Decimal Gage. This gage designates the thickness of sheet iron or steel in mils or thousandths of an inch. It has been adopted by the Association of American Steel Manufacturers, The American Railway Master Mechanics Association, and by the principal railroads in this country and Canada. It obviously has much to recommend it and is coming into general use for the designation of all iron and steel sheets and plates.

ENAMELED COPPER WIRE.

This is a wire insulated with a hard, tough and elastic coating of special varnish laid and baked on in a series of layers.

The insulation is moisture proof and will successfully withstand temperatures that would completely ruin silk or cotton insulations. The insulation thickness is about one-fourth of that of single silk in very small wires while for No. 22 B. & S. or larger the thickness is about the same as that of single silk; furthermore the dielectric strength of the enamel is about four times that of an equal thickness of silk or cotton. For these reasons enameled wire is being used to an even increasing extent. The table below applies to wire made by the General Electric Co., and meeting R. S. A. specifications; it will be noted that in many cases decimal sizes, lying between standard B. & S. gage numbers, are available.

ENAMELED WIRE.

Bare B. & S. Gage	Diam. Wire G. E. Std.	Max. diam. ins. wire	Turns per sq. inch	Ohms per cubic inch	Pounds per cu. inch
14	.064	.067	223	.0485	.235
	.061	.064	244	.0578	.2294
15	.057	.060	278	.0753	.2275
	.054	.057	308	.0934	.2274
16	.051	.0535	349	.1181	.2284
	.049	.0515	376	.1382	.2276
17	.045	.0475	443	.1936	.2272
	.042	.0445	505	.2523	.2247
18	.040	.0425	552	.3046	.2231
	.038	.040	625	.3816	.2267
19	.036	.038	692	.4982	.2258
20	.032	.034	864	.7452	.2232
	.030	.032	975	.9569	.2211
21	.0285	.0305	1075	1.1690	.2204
22	.0255	.0275	1320	1.7930	.2167
23	.0226	.024	1753	2.9243	.2106
24	.020	.022	2066	4.5563	.2081
25	.018	.020	2500	6.8114	.2046
26	.016	.0175	3264	11.258	.2111
27	.014	.0155	4160	18.759	.2061
28	.0126	.0140	5102	28.365	.2044
29	.011	.0123	6612	48.251	.2022
30	.010	.0112	7832	69.186	.1978
31	.009	.0102	9612	104.771	.1962
32	.008	.0092	11815	163.050	.1920
33	.007	.0082	14872	267.937	.1847
34	.0063	.0072	17768	395.345	.1777
35	.00560	.0063	25195	709.454	.1995
36	.0050	.0056	31887	1126.037	.2019

WIRE AND SHEET METAL GAGES COMPARED.

DIAMETERS IN DECIMALS OF AN INCH.

Number of Wire Gage.	American or Brown & Sharpe.	Birmingham or Stubs' Wire.	Washburn & Moen Mfg. Co. Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	Stubs' Steel Wire.	U. S. Stand. for Plate.	Number of Wire Gage.
000000						.46875	000000
00000				.45		.4375	00000
0000	.46	.454	.3938	.4		.40625	0000
000	.40964	.425	.3625	.36		.375	000
00	.3648	.38	.3310	.33		.34375	00
0	.32486	.34	.3065	.305		.3125	0
1	.2893	.3	.2830	.285	.227	.28125	1
2	.25763	.284	.2625	.265	.219	.265625	2
3	.22942	.259	.2437	.245	.212	.25	3
4	.20431	.238	.2253	.225	.207	.234375	4
5	.18194	.22	.2070	.205	.204	.21875	5
6	.16202	.203	.1920	.19	.201	.203125	6
7	.14428	.18	.1770	.175	.199	.1875	7
8	.12849	.165	.1620	.16	.197	.171875	8
9	.11443	.148	.1483	.145	.194	.15625	9
10	.10189	.134	.1350	.13	.191	.140625	10
11	.090742	.12	.1205	.1175	.188	.125	11
12	.080808	.109	.1055	.105	.185	.109375	12
13	.071961	.095	.0915	.0925	.182	.09375	13
14	.064084	.083	.0800	.08	.180	.078125	14
15	.057068	.072	.0720	.07	.178	.0703125	15
16	.05082	.065	.0625	.061	.175	.0625	16
17	.045257	.058	.0540	.0525	.172	.05625	17
18	.040303	.049	.0475	.045	.168	.05	18
19	.03589	.042	.0410	.04	.164	.04375	19
20	.031961	.035	.0348	.035	.161	.0375	20
21	.028462	.032	.03175	.031	.157	.034375	21
22	.025347	.028	.0286	.028	.155	.03125	22
23	.022571	.025	.0258	.025	.153	.028125	23
24	.0201	.022	.0230	.0225	.151	.025	24
25	.0179	.02	.0204	.02	.148	.021875	25
26	.01594	.018	.0181	.018	.146	.01875	26
27	.014195	.016	.0173	.017	.143	.0171875	27
28	.012641	.014	.0162	.016	.139	.015625	28
29	.011257	.013	.0150	.015	.134	.0140625	29
30	.010025	.012	.0140	.014	.127	.0125	30

U. S. STANDARD GAGE.
FOR SHEET AND PLATE, IRON AND STEEL.

No. of gage	Approximate thickness in decimal parts of an inch	Approximate thickness in millimeters	Weight per square foot in pounds avoirdupois	Weight per square meter in kilograms
0000000	0.5000	12.7000	20.00	97.65
000000	0.4687	11.9062	18.75	91.55
00000	0.4375	11.1125	17.50	85.44
0000	0.4062	10.3187	16.25	79.33
000	0.3750	9.5250	15.00	73.24
00	0.3437	8.7312	13.75	67.13
0	0.3125	7.9375	12.50	61.03
1	0.2812	7.1437	11.25	54.93
2	0.2656	6.7469	10.62	51.88
3	0.2500	6.3500	10.00	48.82
4	0.2344	5.9531	9.375	45.77
5	0.2187	5.5562	8.750	42.72
6	0.2031	5.1594	8.125	39.67
7	0.1875	4.7625	7.500	36.62
8	0.1719	4.3656	6.875	33.57
9	0.1562	3.9687	6.250	30.52
10	0.1406	3.5719	5.625	27.46
11	0.1250	3.1750	5.000	24.41
12	0.1094	2.7781	4.375	21.36
13	0.0937	2.3812	3.750	18.31
14	0.07812	1.9844	3.125	15.26
15	0.07031	1.7859	2.812	13.73
16	0.06250	1.5875	2.500	12.21
17	0.05625	1.4287	2.250	10.99
18	0.05000	1.2700	2.000	9.765
19	0.04375	1.1112	1.750	8.544
20	0.03750	0.9525	1.500	7.324
21	0.03437	0.8731	1.375	6.713
22	0.03125	0.7937	1.250	6.103
23	0.02812	0.7144	1.125	5.490
24	0.02500	0.6350	1.000	4.882
25	0.02187	0.5556	0.875	4.272
26	0.01875	0.4762	0.750	3.662
27	0.01719	0.4366	0.687	3.357
28	0.01562	0.3969	0.625	3.052
29	0.01406	0.3572	0.5625	2.746
30	0.01250	0.3175	0.5000	2.441
31	0.01094	0.2778	0.4375	2.136
32	0.01016	0.2580	0.4062	1.983
33	0.009375	0.2381	0.3750	1.831
34	0.008594	0.2183	0.3437	1.678
36	0.007031	0.1786	0.2812	1.373
38	0.006250	0.1587	0.2500	1.221

STANDARD DECIMAL GAGE.
FOR SHEET AND PLATE, IRON AND STEEL.

Standard decimal gage in inches	Approximate thickness in millimeters	Weights per square foot in pounds avoirdupois	
		Iron, Basis: 480 pounds per cubic foot	Steel, Basis: 489.6 pounds per cubic foot
0.002	0.0508	0.08	0.0816
0.004	0.1016	0.16	0.1632
0.006	0.1524	0.24	0.2448
0.008	0.2032	0.32	0.3264
0.010	0.2540	0.40	0.4080
0.012	0.3048	0.48	0.4896
0.014	0.3556	0.56	0.5712
0.016	0.4064	0.64	0.6528
0.018	0.4572	0.72	0.7344
0.020	0.5080	0.80	0.8160
0.022	0.5588	0.88	0.8976
0.025	0.6350	1.00	1.0200
0.028	0.7112	1.12	1.1424
0.032	0.8128	1.28	1.3056
0.036	0.9144	1.44	1.4688
0.040	1.0160	1.60	1.6320
0.045	1.1430	1.80	1.8360
0.050	1.2700	2.00	2.0400
0.055	1.3970	2.20	2.2440
0.060	1.5240	2.40	2.4480
0.065	1.6510	2.60	2.6520
0.970	1.7780	2.80	2.8560
0.075	1.9050	3.00	3.0600
0.080	2.0320	3.20	3.2640
0.085	2.1590	3.40	3.4680
0.090	2.2860	3.60	3.6720
0.095	2.4130	3.80	3.8760
0.100	2.5400	4.00	4.0800
0.110	2.7940	4.40	4.4880
0.125	3.1750	5.00	5.1000
0.135	3.4290	5.40	5.5080
0.150	3.8100	6.00	6.1200
0.165	4.1910	6.60	6.7320
0.180	4.5720	7.20	7.3440
0.200	5.0800	8.00	8.1600
0.220	5.5880	8.80	8.9760
0.240	6.0960	9.60	9.7920
0.250	6.3500	10.00	10.2000

BROWN & SHARP GAGE.
FOR SHEET COPPER AND BRASS.

B. & S. Gage No.	Thickness, inches	Weight, pounds per sq. ft.	
		Copper	Brass
0000	0.4600	20.84	19.69
000	0.4096	18.56	17.53
00	0.3648	16.53	15.61
0	0.3249	14.72	13.90
1	0.2893	13.11	12.38
2	0.2576	11.67	11.03
3	0.2294	10.39	9.82
4	0.2043	9.26	8.74
5	0.1819	8.24	7.79
6	0.1620	7.34	6.93
7	0.1443	6.54	6.18
8	0.1285	5.82	5.50
9	0.1144	5.18	4.90
10	0.1019	4.62	4.36
11	0.09074	4.11	3.88
12	0.08081	3.66	3.46
13	0.07196	3.26	3.08
14	0.06408	2.90	2.74
15	0.05707	2.59	2.44
16	0.05082	2.30	2.18
17	0.04526	2.05	1.94
18	0.04030	1.83	1.73
19	0.03589	1.63	1.54
20	0.03196	1.45	1.38
21	0.02846	1.29	1.22
22	0.02535	1.15	1.08
23	0.02257	1.02	0.966
24	0.02010	0.911	0.860
25	0.01790	0.811	0.766
26	0.01594	0.722	0.682
27	0.01420	0.643	0.608
28	0.01264	0.573	0.541
29	0.01126	0.510	0.482
30	0.01003	0.454	0.429
31	0.008928	0.404	0.382
32	0.007950	0.360	0.340
33	0.007080	0.321	0.303
34	0.006304	0.286	0.270
36	0.005000	0.226	0.214
38	0.003965	0.180	0.170
40	0.003145	0.142	0.135

RESISTANCE OF COPPER WIRE

B. & S. GAGE—SOFT DRAWN—100% CONDUCTIVITY

The resistance of hard drawn copper line wire is about 1.026 times the values shown below; see table page 336 for hard drawn wire.

Gage No.	Diameter in mils.	Cross-section		Resistance at 20° C. or 68° F.*		Weight in pounds		Feet per pound
		Circular mils	Square inches	Ohms per 1000 feet	Ohms per mile	per 1000 feet	per mile	
0000	460.0	211,600	0.1662	0.04901	0.259	640.5	3380	1.561
000	409.6	167,800	0.1318	0.06180	0.326	507.9	2680	1.968
00	364.8	133,100	0.1045	0.07793	0.411	402.8	2130	2.482
0	324.9	105,500	0.08289	0.09827	0.519	319.5	1680	3.130
1	289.3	83,690	0.06573	0.1239	0.654	253.3	1340	3.947
2	257.6	66,370	0.05213	0.1563	0.825	200.9	1060	4.977
3	229.4	52,640	0.04134	0.1970	1.04	159.3	841	6.276
4	204.3	41,740	0.03278	0.2485	1.31	126.4	667	7.914
5	181.9	33,100	0.02600	0.3133	1.65	100.2	529	9.980
6	162.0	26,250	0.02062	0.3951	2.09	79.46	420	12.58
7	144.3	20,820	0.01635	0.4982	2.63	63.02	333	15.87
8	128.5	16,510	0.01297	0.6282	3.32	49.98	264	20.01
10	101.9	10,380	0.008155	0.9989	5.28	31.43	166	31.82
12	80.81	6,530	0.005129	1.588	8.38	19.77	104	50.59
14	64.08	4,107	0.003225	2.525	13.3	12.43	63.3	80.44
15	57.07	3,257	0.002558	3.184	16.8	9.858	52.0	101.4
16	50.82	2,583	0.002028	4.015	21.2	7.818	41.3	127.9
17	45.26	2,048	0.001609	5.064	26.7	6.200	32.7	161.3
18	40.30	1,624	0.001276	6.385	33.7	4.917	26.0	203.4
19	35.89	1,288	0.001012	8.051	42.5	3.899	20.6	256.5
20	31.96	1,022	0.0008023	10.15	53.6	3.092	16.3	323.4
21	28.46	810.1	0.0006363	12.80	67.6	2.452	12.9	407.8
22	25.35	642.4	0.0005046	16.14	85.2	1.945	10.3	514.2
23	22.57	509.5	0.0004002	20.36	108	1.542	8.14	648.4
24	20.10	404.0	0.0003173	25.67	135	1.223	6.46	817.7
25	17.90	320.4	0.0002517	32.37	171	0.9699	5.12	1,031
26	15.94	254.1	0.0001996	40.82	216	0.7692	4.06	1,300
27	14.20	201.5	0.0001583	51.46	272	0.6100	3.22	1,639
28	12.64	159.8	0.0001255	64.90	343	0.4837	2.55	2,067
29	11.26	126.7	0.00009953	81.84	432	0.3836	2.03	2,607
30	10.03	100.5	0.00007894	103.2	545	0.3042	1.61	3,287
31	8.928	79.70	0.00006260	130.1	687	0.2413	1.27	4,145
32	7.950	63.21	0.00004964	164.1	866	0.1913	1.01	5,227
33	7.080	50.13	0.00003937	206.9	1090	0.1517	0.814	6,591
34	6.305	39.75	0.00003122	260.9	1380	0.1203	0.635	8,310
35	5.615	31.52	0.00002476	329.0	1740	0.09542	0.504	10,480
36	5.000	25.00	0.00001964	414.8	2190	0.07568	0.400	13,210
38	3.965	15.72	0.00001235	659.6	3480	0.04759	0.251	21,010
40	3.145	9.888	0.000007766	1049	5540	0.02993	0.158	33,410

*Let C = per cent conductivity, R_{20} = resistance of 100 per cent conductivity wire at 20° C. (from table), R_t = resistance of wire of conductivity C at any temperature $t°$ C. then

$$R_t = R_{20}\left[\frac{100}{C} + 0.00393\,(t - 20)\right]$$

COPPER CABLES CONCENTRIC LAY.
B. & S. GAGE—100% CONDUCTIVITY.

