American Railway Signaling Principles and Practices

CHAPTER XXIV

Power Distribution Systems and Lightning Protection

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POWER DISTRIBUTION SYSTEMS

General.

Power distribution systems for signal purposes have been designed for voltages of the second (over 30 to and including 175), third (over 175 to and including 250), fourth (over 250 to and including 660), and fifth (over 660), ranges. Systems designed for voltages of the second, third and fourth range, in many cases, are utilized for what are commonly known as charging lines which furnish power for charging storage batteries, which in turn operate track circuits or signals, as well as furnish power for signal lighting.

Distribution systems of the fourth range have, however, in many cases been designed for normal alternating current operation of signal apparatus. The voltage in the fourth range usually selected for service of this type is either 440 or 550 volts. Distribution systems of these voltages have also been used for the control of alternating current apparatus designed for the operation of cab signals or train control devices.

Power distribution systems of the fifth range are used where most of the signal apparatus is operated from alternating current and where the signals themselves are usually of the light type. The ordinary voltages impressed on a power distribution system in this range are 2200, 3300, 4400 and 6600 volts at a frequency of 25, 60 or 100 cycles. A frequency of 60 cycles is most generally used for railway signaling but 25 cycles obtained from rotary converters or rectifiers from a 25-cycle source of supply is frequently used on railroads using direct current propulsion. A frequency of 100 cycles was brought about by the installation of cab signal and train control devices to avoid interference to this type of equipment from commercial sources of 60-cycle power. A special frequency of 91⅔ cycles has been adopted for signal purposes on an electrified railroad system of one of the larger railroads where joint direct current-alternating current propulsion operation is being used since it developed that due to the direct current-alternating current rail return circuits being tied together at the substation, a fourth harmonic of the 25-cycle propulsion current resulted, creating an interference with the operation of the 100-cycle cab signal equipment.

The source of power for signal charging lines in many cases, especially in voltages up to and including the fourth range, is a commercial source. The same holds true of certain installations of some of the voltages in the fifth range; however, on many of the larger railroads generating stations and transmission lines of sufficient capacity have been installed for the generation of the alternating current for the operation of their signal apparatus. In most cases the power generated is single phase, but in some cases where power is obtained from a commercial source, one phase of a three-phase system is used, or a three-phase signal transmission line may be used.

Construction—open line.

Signal transmission lines built for voltages of 550 volts or less are usually placed on the cross-arms of existing telegraph and telephone lines, the usual practice being to assign two pins of a cross-arm to this circuit, using a distinctive insulator to mark the circuit. In some cases a suitable bracket designed as an extension on top of the pole supporting the signal transmission line is used, equipped with a cross-arm to support the wires. The latter design is used mostly for voltages above 550 volts.

Power distribution systems of the fifth range are usually built on a separate pole line on the opposite side of the railroad from the telegraph and telephone line. In some cases the signal line control circuits are placed on a separate arm of the same pole line with the signal power transmission system. On railroads where a catenary electrified system is used, the signal power transmission line is usually attached to the structure supporting the catenary system. In this case the signal power line is installed above the catenary system fastenings and below the propulsion power transmission wires which are usually supported on top of the catenary pole structures.

Figure 1 illustrates a telegraph and telephone line with a 440-volt signal transmission line on top of pole. Figure 2 illustrates a signal power transmission line mounted on a catenary pole.

The conductors of signal power transmission lines of the fourth range located on cross-arms of telegraph and telephone lines are usually insulated. Where transmission systems are mounted on separate pole lines or on catenary supporting structures, bare wire is generally used. Solid copper wire is the conductor ordinarily used; however, in some cases stranded copper wire or stranded aluminum wire with steel center is used. The size of the conductor should be sufficient to have the necessary mechanical strength for the length of span and loading specified and also to limit the voltage drop to less than 10 per cent where possible. For charging lines of the fourth range or under it may be necessary to allow a voltage drop as high as 20 per cent, where the distances between available commercial supply points are too great to obtain a smaller voltage drop without going to an excessive size and cost of line conductor. Drops greater than 10 per cent should be avoided wherever possible on account of the line losses involved.

Construction—underground line.

There are in service signal power transmission lines installed in ducts or conduit underground, where the usual practice is to install twin conductor rubber-insulated lead sheath or non-metallic cables with transformer and sectionalizing switches located in manholes or in metal sectionalizing cases provided with primary fused cut-outs and mounted on concrete foundations. The oil switch and transformer are installed as indicated in Fig. 3. In the circuit between the oil switch and the transformer, cut-outs are usually installed in order that the transformer may be isolated from the oil switch when required.

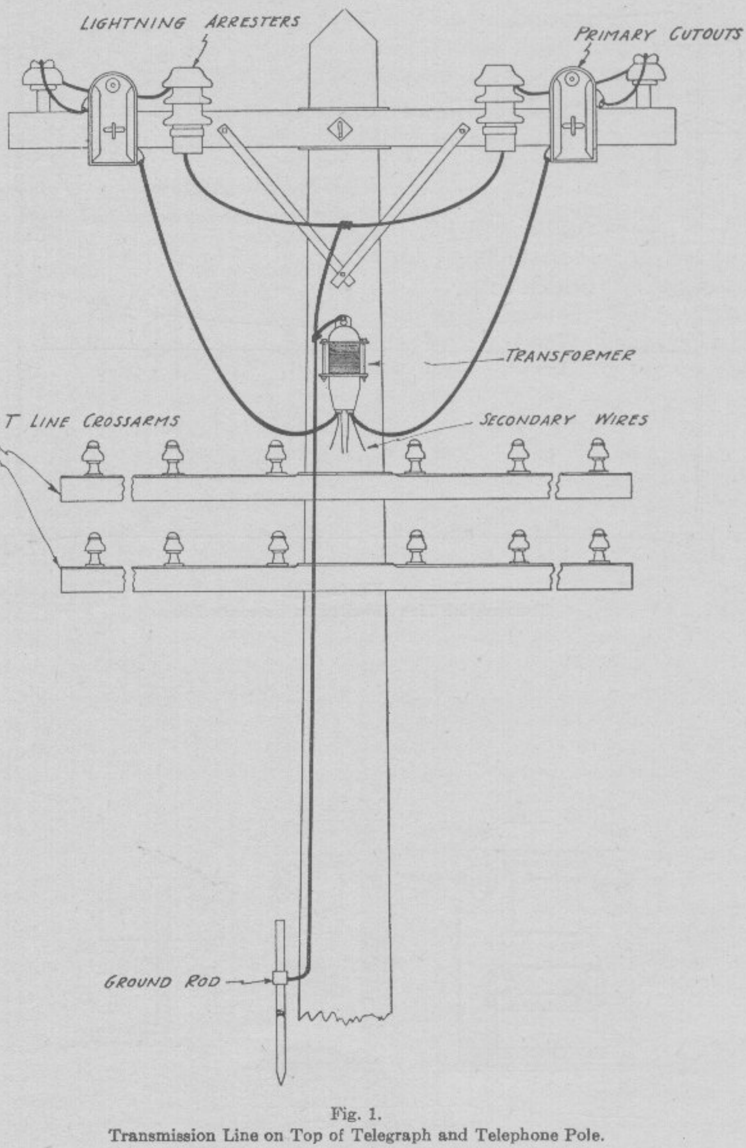

Fig. 1.
Transmission Line on Top of Telegraph and Telephone Pole.

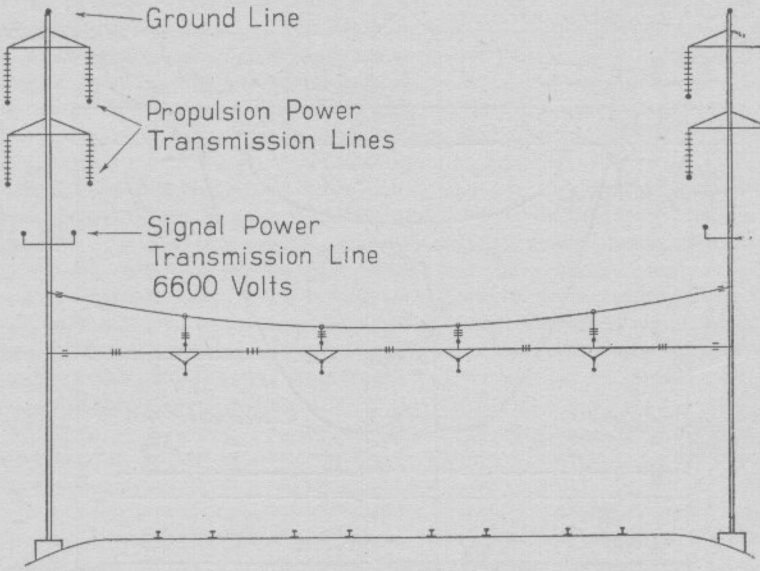

Fig. 2.
Transmission Line Mounted on Catenary Pole.

