American Railway Signaling Principles and Practices

CHAPTER IX

RECTIFIERS AND BATTERY CHARGERS

Published by the Signal Section, A. A. R.
30 Vesey Street, New York 7, N. Y.

REVISED JANUARY 1948

PUBLISHED BY
ASSOCIATION OF AMERICAN RAILROADS, SIGNAL SECTION
30 VESEY STREET, NEW YORK 7, N. Y.

CHAPTER IX

RECTIFIERS AND BATTERY CHARGERS

Developments in the signal field, principally the current requirements of light signals, led to the extensive use of alternating current as the primary source of power for signal systems which were nominally direct current systems. In general the alternating current supply is used in those systems for normal lighting, and with primary or storage batteries providing reserve power during periods of alternating current power interruptions.

The direct current relay circuits can be energized directly from rectifiers connected to the alternating current source which is the system generally employed when primary battery furnishes the reserve source of power.

Another method is to connect the direct current relay circuits to the primary battery, connecting a rectifier in multiple with the battery, the rectifier being adjusted to carry the normal connected relay load, thereby prolonging the service life of the battery to a considerable extent. However, provision should be made to allow a current of a few milliamperes to flow from the battery under normal load conditions so as to maintain the battery in an active state. Rectifiers designed for this application automatically adapt current output to the load requirements and when properly adjusted will supply all the load current except the few milliamperes which the battery must supply to keep it in an active state.

When auxiliary power is supplied from storage battery, the direct current circuits are generally connected at all times to the storage battery supply. The storage battery is maintained in a charged state by the use of a rectifier which converts the alternating current to direct current causing it to flow into the battery.

Storage or primary batteries must be of sufficient capacity to carry the entire signal (relay and light load) throughout duration of power interruption. It follows that in the engineering of an installation capacity must be determined by the maximum periods of power interruption which can be anticipated.

Whereas alternating current signal systems employing alternating current apparatus throughout are available, there are comparable direct current systems energized from the alternating current source only which employ rectifiers designed to provide direct current for operating direct current apparatus at a constant output voltage, within a predetermined range of varying voltage of alternating current source and varying direct current load conditions.

The Signal Section, Association of American Railroads, defines Rectifier as: A device which converts alternating current into uni-directional current by virtue of a characteristic permitting appreciable flow of current in one direction only. (A.I.E.E.)

Types.

Rectifying devices suitable for signal work include motor-generators commonly known as "MG sets," mercury arc, gas tube, mechanical or vibrating, electrolytic and dry plate rectifiers of the copper-oxide and selenium types.

Motor-Generator Sets

A motor-generator set consists of a motor operated from a local alternating current supply which drives a generator for supplying direct current to charge the battery. In the smaller sizes, as used in signal work, induction motors are used exclusively. Both machines are mounted on the same base and are direct-connected as shown in Fig. 1.

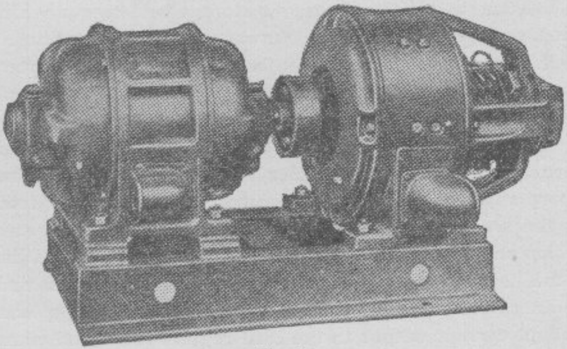

Fig. 1.
Motor-Generator Set.

This method of rectifying alternating current was, perhaps, the first used in the signal field and has been used, principally, to charge batteries at power interlockings.

In the earlier installations the batteries generally were charged at the normal rate until fully charged, at which time the charge would be discontinued, and the battery, until discharged, would carry the load. The battery would then be given another charge. This procedure is called cycle charging.