Circular mils and A. W. G.	Resistance at 25° C. or 77° F.*		Weight in pounds, bare		Standard strands			Flexible strands		
	Ohms per 1000 feet	Ohms per mile	per 1000 feet	per mile	Number of wires	Diameter of wires in mils	Outside diameter, in mils	Number of wires	Diameter of wires, in mils	Outside diameter, in mils
2,000,000	0.00539	0.0285	6180	32600	127	125.5	1631	169	108.8	1632
1,900,000	0.00568	0.0300	5870	31000	127	122.3	1590	169	106.0	1590
1,800,000	0.00599	0.0316	5560	29300	127	119.1	1548	169	103.2	1548
1,700,000	0.00634	0.0335	5250	27700	127	115.7	1504	169	100.3	1504
1,600,000	0.00674	0.0356	4940	26100	127	112.2	1459	169	97.3	1460
1,500,000	0.00719	0.0380	4630	24500	91	128.4	1412	127	108.7	1413
1,400,000	0.00770	0.0407	4320	22800	91	124.0	1364	127	105.0	1365
1,300,000	0.00830	0.0438	4010	21200	91	119.5	1315	127	101.2	1315
1,200,000	0.00899	0.0475	3710	19600	91	114.8	1263	127	97.2	1264
1,100,000	0.00981	0.0518	3400	17900	91	109.9	1209	127	93.1	1210
1,000,000	0.0108	0.0570	3090	16300	61	128.0	1152	91	104.8	1153
950,000	0.0114	0.0600	2930	15490	61	124.8	1123	91	102.2	1124
900,000	0.0120	0.0633	2780	14670	61	121.5	1093	91	99.4	1094
850,000	0.0127	0.0670	2620	13860	61	118.0	1062	91	96.6	1063
800,000	0.0135	0.0712	2470	13040	61	114.5	1031	91	93.8	1031
750,000	0.0144	0.0759	2320	12230	61	110.9	998	91	90.8	999
700,000	0.0154	0.0814	2160	11410	61	107.1	964	91	87.7	965
650,000	0.0166	0.0876	2010	10600	61	103.2	929	91	84.5	930
600,000	0.0180	0.0949	1850	9780	61	99.2	893	91	81.2	893
550,000	0.0196	0.1036	1700	8970	61	95.0	855	91	77.7	855
500,000	0.0216	0.1139	1540	8150	37	116.2	814	61	90.5	815
450,000	0.0240	0.1266	1390	7340	37	110.3	772	61	85.9	773
400,000	0.0270	0.1424	1240	6520	37	104.0	728	61	81.0	729
350,000	0.0308	0.1627	1080	5710	37	97.3	681	61	75.7	682
300,000	0.0360	0.1899	926	4890	37	90.0	630	61	70.1	631
250,000	0.0431	0.228	772	4080	37	82.2	575	61	64.0	576
0000	0.0509	0.269	653	3450	19	105.5	528	37	75.6	533
000	0.0642	0.339	518	2735	19	94.0	470	37	67.3	471
00	0.0811	0.428	411	2170	19	83.7	418	37	60.0	420
0	0.102	0.540	326	1720	19	74.5	373	37	53.4	374
1	0.129	0.681	258	1364	19	66.4	332	37	47.6	333
2	0.162	0.858	205	1082	7	97.4	292	19	59.1	296
3	0.205	1.082	163	858	7	86.7	260	19	52.6	263
4	0.259	1.365	129	680	7	77.2	232	19	46.9	234
5	0.326	1.721	102	540	7	68.8	206	19	41.7	209
6	0.410	2.170	81.0	428	7	61.2	184	19	37.2	186
7	0.519	2.74	64.3	339	7	54.5	164	19	33.1	166
8	0.654	3.45	51.0	269	7	48.6	146	19	29.5	147

*Let C = per cent conductivity, R_{25} = resistance of 100 per cent conductivity cable at 25° C. (from table), R_t = resistance of cable of conductivity C at any temperature $t°$ C., then

$$R_t = R_{25}\left[\frac{100}{C} + 0.00385\,(t - 25)\right].$$

SOLID COPPER WIRE SOFT DRAWN
BRITISH STANDARD WIRE GAGE—100% CONDUCTIVITY

Gage No.	Diameter in mils	Cross-section		Ohms per 1000 feet, 15.6° C. or 60° F.*	Pounds per 1000 feet
		Circular mils	Square inches		
7-0	500	250,000	0.1964	0.04077	756.8
6-0	464	215,300	0.1691	0.04734	651.7
5-0	432	186,600	0.1466	0.05461	564.9
4-0	400	160,000	0.1257	0.06370	484.3
3-0	372	138,400	0.1087	0.07365	418.9
2-0	348	121,100	0.09512	0.08416	366.6
0	324	105,000	0.08245	0.09709	317.8
1	300	90,000	0.07069	0.1132	272.4
2	276	76,180	0.05983	0.1338	230.6
3	252	63,500	0.04988	0.1605	192.2
4	232	53,820	0.04227	0.1894	162.9
5	212	44,940	0.03530	0.2268	136.0
6	192.	36,860	0.02895	0.2765	111.6
7	176	30,980	0.02433	0.3290	93.76
8	160	25,600	0.02011	0.3981	77.49
9	144	20,740	0.01629	0.4915	62.77
10	128	16,380	0.01287	0.6221	49.59
11	116	13,460	0.01057	0.7574	40.73
12	104	10,820	0.008495	0.9423	32.74
13	92	8,464	0.006648	1.204	25.62
14	80	6,400	0.005027	1.592	19.37
15	72	5,184	0.004072	1.966	15.69
16	64	4,096	0.003217	2.488	12.40
17	56	3,136	0.002463	3.250	9.493
18	48	2,304	0.001810	4.424	6.974
19	40	1,600	0.001257	6.370	4.843
20	36	1,296	0.001018	7.864	3.923
22	28	784.0	0.0006158	13.00	2.373
24	22	484.0	0.0003801	21.06	1.465
26	18	324.0	0.0002545	31.46	0.9807
28	14.8	219.0	0.0001720	46.54	0.6630
30	12.4	153.8	0.0001208	66.28	0.4654
32	10.8	116.6	0.00009161	87.38	0.3531
34	9.2	84.64	0.00006648	120.4	0.2562
36	7.6	57.76	0.00004536	176.5	0.1748
38	6.0	36.00	0.00002827	283.1	0.1090
40	4.8	23.04	0.00001810	442.4	0.06974
42	4.0	16.00	0.00001257	637.0	0.04843
44	3.2	10.24	0.000008042	995.3	0.03100
50	1.0	1.000	0.0000007854	10,190	0.003027

*Let C = per cent conductivity, R_{60} = resistance of 100 per cent conductivity wire at 60° F. (from table), R_t = resistance of wire of conductivity C at any temperature t° F., then

$$R_t = R_{60}\left[\frac{100}{C} + 0.00223\,(t - 60)\right].$$

SOLID ALUMINUM WIRE
B. & S. GAGE—61% CONDUCTIVITY

For Stranded Cables See Page 336.

Gage No.	Diameter in mils	Cross-section		Resistance at 20° C. or 68° F.*		Weight in pounds		Feet per pound
		Circular mils	Square inches	Ohms per 1000 feet	Ohms per mile	per 1000 feet	per mile	
0000	460.0	211,600	0.1662	0.0804	0.424	195	1027	5.14
000	409.6	167,800	0.1318	0.101	0.535	154	815	6.48
00	364.8	133,100	0.1045	0.128	0.675	123	646	8.27
0	324.9	105,600	0.08289	0.161	0.851	97.0	512	10.31
1	289.3	83,690	0.06573	0.203	1.073	76.9	406	13.00
2	257.6	66,370	0.05213	0.256	1.353	61.0	322	16.39
3	229.4	52,630	0.04134	0.323	1.706	48.4	255	20.7
4	204.3	41,740	0.03278	0.408	2.15	38.4	203	26.1
5	181.9	33,100	0.02600	0.514	2.71	30.4	160.7	32.9
6	162.0	26,250	0.02062	0.648	3.42	24.1	127.4	41.4
7	144.3	20,820	0.01635	0.817	4.31	19.1	101.0	52.3
8	128.5	16,510	0.01297	1.03	5.44	15.2	80.2	65.9
10	101.9	10,380	0.008155	1.64	8.65	9.55	50.4	104.8
12	80.81	6,530	0.005129	2.61	13.76	6.00	31.7	166.6
14	64.08	4,107	0.003225	4.14	21.9	3.78	19.93	265
15	57.07	3,257	0.002558	5.22	27.6	2.99	15.81	334
16	50.82	2,583	0.002029	6.59	34.8	2.37	12.54	421
17	45.26	2,048	0.001609	8.31	43.8	1.88	9.94	531
18	40.30	1,624	0.001276	10.5	55.3	1.49	7.89	670
19	35.89	1,288	0.001012	13.2	69.7	1.18	6.25	844
20	31.96	1,022	0.0008023	16.7	87.9	0.939	4.96	1,065
21	28.46	810.1	0.0006363	21.0	110.9	0.745	3.93	1,343
22	25.35	642.4	0.0005046	26.5	139.8	0.591	3.12	1,693
23	22.57	509.5	0.0004002	33.4	176.3	0.468	2.47	2,130
24	20.10	404.0	0.0003173	42.1	222	0.371	1.961	2,690
25	17.90	320.4	0.0002517	53.1	280	0.295	1.556	3,390
26	15.94	254.1	0.0001996	67.0	353	0.234	1.233	4,280
27	14.20	201.5	0.0001583	84.4	446	0.185	0.978	5,400
28	12.64	159.8	0.0001255	106	562	0.147	0.776	6,810
29	11.26	126.7	0.00009953	134	709	0.117	0.615	8,580
30	10.03	100.5	0.00007894	169	894	0.0924	0.488	10,820
31	8.928	79.70	0.00006260	213	1127	0.0733	0.387	13,650
32	7.950	63.21	0.00004964	269	1421	0.0581	0.307	17,210
33	7.080	50.13	0.00003937	339	1792	0.0461	0.243	21,700
34	6.305	39.75	0.00003122	428	2260	0.0365	0.1929	27,400
35	5.615	31.52	0.00002476	540	2850	0.0290	0.1530	34,510
36	5.000	25.00	0.00001964	681	3590	0.0230	0.1214	43,500
38	3.965	15.72	0.00001235	1080	5710	0.0145	0.0763	69,200
40	3 145	9.888	0.000007766	1720	9080	0.0091	0.0480	110,000

*Let C = per cent conductivity, R_{20} = resistance of 61 per cent conductivity wire at 20° C. (from table), R_t = resistance of wire of conductivity C at any temperature t° C., then

$$R_t = \frac{61\,R_{20}}{C}\,[1 + 0.004\,(t - 20)].$$

BARE GALVANIZED IRON AND STEEL WIRE

B. W. G.—EXTRA BEST BEST—BEST BEST—STEEL

Size B. W. G.	Diameters in Mils.	Weights. Pounds.		Breaking Weights. Pounds.		Resistance in Ohms per mile.		
		1,000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	304.	1607	4821	9079	2.93	3.42	4.05
1	300	237.	1251	3753	7068	3.76	4.4	5.2
2	284	212.	1121	3363	6335	4.19	4.91	5.8
3	259	177.	932	2796	5268	5.04	5.9	6.97
4	238	149.	787	2361	4449	5.97	6.99	8.26
5	220	127.	673	2019	3801	6.99	8.18	9.66
6	203	109.	573	1719	3237	8.21	9.6	11.35
7	180	85.	450	1350	2545	10.44	12.21	14.43
8	165	72.	378	1134	2138	12.42	14.53	17.18
9	148	58.	305	915	1720	15.44	18.06	21.35
10	134	47.	250	750	1410	18.83	22.04	26.04
11	120	38.	200	600	1131	23.48	27.48	32.47
12	109	31.	165	495	933	28.46	33.3	39.36
13	95	24.	125	375	709	37.47	43.85	51.82
14	83	18.	96	288	541	49.08	57.44	67.88
15	72	13.7	72	216	407	65.23	76.33	90.21
16	65	11.1	59	177	332	80.03	93.66	110.7
17	58	8.9	47	141	264	100.5	120.4	139.
18	49	6.3	33	99	189	140.8	164.8	194.8

COPPER CLAD STEEL WIRE

Standard Underground Cable Co.

This wire consists of a steel core to which is permanently welded a concentric coat of copper. It is made in several grades differing in the relative thickness of the copper coating, the grades being designated by the corresponding conductivity expressed as per cents of Matthiessen's Standard; for example 40% copper clad has a conductivity of 40% of that of a solid copper wire of the same gauge.

Due to the use of the steel core, an appreciable "skin effect" is encountered when copper-clad wire is used for transmitting alternating currents and the reader is referred to page 317 for impedance date at the commercial frequencies; the table below gives the ohmic resistance only.

Gage No.	Diameter in mils	Cross-section		Resistance at 23.9° C. or 75° F.*		Weight in pounds		Feet per pound
		Circular mils	Square inches	Ohms per 1000 feet	Ohms per mile	per 1000 feet	per mile	
0000	460.0	211,600	0.1662	0.123	0.649	595	3140	1.68
000	409.6	167,800	0.1318	0.154	0.813	471	2490	2.12
00	364.8	133,100	0.1045	0.195	1.03	374	1970	2.67
0	324.9	105,500	0.08289	0.246	1.30	297	1570	3.37
1	289.3	83,690	0.06573	0.310	1.64	235	1240	4.26
2	257.6	66,370	0.05213	0.390	2.06	186	982	5.38
3	229.4	52,630	0.04134	0.492	2.60	148	781	6.76
4	204.3	41,740	0.03278	0.622	3.28	117	618	8.55
5	181.9	33,100	0.02600	0.782	4.13	92.9	491	10.76
6	162.0	26,250	0.02062	0.987	5.21	73.7	389	13.57
7	144.3	20,820	0.01635	1.25	6.60	58.5	309	17.09
8	128.5	16,510	0.01297	1.57	8.29	46.4	245	21.6
9	114.4	13,090	0.01028	1.98	10.5	36.8	194	27.2
10	101.9	10,380	0.008155	2.50	13.2	29.2	154	34.2
11	90.74	8,234	0.006467	3.15	16.6	23.1	122	43.3
12	80.81	6,530	0.005129	3.97	21.0	18.3	96.6	54.6
13	71.96	5,178	0.004067	5.00	26.4	14.6	77.1	68.5
14	64.08	4,107	0.003225	6.31	33.3	11.5	60.7	87.0

* Let C = per cent conductivity,
$R_{23.9}$ = resistance of 40 per cent conductivity wire at 23.9° C. (from table),
R_t = resistance of wire of conductivity C at temperature t° C.,

then

$$R_t = \frac{40 R_{23.9}}{C}[1 + 0.00432\,(t - 23.9)].$$

TENSILE STRENGTH OF COPPER WIRE

Size of Wire. B. & S. Gauge.	Breaking Weight of Hard-Drawn. Lbs.	Breaking Weight of Annealed. Lbs.
0000	9971	5650
000	7907	4480
00	6271	3553
0	4973	2818
1	3943	2234
2	3127	1772
3	2480	1405
4	1967	1114
5	1559	883
6	1237	700
7	980	555
8	778	440
9	617	349
10	489	277
11	388	219
12	307	174
13	244	138
14	193	109
15	153	87
16	133	69
17	97	55
18	77	43
19	61	34
20	48	27

Copper Wire.

98% PURE. SPEC. GRAVITY 8.89.

Weight per 1000 feet $= .003027 \times d^2$ or $\frac{d^2}{330.353}$

Weight per mile $= .015983 \times d^2$ or $\frac{d^2}{62.567}$

Resistance per 1000 feet @ 60° F. $= \frac{30.815}{\text{W. per 1000 feet}}$ or $\frac{10180.694}{d^2}$

Resistance per 1000 feet @ 75° F. $= \frac{31.804}{\text{W. per 1000 feet}}$ or $\frac{10507.4}{d^2}$

Specific conductivity of Pure Copper is 100 (100 inches pure copper weighing 100 grains @ 60° F. = 0.1516 ohms), of commercial copper from 96 to 102 per cent. of standard.

The percentage of conductivity of copper is found by measuring the resistance of a sample of the same length and weight as the standard and at the same temperature. R = resistance of standard. r = the resistance of sample. $\frac{100 \times R}{r}$ = per cent. conductivity.

CARRYING CAPACITY OF INSULATED COPPER WIRES

The question of drop is not taken into consideration in these tables.

Copper B. & S. Gauge.	Concealed Rubber-Covered Wires.	Exposed Weatherproof Wires.
	Amperes.	Amperes.
18	3	5
16	6	8
14	12	16
12	17	23
10	24	32
8	33	46
6	46	65
5	54	77
4	65	92
3	76	110
2	90	131
1	107	156
0	127	185
00	150	220
000	177	262
0000	210	312
Circular Mils.		
200,000	200	300
300,000	270	400
400,000	330	500
500,000	390	590
600,000	450	680
700,000	500	760
800,000	550	840
900,000	600	920
1,000,000	650	1,000
1,100,000	690	1,080
1,200,000	730	1,150
1,300,000	770	1,220
1,400,000	810	1,290
1,500,000	850	1,360
1,600,000	890	1,430
1,700,000	930	1,490
1,800,000	970	1,550
1,900,000	1,010	1,610
2,000,000	1,050	1,670

The above table shows the allowable carrying capacity of wires and cables of 98 per cent. conductivity.

The lower limit is specified for rubber-covered wires *to prevent gradual deterioration of the insulation by the heat of the wires,* but not from *fear of igniting the insulation.* *"N. B. of F. U"*

COPPER MAGNET WIRE—SINGLE COTTON COVERED

Bare B. & S.	Wire Dia.	Max. diam. ins. wire	Turns per sq. inch	Ohms per Cu. inch 25°C.	Pounds per cu. inch,
10	.102	.108	85.56	.00726	.2250
11	.091	.097	106.29	.01134	.2223
12	.081	.087	132.02	.0177	.2189
13	.072	.078	164.35	.0280	.2150
14	.064	.070	203.91	.04395	.2106
15	.057	.063	251.86	.06845	.2068
16	.051	.057	307.65	.1044	.2095
17	.045	.051	384.16	.1675	.2046
18	.040	.046	472.19	.2606	.1995
19	.036	.041	595.36	.4291	.2032
20	.032	.0375	710.75	.6130	.1994
21	.0285	.034	864.94	.9399	.1941
22	.0255	.031	1037.0	1.408	.1887
23	.0226	.028	1274.0	2.125	.1829
24	.0200	.025	1600.0	3.531	.1751
25	.0180	.023	1889.0	5.146	.1690
26	.0160	.021	2266.0	7.814	.1617
27	.0140	.0195	2629.0	11.84	.1528
28	.0126	.018	3085.0	17.16	.1455
29	.0110	.016	3906.0	28.51	.1359
30	.0100	.015	4443.0	39.24	.1288
31	.0090	.014	5100.0	55.59	.1208
32	.0080	.013	5932.0	81.86	.1128

COPPER MAGNET WIRE—DOUBLE COTTON COVERED

Bare Wire B. & S. Gage	Diam. Bare Wire	Max. diam. ins. wire	Turns per sq. inch	Ohms per cu. inch @ 25° C.	Pounds per cu. inch.
0	.325	.346	8.352	.0000698	.2308
1	.289	.310	10.400	.0001098	.22972
2	.258	.278	12.93	.0001714	.2275
3	.229	.250	16.00	.0002692	.2262
4	.204	.224	19.926	.0004226	.2251
5	.182	.202	24.50	.0006525	.2215
6	.162	.180	30.855	.001037	.2188
7	.144	.162	38.08	.001619	.2150
8	.129	.144	48.23	.002559	.2112
9	.114	.127	61.98	.004206	.2068
10	.102	.113	78.32	.006644	.2093
11	.091	.102	96.09	.010248	.2047
12	.081	.092	118.156	.015901	.2003
13	.072	.083	145.15	.024711	.1946
14	.064	.075	177.76	.038313	.1887
15	.057	.0675	219.48	.059643	.1826
16	.051	.061	268.63	.091176	.1886
17	.045	.055	330.51	.14411	.1826
18	.040	.050	400.00	.22071	.1754
19	.036	.045	493.73	.35586	.1673
20	.032	.041	594.87	.51304	.1614
21	.0285	.037	730.00	.79283	.1539
22	.0255	.034	864.89	1.1747	.1462
23	.0226	.031	1040.06	1.7345	.1387
24	.0200	.029	1188.87	2.6246	.1286
25	.018	.027	1371.96	3.7376	.1210
26	.016	.025	1600.0	5.5172	.1123
27	.014	.023	1889.8	8.5198	.1023
28	.0126	.021	2267.6	12.6071	.09442
29	.011	.020	2500.0	18.2408	.08470
30	.010	.019	2769.9	24.4648	.07793
31	.009	.018	3086.2	33.6417	.07063
32	.008	.017	3459.8	47.7424	.06347