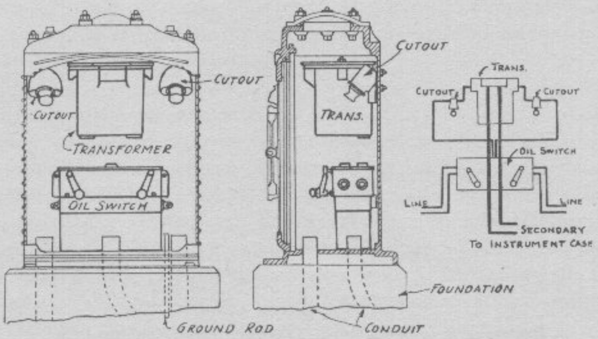

Fig. 3.
Oil Switch and Transformer in Sectionalizing Case.

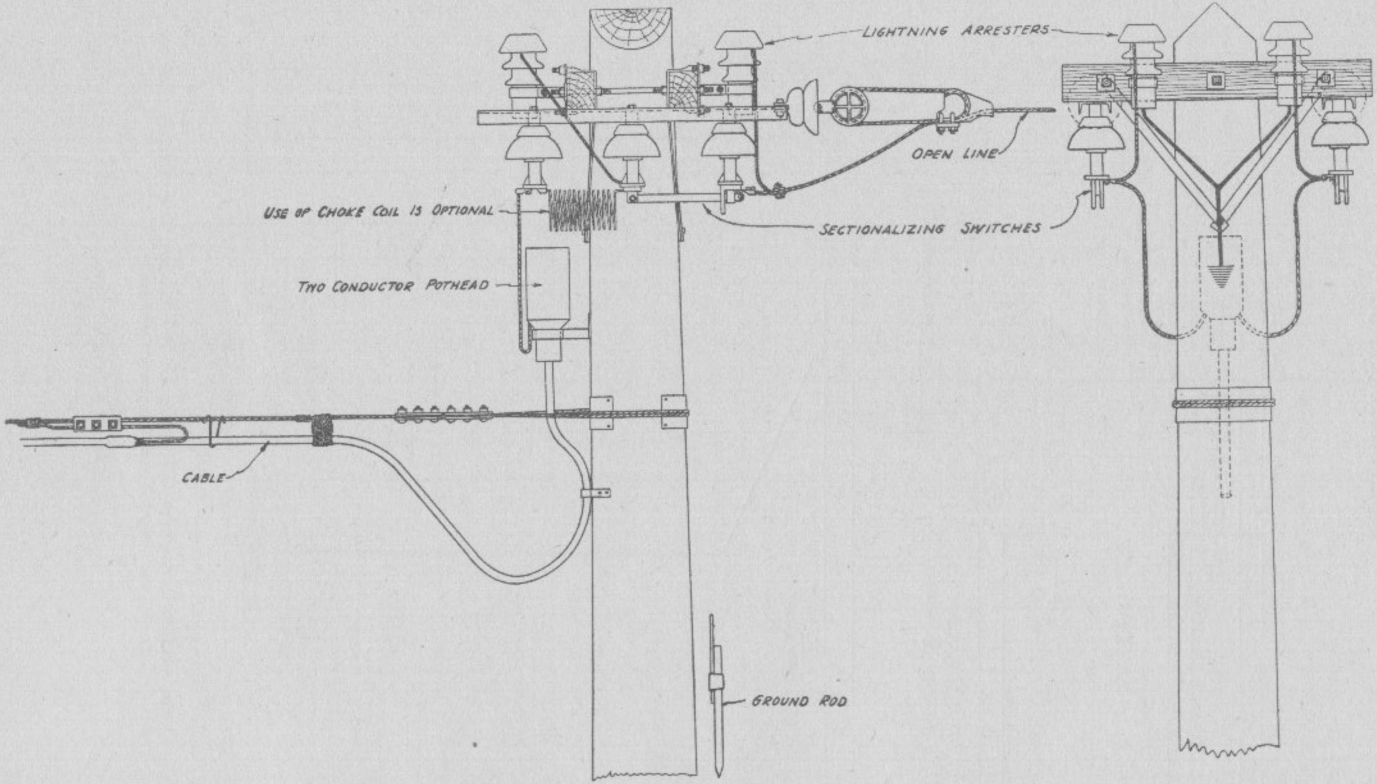

Fig. 4.
Sectionalizing Arrangement between Open Line and Cable.

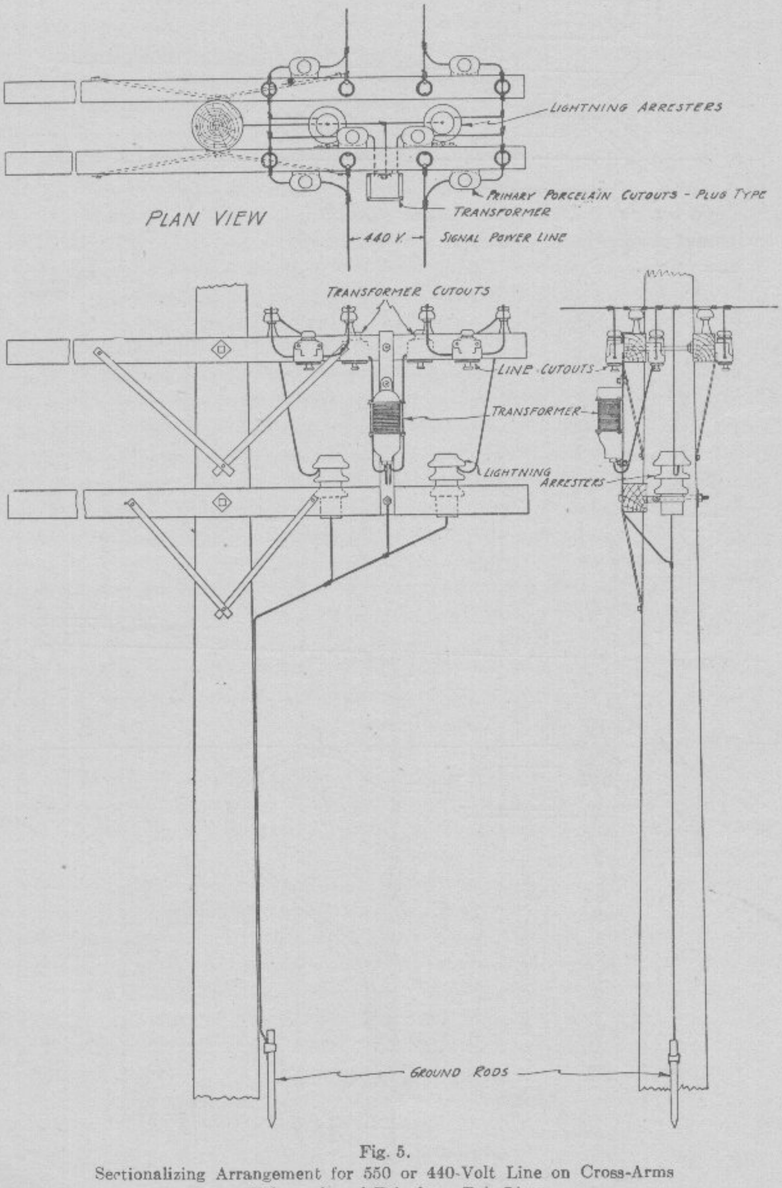

Fig. 5.
Sectionalizing Arrangement for 550 or 440-Volt Line on Cross-Arms on Telegraph and Telephone Pole Line

In underground installations, lightning arresters are not provided as experience has shown that lightning protection at the transformer locations is not required. Other installations of power distribution lines have been made where two-conductor lead-covered cable is suspended on existing telegraph and telephone poles. In this type of construction sectionalizing locations are installed as indicated in Fig. 3. It has also been found necessary, where circumstances require, for a dual installation of open line wires for part of the line and cable installation for the balance of the line. The transformer locations and protection in this type of construction are similar to that explained in the foregoing; however, additional protection has been provided where the type of construction changes, and the arrangement is illustrated in Fig. 4.