The operation of the motor-generator may be arranged for either automatic or non-automatic control. The automatic panel is used where there is no attendant to shut down the set when the charge is completed, and is used in connection with what is known as a contact making ampere-hour meter. It is also equipped with a contactor which does not close until the generator voltage is higher than the battery voltage. Figure 2 illustrates a panel and motor-generator arranged for automatic operation.

Motor-generator sets are frequently installed in duplicate where continuity of operation is essential, as shown in Fig. 3. With this arrangement but one set is operated at a time, the other set being held in reserve.

Mercury Arc

Mercury arc and other tube rectifiers herein described represent early types of electronic devices which due to their rapid development during the past decade are frequently thought of as an entirely new development in electrical devices.

Theory of operation.

The action of this rectifier is based on the peculiar property of mercury

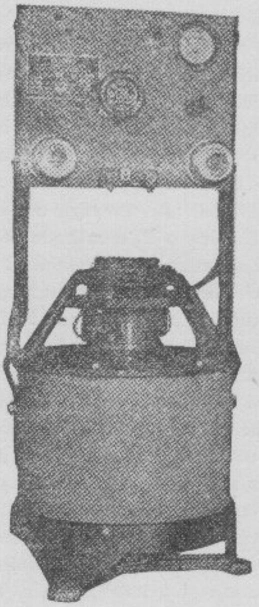

Fig. 2.
Automatic Motor-Generator Set.

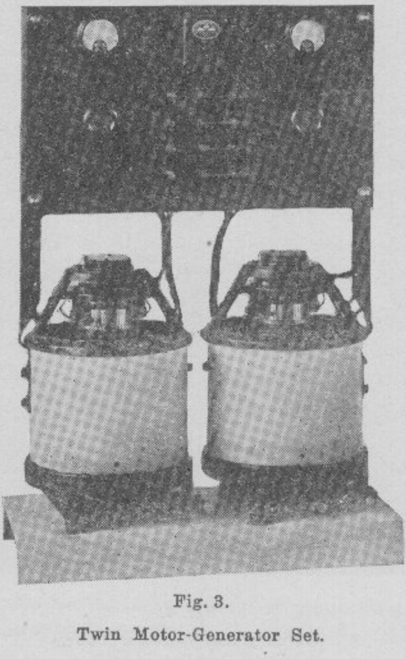

Fig. 3.
Twin Motor-Generator Set.

vapor which permits of a flow of current in but one direction. However, by a system of connections and reactances both waves of the alternating current line are used, resulting in higher efficiency and power factor. This rectifier has three essential parts: the rectifier tube, the main reactance and the panel. The rectifier tube, as illustrated in Fig. 4, is an exhausted glass vessel in which are two graphite electrodes (anodes A and A′) and one mercury cathode B. Each anode is connected to a separate side of the alternating current supply and also through one-half of the main reactance to the negative side of the load. The cathode is connected to the positive side. There is also a small starting electrode C connected to one side of the alternating current circuit through resistance, and used for starting the arc. When the rectifier tube is rocked, so as to form and break a mercury bridge between the cathode B and the starting anode C, a slight arc is formed. This starts what is known as the "cathode spot" and the cathode begins supplying ionized mercury vapor. This condition of excitation, or cathode spot, can be kept up only as long as there is current flowing toward the cathode. (In modern rectifiers, tubes have a pair of "holding anodes" to maintain the arc even with zero load current.) If the direction of supply voltage is reversed, so that the formerly negative electrode, or cathode, becomes positive with the reversal of the alternating current circuit, the current ceases to flow, since, in order to flow in the opposite direction, it would require the formation of a new cathode, which can be accomplished only by special means. Therefore, in the rectifier tube the current must always flow toward the cathode which is kept in a state of excitation by the current itself.