COPPER MAGNET WIRE—SINGLE SILK COVERED

Bare Wire B. & S. Gage	Diam. Bare Wire	Max. diam. ins. wire	Turns per sq. inch	Ohms per cu. inch @ 20 °C.	Pounds per cu. inch,
24	.02010	.2023	2010	4.29	.2027
25	.01790	.0201	2475	6.66	.2023
26	.01594	.0181	3055	10.37	.1976
27	.01420	.0163	3765	16.1	.1865
8	.01264	.0148	4565	24.7	.1830
9	.01126	.0134	5580	38.0	.1707
30	.01003	.0121	6830	58.6	.1724
31	.00893	.0110	8265	89.5	.1688
32	.00795	.0100	10000	136.5	.1624
33	.00708	.0091	12075	207.8	.1499
34	.00631	.0083	14515	315	.1452
35	.00562	.0076	17245	473	.1369
36	.00500	.0070	20400	704	.1292

COPPER MAGNET WIRE—DOUBLE SILK COVERED

Bare Wire B&S Gage	Diam. Bare Wire	Total Thickness of Ins. (nominal)	Max. Ins dia. wire	Turns per sq. in.	Ohms per cu. inch 20° C.	Pounds per cu. inch
24	.02010	.004	.0243	1695	3.62	.1708
25	.01790	.004	.0221	2050	5.52	.1677
26	.01594	.004	.0201	2475	8.40	.1600
27	.01420	.004	.0184	2955	12.7	.1462
28	.01264	.004	.0168	3545	19.1	.1421
29	.01126	.004	.0154	4215	28.7	.1288
30	.01003	.004	.0142	4960	42.6	.1252
31	.008928	.004	.0131	5825	63.1	.1189
32	.00795	.0035	.0116	7420	101.3	.1205
33	.00708	.0035	.0107	8735	150.4	.1084
34	.006305	.0035	.0100	10000	217	.0999
35	.005615	.0035	.0093	11565	317	.0915
36	.00500	.0035	.0087	13210	456	.0837

RESISTANCE OF GERMAN SILVER WIRE
B. & S. GAUGE—70° F

	18% ALLOY. Resistance varies .03 of one per cent. for one degree Centigrade.		30% ALLOY. Resistance varies .022 of one per cent. for one degree Centigrade.	
SIZE.	Ohms per 1000 feet.	Ohms per pound.	Ohms per 1000 feet.	Ohms per pound.
No. 8	11.772	.24702	17.658	.37054
" 9	14.83	.39249	22.22	.58873
" 10	18.72	62443	28.08	.93666
" 11	23.598	.99281	35.397	1.4927
" 12	29.754	1.5785	44.631	2.3676
" 13	37.512	2.5101	56.268	3.7650
" 14	47.304	3.9911	70.956	5.9862
" 15	59.652	6.3462	89.478	9.5192
" 16	75.222	10.090	112.833	15.135
" 17	94.842	16.045	142.263	24.066
" 18	119.61	25.511	179.41	38.266
" 19	155.106	42.909	232.659	64.362
" 20	190.188	64.498	285.282	96.524
" 21	239.814	102.56	359.721	153.84
" 22	302.382	163.06	453.573	244.60
" 23	381.33	259.33	571.99	388.99
" 24	480.834	412.37	721.251	618.55
" 25	606.312	655.61	909.468	983.43
" 26	764.586	1042.7	1146.879	1563.8
" 27	964.134	1657.7	1446.201	2486.6
" 28	1215.756	2636.0	1823.634	3953.9
" 29	1533.06	4191.5	2299.59	6287.2
" 30	1933.038	6666.5	2899.557	9999.6
" 31	2437.236	10594.	3655.854	15890.
" 32	3073.77	16850.	4610.65	25275.
" 33	3875.616	26788.	5813.424	40181.
" 34	4888.494	42618.	7332.741	63927.
" 35	6163.974	67759.	9245.961	101640.
" 36	7770.816	107700.	11656.224	161540.
" 37	9797.166	171170.	14695.749	256770.
" 38	12357.198	269820.	18535.797	404740.
" 39	15570.828	428720.	23356.242	643070.
" 40	19653.57	682540.	29480.35	1023800.

TWIST DRILL AND DRILL ROD GAGE

(Brown & Sharp Mfg. Co.)

No.	Size in Decimals.	No.	Size in Decimals.	No.	Size in Decimals.	No.	Size in Decimals.	No.	Size in Decimals.	No.	Size in Decimals.
1	.2280	15	.1800	29	.1360	42	.0935	55	.0520	68	.0310
2	.2210	16	.1770	30	.1285	43	.0890	56	.0465	69	.02925
3	.2130	17	.1730	31	.1200	44	.0860	57	.0430	70	.0280
4	.2090	18	.1695	32	.1160	45	.0820	58	.0420	71	.0260
5	.2055	19	.1660	33	.1130	46	.0810	59	.0410	72	.0250
6	.2040	20	.1610	34	.1110	47	.0785	60	.0400	73	.0240
7	.2010	21	.1590	35	.1100	48	.0760	61	.0390	74	.0225
8	.1990	22	.1570	36	.1065	49	.0730	62	.0380	75	.0210
9	.1960	23	.1540	37	.1040	50	.0700	63	.0370	76	.0200
10	.1935	24	.1520	38	.1015	51	.0670	64	.0360	77	.0180
11	.1910	25	.1495	39	.0995	52	.0635	65	.0350	78	.0160
12	.1890	26	.1470	40	.0980	53	.0595	66	.0330	79	.0145
13	.1850	27	.1440	41	.0960	54	.0550	67	.0320	80	.0135
14	.1820	28	.1405								

MISCELLANEOUS FORMULAE FOR COPPER WIRES

Diameter in 0.001 inches Squared = Circular Mils.
Circular Mils × 0.7854 = Square Mils.
0.000003027 × Circular Mils = Pounds per foot.
0.003027 × Circular Mils = Pounds per 1000 ft.
0.015983 × Circular Mils = Pounds per mile
0.003854 × Square Mils = Pounds per 1000 ft.
330,353 ÷ Circular Mils = Feet per pound
0.096585 × Circular Mils = Feet per ohm.
10.353568 ÷ Circular Mils = Ohms per foot
Breaking weight of Wire ÷ Area = Breaking weight per sq. inch.
Breaking weight per sq. in. × Area = Breaking weight of wire.
Weight of copper = 1⅛ times weight of iron wire of same diameter.

STANDARD WROUGHT IRON PIPE
BLACK OR GALVANIZED

Size	Diameters		Thickness	Weight per foot		Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings		Diameter	Length	Weight
⅛	.405	.269	.068	.244	.245	27	.562	⅞	.029
¼	.540	.364	.088	.424	.425	18	.685	1	.043
⅜	.675	.493	.091	.567	.568	18	848	1⅛	.070
½	.840	.622	.109	.850	.852	14	1.024	1⅜	.116
¾	1.050	.824	.113	1.130	1.134	14	1.281	1⅝	.209
1	1.315	1.049	.133	1.678	1.684	11½	1.576	1⅞	.343
1¼	1.660	1.380	.140	2.272	2.281	11½	1.950	2⅛	.535
1½	1.900	1.610	.145	2.717	2.731	11½	2.218	2⅜	.743
2	2.375	2.067	.154	3.652	3.678	11½	2.760	2⅝	1.208
2½	2.875	2.469	.203	5.793	5.819	8	3.276	2⅞	1.720
3	3.500	3.068	.216	7.575	7.616	8	3.948	3⅛	2.498
3½	4.000	3.548	.226	9.109	9.202	8	4.591	3⅝	4.241
4	4.500	4.026	.237	10.790	10.889	8	5.091	3⅝	4.741
4½	5.000	4.506	.247	12.538	12.642	8	5.591	3⅝	5.241
5	5.563	5.047	.258	14.617	14.810	8	6.296	4⅛	8.091
6	6.625	6.065	.280	18.974	19.185	8	7.358	4⅛	9.554
7	7.625	7.023	.301	23.544	23.769	8	8.358	4⅛	10.932
8	8.625	8.071	.277	24.696	25.000	8	9.358	4⅝	13.905
8	8.625	7.981	.322	28.554	28.809	8	9.358	4⅝	13.905
9	9.625	8.941	.342	33.907	34.188	8	10.358	5⅛	17.236
10	10.750	10.192	.279	31.201	32.000	8	11.721	6⅛	29.877
10	10.750	10.136	.307	34.240	35.000	8	11.721	6⅛	29.877
10	10.750	10.020	.365	40.483	41.132	8	11.721	6⅛	29.877
11	11.750	11.000	.375	45.557	46.247	8	12.721	6⅛	32.550
12	12.750	12.090	.330	43.773	45.000	8	13.958	6⅛	43.098
12	12.750	12.000	.375	49.562	50.706	8	13.958	6⅛	43 098
13	14.000	13.250	.375	54.568	55.824	8	15.208	6⅛	47.152
14	15.000	14.250	.375	58.573	60.375	8	16.446	6⅛	59.493
15	16.000	15.250	.375	62.579	64.500	8	17.446	6⅛	63.294

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

TRIGONMETRIC SINES AND COSINES

Deg.	0'	10'	20'	30'	40'	50'	60'	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02909	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05815	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17938	0.18224	0.18510	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31455	0.31731	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
	60'	50'	40'	30'	20'	10'	0'	Deg.

TRIGONMETRIC SINES AND COSINES

Deg.	0′	10′	20′	30′	40′	50′	60′	
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41205	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43314	0.43576	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62252	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68836	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC SINES AND COSINES

Deg.	0′	10′	20′	30′	40′	50′	60′	
45	0.70711	0.70916	0.71121	0.71325	0.71529	0.71732	0.71934	44
46	0.71934	0.72136	0.72337	0.72537	0.72737	0.72937	0.73135	43
47	0.73135	0.73333	0.73531	0.73728	0.73924	0.74120	0.74315	42
48	0.74315	0.74509	0.74703	0.74896	0.75088	0.75280	0.75471	41
49	0.75471	0.75662	0.75851	0.76041	0.76229	0.76417	0.76604	40
50	0.76604	0.76791	0.76977	0.77163	0.77347	0.77531	0.77715	39
51	0.77715	0.77897	0.78079	0.78261	0.78442	0.78622	0.78801	38
52	0.78801	0.78980	0.79158	0.79335	0.79512	0.79688	0.79864	37
53	0.79864	0.80038	0.80212	0.80386	0.80558	0.80730	0.80902	36
54	0.80902	0.81072	0.81242	0.81412	0.81580	0.81748	0.81915	35
55	0.81915	0.82082	0.82248	0.82413	0.82577	0.82741	0.82904	34
56	0.82904	0.83066	0.83228	0.83389	0.83549	0.83708	0.83867	33
57	0.83867	0.84025	0.84183	0.84339	0.84495	0.84650	0.84805	32
58	0.84805	0.84959	0.85112	0.85264	0.85416	0.85567	0.85717	31
59	0.85717	0.85866	0.86015	0.86163	0.86310	0.86457	0.86603	30
60	0.86603	0.86748	0.86892	0.87036	0.87178	0.87321	0.87462	29
61	0.87462	0.87603	0.87743	0.87882	0.88020	0.88158	0.88295	28
62	0.88295	0.88431	0.88566	0.88701	0.88835	0.88968	0.89101	27
63	0.89101	0.89232	0.89363	0.89493	0.89623	0.89752	0.89879	26
64	0.89879	0.90007	0.90133	0.90259	0.90383	0.90508	0.90631	25
65	0.90631	0.90753	0.90875	0.90996	0.91116	0.91236	0.91355	24
66	0.91355	0.91473	0.91590	0.91706	0.91822	0.91936	0.92051	23
67	0.92051	0.92164	0.92276	0.92388	0.92499	0.92609	0.92718	22
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC SINES AND COSINES

Deg.	0′	10′	20′	30′	40′	50′	60′	
68	0.92718	0.92827	0.92935	0.93042	0.93148	0.93253	0.93358	21
69	0.93358	0.93462	0.93565	0.93667	0.93769	0.93869	0.93969	20
70	0.93969	0.94068	0.94167	0.94264	0.94361	0.94457	0.94552	19
71	0.94552	0.94646	0.94740	0.94832	0.94924	0.95015	0.95106	18
72	0.95106	0.95195	0.95284	0.95372	0.95459	0.95545	0.95631	17
73	0.95631	0.95715	0.95799	0.95882	0.95964	0.96046	0.96126	16
74	0.96126	0.96206	0.96285	0.96363	0.96440	0.96517	0.96593	15
75	0.96593	0.96668	0.96742	0.96815	0.96887	0.96959	0.97030	14
76	0.97030	0.97100	0.97169	0.97237	0.97305	0.97371	0.97437	13
77	0.97437	0.97502	0.97566	0.97630	0.97692	0.97754	0.97815	12
78	0.97815	0.97875	0.97934	0.97993	0.98050	0.98107	0.98163	11
79	0.98163	0.98218	0.98272	0.98326	0.98378	0.98430	0.98481	10
80	0.98481	0.98531	0.98580	0.98629	0.98676	0.98723	0.98769	9
81	0.98769	0.98814	0.98858	0.98902	0.98944	0.98986	0.99027	8
82	0.99027	0.99067	0.99106	0.99145	0.99182	0.99219	0.99255	7
83	0.99255	0.99290	0.99324	0.99357	0.99390	0.99421	0.99452	6
84	0.99452	0.99482	0.99511	0.99540	0.99567	0.99594	0.99620	5
85	0.99620	0.99644	0.99669	0.99692	0.99714	0.99736	0.99756	4
86	0.99756	0.99776	0.99795	0.99814	0.99831	0 99847	0.99863	3
87	0.99863	0.99878	0.99392	0.99905	0.99917	0.99929	0.99939	2
88	0.99939	0.99949	0.99958	0.99966	0.99973	0.99979	0.99985	1
89	0.99985	0.99989	0.99993	0.99996	0.99998	0.99999	1.00000	0
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC TANGENTS AND COTANGENTS

Deg.	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02037	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0,04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0 06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12279	83
7	0.12279	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20043	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21865	0.22170	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0,27733	0.28046	0.28360	0.28675	74
16	0.28675	0.28989	0.29305	0.29621	0.29938	0.30255	0 30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0 32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34759	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37389	0.37720	0 38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39728	0 40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42448	67
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC TANGENTS AND COTANGENTS

Deg.	0′	10′	20′	30′	40′	50′	60′	
23	0.42448	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49496	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54673	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58514	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75813	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83416	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94897	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC TANGENTS AND COTANGENTS

Deg.	0′	10′	20′	30′	40′	50′	60′	
45	1.00000	1.00584	1.01170	1.01761	1.02355	1.02952	1.03553	44
46	1.03553	1.04158	1.04766	1.05378	1.05994	1.06613	1.07237	43
47	1.07237	1.07864	1.08496	1.09131	1.09770	1.10414	1.11061	42
48	1.11061	1.11713	1.12369	1.13029	1.13694	1.14363	1.15037	41
49	1.15037	1.15715	1.16398	1.17085	1.17777	1.18474	1.19175	40
50	1.19175	1.19882	1.20593	1.21310	1.22032	1.22758	1.23490	39
51	1.23490	1.24227	1.24969	1.25717	1.26471	1.27230	1.27994	38
52	1.27994	1.28765	1.29541	1.30323	1.31111	1.31904	1.32705	37
53	1.32705	1.33511	1.34323	1.35142	1.35968	1.36800	1.37638	36
54	1.37638	1.38484	1.39336	1.40195	1.41061	1.41934	1.42815	35
55	1.42815	1.43703	1.44598	1.45501	1.46412	1.47330	1.48256	34
56	1.48256	1.49190	1.50133	1.51084	1.52043	1.53010	1.53987	33
57	1.53987	1.54972	1.55966	1.56969	1.57981	1.59002	1.60034	32
58	1.60034	1.61074	1.62125	1.63185	1.64256	1.65337	1.66428	31
59	1.66428	1.67530	1.68643	1.69766	1.70901	1.72047	1.73205	30
60	1.73205	1.74375	1.75556	1.76749	1.77955	1.79174	1.80405	29
61	1.80405	1.81649	1.82906	1.84177	1.85462	1.86760	1.88073	28
62	1.88073	1.89400	1.90742	1.92098	1.93470	1.94858	1.96261	27
63	1.96261	1.97681	1.99116	2.00569	2.02039	2.03526	2.05030	26
64	2.05030	2.06553	2.08094	2.09654	2.11234	2.12832	2.14451	25
65	2.14451	2.16090	2.17749	2.19430	2.21132	2.22857	2.24604	24
66	2.24604	2.26374	2.28167	2.29984	2.31826	2.33693	2.35585	23
67	2.35585	2.37504	2.39449	2.41421	2.43422	2.45451	2.47509	22
	60′	50′	40′	30′	20′	10′	0′	Deg.