Transformer locations.

Transformers are installed at signal or cut-section locations where a source of power is required. On transmission systems of the fourth range, air-cooled transformers are generally used; however, for voltages of the fifth range transformers of the oil-cooled type are more practical. Transformers are usually furnished with secondary voltages of 110 or 220 volts as local busses of alternating current signal systems are of this voltage; however, in some cases a local bus voltage of 55 volts is used. At transformer locations installed on distribution systems of the fourth range, a sectionalizing arrangement, in some instances, is provided on the pole as shown in Fig. 5. In others, the sectionalizing is provided in a case on the ground as shown in Fig. 6.

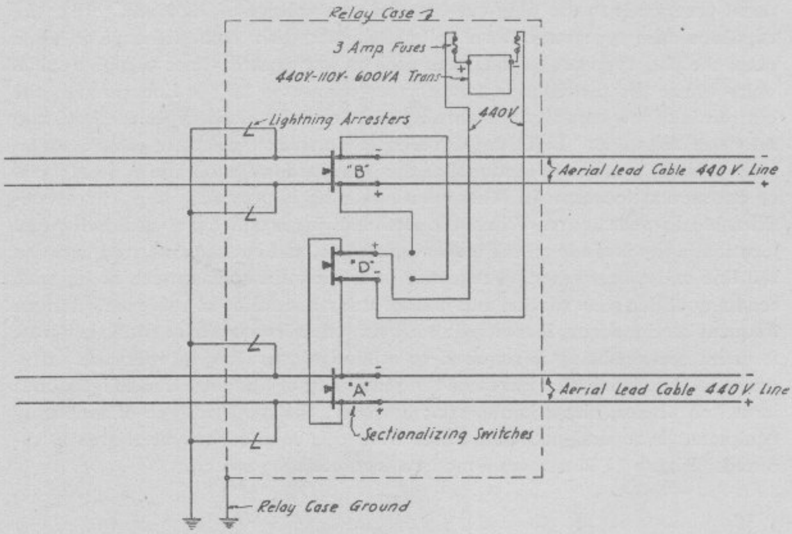

Fig. 6.
Sectionalizing Arrangement in Case on Ground Adjacent to Telegraph and Telephone Pole.

Lightning arresters of the proper type and voltage are installed on the line at the pole. In addition, in some installations, lightning arresters have been provided on the two adjacent poles. At transformer locations where the fifth voltage ranges are used, the transformers and sectionalizing arrangements are provided in an assembly on the pole; the secondary circuits from the transformer being taken from the pole to the location in a manner standard with each railroad.

Sectionalizing switches of various types have been used. In some installations, pole-operated knife switches mounted on top of the pole have been installed. With such an installation pole steps are required and a switch pole secured to the supporting pole used for opening the sectionalizing switches. Other installations have been made with sectionalizing switches so equipped that they could be operated by means of a handle at the base of the pole. Where this type of switch is installed, a suitable locking device on the handle is provided to prevent malicious interference.

Suitable lightning arresters, properly grounded, are provided and in most cases grounding of the transformer case in multiple with the lightning arrester ground is also provided. Where the transformer assembly is mounted on a catenary pole, it is the usual practice to ground the lightning arrester with the transformer case to the catenary supporting structure. Figure 7 illustrates a transformer sectionalizing arrangement on a separate wood pole and Fig. 8 illustrates an assembly on a catenary pole.

Cut-outs of various types are used between the line and the transformer. The plug type is shown in Fig. 9. A later type is illustrated in Fig. 10. The usual practice is to use plug cut-outs up to a voltage of 2200 and to use the expulsion fuse type cut-out on voltages higher than 2200, although in some cases the plug type cut-out has been used on low capacity lines as high as 3300 volts where the distribution transformer connected to the line through the cut-out is of low capacity. Lightning arresters of various types are used and are described under "Lightning Protection" in this chapter. In some installations it is the practice to sectionalize the power transmission line at each signal or cut-section location, in others sectionalizing is provided at points a considerable distance apart. Where the sectionalizing is omitted at each individual location, a tap is made on the transmission line, and cut-outs inserted between the line and transformer. Frequence of sectionalizing has much to do with economy of line construction and it is for this reason that in many installations frequent sectionalizing is omitted; however, on railroads where traffic is dense, frequent sectionalizing is required to minimize operating interference. Frequent sectionalizing also increases the possibility of line drop due to resistance in switch blades, hinge joints, etc.; however, the modern type of switching equipment is so designed that losses from this source have been greatly reduced. Figure 11 illustrates a modern sectionalizing switch.

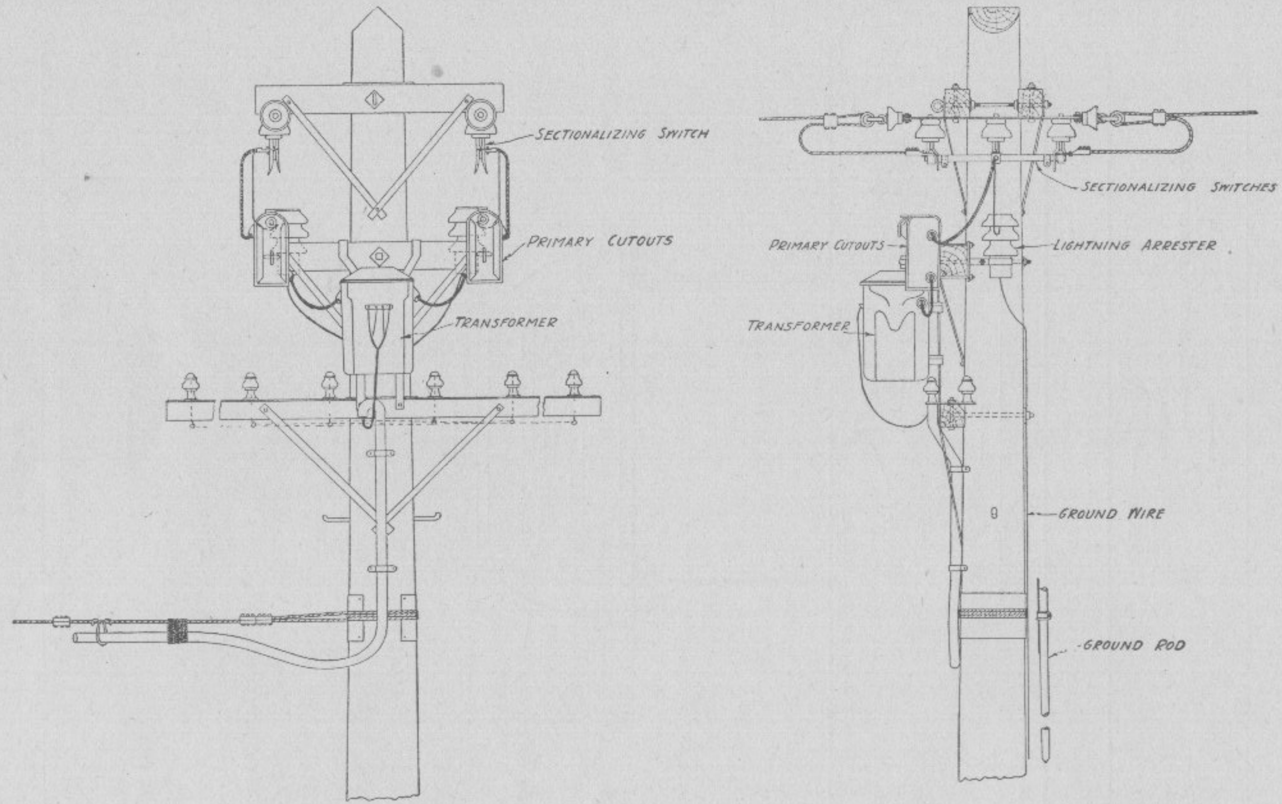

Fig. 7.
Sectionalizing Arrangement on Separate Pole Line.