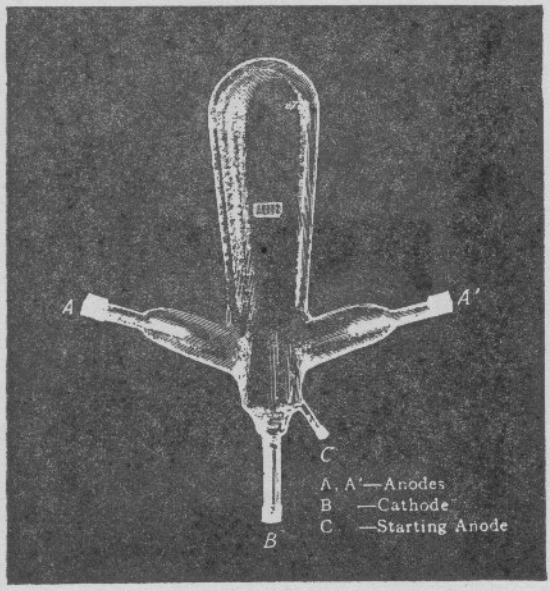

Fig. 4.
Mercury Arc Rectifier Tube.

Such a tube would cease to operate on alternating current voltage after one-half of the cycle if some means were not provided to maintain the flow of current continuously toward the cathode.

The maintenance of the current flow is accomplished by the main reactance. As the current alternates, first one anode and then the other becomes positive, the current flowing from the positive anode through the mercury vapor, toward the cathode, thence through the battery, or other load, and back through one-half of the main reactance to the opposite side of the alternating current supply circuit. As the current flows through the main reactance, it charges it, and while the value of the alternating current wave is decreasing, reversing and increasing, the reactance discharges, thus maintaining the arc until the voltage reaches the value required to maintain the current against the counter electromotive force of the load and reducing the fluctuations in the direct current. In this way, a true continuous current is produced with very little loss in transformation.

Current is conducted through the tube by the ionized mercury vapor. This vapor consists of electrons, positive ions and negative ions moving about in all directions and colliding with each other continually. As the tubes are very carefully evacuated, the number of air and water vapor molecules present is very small. The electrons are the small negative charges of electricity which are one of the two constituents of atoms of all kinds. The ions are the mercury atoms which have lost or gained one or more electrons. Compared to electrons, the mercury ions are very large bodies, the mass of mercury ion being 368,000 times that of an electron.

Conduction of electricity through the ionized gas is accomplished by general drift of positive ions in the direction of the current and the general drift of electrons in the opposite direction. During the process of conduction electrons hit the graphite anode and flow out through it as the current. Other electrons enter the space inside the tube from the mercury cathode. This is accomplished by the formation of the cathode spot on the mercury which is the spot one observes moving continually on its surface. It requires for its maintenance a drop of about ten volts, and this voltage, which must also occur across an extremely small distance, removes the electrons from the mercury against the atomic forces tending to prevent their passage through the surface. The positive ions are produced by the electrons colliding with neutral atoms after they have left the cathode.

If the voltage on the tube is reversed, the electrons will be drawn toward the mercury and the positive ions toward the graphite electrode. This gives a pulse of current through the tube in the inverse direction. If this current is to continue, the graphite electrode must become a source of electrons. This it will not do because the voltage applied, though many times enough for the purpose, does not occur across the small distance required. Instead it is nearly uniformly distributed over the entire distance between the electrodes, leaving only a very small voltage to appear across the space in which the removal of the electrons from the graphite would have to be accomplished.

Operation.

Figure 5 illustrates an elementary diagram of connections and the operation is about as follows: Assume the instant that the terminal H of the supply transformer is positive, the anode A is then positive and the arc is free to flow between A and B. Following the direction of the arrow still further, the current passes through the battery J, through one-half of the main reactance coil E, and back to the negative terminal G of the transformer. When the impressed electromotive force falls below a value sufficient to maintain the arc against the counter electromotive force of the arc and load, the reactance E, which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly.