TRIGONMETRIC TANGENTS AND COTANGENTS

Deg.	0′	10′	20′	30′	40′	50′	60′	
68	2.47509	2.49597	2.51715	2.53865	2.56047	2.58261	2.60509	21
69	2.60509	2.62791	2.65109	2.67462	2.69853	2.72281	2.74748	20
70	2.74748	2.77255	2.79802	2.82391	2.85024	2.87700	2.90421	19
71	2.90421	2.93189	2.96004	2.98869	3.01783	3.04749	3.07768	18
72	3.07768	3.10842	3.13972	3.17159	3.20406	3.23714	3.27085	17
73	3.27085	3.30521	3.34023	3.37594	3.41236	3.44951	3.48741	16
74	3.48741	3.52609	3.56558	3.60588	3.64705	3.68909	3.73205	15
75	3.73205	3.77595	3.82083	3.86671	3.91364	3.96165	4.01078	14
76	4.01078	4.06107	4.11256	4.16530	4.21933	4.27471	4.33148	13
77	4.33148	4.38969	4.44942	4.51071	4.57363	4.63825	4.70463	12
78	4.70463	4.77286	4.84301	4.91516	4.98940	5.06584	5.14455	11
79	5.14455	5.22567	5.30928	5.39552	5.48451	5.57638	5.67128	10
80	5.67128	5.76937	5.87080	5.97576	6.08444	6.19703	6.31375	9
81	6.31375	6.43484	6.56055	6.69116	6.82694	6.96823	7.11537	8
82	7.11537	7.26873	7.42871	7.59575	7.77035	7.95302	8.14435	7
83	8.14435	8.34496	8.55555	8.77689	9.00983	9.25530	9.51436	6
84	9.51436	9.78817	10.07803	10.38540	10.71191	11.05943	11.43005	5
85	11.43005	11.82617	12.25051	12.70621	13.19688	13.72674	14.30067	4
86	14.30067	14.92442	15.60478	16.34986	17.16934	18.07500	19.08114	3
87	19.08114	20.20555	21.47040	22.90377	24.54176	26.43160	28.63625	2
88	28.63625	31.24158	34.36777	38.18846	42.96408	49.10388	57.29000	1
89	57.29000	68.75009	85.93979	114.58865	171.88540	343.77371	+ ∞	0
	60′	50′	40′	30′	20′	10′	0′	Deg.

THE METRIC SYSTEM
TOGETHER WITH THE CUSTOMARY EQUIVALENTS

	Linear.		Square.	
	Metres to Feet.	Kilometres to Miles.	Square Metres to Sq. Feet.	Hectares to Acres.
1=	3.28083	0.62137	10.764	2.471
2=	6.56167	1.24274	21.528	4.942
3=	9.84250	1.86411	32.292	7.413
4=	13.12333	2.48548	43.055	9.884
5=	16.40417	3.10685	53.819	12.355
6=	19.68500	3.72822	64.583	14.826
7=	22.96583	4.34959	75.347	17.297
8=	26.24667	4.97096	86.111	19.768
9=	29.52750	5.59233	96.874	22.239

	Cubic.		Capacity.	Weight.
	Cu. Decimetres to Cubic Inches.	Cu. Metres to Cu. Yards.	Litres to Quarts.	Kilogrammes to Pounds Avoirdupois.
1=	61.023	1.308	1.0567	2.20462
2=	122.047	2.616	2.1134	4.40924
3=	183.070	3.924	3.1700	6.61386
4=	244.093	5.232	4.2267	8.81849
5=	305.117	6.540	5.2834	11.02311
6=	366.140	7.848	6.3401	13.22773
7=	427.163	9.156	7.3968	15.43235
8=	488.187	10.464	8.4534	17.63697
9=	549.210	11.771	9.5101	19.84159

Customary to Metric.

	Linear.		Square.	
	Feet to Metres.	Miles to Kilometres.	Sq. Feet to Sq. Decimetres.	Acres to Hectares.
1=	0.304801	1.60935	9.290	0.4047
2=	0.609601	3.21869	18.581	0.8094
3=	0.914402	4.82804	27.871	1.2141
4=	1.219202	6.43739	37.161	1.6187
5=	1.524003	8.04674	46.452	2.0234
6=	1.828804	9.65608	55.742	2.4281
7=	2.133604	11.26543	65.032	2.8328
8=	2.438405	12.87478	74.323	3.2375
9=	2.743205	14.48412	83.613	3.6422

	Cubic.		Capacity.	Weight.
	Cu. Feet to Cu. Metres.	Bushels to Hectolitres.	Quarts to Litres.	Avoirdupois Pounds to Kilogrammes.
1=	0.02832	0.35242	0.94636	0.45359
2=	0.05663	0.70485	1.89272	0.90719
3=	0.08495	1.05727	2.83908	1.36078
4=	0.11327	1.40969	3.78544	1.81437
5=	0.14158	1.76211	4.73180	2.26796
6=	0.16990	2.11454	5.67816	2.72156
7=	0.19822	2.46696	6.62452	3.17515
8=	0.22654	2.81938	7.57088	3.62874
9=	0.25485	3.17181	8.51724	4.08233

TABLE OF DECIMAL EQUIVALENTS

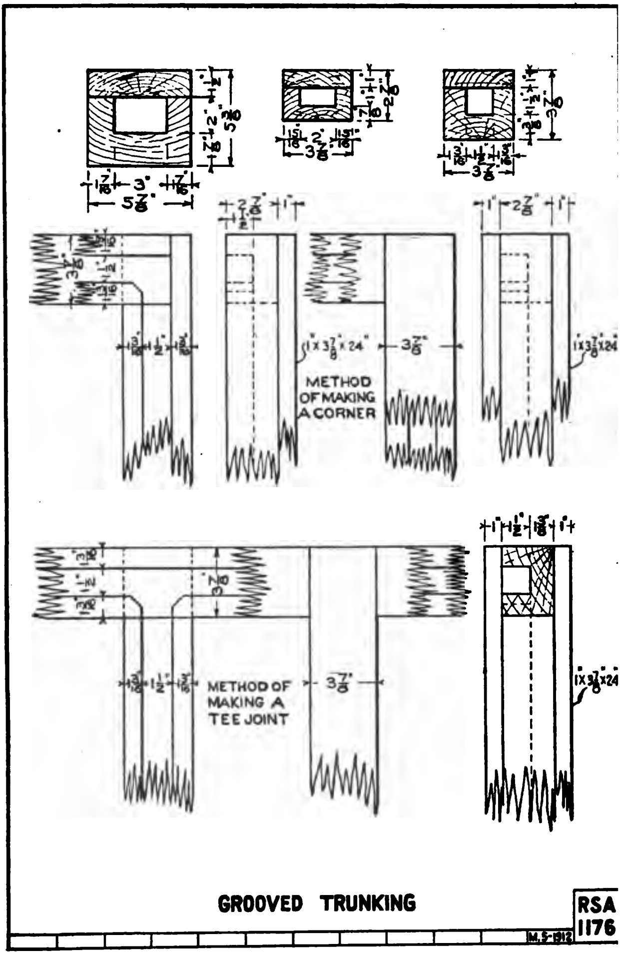
8ths	16 ths	32 nds	64 ths	Decimal	8ths	16 ths	32 nds	64 ths	Decimal
			1	.015625				33	.515625
		1	2	.03125			17	34	.53125
			3	.046875				35	.546825
	1	2	4	.0625		9	18	36	.5625
			5	.078125				37	.578125
		3	6	.09375			19	38	.59375
			7	.109375				39	.609375
1	2	4	8	.125	5	10	20	40	.625
			9	.146325				41	.640625
		5	10	.15625			21	42	.65625
			11	.171875				43	.671875
	3	6	12	.1875		11	22	44	.6875
			13	.203125				45	.703125
		7	14	.21875			23	46	.71875
			15	.234375				47	.734275
2	4	8	16	.25¼	6	12	24	48	.75¾
			17	.265625				49	.765625
		9	18	.28125			25	50	.78125
			19	.296875				51	.796875
	5	10	20	.3125		13	26	52	.8125
			21	.328125				53	.828125
		11	22	.34375			27	54	.84375
			23	.359375				55	.859375
3	6	12	24	.375	7	14	28	56	.875
			25	.390625				57	.890625
		13	26	.40625			29	58	.90325
			27	.421875				59	.921875
	7	14	28	.4375		15	30	60	.9375
			29	.453125				61	.953925
		15	30	.46875			31	62	.96875
			31	.484375				63	.984375
4	8	16	32	.5½	8	16	31	64	1.

TRUNKING—SIZES AND CAPACITY

No. U. S. & S.	Inside Dimensions of Groove	Outside Dim. Trunking Alone	Capping Alone	Capacity	
				No. 9 Single Cond.	5 Wire Cable
4	1½"x 1½"	2⅞"x 3⅞"	⅞"x 3⅞"	8	1
20	1½"x 2"	2⅞"x 4⅞"	⅞"x 4⅞"	10	2
16	2" x 3"	3⅞"x 5⅞"	1⅜"x 5⅞"	20	4
9	2" x 5"	3⅜"x 7¾"	1⅜"x 7¾"	32	6
10	2¼"x 7"	5⅜"x 9¾"	1⅞"x10¾"	54	8
46	3¼"x 7"	6⅜"x 9¾"	1¼"x10¾"	72	14
11	4¼"x 7"	7⅜"x 9¾"	1⅞"x10¾"	99	18
12	3¾"x12"	7⅜"x15¾"	1¼"x16¾"	160	32
13	3¾"x16"	7¾"x19¾"	1¼"x20¾"	210	42
51	4⅝"x15½"	9¼"x19¼"	1⅜"x20¼"	240	52
34	5⅛"x19½"	9¾"x23¼"	1⅜"x24¼"	338	66

NOTE—The wire capacities given in the above table allow 25 per cent. spare space. The capacity for wires smaller than No. 9 as used in signal work, is considered to be the same as that given for No. 9, there being no great difference in the wire diameters; a No. 6 wire will take up about the same space as two No. 9 wires. Trunking Nos. 4 and 16 are standard R. S. A. sizes. Nos. 4, 20 and 16 cover grooved trunking, while the remaining sizes are built up.

R. S. A. GROOVED TRUNKING



SQUARE HEAD LAG SCREWS

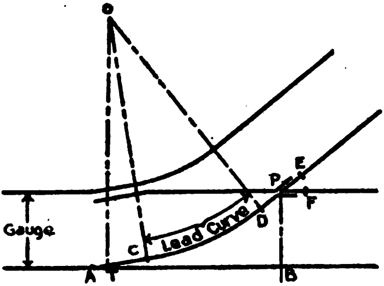
Diameter in Inches	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
Length in Inches	Average Weight per Hundred								
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1½	4.2	6.5	9.2	13.0	....	....	....	....	....
1¾	4.7	7.1	10.0	13.8	....	....	....	....	....
2	5.2	7.7	10.9	14.9	23.0	24.8	....	....	....
2¼	5.7	8.4	11.8	16.1	24.5	27.3	....	....	....
2½	6.2	9.2	12.7	17.4	26.0	29.0	43.0	....	....
3	7.2	10.6	14.6	19.0	29.2	32.9	48.3	75.0	....
3½	8.2	12.0	16.6	21.5	32.5	36.9	53.8	78.5	90
4	9.2	13.5	18.8	24.0	35.9	41.0	59.6	82.0	99
4½	10.2	15.0	20.7	26.5	39.3	44.9	65.5	86.0	108
5	11.3	16.5	22.8	29.0	42.7	48.8	71.5	90.0	118
5½	12.4	18.0	24.9	31.5	46.1	52.7	77.5	98.0	128
6	13.5	19.5	27.0	34.0	49.5	56.6	83.5	106.0	138

COMMON WIRE NAILS

Size	Length in Inches	Diameter in Inches	Approx. Number to Lb.	Approx. Lbs. per 1000
2D	1	.072	876	1.14
3D	1¼	.080	568	1.76
4D	1½	.100	316	3.16
5D	1¾	.100	271	3.69
6D	2	.113	181	5.53
7D	2¼	.113	161	6.21
8D	2½	.131	106	9.43
9D	2¾	.131	96	10.4
10D	3	.148	69	14.5
12D	3¼	.148	63	15.9
16D	3½	.162	49	20.4
20D	4	.192	31	32.3
30D	4½	.207	24	41.7
40D	5	.225	18	55.6
50D	5½	.244	14	71.4
60D	6	.263	11	90.9

TABLE OF TURNOUTS FROM STRAIGHT TRACK

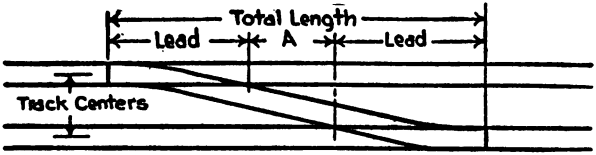
Gauge, 4 Feet, 8½ Inches. Throw of Switch, 5 Inches



Frog Number	Frog Angle FPE	Length Point of Frog to Toe PD	Length Point of Frog to Heel PE	Length of Switch Rail AC	Switch Angle BAC = TOC	Radius of Center Line OC−½ ga	Degree of Lead Curve	Lead-Dist. Actual Point of Switch Rail to Actual Point of Frog AB
	Deg. Min. Sec.	Ft. In.	Ft. In.	Ft. In.	Deg. Min. Sec.	Ft.	Deg Min. Sec.	Ft.
6	9-31-38	4– 0	7– 0	11–0	2-36-19	265.39	21-43-04	47.98
7	8-10-16	4– 5	8– 1	16–6	1-44-11	362.08	15-52-29	62.10
8	7-09-10	4– 9	8– 9	16–6	1-44-11	487.48	11-46-27	67.98
9	6-21-35	6– 0	10– 0	16–6	1-44-11	605.18	9-28-42	72.28
9½	6-01-32	6– 0	10– 0	16–6	1-44-11	695.45	8-14-45	75.71
10	5-43-29	6– 0	10– 6	16–6	1-44-11	790.25	7-15-18	77.93
11	5-12-18	6– 0	11– 6	22–0	1-18- 8	922.65	6-12-47	94.31
12	4-46-19	6– 5	12– 1	22–0	1-18- 8	1098.73	5-12-59	100.80
15	3-49-06	7– 8	14–10	33–0	0-52- 5	1744.38	3-17-01	133.28
16	3-34-47	8– 0	16– 0	33–0	0-52- 5	1993.24	2-52-59	137.57
18	3-10-56	8–10	17– 8	33–0	0-52- 5	2546.31	2-14-31	146.51
20	2-51-51	9– 8	19– 4	33–0	0-52- 5	3257.26	1-45-32	157.42
24	2-23-13	11– 4	23– 2	33–0	0-52- 5	4886.16	1-10-21	177.22

TABLE OF CROSSOVERS

Gauge, 4 Feet, 8½ Inches. Throw of Switch, 5 Inches



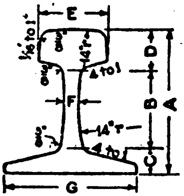
Frog Number	Lead	Distance (A) between Frog Points for Track Centers Below					
		11′	12′	13′	14′	15′	16′
	Feet	Feet	Feet	Feet	Feet	Feet	Feet
6	47.98	9.5	15.5	21.5	27.5	33.5	39.5
7	62.10	11.1	18.1	25.1	32.1	39.1	46.1
8	67.98	12.7	20.7	28.7	36.7	44.7	52.7
9	72.28	14.2	23.2	32.2	41.2	50.2	59.2
9½	75.71	15.0	24.5	34.0	43.5	53.0	62.5
10	77.93	15.8	25.8	35.8	45.8	55.8	65.8
11	94.31	17.4	28.4	39.4	50.4	61.4	72.4
12	100.80	19.0	31.0	43.0	55.0	67.0	79.0
15	133.28	23.8	38.8	53.8	68.8	83.8	98.8
16	137.57	25.3	41.3	57.3	73.3	89.3	105.3
18	146.51	28.4	46.4	64.4	82.4	100.4	118.4
20	157.42	31.6	51.6	71.6	91.6	111.6	131.6
24	177.22	38.0	62.0	86.0	110.0	134.0	158.0

Frog Number	Total Length of Crossover for Track Centers Below					
	11′	12′	13′	14′	15′	16′
	Feet	Feet	Feet	Feet	Feet	Feet
6	105.5	111.5	117.5	123.5	129.5	135.5
7	135.3	142.3	149.3	156.3	163.3	170.3
8	148.7	156.7	164.7	172.7	180.7	188.7
9	158.8	167.8	176.8	185.8	194.8	203.8
9½	166.4	175.9	185.4	194.9	204.4	213.9
10	171.7	181.7	191.7	201.7	211.7	221.7
11	206.0	217.0	228.0	239.0	250.0	261.0
12	220.6	232.6	244.6	256.6	268.6	280.6
15	290.4	305.4	320.4	335.4	350.4	365.4
16	300.4	316.4	332.4	348.4	364.4	380.4
18	321.4	339.4	357.4	375.4	393.4	411.4
20	346.4	366.4	386.4	406.4	426.4	446.4
24	392.4	416.4	440.4	464.4	488.4	512.4

Note.—Distance (A) between frog points based on formula: Distance = (track centers − 2 x gauge) x frog number.