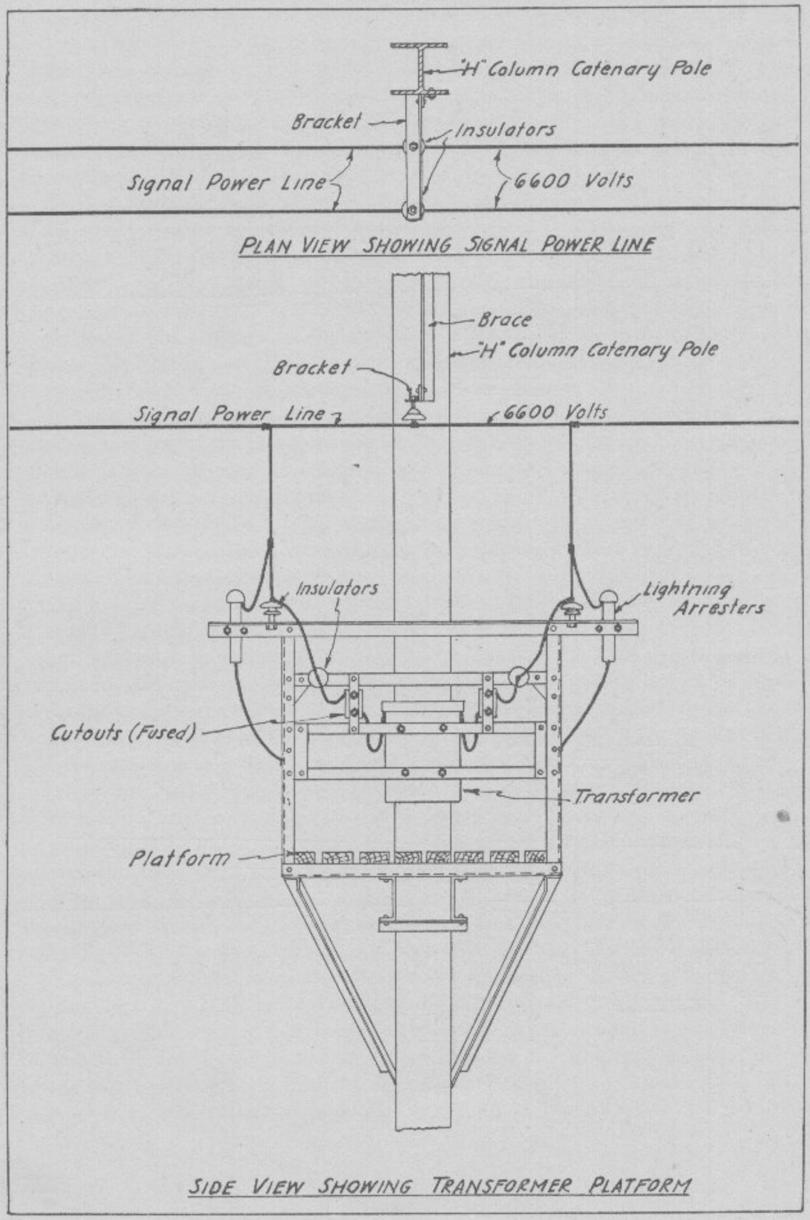

Fig. 8.
Sectionalizing Arrangement on Catenary Pole.

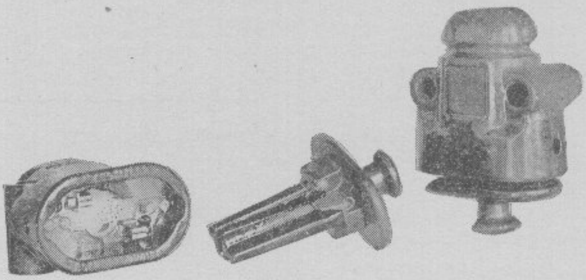

Fig. 9
Cut-out—Plug Type.

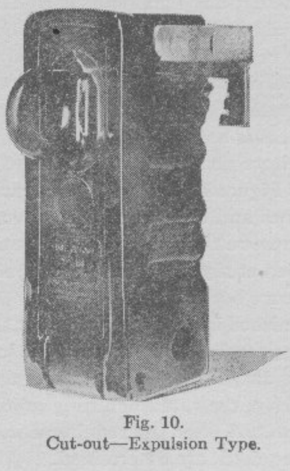

Fig. 10.
Cut-out—Expulsion Type.

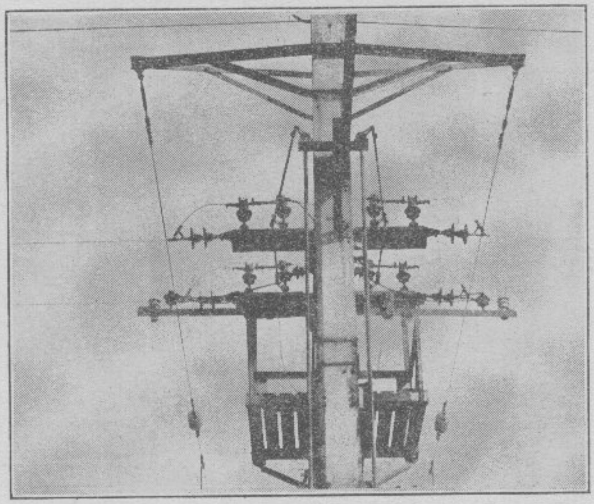

Fig. 11.
Hand-Operated Sectionalizing Switch Mounted on Catenary Pole.

Transformers, both of the air-cooled and oil-cooled types, have been designed to meet all the needs of present-day signal systems. The size of the transformer has been reduced to a minimum to save space and the transformers have also been designed at various capacities in order that they may suitably meet the needs of the service. Considerable study, both by commercial companies and the railroads, has been made to improve the design to a point where a most efficient distribution system is now available.

Such devices as capacitors and similar equipment have been designed for this particular purpose. Figure 12 illustrates a capacitor used in many cases on signal transmission lines and experience has proven that where capacitors have been installed to improve the power factor, gratifying results have been obtained. A more detailed study of transmission systems can be obtained in any modern text or reference book.

The information as furnished in the foregoing is for the purpose of familiarizing, in a general way, the practical signalman who is interested in knowing the principles of signal power distribution for ordinary signal systems. The wire sizes, the necessary capacity, the rated lightning protection and other similar details can only be determined after the requirements of the service for which the transmission line is required, are determined.

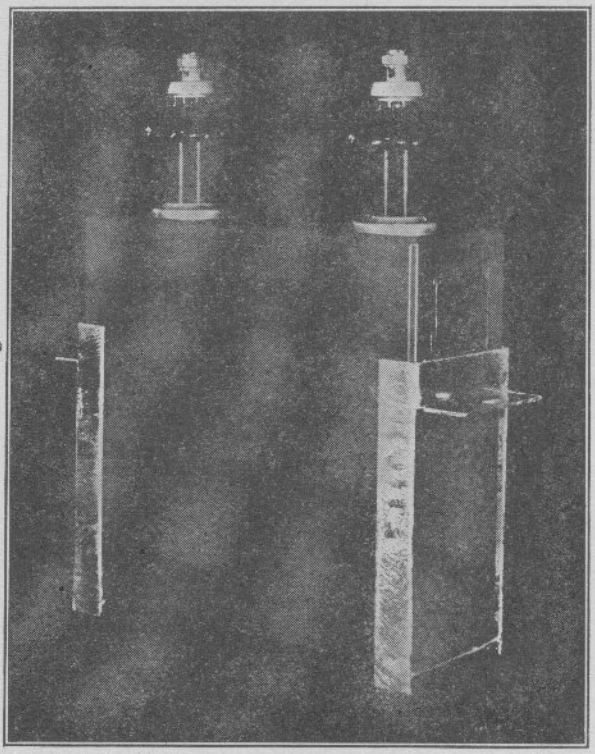

Fig. 12.
Capacitor for Use on Power Distribution Systems.

LIGHTNING PROTECTION

Railway signaling has always been a highly specialized art. The trend for the past 25 years has been from mechanically operated units to apparatus controlled and operated electrically. Simultaneously with the evolution of the art, the range of usefulness has correspondingly increased from an interlocking plant covering switches and train movements at a local point to an extensive electrical system embracing the operation of switches and control of traffic for an entire division, from a central location.

As the signal system has been developed to embrace more comprehensively the operation of large sections, there has been a corresponding development of a great variety of electrical units designed to function and coordinate with other electrical units of the system in a predetermined manner, so that not only flexible train operation is obtained, but the system will function in such a manner that in case of any irregularity the traffic will be protected. Obviously, this expansion of the signal system has necessitated a definite increase in the amount of aerial line wires and other circuits that may be subjected to or injured by atmospheric electrical disturbances. It, therefore, has been apparent to insure continuity of service and safety of operation that protection against such disturbances should be the most efficient that it is possible to develop.