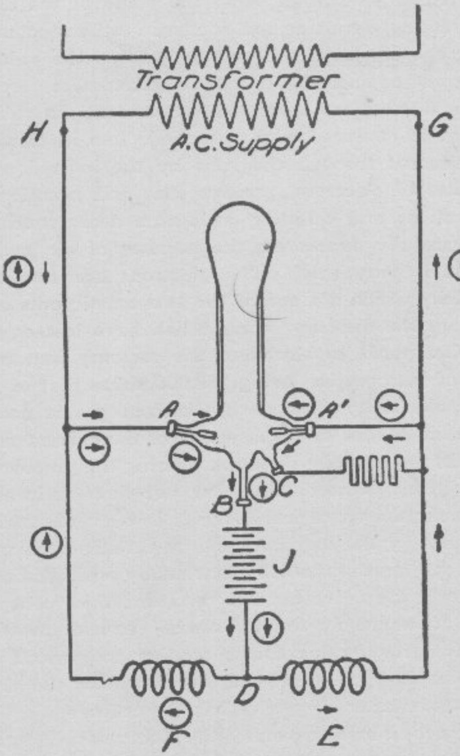

Fig. 5.
Circuit Connections for Mercury Arc Rectifier.

This serves to maintain the arc in the rectifier tube until the electromotive force of the supply has passed through zero, reversed, and built up to such a value as to cause the anode A' to have a sufficient positive value to start the arc between it and the cathode B. The discharge circuit of the reactance coil E is now through the arc A'-B instead of through its former circuit. Consequently, the arc A'-B is now supplied with current, partly from the transformer and partly from the reactance coil E. The new circuit from the transformer is indicated by the arrows enclosed in circles.

Figure 6 illustrates a 30-ampere mercury arc rectifier, charging panel and reactance.

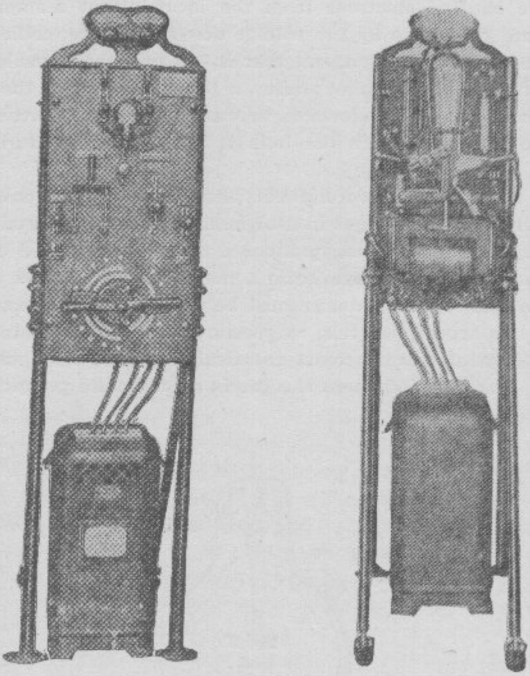

Fig. 6.
Mercury Arc Rectifier, Charging
Panel and Reactance.

Gas Tube

The two types of gas-filled hot cathode rectifiers in general use are the Rectigon and Tungar. The names have no particular significance and were applied in order to give them distinctive trade-names, their technical names being of too great length for trade purposes.

A vacuum tube containing a hot and a cold electrode acts as a rectifier, and following this principle these rectifiers were developed.

Theory of operation.

In the bulb there is argon, an inert gas, at low pressure, which is ionized by the electrons emitted from the incandescent filament. This ionized gas acts as the principal current carrier, with the result that the bulb operates with a very low voltage drop, 3 to 8 volts, and is capable of passing a current of several amperes, the current limit depending on the design and size of the bulb.

Figure 7 shows a bulb of the hot cathode rectifier type in which the cathode (lower electrode) consists of a filament of small tungsten wire coiled into a closely-wound spiral, and a graphite anode (upper electrode) of relatively large cross-section. The bulb is constructed of heat-resisting glass.