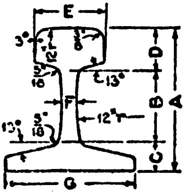
RAIL SECTIONS

A. R. A. RAILS—TYPE "A"



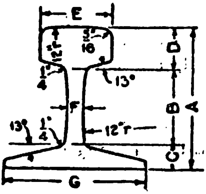
Weight per Yard	A	B	C	D	E	F	G
Lbs.	In.	In.	In.	In.	In.	In.	In.
60	4 1/2	2 29/64	13/16	1 15/64	2 1/4	15/32	4
70	4 3/4	2 1/2	29/32	1 11/32	2 3/8	1/2	4 1/4
80	5 1/8	2 23/32	31/32	1 7/16	2 1/2	33/64	4 5/8
90	5 5/8	3 5/32	1	1 15/32	2 9/16	9/16	5 1/8
100	6	3 3/8	1 1/16	1 9/16	2 3/4	9/16	5 1/2

A. R. A. RAILS—TYPE "B"



Weight per Yard	A	B	C	D	E	F	G
Lbs.	In.	In.	In.	In.	In.	In.	In.
60	4 3/16	2 1/16	7/8	1 1/4	2 1/8	31/64	3 11/16
70	4 35/64	2 17/64	59/64	1 23/64	2 3/8	33/64	4 3/64
80	4 15/16	2 15/32	1	1 15/32	2 7/16	35/64	4 7/16
90	5 17/64	2 5/8	1 1/32	1 39/64	2 9/16	9/16	4 49/64
100	5 41/64	2 55/64	1 5/64	1 45/64	2 21/32	9/16	5 9/64

A. S. C. E. RAILS



Weight per Yard	A	B	C	D	E	F	G
Lbs.	In.	In.	In.	In.	In.	In.	In.
55	4 1/16	2 11/64	23/32	1 11/64	2 1/4	15/32	4 1/16
60	4 1/4	2 17/64	49/64	1 7/32	2 3/8	31/64	4 1/4
65	4 7/16	2 3/8	25/32	1 9/32	2 13/32	1/2	4 7/16
70	4 5/8	2 15/32	13/16	1 11/32	2 7/16	33/64	4 5/8
75	4 13/16	2 35/64	27/32	1 27/64	2 15/32	17/32	4 13/16
80	5	2 5/8	7/8	1 1/2	2 1/2	35/64	5
85	5 3/16	2 3/4	57/64	1 35/64	2 9/16	9/16	5 3/16
90	5 3/8	2 55/64	59/64	1 19/32	2 5/8	9/16	5 3/8
95	5 9/16	2 63/64	15/16	1 41/64	2 11/16	9/16	5 9/16
100	5 3/4	3 5/64	31/32	1 45/64	2 3/4	9/16	5 3/4
110	6 1/8	3 11/32	1	1 25/32	2 7/8	37/64	6 1/8

LOGARITHMS.

1. Theory. The power n to which a fixed number, say B, called the Base, must be raised in order to equal a given number A is called the logarithm of A to the base B; thus if $B^n = A$, then n is the logarithm of A to the base B. When 10 is the base, as in the common or Briggs system, the logarithm of 100 is 2, for $10^2 = 100$ and likewise the logarithm of $1000 = 3$. In general

$$\log xy = \log x + \log y. \qquad (1)$$

$$\log \frac{x}{y} = \log x - \log y. \qquad (2)$$

$$\log x^n = n \log x. \qquad (3)$$

For example,

$$\begin{aligned} \log_{10} 376.42 &= \log (100 \times 3.7642) \\ &= \log 100 + \log 3.7642 \\ &= 2 + \log 3.7642 \end{aligned}$$

The integral part of a logarithm is called the *Characteristic*; the fraction or decimal part is the *Mantissa*. The characteristic of the log of a number greater than 1 is positive and 1 less than the number of digits in its integral part; thus log 4580 = 3.6609. The characteristic of the logarithm of a decimal is negative and numerically one greater than the number of cyphers immediately following the decimal point, but to avoid writing a negative characteristic before a positive mantissa, it is customary to add 10 to the characteristic and to indicate that this added number is to be subtracted from the whole logarithm; thus $\log 0.00458 = \bar{3}.6609 = 7.6609 - 10$. The standard log tables on the following pages give the mantissa only, the characteristic of the number being easily determined by the above rules.

2. Examples. Equations (1), (2) and (3) respectively, are used as the basis of multiplication, division and raising a given number to a given power; for example,

Multiply 376.2 by 0.587

$$\begin{aligned} \log 376.2 &= 2 + 0.57541 \\ \log 0.587 &= -1 \underline{+ 0.76863} \\ &= 1 + 1.34404 \text{ by addition} \\ &= 2.34404 \end{aligned}$$

and from the tables the number whose log is 2.34404 = 220.8

Divide 37.62 by 587

$$\begin{aligned} \log 37.62 &= 1 + 0.57541 = 1.57541 \\ \log 587 &= 2 + 0.76863 = \underline{2 + 0.76863} \\ &= -2 + 0.80678 \end{aligned}$$

by subtraction and from the tables the number whose log is $-2 + 0.80678 = 0.06409$.

COMMON LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9
10	00000	00432	00860	01283	01703	02119	02531	02938	03342	03743
11	04139	04532	04922	05308	05690	06070	06446	06819	07188	07555
12	07918	08279	08636	08991	09342	09691	10037	10380	10721	11059
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301
14	14613	14921	15229	15534	15836	16137	16435	16732	17026	17319
15	17609	17897	18184	18469	18752	19033	19312	19590	19866	20140
16	20412	20683	20952	21218	21484	21748	22010	22271	22530	22788
17	23045	23299	23552	23804	24054	24303	24551	24797	25042	25285
18	25527	25767	26007	26245	26481	26717	26951	27184	27415	27646
19	27875	28103	28330	28555	28780	29003	29225	29446	29666	29885
20	30103	30319	30535	30749	30963	31175	31386	31597	31806	32014
21	32222	32428	32633	32838	33041	33243	33445	33646	33845	34044
22	34242	34439	34635	34830	35024	35218	35410	35602	35793	35983
23	36173	36361	36548	36735	36921	37106	37291	37474	37657	37839
24	38021	38201	38381	38560	38739	38916	39093	39269	39445	39619
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330
26	41497	41664	41830	41995	42160	42324	42488	42651	42813	42975
27	43136	43296	43456	43616	43775	43933	44090	44248	44404	44560
28	44716	44870	45024	45178	45331	45484	45636	45788	45939	46089
29	46240	46389	46538	46686	46834	46982	47129	47275	47421	47567
30	47712	47856	48000	48144	48287	48430	48572	48713	48855	48995
31	49136	49276	49415	49554	49693	49831	49968	50105	50242	50379
32	50515	50650	50785	50920	51054	51188	51321	51454	51587	51719
33	51851	51982	52113	52244	52374	52504	52633	52763	52891	53020
34	53148	53275	53402	53529	53655	53781	53907	54033	54157	54282
35	54407	54530	54654	54777	54900	55022	55145	55266	55388	55509
36	55630	55750	55870	55990	56110	56229	56348	56466	56584	56702
37	56820	56937	57054	57170	57287	57403	57518	57634	57749	57863
38	57978	58092	58206	58319	58433	58546	58658	58771	58883	58995
39	59106	59217	59328	59439	59549	59659	59769	59879	59988	60097
40	60206	60314	60422	60530	60638	60745	60852	60959	61066	61172
41	61278	61384	61489	61595	61700	61804	61909	62013	62118	62221
42	62325	62428	62531	62634	62736	62838	62941	63042	63144	63245
43	63347	63447	63548	63648	63749	63848	63948	64048	64147	64246
44	64345	64443	64542	64640	64738	64836	64933	65030	65127	65224
45	65321	65417	65513	65609	65705	65801	65896	65991	66086	66181
46	66276	66370	66464	66558	66651	66745	66838	66931	67024	67117
47	67210	67302	67394	67486	67577	67669	67760	67851	67942	68033
48	68124	68214	68304	68394	68484	68574	68663	68752	68842	68930
49	69020	69108	69196	69284	69372	69460	69548	69635	69722	69810
50	69897	69983	70070	70156	70243	70329	70415	70500	70586	70671
51	70757	70842	70927	71011	71096	71180	71265	71349	71433	71516
52	71600	71683	71767	71850	71933	72015	72098	72181	72263	72345
53	72428	72509	72591	72672	72754	72835	72916	72997	73078	73158
54	73239	73319	73399	73480	73559	73639	73719	73798	73878	73957

COMMON LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9
55	74036	74115	74193	74272	74351	74429	74507	74585	74663	74741
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742
60	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169
62	79239	79309	79379	79448	79518	79588	79657	79726	79796	79865
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888
66	81954	82020	82085	82151	82216	82282	82347	82412	82477	82542
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83821
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672
72	85733	85793	85853	85913	85973	86033	86093	86153	86213	86272
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855
83	91907	91960	92012	92064	92116	92168	92220	92272	92324	92376
84	92427	92479	92531	92582	92634	92685	92737	92788	92839	92890
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331
92	96378	96426	96473	96520	96567	96614	96661	96708	96754	96801
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181
96	98227	98272	98317	93362	98407	98452	98497	98542	98587	98632
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519
99	99563	99607	99651	99694	99738	99782	99825	99869	99913	99956

THERMOMETERS

CENTRIGADE AND FAHRENHEIT

Rises in temperature in electrical apparatus, such for example as transformers and generators, are specified in Centigrade degrees and in fact all scientific heat measurements are carried out on this basis. The fundamental scale readings of the Centigrade thermometer as compared to the Fahrenheit thermometer are as follows:—

	Boiling Point	Freezing Point
Centigrade	100°	0°
Fahrenheit	212°	32°

Hence to transpose from one scale to the other

$$F^\circ = \left(\frac{9}{5} \times C^\circ\right) + 32^\circ \quad \text{and} \quad C^\circ = \frac{5}{9}\left(F^\circ - 32^\circ\right)$$

COMPARISON BETWEEN CENTIGRADE AND FAHRENHEIT SCALES

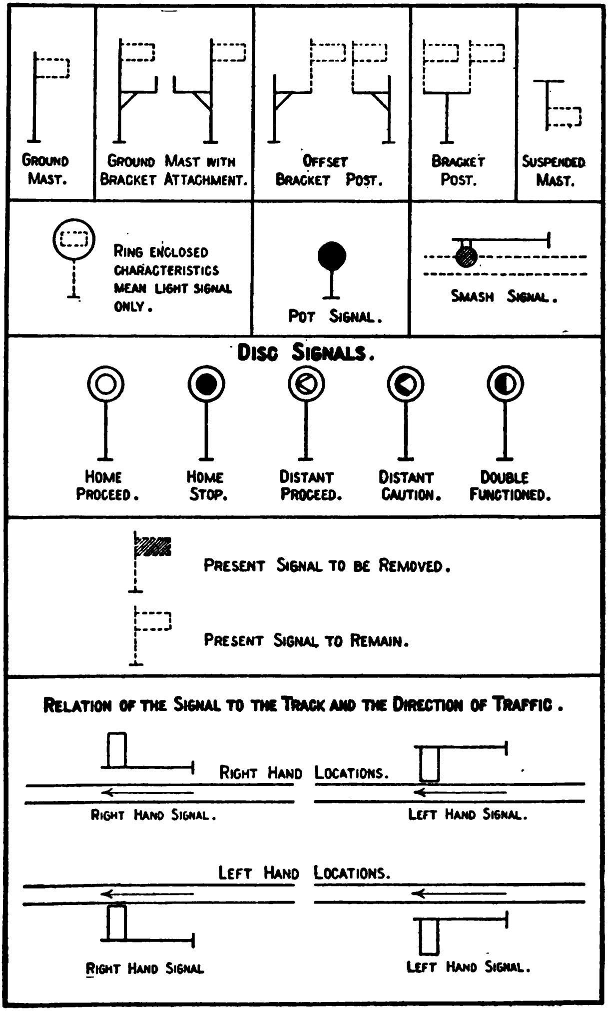
Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
−5	−20.55	11	−11.66	27	−2.77	43	6.11	59	15.00
−4	−20.00	12	−11.11	28	−2.22	44	6.66	60	15.55
−3	−19.44	13	−10.55	29	−1.66	45	7.22	61	16.11
−2	−18.88	14	−10.00	30	−1.11	46	7.77	62	16.66
−1	−18.33	15	− 9.44	31	− .55	47	8.33	63	17.22
Zero	−17.77	16	− 8.88	32	Zero	48	8.88	64	17.77
+1	−17.22	17	− 8.33	33	+ .55	49	9.44	65	18.33
2	−16.66	18	− 7.77	34	1.11	50	10.00	66	18.88
3	−16.11	19	− 7.22	35	1.66	51	10.55	67	19.44
4	−15.55	20	− 6.66	36	2.22	52	11.11	68	20.00
5	−15.00	21	− 6.11	37	2.77	53	11.66	69	20.55
6	−14.44	22	− 5.55	38	3.33	54	12.22	70	21.11
7	−13.88	23	− 5.00	39	3.88	55	12.77	71	21.66
8	−13.33	24	− 4.44	40	4.44	56	13.33	72	22.22
9	−12.77	25	− 3.88	41	5.00	57	13.88	73	22.77
10	−12.22	26	− 3.33	42	5.55	58	14.44	74	23.33

COMPARISON BETWEEN CENTIGRADES AND FAHRENHEIT SCALES.—Continued.

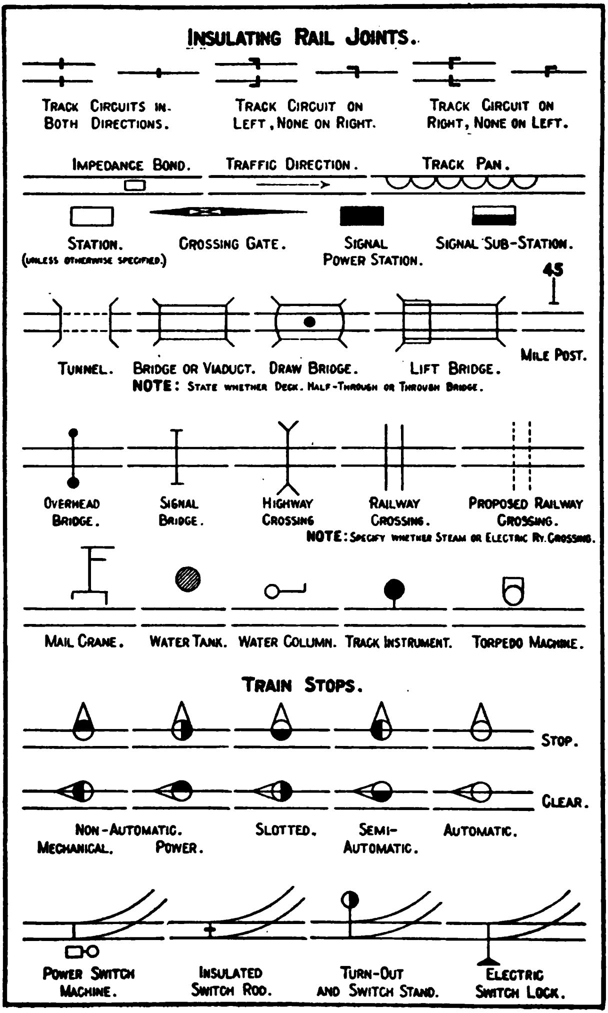
Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
75	23.88	121	49.44	167	75.00	213	100.55	259	126.11
76	24.44	122	50.00	168	75.55	214	101.11	260	126.66
77	25.00	123	50.55	169	76.11	215	101.66	261	127.22
78	25.55	124	51.11	170	76.66	216	102.22	262	127.77
79	26.11	125	51.66	171	77.22	217	102.77	263	128.33
80	26.66	126	52.22	172	77.77	218	103.33	264	128.88
81	27.22	127	52.77	173	78.33	219	103.88	265	129.44
82	27.77	128	53.33	174	78.88	220	104.44	266	130.00
83	28.33	129	53.88	175	79.44	221	105.00	267	130.55
84	28.88	130	54.44	176	80.00	222	105.55	268	131.11
85	29.44	131	55.00	177	80.55	223	106.11	269	131.66
86	30.00	132	55.55	178	81.11	224	106.66	270	132.22
87	30.55	133	56.11	179	81.66	225	107.22	271	132.77
88	31.11	134	56.66	180	82.22	226	107.77	272	133.33
89	31.66	135	57.22	181	82.77	227	108.33	273	133.88
90	32.22	136	57.77	182	83.33	228	108.88	274	134.44
91	32.77	137	58.33	183	83.88	229	109.44	275	135.00
92	33.33	138	58.88	184	84.44	230	110.00	276	135.55
93	33.88	139	59.44	185	85.00	231	110.55	277	136.11
94	34.44	140	60.00	186	85.55	232	111.11	278	136.66
95	35.00	141	60.55	187	86.11	233	111.66	279	137.22
96	35.55	142	61.11	188	86.66	234	112.22	280	137.77
97	36.11	143	61.66	189	87.22	235	112.77	281	138.33
98	36.66	144	62.22	190	87.77	236	113.33	282	138.88
99	37.22	145	62.77	191	88.33	237	113.88	283	139.44
100	37.77	146	63.33	192	88.88	238	114.44	284	140.00
101	38.33	147	63.88	193	89.44	239	115.00	285	140.55
102	38.88	148	64.44	194	90.00	240	115.55	286	141.11
103	39.44	149	65.00	195	90.55	241	116.11	287	141.66
104	40.00	150	65.55	196	91.11	242	116.66	288	142.22
105	40.55	151	66.11	197	91.66	243	117.22	289	142.77
106	41.11	152	66.66	198	92.22	244	117.77	290	143.33
107	41.66	153	67.22	199	92.77	245	118.33	291	143.88
108	42.22	154	67.77	200	93.33	246	118.88	292	144.44
109	42.77	155	68.33	201	93.88	247	119.44	293	145.00
110	43.33	156	68.88	202	94.44	248	120.00	294	145.55
111	43.88	157	69.44	203	95.00	249	120.55	295	146.11
112	44.44	158	70.00	204	95.55	250	121.11	296	146.66
113	45.00	159	70.55	205	96.11	251	121.66	297	147.22
114	45.55	160	71.11	206	96.66	252	122.22	298	147.77
115	46.11	161	71.66	207	97.22	253	122.77	299	148.33
116	46.66	162	72.22	208	97.77	254	123.33	300	148.88
117	47.22	163	72.77	209	98.33	255	123.88	400	204.44
118	47.77	164	73.33	210	98.88	256	124.44	600	315.55
119	48.33	165	73.88	211	99.44	257	125.00	800	426.66
120	48.88	166	74.44	212	100.00	258	125.55	1000	537.77

[illegible] SIGNAL SYMBOLS

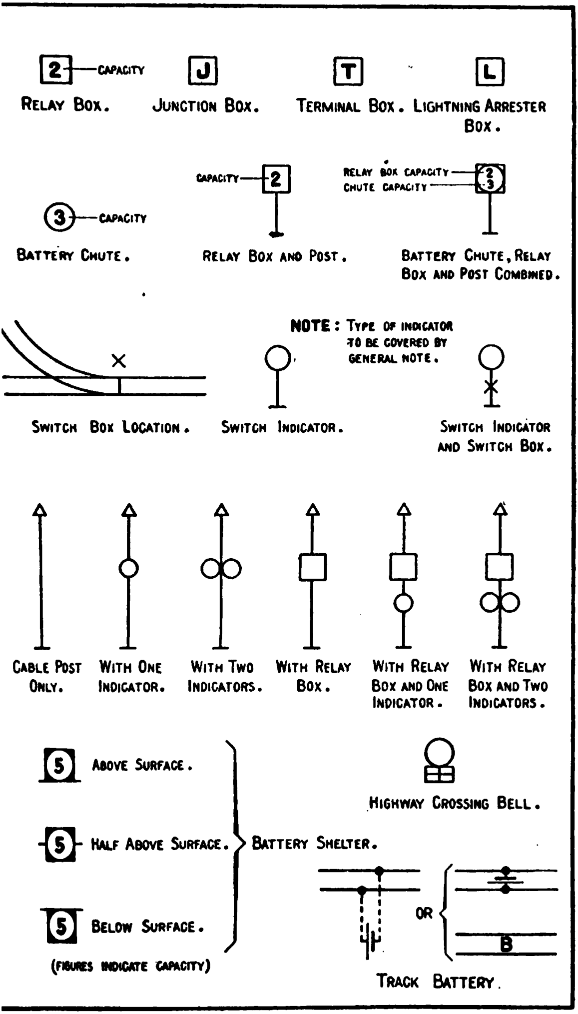
R. S. A. SIGNAL SYMBOLS.