The need of lightning protection first began to manifest itself as an adjunct to protect signal circuits. At that time practically nothing was known, as compared with present-day data, of the phenomena of electrical atmospheric disturbances, neither was there at that time any way of obtaining information or any instruments or facilities for accurately determining the intensity of lightning discharges.

The Railway Signal Association, an association of railway signal engineers, their associates and subordinates, organized for the study of railway signaling problems, later on the Signal Section of the American Railway Association and today identified as the Signal Section of the Association of American Railroads, recognized early in 1914 the importance of protection against lightning discharges and accordingly at an Annual meeting held in September 1914 a special committee on lightning protection was authorized to prepare general requisites covering lightning arresters which were used as a basis for specifications, resulting in the adoption of Specification 52—Low-Voltage Lightning Arrester. The specification reads:

1. *Purpose.*

(a) The purpose of this specification is to provide a lightning arrester of the indoor type for circuits of first voltage range, d.c., and first and second voltage range, a.c.

2. *Drawings.*

(a) Purchaser's drawings referred to in this specification form an essential part hereof.

(b) Contractor shall furnish with his tender, drawings forming an essential part thereof.

3. *Tender.*

(a) The tender shall be for apparatus meeting the requirements of this specification. If the Contractor wishes to vary from the specification, a tender may be submitted covering the apparatus he desires to furnish. This tender shall be accompanied by full information showing wherein the requirements of this specification are not met.

4. *Alternates.*

(a) The provisions contained in the alternate requisites section of this specification form a part hereof only when substituted for the provisions contained in this specification.

5. *Material and workmanship.*

(a) Material and workmanship shall be first-class in every respect.

6. *General design.*

(a) Arrester shall be of general design approved by the Purchaser.

(b) Arrester shall be so designed that moisture will not cause appreciable current leakage or interfere with the normal operation of the signal system.

(c) Arrester shall be so designed that the discharge path shall be non-conducting at maximum rated voltage and conducting at not less than 700 volts d.c. *R-6-c.

(d) Arrester shall be so designed that the 60-cycle voltage r.m.s. at which the discharge path becomes conducting shall not vary more than 20 per cent plus or minus from the value specified by the Contractor. *R-6-d.

(e) Arrester shall be so designed that it will withstand the tests described in section 15, without being grounded, materially damaged, or changed in operating characteristics.

7. *Base.*

(a) Arrester shall be provided with a base which shall be of porcelain or other fire-resisting and waterproof insulating materials of high dielectric and mechanical strength. *R-7-a.

8. *Binding posts.*

(a) Binding posts shall conform to Drawing 1070, detail 107010. They shall be so mounted that they cannot turn in the base or frame to which they are fastened.

(b) Binding posts shall be so arranged that shrinkage of binding post support will not loosen wire connections.

(c) Binding posts for ground connections shall be so arranged that they may be connected together on adjacent arresters by means of a metal strip or bus bar.

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* Alternate requisites section.

9. *Finish.*

(a) All corrodible exposed metal parts shall be nickel plated. *R-9-a.

10. *Insulation.*

(a) Material used for insulation shall be such as will not be injuriously affected by atmospheric conditions.

11. *Dielectric requirements.*

(a) A surface leakage distance of not less than $\frac{3}{8}$ in. shall be provided between any exposed metallic part of the apparatus carrying current and any other metallic part thereof except the discharge path.

12. *Identification.*

(a) Each arrester shall be plainly marked with the Manufacturer's name and with the high-voltage limits, a.c. and d.c., for which the arrester is designed.

13. *Inspection.*

(a) Purchaser may inspect material at all stages of manufacture.

(b) Purchaser may inspect the completed product to determine that the requirements of this specification have been met.

(c) If material has not been accepted at point of production and if, upon arrival at destination, it does not meet the requirements of this specification, it may be rejected, and the Contractor, upon request, shall advise the Purchaser what disposition is to be made of the rejected material. Contractor shall pay all freight charges.

(d) If Purchaser is to make inspection at point of production it shall be so stated.

14. *Tests.*

(a) Contractor shall furnish, if required, complete test data, in accordance with section 15, on each type of arrester he proposes to furnish.

(b) Purchaser may require the Contractor to verify the data submitted.

(c) Verification tests may be made at point of production, or at any properly equipped laboratory, and may also be made at destination.

(d) Contractor shall provide apparatus and labor for making required tests under supervision of the Purchaser.

(e) Contractor shall give the Purchaser sufficient notice of time when material will be ready for testing.

(f) Contractor shall state where tests, if required, are to be made. Purchaser shall state which of the tests herein specified are to be made and what portion of the material shall be tested.

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*Alternate requisites section.

15. *Description of tests.*

(a) Impulse test.*

1. Average rate of impulse voltage rise across arrester terminals to beginning of arrester discharge 10 kv. per microsecond.

2. Average rate of current rise after beginning of discharge 75 amperes per microsecond to a crest of 750 amperes.

3. After reaching crest value in 10 microseconds, the discharge current should thereafter decrease to one-half of crest value in not less than 10 microseconds.

4. At the completion of the impulse test the arrester shall have satisfactorily demonstrated its ability to protect, of which its volt-time and ampere-time characteristics are measures.

(b) Operating cycle tests.

1. The arrester should be connected across a circuit, whose generated voltage equals at least 95 per cent of the maximum voltage rating of the arrester and of such power capacity that the generated voltage across the arrester shall not be decreased more than 10 per cent below the applied voltage for the duration of power follow current, if any. A surge generator shall cause the arrester to discharge an impulse current of 750 amperes (plus or minus 20 per cent), this discharge superimposed on the applied power voltage.

2. Standard operating duty test of a lightning arrester shall be 30 standard operating cycles as outlined, at intervals not greater than one minute.

3. At completion of standard operating duty test, the condition of arrester should be judged by:

(a) Volt-time and ampere-time impulse characteristics, as determined by typical impulse test.

(b) Insulation resistance (megger test).

(c) Physical condition.

16. *Packing.*

(a) Material shall be so prepared as to permit convenient handling and to protect against loss or damage during shipment.

17. *Marking.*

(a) Purchaser's order, requisition and package number, name of Consignor, and name and address of Consignee, shall be plainly marked on outside of package.

(b) Detail list of loose pieces, containers and their contents shall be furnished for each shipment. Where carload shipments are made, routing and car identification shall be shown.

(c) Where carload shipments are made, name and address of Consignee may be omitted.

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* A tolerance of 10 per cent is permissible in voltage and current surges.

18. *Warranty.*

(a) Contractor shall warrant the material covered by this specification to be free from defects in material and workmanship under ordinary use and service, his obligation under this warranty being limited to manufacturing, at point of production, any part or parts to replace those which shall be found defective within one year after shipment to the Purchaser. This warranty shall not apply to any apparatus which shall have been repaired or altered in any way by anyone other than the Manufacturer thereof, so as to affect, in the Contractor's judgment, its proper functioning or reliability, or which has been subject to misuse, negligence or accident.

Alternate requisites.

R-6-c.

Arrester shall be so designed that the discharge path shall be non-conducting at maximum rated voltage and shall become conducting at not less than .... volts d.c.

R-6-d.

Arresters shall be so designed that the 60-cycle voltage r.m.s. at which the discharge path becomes conducting shall be between .... and .... volts as specified by the Contractor.

R-7-a.

Arrester shall be adapted for mounting on terminal shown on Drawing 1056, detail 10565.

R-9-a.

All corrodible exposed metal parts shall be .... plated.

It was at first believed necessary or at least desirable to use choke coils in connection with lightning arresters, but later development indicated that the choke coil for the current used in railway signaling was of little importance and has, therefore, not been included in later developments.

Since 1915 there has been a continual effort made to develop a thoroughly scientific instrument that would protect railway signal circuits. In 1916 the Special Committee on Lightning Protection recognized that no matter how efficient they could build a lightning arrester, it would be practically worthless unless there was developed a proper grounding or ground connection. Accordingly, Specification 60—Installation of Made Ground for Protection Against Abnormal Potentials was adopted. The specification reads:

1. *Purpose.*

(a) The purpose of this specification is to provide a low-resistance path to earth for abnormal potentials.

2. *Drawings.*

(a) Purchaser's drawings referred to in this specification form an essential part hereof.

(b) Contractor shall furnish with his tender, drawings forming an essential part thereof.

3. *Tender.*

(a) The tender shall be for apparatus meeting the requirements of this specification. If the Contractor wishes to vary from the specification, a tender may be submitted covering the apparatus he desires to furnish. This tender shall be accompanied by full information showing wherein the requirements of this specification are not met.