The bulb rectifies, because on the half cycle when the graphite anode is positive the emitted electrons from the incandescent filament are being forced toward the anode by the voltage across the tube, colliding with the gas molecules and ionizing them, that is, making them conductive in the direction of anode to cathode; while on the other half of the cycle, when the anode is negative, any electrons that are emitted are driven back to the filament, so that the gas in the bulb is non-conductive during that half cycle.

Bulbs of this type are carefully exhausted to the highest possible vacuum and then filled with argon gas in a high state of purity. Certain impurities, even in very small quantities, produce a more or less rapid disintegration of the cathode, and also have quite a marked effect on the voltage characteristics of the rectifier. Means must be used to insure absolute purity of the gas and to accomplish this, magnesium is introduced into the bulb at the time of manufacture to react chemically with such impurities as may be present. This reaction keeps the gas in a pure state practically throughout the life of the bulb.

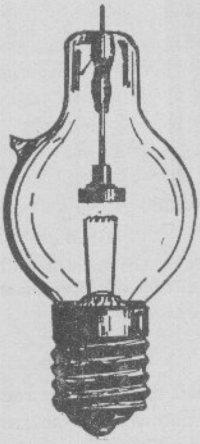

Fig. 7.
Hot Cathode Rectifier Bulb.

The dark gray or silvery appearance of the bulb is caused by condensation of the magnesium on the interior of the bulb during manufacture. This is not in the least detrimental to the bulb and gives no indication of its life.

The general principles briefly described apply equally well to the half-wave and full-wave types of rectifiers. The half-wave rectifiers are desirable for low-wattage service on account of the lower cost of manufacture. On larger sizes the lower power factor makes them objectionable from the power supply viewpoint. Two half-wave rectifiers may be connected to power lines so as to utilize both half waves.

Figure 8 shows the circuit connections for a half-wave rectifier of the hot cathode type in its simplest form. The equipment in this case consists of the bulb (B), with filament (cathode) (F) and anode (A), transformer, adjustable resistor (R), and the load which is shown as a storage battery.

Assuming an instant when the side "C" of the alternating current supply is positive, the current follows the direction of the arrows through the

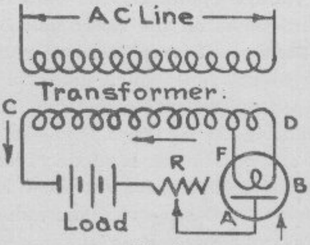

Fig. 8.
Circuit Connections for a Half-Wave Rectifier.

load, rheostat, bulb, and back to the opposite side of the alternating current line. A certain amount of the alternating current is used to excite the filament, the amount depending on the capacity of the bulb. In some designs of rectifier outfits the rheostat is omitted and the regulation obtained by means of an adjustable reactor or taps on the transformer winding. In some of the higher voltage outfits the charging current is varied by a resistance. When the alternating current supply reverses and the side (D) becomes positive, the current is prevented from flowing for the reason before mentioned, *i.e.*, the current is permitted to flow from the anode to the cathode or against the flow of emitted electrons from the cathode, but it cannot flow from the cathode to the anode with the flow of electrons.

Figure 9 shows the general method of connecting two hot cathode rectifier bulbs with a single load. In this case both waves are used and the resultant current is a pulsating uni-directional current. The pulsating characteristic frequently referred to as "a direct current ripple" may be stabilized by means of reactance in series with the load. However, treatment of this kind is unnecessary in battery charging.

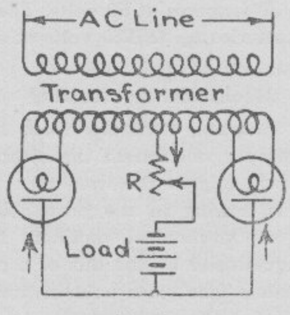

Fig. 9.
Circuit Connections for a Full-Wave Rectifier.