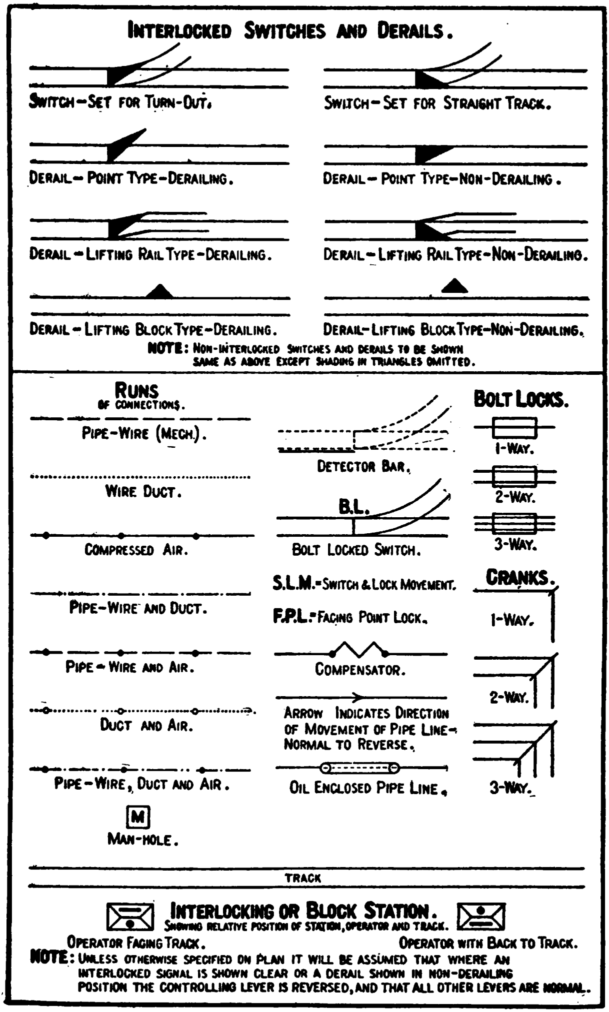
R. S. A. LOCATION SYMBOLS.



R. S. A. LOCATION SYMBOLS.



R. S. A. TRACK SYMBOLS, ETC.

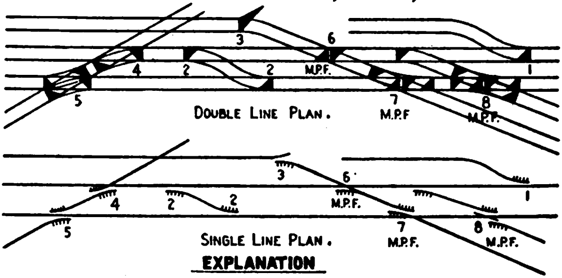


NOTE: NON-INTERLOCKED SWITCHES AND DERAILS TO BE SHOWN SAME AS ABOVE EXCEPT SHADING IN TRIANGLES OMITTED.

NOTE: UNLESS OTHERWISE SPECIFIED ON PLAN IT WILL BE ASSUMED THAT WHERE AN INTERLOCKED SIGNAL IS SHOWN CLEAR OR A DERAIL SHOWN IN NON-DERAILING POSITION THE CONTROLLING LEVER IS REVERSED, AND THAT ALL OTHER LEVERS ARE NORMAL.

R. S. A. LEADOUT SYMBOLS, ETC.

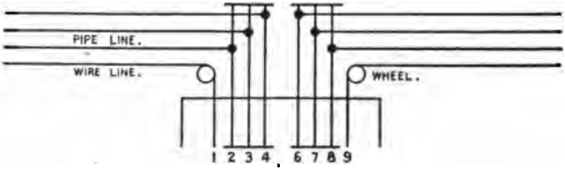
INTERLOCKED SWITCHES, DERAILS, ETC.



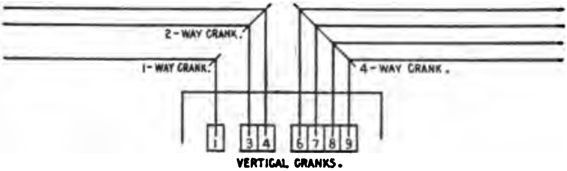
EXPLANATION

1 – SIMPLE TURN-OUT.
2 – SIMPLE CROSS-OVER.
3 – DERAIL – POINT TYPE.
4 – SINGLE SLIP SWITCH.
5 – DOUBLE SLIP SWITCH.
6 – MOVABLE POINT CROSSING FROG. (M.P.F.)
7 – SINGLE SLIP SWITCH WITH M.P.F.
8 – DOUBLE SLIP SWITCH WITH M.P.F.

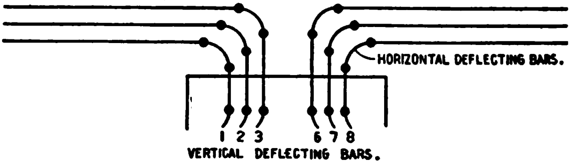
ROCKING SHAFT LEAD-OUT.



CRANK LEAD-OUT.



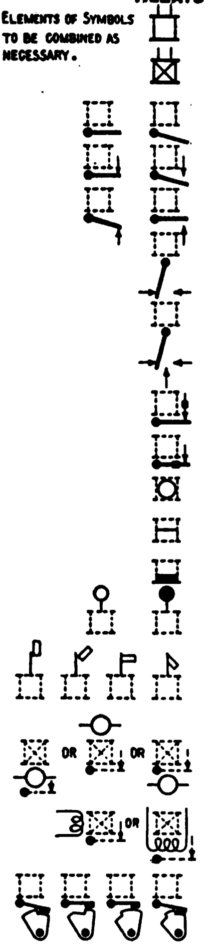
DEFLECTING BAR LEAD-OUT.



R. S. A. SYMBOLS FOR RELAYS, ETC.

Relays, Indicators and Locks.

Elements of Symbols to be Combined as Necessary.



D. C. Electro Magnet.

A. C. Electro Magnet.

Coil Energized or De-energized.

Neutral Front Contact – Closed or Open.

Neutral Back Contact – Closed or Open.

Polarized Armature – With Contacts.

3-Position Armature – With Contacts.

High Current Contact.

Magnetic Blow-out Contact.

Bell Attachment.

Double Winding – Specify if Differential.

Slow Acting.

Disc Type Indicator. ○ = Disc Invisible. ● = Disc Visible.

Semaphore Type Indicator. ⚑ = 3-Position.

Wire Wound Rotor.

Stationary Winding. ☒ = High Voltage Winding.

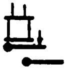
Electric Lock – Show Segments for Lever in Normal Position.

(See next page for examples of combinations.)

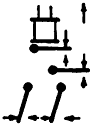
R. S. A. SYMBOLS FOR RELAYS, ETC.

Relays, Indicators and Locks.

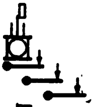
Examples of Combinations.



D.C. RELAY – Neutral – Energized –
One Independent Front Contact Closed –
One Independent Back Contact Open.



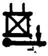
D.C. RELAY – Polarized – Energized –
Two Combination Front and Back Neutral Contacts –
Two Polarized Contacts Closed –
Two Polarized Contacts Open.



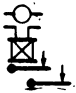
D.C. INDICATOR – Semaphore Type – Energized –
Three Front Contacts Closed –
Bell Attachment.

D.C. INDICATOR – Semaphore Type – Arm Horizontal –
Energized – Without Contacts.

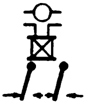
NOTE: Indicators (or repeaters) without contacts should be shown with armatures to indicate whether energized or de-energized.



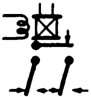
A.C. RELAY – One Energizing Circuit Type (Single Phase)
Energized – One Front Contact.



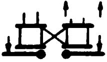
A.C. RELAY – Two Energizing Circuit Type – Energized –
Wire Wound Rotor –
Two Neutral Front Contacts.



A.C. RELAY – Two Energizing Circuit Type – Energized –
Wire Wound Rotor –
Two Polarized Contacts.



A.C. RELAY – Two Energizing Circuit Type – Energized –
Stationary Windings –
One Neutral Front Contact –
Two 3-Position Contacts.



D.C. INTERLOCKED RELAY.

D.C. ELECTRIC BELL.

Designate resistance in ohms of all D.C. relays, indicators and locks.

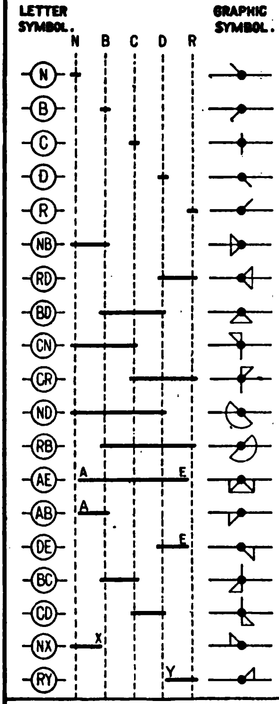
R. S. A. SYMBOLS FOR LEVER CONTACTS

CIRCUIT CONTROLLERS OPERATED BY LEVERS.

USE EITHER LETTER SYSTEM OR GRAPHIC SYSTEM.

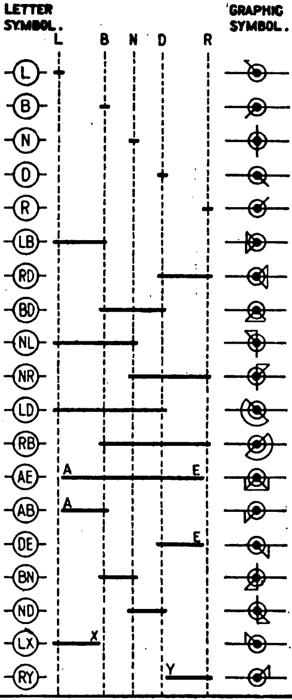
LEVERS WITH EXTREME END POSITION AS NORMAL.

N-FULL NORMAL POSITION OF LEVER
B-NORMAL INDICATION POSITION.
C-CENTRAL POSITION.
D-REVERSE INDICATION POSITION.
R-FULL REVERSE POSITION.



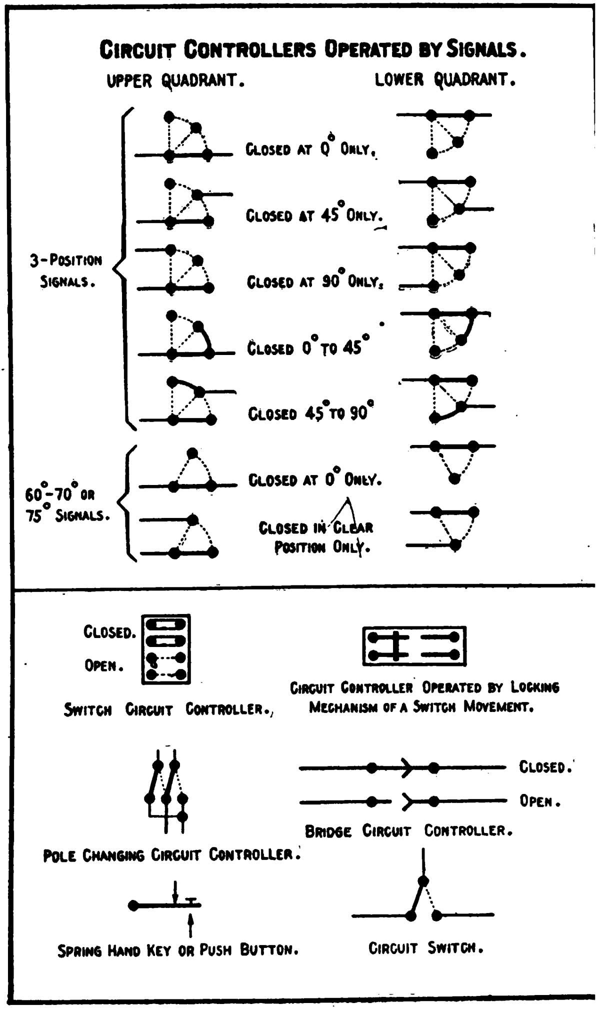
LEVERS WITH MIDDLE POSITION AS NORMAL.

N-NORMAL POSITION.
L-FULL REVERSE POSITION TO THE LEFT.
B-INDICATION POSITION TO THE LEFT.
D-INDICATION POSITION TO THE RIGHT.
R-FULL REVERSE POSITION TO THE RIGHT.

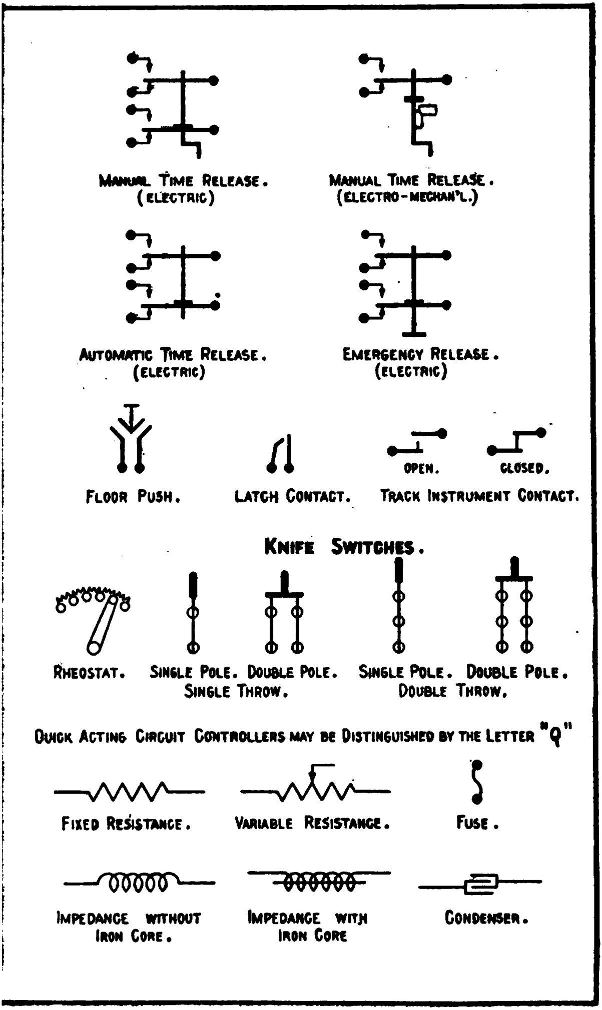


NOTE: HEAVY HORIZONTAL LINES INDICATE PORTION OF CYCLE OF LEVER THROUGH WHICH CIRCUIT IS CLOSED.