4. *Alternates.*

(a) The provisions contained in the alternate requisites section of this specification form a part hereof only when substituted for the provisions contained in this specification.

5. *Material and workmanship.*

(a) Material and workmanship shall be first-class in every respect.

6. *Ground element.*

(a) Ground element shall be made of galvanized iron rod in accordance with Drawing 1424. *R-6-a.

(b) Galvanizing shall be in accordance with Specification 2912.

7. *Ground lead.*

(a) Lead between the single or multiple ground elements and the lightning arrester shall consist of a soft-drawn copper wire not smaller than No. 6 A.W.G.

(b) Ground lead shall be run as directly as practicable to the ground element, avoiding acute angles.

(c) Air space of $\frac{3}{8}$ in. or equivalent insulation shall be maintained between ground lead and operating circuits.

8. *Terminals.*

(a) Ground lead shall be fastened to the ground element in accordance with Drawing 1424.

9. *Location.*

(a) Ground element shall be located as close as practicable to lightning arresters.

(b) Ground element shall be driven into the ground at least 8 ft. wherever practicable.

(c) Multiple ground elements shall be placed not closer than 6 ft.

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* Alternate requisites section.

10. *Resistance.*

(a) Resistance between the ground element and the surrounding earth should not exceed 15 ohms.

(b) If the specified resistance cannot be obtained by driving a single ground element or driving multiple ground elements, the ground near the elements shall be treated by applying at least 50 lb. common rock salt spread at the top of each ground element and thoroughly saturating the salt with water immediately and again after several days.

(c) Resistance of grounds shall be tested with an approved instrument designed for the purpose.

11. *Inspection of installation.*

(a) Contractor shall advise the Purchaser .... days in advance of the time the installation will be completed and ready for final inspection. Purchaser will make inspection and tests within .... days after completion of the work.

12. *Tests.*

(a) Contractor shall make such tests as may be necessary to demonstrate, to the satisfaction of the Purchaser, that the apparatus, as installed, is in accordance with the requirements of the specifications and contract. Contractor shall provide such instruments and apparatus as may be necessary for making the test. The instruments and apparatus shall remain the property of the Contractor.

(b) Contractor shall tag all ground leads at terminal and indicate on same date of test and resistance recorded.

13. *Completion.*

(a) When the installation is completed, apparatus and surface of the ground which has been affected by the installation shall be left in a neat and clean condition.

Alternate requisite.

R-6-a.

Ground element shall be made of:

1. Copper-covered iron or steel rod.
2. Galvanized iron pipe.
3. ....

Further study and research by the Committee in cooperation with manufacturers' laboratories indicated that direct strokes of lightning are very infrequent and that over 90 per cent of the insulation failures and damage to equipment in actual practice comes from electrostatically induced voltages attending thunderstorms. It was found that electrostatically charged wires above the earth and beneath the thunderclouds could damage equipment by unbalancing the equilibrium of charges between the clouds, wires and earth; the effect of which shows the necessity of low-resistance grounds.

It is recognized that a lightning arrester is fundamentally an over-voltage device. Its function is primarily to limit the magnitude of lightning or surge voltages to a safe level for the apparatus insulation. When the arrester operates to discharge a lightning impulse, the circuit must not be disturbed by the action of the arrester. The degree and fidelity of protection afforded to the insulation of the apparatus depends directly upon the level of impulse voltage allowed by the arrester. This level of voltage is determined by the value of voltage required to break down the gap and start discharge through the arrester; also by the subsequent voltage across the arrester attending the flow of lightning current through arrester, frequently called the IR voltage. These considerations are fundamental regardless of the particular location or application of the arrester.

Before the advent of laboratory and field research facilities for making exacting studies of lightning surges and their influence on electric systems, there was speculation and conjecture as to the exact nature of the service duty of arresters. Lightning was thought of as direct current, alternating current, high-frequency oscillations, etc , therefore the performance of lightning arresters was checked by a variety of direct current and alternating current and sustained high-frequency tests. Instruments such as Klydonographs, surge voltage recorders and principally cathode-ray oscillographs have enabled extensive field studies of the characteristics and behavior of lightning surges, resulting traveling waves and their reflections and short time impulses in general. The exact shape and duration of lightning impulses on electric circuits have been recorded and artificial lightning generators have been made to reproduce impulses of corresponding characteristics. Thus much of the mystery has been removed and the art of lightning protection has been distinctly advanced, both as regards the function and specific performance of arresters and the lightning breakdown characteristics of insulation of apparatus. In ordinary power analyses, a cycle or $^1/_{60}$ of a second is a common measure. However, the direction of lightning surges into harmless paths requires careful consideration of what can take place in one one-millionth of a second and the microsecond has become the universal time unit in lightning protective engineering. This time unit almost defies conception. A microsecond is to a second what one minute is to 23 months or what one inch is to 16 miles. The actual service duty of lightning arresters most essentially involves their response and behavior under these short time voltage applications.

A cable laid in or on the earth is not immune to lightning disturbances; it needs to be provided with an electrostatic shield. Soil of good conductivity provides a fair shield for cables located in it, but where the soil conductivity is poor, that is not the case. Cable systems are not liable to be troubled by lightning unless they connect to open-line wires.

A lead-covered cable provides a perfectly shielded circuit because the sheath completely surrounds the conductors. In open-line construction this high degree of shielding may be approached by means of grounded shield wire installations by the use of which overhead open-line wires may be made more secure against lightning disturbances. Any grounded conductor near a circuit will so divert the electrostatic field from a cloud that the voltage induced in the circuit will be less than if the grounded conductors were not there. The degree of shielding afforded by overhead ground wire is not a fixed quantity. Their value in reducing lightning voltages on a line depends on several things: the number of ground wires used, their position relative to the protected circuits and to each other, the height of the lines and the ground wires above the earth, the conductivity of the soil under the lines, the number and resistance of the earth connections to the ground wires. One ground wire directly over the circuit will afford a certain amount of protection. Under most favorable circumstances it may reduce the induced voltage to 60 per cent of that which would occur under the same conditions without the ground wire. Two ground wires are better than one and additional wires at the sides of the circuit will still further improve conditions. Such an installation is in effect an approach to a cable.

The modern lightning arrester is a highly efficient protective device. It consists essentially of a spark gap set to flash over at some predetermined voltage, and in series with the gap is what is known as the valve or characteristic element.

Considering their protective characteristics only, lightning arresters have two functions to perform. One is to hold the impulse voltage across equipment to a safe value; the other is to absorb surge energy. Another function, not directly related to their protective characteristics, is that since they are connected to circuits carrying normal line voltage and current, they must possess valve characteristics that will positively cut off power current flow following a lightning discharge through them. If lightning arresters do not have positive valve characteristics they represent a hazard to the circuit on which they are installed, causing arrester grounds or short circuits from their failure to properly interrupt the flow of system current following the lightning discharge to ground.

The ability of an arrester to confine to a safe value impulse voltage across equipment and to absorb surge energy likewise are functions primarily of the characteristic element, and are based on its resistance or impedance and represents characteristics which in a measure are opposing factors in the final protective characteristics which the arrester may possess. This will be perfectly apparent when it is considered that the only way energy can be absorbed in a lightning arrester is by means of resistance in the discharge path. If it is desired to absorb more of the surge energy, more resistance must be used. However, as more resistance is introduced into the discharge path higher voltages are necessarily built up across this resistance to surge current flowing through it. Any attempt to absorb all the energy in a surge would probably require the use of so much resistance that the arrester would be of very little value in reducing the voltage and consequently would be of little value in affording protection to equipment.

The relation that exists between the internal impedance of lightning arresters and their actual protective characteristics offers a wide field for discussion, particularly so since lightning arresters are designed to function properly under a wide range of operating conditions.

The best approach to the proper solution of the many problems introduced into lightning arrester design is to be found by laboratory studies made on lightning arresters with modern impulse testing equipment and actual field performance records of the lightning arrester over a long period of time and under widely different conditions.

Types of arresters for fourth and fifth voltage range.

The two main types of arresters that have been extensively used for the protection of signal transmission lines of the fourth and fifth voltage range (251 volts and over) are the gap and resistance type and the multi-gap type.

In the gap and resistance type, after the gaps have been broken down, the current flow is proportional to the voltage. The design of such an arrester is a compromise between the requirements for low impedance from the standpoint of the surge and for high impedance from the standpoint of power current. In the valve type, the current flow is proportional to the excess voltage, no current flow due to line voltage. Low impedance has no disadvantages.