The principle on which a storage battery is charged is shown in Fig. 10. One cycle of half-wave rectification is shown. On the upper half of the cycle when the transformer voltage exceeds the battery voltage (point A), the bulb anode becomes positive, making the bulb conductive, and the charging current flows through the battery. When the transformer voltage falls below the battery voltage (point B) the bulb is no longer conductive and the charging current ceases on the lower half of the wave.

The rated output of these rectifiers is based on readings of direct current instruments of the D'Arsonval type which give the average value of the voltage and current. A direct current ammeter indicates the true current which is effective in charging the batteries.

If an alternating current instrument is used, which gives the root mean square value of the current on half-wave rectifiers, it will read from 75 to 100 per cent higher, and on full-wave rectifiers about 25 per cent higher than the D'Arsonval type instrument. Both of these instruments would read identically on a continuous or non-pulsating current.

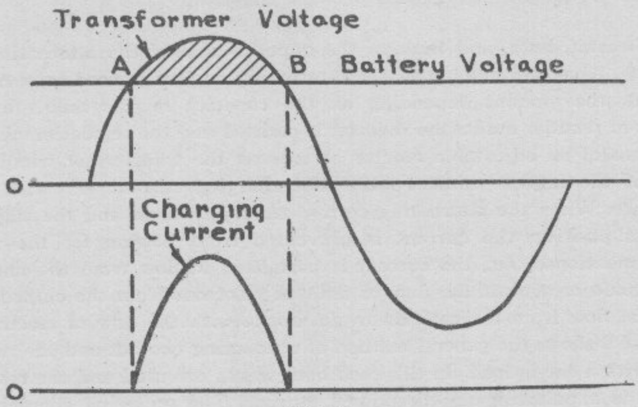

Fig. 10.

Diagram Showing One Cycle of Half-Wave Rectification.

The bulbs range in size from ½ ampere capacity at 7.5 volts, to 6 amperes at 75 volts, and 30 amperes at 50 volts. The 2 and 5-ampere bulbs are designed to charge batteries up to 120 volts at a low rate.

Mechanical or Vibrating

The theory is that a vibrating armature opens and closes a contact at certain given times in proper relation to the alternations of the current. The contacting parts touch only at the time that the current taken from the alternating system is flowing in the proper direction to charge the battery. Certain types of mechanical rectifiers have the armature or vibrating reed tuned magnetically by the flux of a permanent magnet. The armature is equipped with a face plate held in tension in the field of the magnet. By varying this field the natural frequency of vibration of the armature is changed. The moving contact must be flexible or have a cushion effect, so it is mounted on a light spring and given the proper tension by means of two backing springs. The contacts are generally of platinum iridium or tungsten on account of the non-oxidizing characteristics of these metals. The stationary contact is mounted on a screw; adjusting this screw gives the proper and exact opening between contacts. The alternating current actuating coil is adjustable for tuning the charging wave to the proper phase relation.

Figure 11 illustrates a mechanical battery charger.

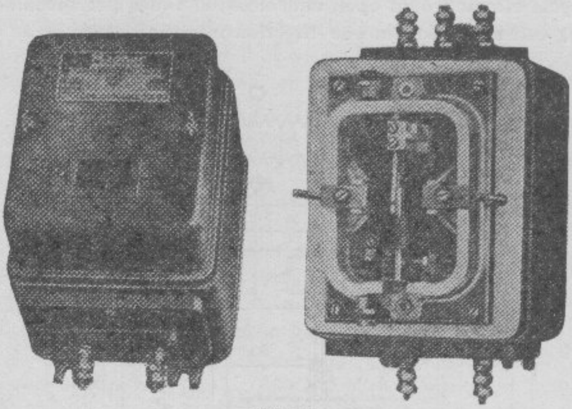

Fig. 11.
Mechanical Battery Charger.

Other types of mechanical rectifiers are similar in construction, except with regard to the vibrating contact, which is suspended from the armature supported on a shaft, no springs or reeds being used. The contact swings perfectly free and follows the reversal or alternations of the current over frequency variations up to 18 per cent above or below normal.