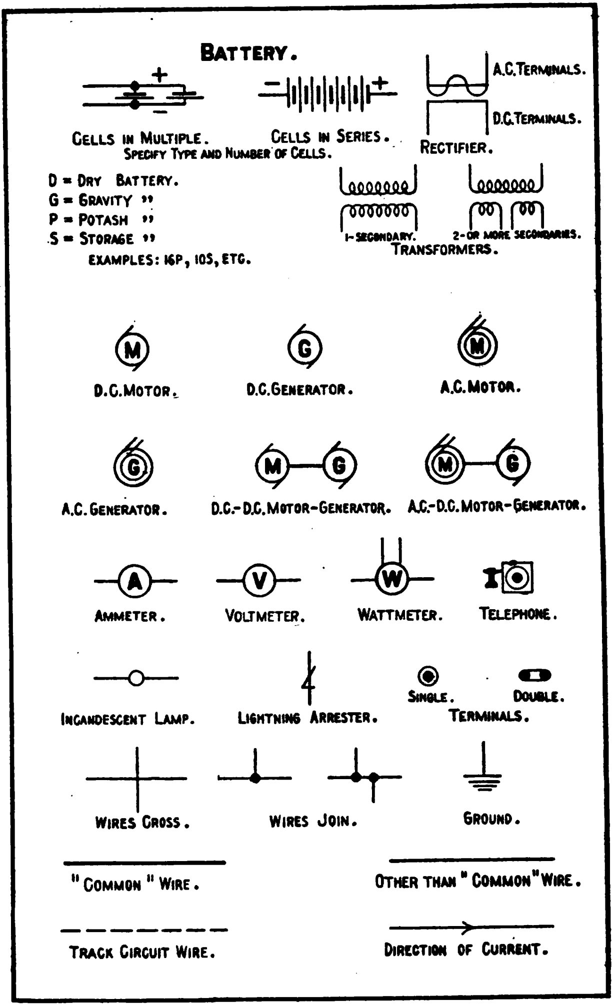
R. S. A. SYMBOLS FOR SIGNAL CIRCUIT CONTROLLER



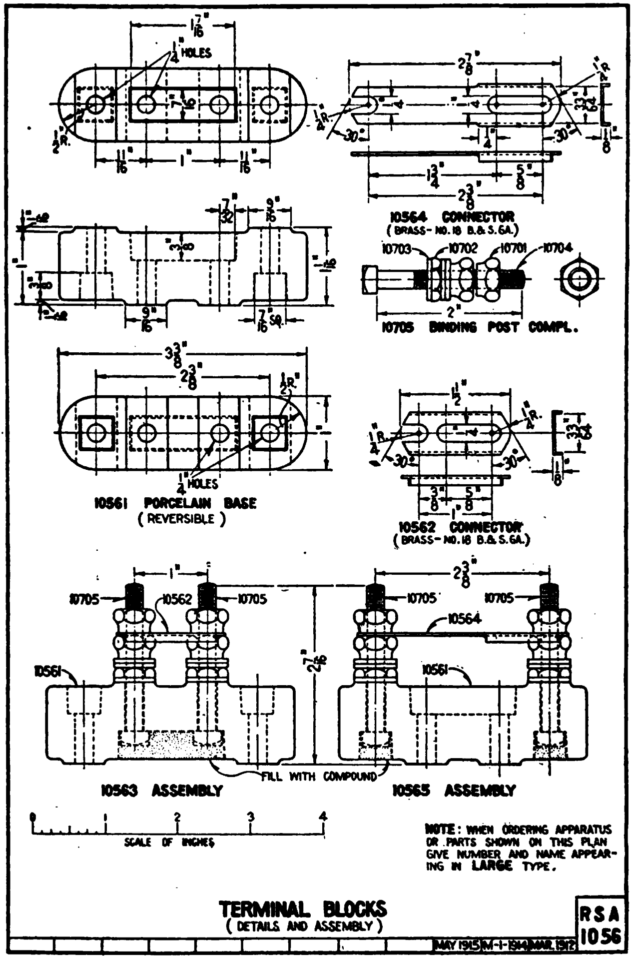
R. S. A. SYMBOLS FOR TIME RELEASES, ETC.



R. S. A. SYMBOLS FOR BATTERIES, ETC.



R. S. A. PORCELAIN TERMINAL BLOCK



SPECIFICATIONS FOR PORTLAND CEMENT CONCRETE. (R. S. A.)

1. **General.** These specifications are for making concrete as used in signal construction.

2. **Cement.** Cement shall be Portland, either American or Foreign, which will meet the requirements of the.......... specifications.

3. **Sand.** Sand shall be clean, sharp, coarse, and of grains varying in size. It shall be free from sticks and other foreign matter, but it may contain clay or loam not to exceed five (5) per cent. Crusher dust, screened to reject all particles over one-fourth (1–4) inch in diameter, may be used instead of sand if approved by the Engineer.

4. **Stone.** Stone shall be sound, hard and durable, crushed to sizes not exceeding two (2) inches in any direction, For reinforced concrete, sizes usually are not to exceed three-fourths (3–4) inch in any direction, but may be varied to suit character of reinforcing material.

5. **Gravel.** Gravel shall be composed of clean pebbles of hard and durable stone of sizes not exceeding two (2) inches in diameter and shall be free from clay and other impurities except sand. When containing sand in any considerable quantity, the amount of sand per unit of volume of gravel shall be determined accurately, to admit of the proper proportion of sand being maintained in the concrete mixture.

6. **Water.** Water shall be clean and reasonably clear, free from sulphuric acid or strong alkalies.

7. **Measure.** The unit of measure shall be the barrel, which shall be taken as containing three and eight-tenths (3.8) cu. ft. Four (4) bags containing ninety-four (94) pounds of cement each shall be considered the equivalent of one (1) barrel. Fine and coarse aggregates shall be measured separately as loosely thrown into the measuring receptacle.

8. **Density of Ingredients.**

(a) For pipe carrier foundations and reinforced concrete, a density proportion based on 1:6 is recommended, i.e., one

(1) part of cement to a total of six (6) parts of fine and coarse aggregates measured separately.

(b) For signal and other foundations made in place a density proportion based on 1:9 is recommended, i.e., one (1) part of cement to a total of nine (9) parts of fine and coarse aggregates measured separately.

9. Mixing.

(a) Tight platforms shall be provided of sufficient size to accommodate men and materials for progressive and rapid mixing. Batches shall not exceed one (1) cu. yd. and smaller batches are preferable.

(b) Spread the sand evenly upon the platform, then the cement upon the sand, and mix thoroughly until of an even color. Add all the water necessary to make a thin mortar and spread again; add the gravel if used, and finally the broken stone, both of which, if dry, should first be thoroughly wet down. Turn the mass with shovels or hoes until thoroughly incorporated, and all the gravel and stone is covered with mortar; this will probably require the mass to be turned four (4) times.

(c) Another approved method, which may be permitted at the option of the Engineer in charge, is to spread the sand, then the cement and mix dry, then the grave or broken stone. Add water and mix thoroughly as above.

(d) A machine mixer may be used whenever the volume of work will justify the expense of installing the plant. The necessary requirements for the machine will be that a precise and regular proportioning of materials can be controlled and that the product delivered shall be of the required consistency and thoroughly mixed.

10. Consistency.

The concrete will be of such consistency that when dumped in place it will not require much tamping. It shall be spaded down and tamped sufficiently to level off, and the water should rise freely to the surface.

11. Forms.

(a) Where necessary, forms shall be well built, substantial and unyielding, properly braced, or tied together by means of wire or rods, and shall conform to lines given.

(b) For all important work, the lumber used for face work shall be dressed on one (1) side and both edges to a uniform thickness and width, and shall be sound and free from loose knots, secured to the studding or uprights in horizontal lines.

(c) For backing and other rough work undressed lumber may be used.

(d) Where corners of the masonry and other projections, liable to injury, occur, suitable moldings shall be placed in the angles of the forms to round or bevel them off.

(e) Lumber once used in forms shall be cleaned before being used again.

(f) The forms must not be removed within thirty-six (36) hours after all the concrete in that section has been placed. In freezing weather they must remain until the concrete has had a sufficient time to become thoroughly hardened.

(g) In dry, but not freezing weather, the forms shall be drenched with water before the concrete is placed against them.

12. **Disposition.**

(a) Each layer shall be left somewhat rough to insure bonding with the next layer above; and if it be already set, shall be thoroughly cleaned and scrubbed with coarse brushes and water before the next layer is placed upon it.

(b) Concrete shall be deposited in the molds in layers of uniform thickness throughout.

(c) The work shall be carried up in sections of convenient length and each section completed without intermission.

(d) In no case shall work on a section stop within eighteen (18) inches of the top.

(e) Concrete shall be placed immediately after mixing and any having an initial set shall be rejected.

13. **Facing.**

(a) The facing will be made by carefully working the coarse material back from the form by means of a shovel bar or similar tool, so as to bring the excess mortar of the concrete to the face.

(b) About one (1) inch of mortar (not grout) of the same proportions as used in the concrete may be placed next to the forms immediately in advance of the concrete.

(c) Care must be taken to remove from the inside of the forms any dry mortar in order to secure a perfect face.

14. Finishing.

(a) After the forms are removed, which should generally be as soon as possible after the concrete is sufficiently hardened, any small cavities or openings in the face shall then be neatly filled with mortar. The entire face shall then be washed with a thin grout of the consistency of whitewash mixed in the same proportion as the mortar of the concrete. The wash shall be applied with a brush. The earlier the above operations are performed the better will be the result.

(b) The top surface of all crank, compensator, well hole, lock, dwarf and high signal foundations shall be rubbed smooth by hand and shall be true to grade and line.

15. Waterproofing. Where waterproofing is required, a thin coat of mortar or grout shall be applied for a finishing coat upon which shall be placed a covering of suitable waterproofing material.

16. Freezing Weather. Concrete to be left above the surface of the ground shall not be constructed in freezing weather, except by special instructions. In this case the sand, water and broken stone shall be heated, and in severe cold, salt shall be added in proportion of about two (2) pounds per cu. yd.

17. Reinforced Concrete. Where concrete is deposited in connection with metal reinforcing, the greatest care must be taken to insure the coating of the metal with mortar, and the thorough compacting of the concrete around the metal. Whenever it is practicable the metal shall be placed in position first. This can usually be done in the case where the metal occurs in the bottoms of the forms, by supporting the metal on transverse wires, or otherwise, and then flushing the bottoms of the forms with cement mortar, so as to get the mortar under the metal, and depositing the concrete immediately afterward. The mortar for flushing the bars shall be composed of one (1) part cement and two (2) parts sand. The metal used in the concrete shall be free from dirt, oil, or grease. All mill scale shall be removed by hammering the metal, or preferably by pickling the same in a weak solution of muriatic acid. No salt shall be used in reinforced concrete when laid in freezing weather.

HOW TO REMEMBER THE WIRE TABLE

By Chas. F. Scott.

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The wire table for the B. & S. gage copper wire has a few simple relations, such that if a few constants are carried in the memory the whole table can be constructed mentally with approximate accuracy.

Resistance. A wire which is three sizes larger than another wire has twice the weight and half the resistance.

No. 10 wire has a resistance of 1 ohm per thousand feet; No. 7 wire which is three sizes larger, has .5 of an ohm per thousand feet; No. 4 wire, which is three sizes larger than No. 7, has .25 of an ohm; No. 13 wire, which is three sizes smaller than No. 10, has 2 ohms; No. 16 wire, which is three sizes smaller than No. 13, has 4 ohms. It is easy, therefore, knowing the resistance of No. 10, to find the resistance of No. 7, No. 4, No. 1 and No. 000; also of No. 13, No. 16, No. 19, etc.

A wire which is ten sizes larger than another wire has ten times the weight and one-tenth the resistance.

As the resistance of No. 10 is 1 ohm per thousand feet, the resistance of No. 0 is .1 of an ohm, and the resistance of No. 20 wire is 10 ohms. as the resistance of No. 4 is .25 of an ohm, the resistance of No. 14 is 2.5 ohms, and of No. 24, 25 ohms.

In the following table the first column contains the sizes of wire which differ from one another by three sizes. The resistance of each wire in this column is seen to be twice that of the next larger size, and one-half that of the next smaller size. There is, therefore, no difficulty in remembering this column. In the second division of the table, the wires are ten sizes smaller than those in the first division; thus No. 11 corresponds to No. 1and the resistance is ten times as great. In the third division of the table, the wires are ten times larger than those in the first division; thus No. 0 corresponds with No. 10 and the resistance is one-tenth as great.

Size	Ohms	Size	Ohms	Size	Ohms
No. 1	.125	No. 11	1.25		
No. 4	.25	No. 14	2.5		
No. 7	.5	No. 17	5	No. 0000	.05
No. 10	1	No. 20	10	No. 0	.1
No. 13	2	No. 23	20	No. 3	.2
No. 16	4	No. 26	40	No. 6	.4
No. 19	8	No. 29	80	No. 9	.8
No. 22	16	No. 32	160	No. 12	1.6
No. 25	32	No. 35	320	No. 15	3.2

From this table several new relations may be observed.

If the wire is one size smaller, the resistance is 25 per cent. greater. For example: Compare No. 11 with No. 10, No. 12 with No. 11, No. 13 with No. 12, etc.

If the wire is two sizes smaller, the resistance is 60 per cent. greater. For example: Compare No. 12 with No. 10, No. 16 with No. 14, No. 15 with No. 13.

If the wire is one size larger, the resistance is 80 per cent. of that of the smaller wire. For example: Compare No. 9 with No. 10, No. 10 with No. 11.

If the wire is two sizes larger, the resistance is 63 per cent. of that of the smaller wire. For example: Compare No. 11 with No. 13, No. 4 with No. 6.

From the foregoing the following are the ratios of resistance between wires of consecutive sizes:

.50, .63, .80, 1.00, 1.25, 1.60, 2.00

Weight. The weight of a wire is inversely proportional to its resistance. Therefore, the foregoing relations are the same for weight as for resistance, excepting that the weights increase as the size of the wire increases, instead of diminishing. The weights of successive sizes of wire, therefore, bear the following relation, beginning with the smaller wire:

.50, .63, .80, 1.00, 1.25, 1.60, 2.00

If the weight of any size of wire is known, it is, therefore, seen that the weight of the next larger size is 25 per cent. greater; the weight of the second larger size is 60 per cent. more also, the weight of the sixth larger size will be four times as great, and the weight of the tenth larger size will be ten times as great. The weight of the third larger size is double.

The weight of 1,000 feet of No. 10 copper wire is 31.4 pounds. Therefore, the weight of No. 7 wire is 62.8 pounds; the weight of No. 0 wire is 314 pounds. The weight of No. 5 wire is 100 pounds per thousand feet, which is a convenient figure to remember. The weight of No. 2 wire is, therefore, 200 pounds, and the weight of No. 00 is 400 pounds.

Area. The area of No. 10 wire is approximately 10,000 circular mils (more precisely 10,380). The area is proportional to the weight. The area of No. 7 wire is, therefore, about 20,000 circular mils, of No. 0 wire 100,000, and of No. 0000 wire 200,000. The precise area of No. 10 wire is 10,380 circular mils. Taking this figure for easy calculation as 10,400, and following the process above indicated, the area of No. 0000 wire is found to be 208,000, which is very nearly 211,600 the figure in the wire table.

Diameter. The diameter of No. 10 wire is approximately 0.10 inch (more precisely 0.102). The diameters follow the same ratio as the circular mils and weights, except that this ratio applies to alternative sizes. Therefore, the sixth smaller size has half the diameter, and the twentieth smaller size has one-tenth the diameter. Therefore, as No. 10 is 0.10 inch, No. 16 is 0.05 inch, and No. 30 is 0.01 inch; also No. 4 is 0.20 inch, and No. 000 is 0.40 inch; also No. 0 (two sizes smaller than No. 000) has 80 per cent. less diameter, or 0.32 inch. No. 00, lying between these sizes, may be presumed to be about 10 per cent. less than No. 000, or .36 inch; the diameter given in the wire table is 0.3648.

Reference to a complete wire table will show that the figures in the above examples, and other figures which may be determined in the same way, are correct within a few per cent. A little practice in mental arithmetic will enable anyone to determine the approximate weight and resistance of wire of any size.

Summary. The things to be remembered regarding B. & S. gage copper wire are as follows:

A wire which is three sizes larger than another wire has half the resistance, twice the weight and twice the area. A wire which is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area.

No. 10 wire is 0.10 inch in diameter (more precisely 0.102); it has an area of 10,000 circular mils (more precisely 10,380); it has a resistance of 1 ohm per thousand feet at 20 degrees Centigrade, (60° Fahrenheit), and weighs 32 pounds (more precisely 31.4 lbs.) per thousand feet.

The weight of 1,000 feet of No. 5 wire is 100 pounds.

The relative values of resistance (for decreasing sizes) and of weight and area (for increasing sizes) for consecutive sizes are:

.50, .63, .80, 1.00, 1.25, 1.60, 2.00

The relative values of the diameters of alternate sizes of wire are:

.50, .63, .80, 1.00, 1.25, 1.60, 2.00

Circular Mils. Conductors of large size are usually specified in circular mils. For example, 500,000 circular mils. 750,000 circular mils.

As No. 10 wire has approximately 10,000 circular mils and a resistance of 1 ohm per thousand feet and as a length of wire which has a given resistance is proprotional to its area, it follows, therefore, that the length in feet of a copper conductor having a resistance of 1 ohm may be found by dropping one cipher from the number expressing its circular mils; for example, No. 10 wire has 10,000 circular mils and a resistance of 1 ohm per thousand feet; a 300,000 circular mil conductor has a resistance of 1 ohm per 30,000 feet, and a 1,000,000 circular mil conductor has a resistance of 1 ohm per 100,000 feet. The weight of a given length is proportional to its area; therefore, the weight of a conductor having 500,000 circular mils is greater than that of No. 10 wire in the same ratio that its area is greater. Five hundred thousand circular mils is fifty times that of No. 10 wire, or approximately fifty times 32 pounds, which equals 1,600 pounds per thousand feet. In this way, the approximate characteristics of copper conductors of all sizes may be quickly ascertained.

To find resistance, drop one cipher from the number of circular mils; the result is the number of feet per ohm.

To find weight, drop four ciphers from the number of circular mils and multiply by the weight of No. 10 wire.