It will be noted from the following descriptions of valve type lightning arresters that there is a similarity in the basic principle and construction.

The Crystal Valve lightning arrester essentially consists of an arcing unit assembly consisting of accurately spaced brass discharge plates capable of handling many lightning discharges with little deterioration, the spacers for the discharge plates are accurately ground ceramic insulators. The top of the arcing unit is terminaled outside of the porcelain body for connection to the transmission line. The bottom of the arcing unit rests on a column of crystals that are packed into the glazed porcelain body. These crystals form the valve or characteristic element of the arrester. Into the base of the column of crystals is sealed the ground terminal of the arrester.

The length of the spark gap element and the column of crystals is dependent upon the voltage for which the arrester is designed. The higher the voltage the longer the spark gap assembly and the column crystals.

A sectional view of a typical Crystal Valve lightning arrester, showing construction and principle, is shown in Fig. 13.

The Compression Chamber type of lightning arrester consists essentially of an air gap in series with a small amount of limiting resistance placed between line and ground. The spark gap electrodes are made of brass separated by a porcelain spacer. In Fig. 14 it will be noted that the brass electrodes with the small porcelain separator make a small closed chamber, which, during the lightning discharge, holds gases formed by the arc. The gases becoming slightly compressed assist in extinguishing the arc by partially smothering it.

The Pellet type of lightning arrester consists of one or more series gaps connected to the line lead at the top of the porcelain tube and in a hermetically sealed gap chamber. The valve column consists of the litharge coated pellets that fill the lower part of the porcelain tube and are in electrical contact with the ground lead. The number of arc gaps and the length of column of pellets is dependent upon the line voltage for which the arrester is designed. This type is shown in Fig. 15.

The Autovalve type of lightning arrester consists of a cylindrical block of porous material with comparatively high resistivity, connected through a series gap between the line and ground. Even though the resistivity is com-

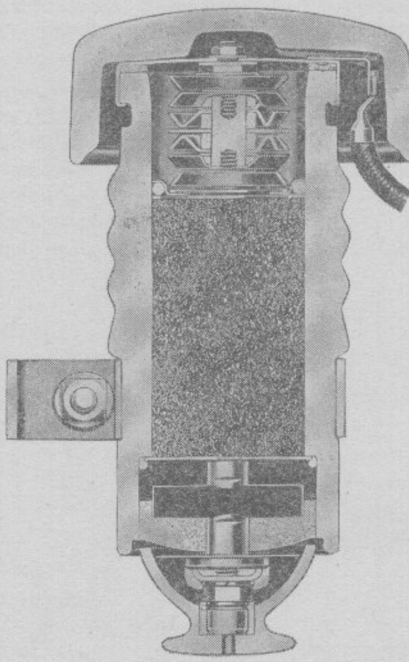

Fig. 13.

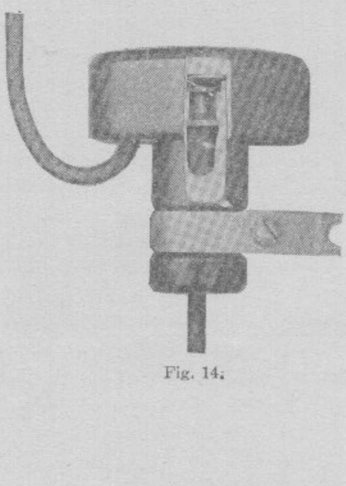

Fig. 14.

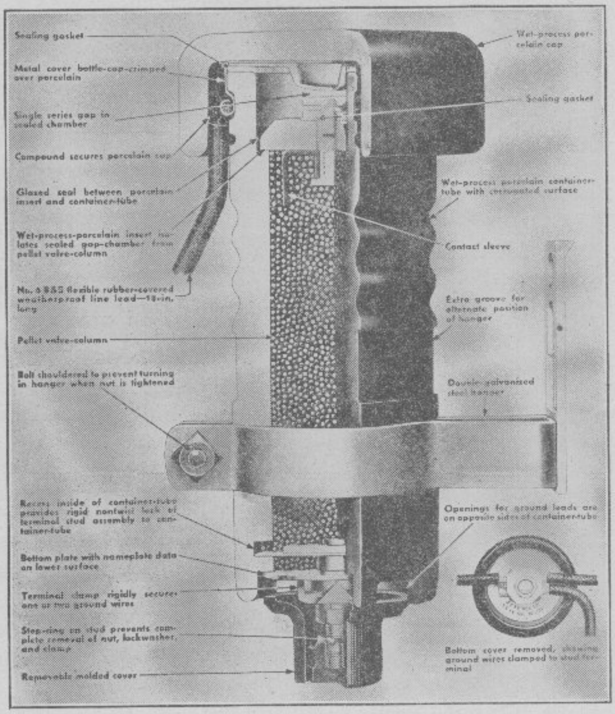
Sealing gasket
Metal cover bottle-cap-crimped over porcelain
Single series gap in sealed chamber
Compound secures porcelain cap
Glazed seal between porcelain insert and container-tube
Wet-process-porcelain insert isolates sealed gap-chamber from pellet valve-column
No. 6 B&S flexible rubber-covered weatherproof line lead—18-in. long
Pellet valve-column
Bolt shouldered to prevent turning in hanger when nut is tightened
Recess inside of container-tube provides rigid nontwist lock of terminal stud assembly to container-tube
Bottom plate with nameplate data on lower surface
Terminal clamp rigidly secures one or two ground wires
Stop-ring on stud prevents complete removal of nut, lockwasher, and clamp
Removable molded cover
Wet-process porcelain cap
Sealing gasket
Wet-process porcelain container-tube with corrugated surface
Contact sleeve
Extra groove for alternate position of hanger
Double galvanized steel hanger
Openings for ground leads are on opposite sides of container-tube
Bottom cover removed, showing ground wires clamped to stud terminal

Fig. 15.

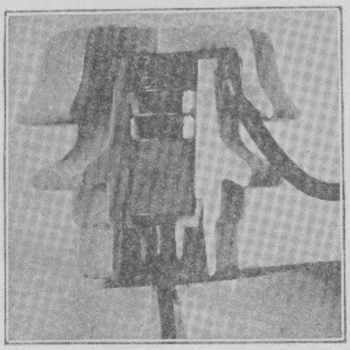

Fig. 16.

paratively high the resistance through which the discharge has to flow is low since the cylindrical block has a large area. The top of the spark gap is terminaled for connection to line, while the base of the cylindrical porous block rests on the terminaled connection for ground; the complete arrester is enclosed in porcelain. This type is shown in Fig. 16.

Types of arresters for first, second and third voltage range.

There are several different types of lightning arresters used on signal circuits of the first, second and third voltage range (0 to 250 volts).

The Autovalve lightning arrester consists of small discs separated by mica washers and held by springs between two terminals in such a manner that the terminals may be used for mounting on A.A.R. terminal blocks. Lightning arresters of this type can be connected between line signal circuit and ground or they may be connected across the terminals of relay controls, transformers or rectifiers. This type is shown in Fig. 17.

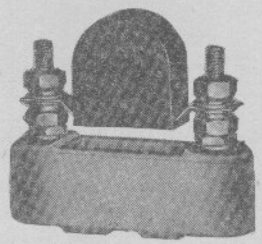

Fig. 17.

The Crystal Valve lightning arrester consists of a cartridge which is made of Isolantite filled with crystallite, the ends of which are capped with brass discs which are called contact discs. One of these contact discs is terminaled in a suitable cap and terminal for mounting on an A.A.R. terminal block. The other contact disc, together with brass electrode, form the spark gap and are terminaled for mounting. Lightning arresters of this type are connected between line and ground. This type is shown in Fig. 18.

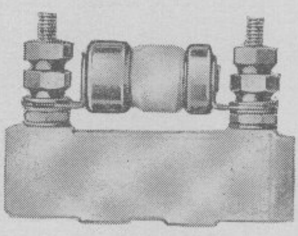

Fig. 18.

The Thyrite signal lightning arrester consists of a molded insulation base equipped with clips for mounting on an A.A.R. terminal block. Into this base the Thyrite signal arrester assembly is inserted. The arrester assembly consists of a grooved brass disc and a flat brass disc separated by an annular mica spacer; this gap in series with a Thyrite disc ⅛ inch thick is held firmly by spring contacts in a housing of two circular molded Texolite shells. The shells enclosing the gap unit can be readily separated by unscrewing the halves so that the parts can be inspected. Lightning arresters of this type may be connected between line and ground or line to line in shunt with apparatus terminals. This type is shown in Fig. 19.