A transformer is enclosed in the same casing as the rectifier for transforming the line voltage to the proper value for charging the storage battery and to protect apparatus connected to the storage battery against the flow of current from the alternating current supply line. The efficiency of these rectifiers is low and they interfere with radio reception; the latter may be materially reduced by the use of a condenser bridging the vibrating contact.

When the alternating current supply is interrupted the vibrating member should assume the central or open position to prevent the battery from discharging through the rectifier. Careful maintenance is necessary to insure the proper opening of the contact.

Figure 12 illustrates a wiring diagram for a mechanical battery charger.

The secondary is tapped to supply current to the actuating coil as shown in Fig. 12 and the vibrating reed extending through this coil is thereby magnetized. Due to the alternations through the coil the polarity of the ends of the reed is constantly reversing. The rapidity of this reversal of polarity is entirely dependent upon the frequency of the alternating current supply.

At the instant that the lower end of the reed to which the face plate is attached is a north pole, it will be attracted by the south pole of the permanent magnet. This will cause the reed to be pulled to the right and close the contacts. While contacts are in this position current will flow into the battery. The next instant the current through the coil reverses which in turn reverses the polarity of the reed. Then the face plate becomes a south pole and is repelled by the south pole and attracted by the north pole of the permanent magnet. This causes the reed to be pulled to the left, opening the contact. This opens the circuit to the battery and no current flows in the charging circuit at this instant. The contacts of a rectifier operating on a 60-cycle circuit would open and close 60 times per second and cause a pulsating current to flow in one direction into the battery.

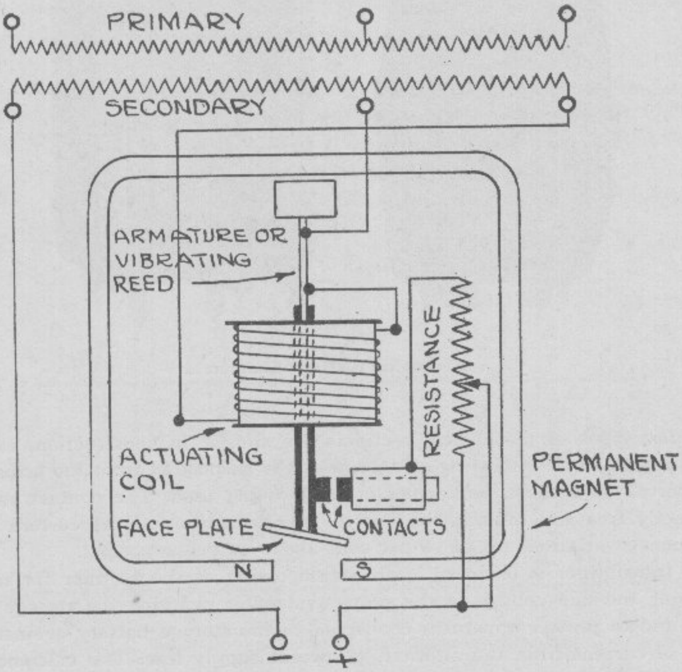

Fig. 12.

Circuit Connections for Mechanical Battery Charger.

Electrolytic

Several different types of electrolytic rectifiers are theoretically possible, but so far the only one that has been developed commercially is the tantalum lead combination using sulphuric acid electrolyte with ferrous sulphate as a depolarizing agent.

Historical.

Tantalum has been known in its compounds since 1801 and relatively pure tantalum metal has been made since 1903. At that time it was used for lamp filaments and it is estimated that over 100 million tantalum lamps were used in the United States before the tungsten lamp superseded it. Very little was done with metallic tantalum until 1922 when Dr. C. W. Balke developed a commercial process for making pure ductile tantalum at a reasonable cost.