WRITTEN CIRCUITS

While much is being done toward standardization of railway signaling matters in general, little has yet been done toward standardizing signal nomenclature. Referring especially to the field of electrical signaling, all recognize the necessity for not only suitable nomenclature, but also abbreviations of same. In other words, we must have commonly accepted names for devices used for various purposes, and suitably suggestive abbreviations for use in place of them. In preparing circuit plans of small proportions, we can write out the complete name of an operated unit or wire, but with large plans this is not practical, and abbreviations are thus highly desirable, if not entirely necessary. This necessity having been generally recognized, various railroads, as well as signal companies, have been independently devising codes of abbreviations for naming units and wires. These independent efforts have naturally resulted in several more or less different codes. It is only natural that the signal companies possibly more than the railroads should feel the necessity for concerted action along this line. They, therefore, have undertaken to evolve a code of signal nomenclature and abbreviations which would, as near as possible, combine all of the good suggestions involved in the various independent systems extant.

The Manufacturers' Committee at the outset considered that the first move should be to evolve a system of abbreviations to cover electrically operated units, and recognized that the system must be somewhat elastic, in order to cover the multitude of conditions involved. They saw that this system must be, in a sense, a language, and while they might lay down certain rules for using this language, they realized that much liberty must be allowed in order to make the system sufficiently flexible to cover varied conditions. It is expected, therefore, that within certain limits, one person may name a unit differently than another. This variation will be due largely to two persons placing different relative importance upon the various functions of the unit. However, if the system is followed consistently, the meaning can not be mistaken. For instance a relay which controls the home or 45° function of a a signal may be named by one engineer "HR," meaning "Home or 45° control relay." Another may choose to name it merely "H", which has exactly the same meaning. If the signal chances to be one governing east-bound movements another may desire to use "EH", meaning "Eastbound home or 45° control relay." Still another, if the relay should have an indicating attachment (indicator), may desire to emphasize this characteristic and use "KH", meaning "Indicating home or 45° control relay."

Having named the devices, we turn to the naming of the wires which control them, and as the two are always associated it seems most natural to use the same name, except to add a suffix number to differentiate the positions in the circuit.

While nomenclature, as described above, applies to circuits drawn up in any form, the discussion thus far leads us very naturally to the subject of "Written Circuits." The old method of drawing up signal circuit plans starts with the track plan, more or less to scale, and shows the symbols for the various pieces of apparatus. These symbols, in a general way, are placed in their proper relative positions, after which lines are drawn representing wires connecting those points which should be electrically connected. This method is quite adequate for small installations, but it is entirely insufficient for many of the installations of large proportions with which signal engineers are having to contend more and more. The plans are likely to become prohibitive in size and the wires, as indicated by the lines, take such indirect courses that they are extremely difficult to follow. On account of these difficulties, some little thought has been given, during the last few years, to the matter of simplified circuits, which have been termed "Written circuits." In written circuits little or no attempt is made to show the units in their proper relative positions and, instead, much emphasis is placed upon the importance of arranging circuits in straight lines, as far as possible, so as to render them easy to follow. This necessitates a complete nomenclature of the units for ready reference. The Manufacturers' Committee, therefore, considered it quite opportune to propose, at this time, a standard scheme for written circuits as a logical sequence to the subject of nomenclature.

All this work on the part of the Manufacturers' Committee is, in a sense, a continuation of their work on Standard Symbols, which was completed in 1911, and is respectfully submitted to those interested in railway signaling with the request that the same hearty co-operation may be enjoyed as in the case of Standard Symbols.

NOMENCLATURE OF ELECTRICALLY OPERATED UNITS

The term Electrically Operated Unit is used to signify a signaling device in which a magnetic coil in some form is usually essential to its operation; as for instance a relay, signal operating mechanism, electric lock, indicator, etc.

In order to provide a concise, suggestive graphic code for marking these units on plans, the following system has been evolved, which makes use of a designation made up of two parts, namely:

1st. Numerical Prefix. The number of the principal lever, signal, track circuit, etc., entering into the control of or controlled by the unit.

2nd. Alphabetic Term. Consisting of one or two letters. The first letter, when used, describes specifically the operated unit. The second letter designates the general kind of unit.

The complete designation of a unit is written as follows:

	(Numerical Prefix)	(First Letter)	(Second Letter)
As	10	H	R

Written 10HR (without dots or dashes).

In this example the number "10" is the number of a signal. "10R" means relay having to do with signal 10 and "10HR" means home or 45° relay for signal 10. In other words the letter "R" means relay in general and corresponds with a noun in ordinary language. The letter "H" indicates that the function of this relay is to control a home signal and corresponds with an adjective in ordinary language. And the number "10" definitely indicates the signal which this home relay controls.

TABLE OF MEANINGS OF LETTERS

(As applied to operated units)

First Letter	descriptive or adjectival term	Second Letter	designative or noun term
A	—Approach or annunciating.	A	—Annunciator.
B	—Block.	B	—
C	—	C	—
D	—Distant or 90°.	D	—Distant or 90° relay.
E	—East or Eastbound—East bound route locking.	E	—Electric light.
F	—Traffic.	F	—
G	—Signal.	G	—Signal operating mechanism.
H	—Home or 45°.	H	—Home or 45° relay.
J	—	J	—
K	—Indicating (visually).	K	—Indicator (visual).
L	—Locking—Left.	L	—Lock preventing initial movement of a lever from normal or reverse positions.
M	—	M	—Lock preventing final or indication movement of a lever.
N	—Normal—North or North bound—North bound route locking.	N	—
P	—Repeating.	P	—Repeater.
Q	—	Q	—Local coil (Double element relay).
R	—Reverse—Right—Red.	R	—Relay.
S	—South or South bound—South bound route locking	S	—Stick relay.
T	—Track circuit.	T	—Telephone.
U	—	U	—
V	—Train stop.	V	—Train stop.
W	—Switch—West or West bound — West bound route locking.	W	—Switch operating mechanism.
X	—Bell.	X	—Bell.
Y	—Slotting.	Y	—Slot
Z	—Special (to be explained on plan).	Z	—Special unit (to be explained on plan).

NOTE:—In case of three-position levers, where it is necessary to distinguish between right and left positions, use R (right) or L (left) before the lever number; as R10, L10.

Also when one lever controls two or more signals use letters A, B, C, etc., as prefixes to lever numbers; as A10, B10, C10, etc.

In case of three-position levers controlling two or more signals in each position use combinations as follows: RA10, RB10, LA10, etc.

TRACK CIRCUIT NUMBERING

A track circuit is designated by the letter "T" preceded by a number.

Track circuits within interlocking limits are numbered from switches lying within them, which are chosen in the following order:

Take number of an M. P. Frog or in its absence
Take number of a Switch or in its absence
Take number of a Derail.

When there are no interlocked switches in a track circuit, it is numbered from a signal governing over the track circuit.

Example:

10T meaning track circuit in which switch 10 is located or track circuit in block of signal 10 which does not contain an interlocked switch.

In case of a plurality of track sections which by the above rules would have like designations, they will be distinguished by progressive alphabetical prefixes, as:

10T, A10T, B10T, C10T, etc.

Track circuits, in which there are no interlocked switches, and which do not govern signals (as track circuits controlling annunciators only), are given arbitrary numbers O1T, O2T, etc. In many cases these arbitrary numbers 1, 2, etc., may indicate the track numbers.

EXAMPLES OF COMMON COMBINATIONS

Note:—When the second or designative letter alone describes the characteristics of the unit sufficiently, the first or descriptive letter may be omitted; that is to say the noun may be used without the adjective. For instance, if there is but one annunciator on a track the letter A (meaning "annunciator") is sufficient. If there are two annunciators on a track, one operated by track section or sections in the rear of the distant signal and one operated by track between home and distant signals, these will be named DA and HA respectively.

The designation of an operated unit numbered from a track circuit is made up of the number of the track circuit followed by the letter "T" and the proper second letter; as 10TK, 10TP, 10TR.

10A —Annunciator indicating approach to signal 10. (First letter not required).
10HA —Annunciator indicating approach to home signal 10.
10DA —Annunciator indicating approach to distant signal 10.

10EA —Eastbound annunciator indicating approach to signal 10.

10D —Relay controlling distant or 90° position of signal 10.

10KD —Distant or 90° relay for signal 10 with indicating attachment.

10DG —Distant or 90° signal operating mechanism of signal 10.

10HG —Home or 45° signal operating mechanism of signal 10.

10RG —Stop indication device of signal 10 (as with light signals).

10H —Relay controlling home or 45° position of signal 10.

10KH —Home or 45° relay for signal 10 with indicating attachment.

10BK —Indicator controlled by track circuits in block of signal 10.

10FK —Traffic indicator for traffic lever 10 or for track number 10.

10NK —Indicator indicating normal position of unit 10.

10RK —Indicator indicating reverse position of unit 10.

10TK —Indicator indicating condition of track circuit 10T.

10WK —Switch indicator in block of signal 10 or indicator indicating position of switch 10.

10L —Lock locking lever 10 in full normal or full reverse positions or both.

10NL —Lock locking lever 10 in full normal position.

10RL —Lock locking lever 10 in full reverse position.

10FL —Traffic lock locking lever 10.

10M —Lock preventing lever 10 from making its final or indication stroke.

10NM —Lock preventing lever 10 from making normal indication stroke.

10RM —Lock preventing lever 10 from making reverse indication stroke.

10BP —Relay or indicator repeating track circuits in block of signal 10.

10GP —Relay or indicator repeating signal 10.

10HP —Relay or indicator repeating home or 45° position of signal 10.

10DP —Relay or indicator repeating distant or 90° position of signal 10.

10TP —Relay or indicator repeating track relay 10TR.
10NP —Relay or indicator repeating normal position of unit 10.
10RP —Relay or indicator repeating reverse position of unit 10.
10WP —Relay or indicator repeating position of switch 10.
10Q —Local coil of relay 10R.
10TQ —Local coil of track relay 10TR.
10HQ —Local coil of home or 45° relay controlling signal 10.
10AR —Relay controlled by approach section for signal 10.
10HR —Relay controlling home or 45° position of signal 10.
10DR —Relay controlling distant or 90° position of signal 10
10TR —Track relay for track circuit 10T.
10S —Stick relay used in connection with unit 10 or track circuit 10T.
10AS —Approach stick relay used with unit 10.
10LS —Stick relay for locking used with unit 10.
10ES —Stick relay for eastbound route locking used with unit 10.
Note:—Use N, S and W likewise.
10T —Telephone 10 (arbitrary number).
10RW —Reverse switch operating mechanism of switch 10.
10NW —Normal switch operating mechanism of switch 10.
10X —Bell 10 (arbitrary number).
10DY —Distant or 90° hold-arm or slot of signal 10.
10HY —Home or 45° hold-arm or slot of signal 10.

The above list, while not presumed to be exhaustive, covers many of the most common combinations. Others may be made up as required.

WIRE NOMENCLATURE

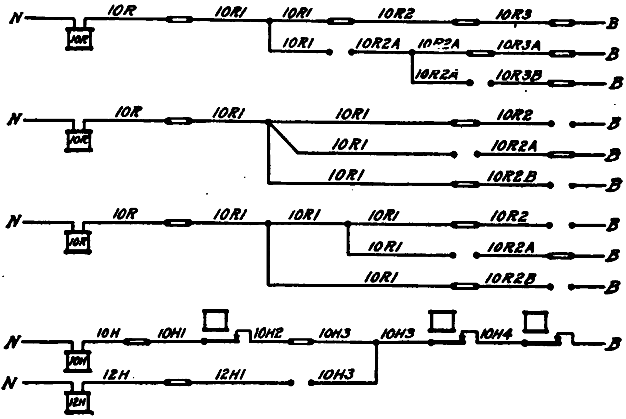
A wire carrying positive energy to one or more operated units is in general designated by the name of the principal operated unit controlled by it, followed by a number indicating the number of circuit controlling contacts in the circuit between the wire and the unit.

A wire carrying negative energy to one or more operated units is designated in the same manner except that the designation is preceded by the letter "N." However, this letter may be omitted if desired.

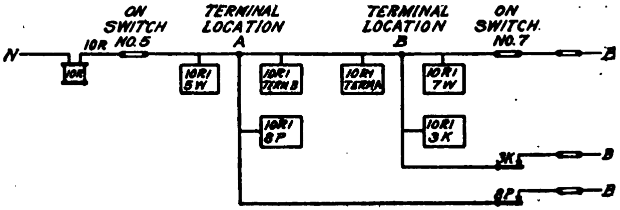
Example:

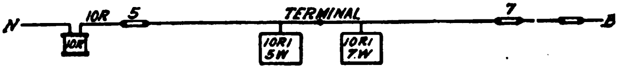
In case of branch wiring the above method is applied to the principal circuit. The letter "A" is appended to distinguish the first branch, the letter "B" distinguishes the second, etc.

Examples:



Two or more wires leading from the same branching point or group of connected branching points bear the same wire designation as shown in the preceding examples. In the installation such wires are frequently not connected together in the same order or with the same arrangement of terminals as that conventionally shown on the circuit plans. In such cases the designation of the device or terminal location to which each wire leads, may be added to the wire designation on the tag (under the wire designation or on the back of the tag as may be most convenient). In this case a group of terminals, which are connected together by wires having the same wire designation, are distinguished by the letters "A," "B," "C," etc., when necessary. In the following examples the tags are indicated by rectangles attached to the lines representing the wires.





Other wire designations are as follows:

C—Common Wire, or in combination when necessary as follows:

CH	meaning 110 volt D. C. common.
CL	meaning low voltage D. C. common.
C10	meaning common for 10 volt D. C. system.
C20	meaning common for 20 volt D. C. system.
CX	meaning A. C. common.
CX55	meaning A. C. 55 volt common.

B—Positive Energy or in combinations where necessary as follows:

BH	meaning 110 volt D. C. positive.
BL	meaning low voltage D. C. positive.
B10	meaning positive of 10 volt D. C. energy.
B20	meaning positive of 20 volt D. C. energy.
BX	meaning A. C. positive energy.
BX55	meaning A. C. 55 volt positive evergy.

N—Negative Energy or in combinations when necessary as follows:

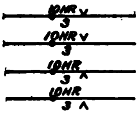
NH	meaning 110 volt D. C. negative.
NL	meaning low voltage D. C. negative.
N10	meaning negative of 10 volt D. C. energy.
N20	meaning negative of 20 volt D. C. energy.
NX	meaning A. C. negative energy.
NX55	meaning A. C. 55 volt negative energy.

EB—Positive lighting wire (not a Light Signal wire).
EN—Negative lighting wire (not a Light Signal wire).
TB—Positive track feed wire with number of track circuit preceding, as 10TB.
TN—Negative track feed wire with number of track circuit preceding, as 10TN.
RB—Positive track relay wire with number of track circuit preceding, as 10RB.
RN—Negative track relay wire with number of track circuit preceding, as 10RN.

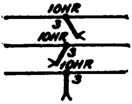
SYMBOLS FOR OPERATED UNITS.

An operated unit is represented by a rectangle with the numerical and alphabetical designations indicated therein, as:

RELAY AND INDICATOR CONTACTS.

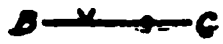


Front contact of 2-position relay closed.
Front contact of 2-position relay open.
Back contact of 2-position relay closed.
Back contact of 2-position relay open.



Polar and 3-position relay contact, closed when normal.
Polar and 3-position relay contact, closed when reversed.
Polar and 3-position relay contact, closed when de-energized.

Note:—Fig. "3" above indicates third contact of relay counting from left to right.
With 2 position relay contacts:

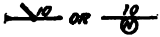
means battery flows from heel to point.


means battery flows from point to heel.

Indicate direction of current through polar and 3-position contacts by arrow point, thus

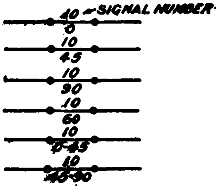

CIRCUIT CONTROLLERS OPERATED BY LEVERS.

Use R. S. A. symbols as shown on page 512 as follows:



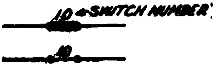
CIRCUIT CONTROLLERS OPERATED BY SIGNALS.

Closed at 0° only.
Closed at 45° only.
Closed at 90° only.
Closed at 60° only.
Closed between 0° and 45°.
Closed between 45° and 90°.



CIRCUIT CONTROLLERS OPERATED BY SWITCH POINTS.

Closed when switch is normal.
Closed when switch is reversed.

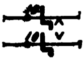


CIRCUIT CONTROLLERS OPERATED BY LOCKING MECHANISM OF SWITCH MOVEMENT.

Closed.
Open.

TIME RELEASE CONTACTS.

Normally closed.
Normally open.



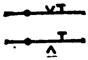
Note:—10 indicates number of signal whose route is released.

LATCH CONTACTS.

Normally closed.
Normally open.

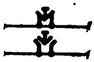
PUSH BUTTON AND STRAP KEYS.

Normally closed.
Normally open.



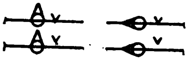
FLOOR PUSH.

Normally closed.
Normally open.

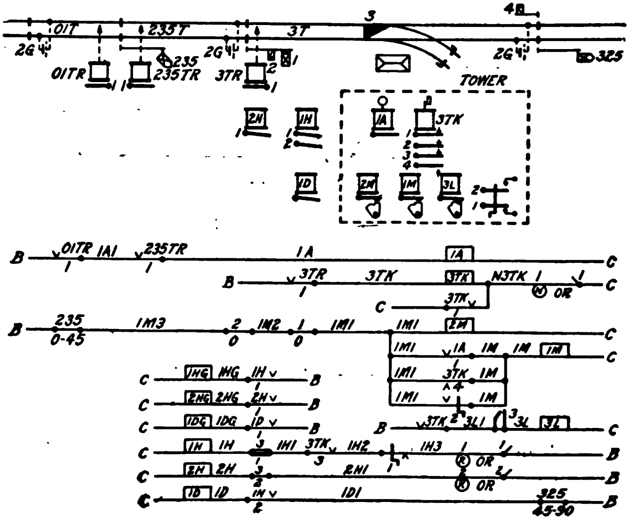


TRAIN STOP CONTACT.

Closed.
Open.



Following is an example of a written circuit plan:



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