Fig. 19.

The Rare Gas lightning arrester consists of a cartridge with two brass ferrules similar to a renewable cartridge fuse, that fit into spring clips on a block of insulating material. The cartridge is essentially a glass tube, containing a rare gas, in which are sealed two electrodes accurately spaced, between which the electrical discharge passes when the electrical circuit is dissipating an overvoltage surge.

Lightning arresters of this type can be connected between line and ground and across the terminals of any instrument that is to be protected. This type is shown in Fig. 20.

The Spark Gap Pin Point lightning arrester consists of individual pins that are electrodes of non-arcing material, supported in brass bushings which extend through the terminal connection and into glass tubes. The terminal connectors are spaced by a molded bakelite block which gives a long leakage path and definitely fixes the air gaps. Two clamp springs which fit over projecting lugs on the spacer hold the pins in place and serve to hold the cartridge together. These two clamp springs are held in compression by two cotter pins, one on each end of the spacer. This pin point arrester unit may be mounted on an A.A.R. terminal block.

This type of lightning arrester, shown in Fig. 21, may be connected between line and ground and across the terminals of any instrument that is desired to be protected.

The Choke Coil Spark Gap type of lightning arrester consists of a heavy porcelain block on the top surface of which are mounted two saw-tooth spark plates with a disc of carborundum or special carbon between them. On the inside of the block there is a recess containing a choke coil, the ends of this coil are connected to the posts which hold the spark plates in place. The center post which supports the carborundum or carbon discs is entirely insulated

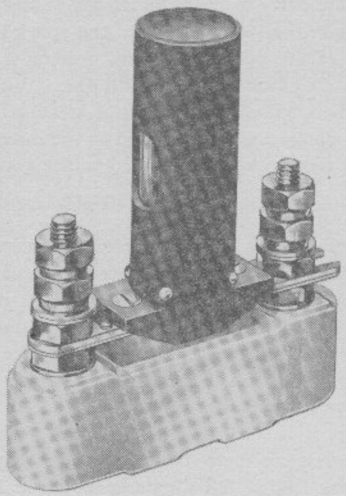

Fig. 20.

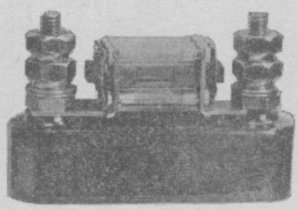

Fig. 21.

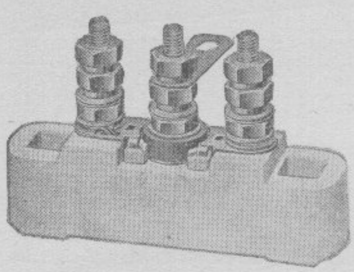

Fig. 22.

from the other metallic parts of the arrester and is known as the ground post. To prevent any longitudinal movement of the spark plates, they are turned down over the edge of the porcelain block, making it almost impossible for the spark plates to move closer to the ground disc. With arresters of this type the line is connected to one of the terminals attached to the choke coil, the other terminal of the choke coil is connected to the instrument to be protected, while the center or ground post is connected to the ground wire. This type is shown in Fig. 22.

The discharge block type of lightning arrester consists of a molded bakelite base, on the top surface of which are mounted three carborundum blocks and 2 sawtooth spark plates. The three carborundum blocks are mounted in line with a fixed spark gap between them and held in place with terminal posts. The metallic sparking plates are mounted on opposite sides of the carborundum block assembly with a fixed spark gap between the sawtooth edges of the metallic plates and the carborundum blocks. In this type of lightning arrester the center post is known as the ground post. The remaining two carborundum blocks are connected to line circuits while the metallic plates are connected to track leads. This type is shown in Fig. 23 and is used for circuits for first voltage range.

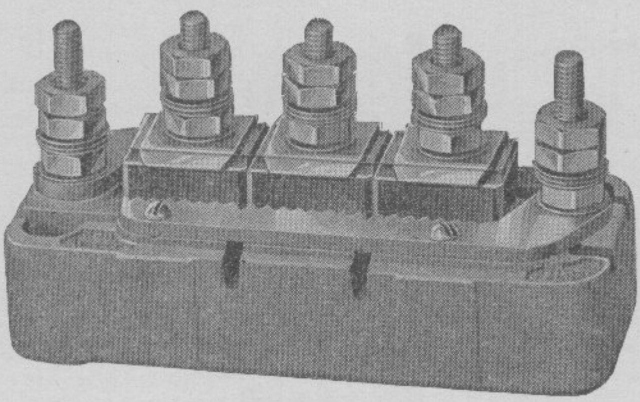

Fig. 23.

Application.

An application of lightning arresters to signal circuits with a voltage of the first, second or third range is shown in Fig. 24.

Referring to Fig. 24 it will be noted that in using the A.A.R. symbol for lightning arresters, it is not possible to show just how the connections are made to the arrester. In order that it may be clear just how the lightning arresters protecting the incoming line wires are connected, the following description is given:

The line wire is connected to one terminal of the lightning arrester and the wire leading to the apparatus to be protected is connected to the other terminal while the ground terminals are all bussed together and connected to earth through the ground lead.

The arresters shown in the junction box on the pole are sometimes omitted.

The arresters shown on the track battery connections are somewhat different than those shown on the line wires in that the wires from the rail are connected to one terminal and the wire leading to the battery is connected to the same terminal; thus, one arrester provides both sides of the circuit. The ground terminal is connected to earth.

Another arrangement for connecting lightning arresters is shown in the connections from the rails to the track relays, where, in addition to the arresters connected the same as described for the line circuits, a shunt type arrester similar to that shown in Fig. 20 is connected across the two wires leading to the track relay coils. No ground connection is used.

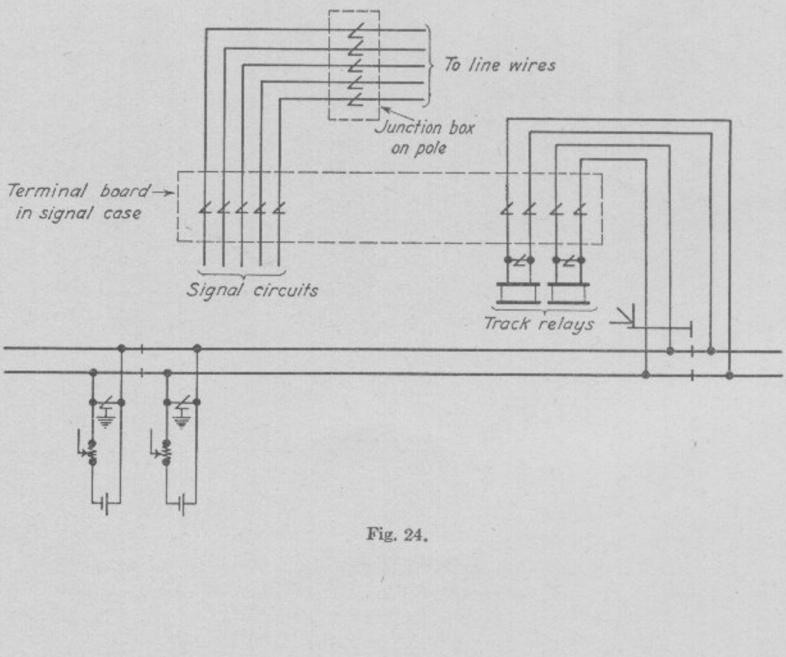

Fig. 24.

An application of lightning arresters to signal power circuits with a voltage of the fourth or fifth range is shown in Fig. 25.

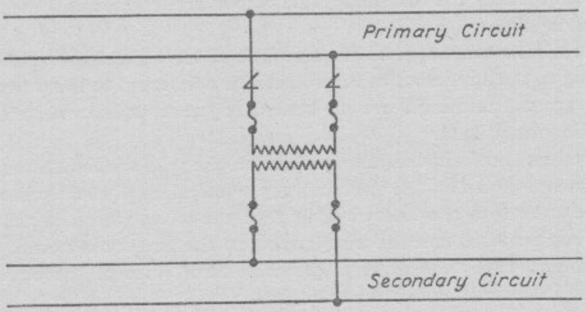

Fig. 25.