The laboratories started intensive work to unearth uses for this newly available metal and developed a rectifier, known as Balkite, using electrodes of tantalum and lead in a sulphuric acid electrolyte. The possibilities of such a device in the radio field led to rapid commercial development and within several years hundreds of thousands of these rectifiers were in service. It is interesting to note, however, that one of the first experimental installations was in railway signal service. It was realized that this service was quite severe and would bring out the failings of the rectifier, if any, in a very short time.

Some of the properties of metallic tantalum may be of interest. It is characterized by great resistance to wet chemical corrosion. No mineral acid except hydrofluoric affects it. Its melting point is very high, being 2,996 degrees Centigrade. Its density is 16.6 (roughly twice that of copper). Its electrical resistance is 14.6 microhm-cm. (eight times that of copper). When pure it can be swaged, rolled and drawn cold without difficulty. Occluded gases make it difficult to work and one of the problems of its manufacture is to prevent absorption of gas by the metal.

Description of apparatus.

Each electrolytic charger consists of one or more rectifier cells and a suitable transformer. These rectifier cells are made in various sizes to meet requirements and consist of lead and tantalum electrodes supported from a hard rubber cover, immersed in a sulphuric acid electrolyte in a glass cell jar. In the small cells the cover screws onto the jar while in the larger sizes it is grooved to fit the top. The condition and operation of the cell is visible through the clear glass jar.

Types C-1 and C-11 cells illustrated in Fig. 13 are half-wave rectifiers. Either may be used for charging track, line or signal batteries. The rated capacity of these cells is 3 amperes to batteries of 8 volts or less and 1 ampere to batteries of 8 to 12 volts. Batteries of 12 to 14 volts may be charged at 0.5 ampere. The normal operating period is 2,750 ampere hours between additions of water. Type C-11 cell has the same rectifying electrodes as Type C-1, but has slightly more than twice the electrolyte capacity and therefore more than twice the normal operating period, or 6,000 ampere hours.

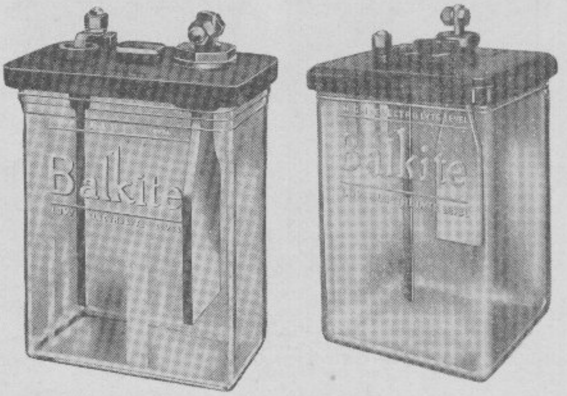

Fig. 13.
Half-Wave Electrolytic Cells Type C-1 (left), Type C-11 (right).

Type C-9 cells illustrated in Fig. 14 were developed to meet the need of charging line and signal batteries where rates of ½ ampere or less were required. The capacity of this cell is ½ ampere to batteries of 14 volts or less and its normal operating period is 1,350 ampere hours between additions of water. It is 4 inches by 6 inches by 7⅞ inches high over all.

Fig. 14.
Electrolytic Cell, Type C-9.

Types C-10 and C-12 cells illustrated in Fig. 15, are full-wave rectifiers known as "taper rectifiers" because of their peculiar inherent characteristic when connected to a transformer having good regulation. Under such conditions, the rate of charge follows the load demand on the battery to a marked degree, as shown in Fig. 16, increasing as the battery is used, and tapering to a small trickle rate as the battery becomes charged. In rectifiers of this type, adjustment is made by changing transformer taps rather than resistance control because of the ballast effect of resistance. Type C-10 cell has a rated capacity of 4 amperes to batteries of 8 volts or less, 3.3 amperes to batteries of 10 or 11 volts, 2.5 amperes to batteries of 12 or 13 volts, and 1 ampere to batteries of 14 to 15 volts, based on a normal operating period of 6,000 ampere hours.

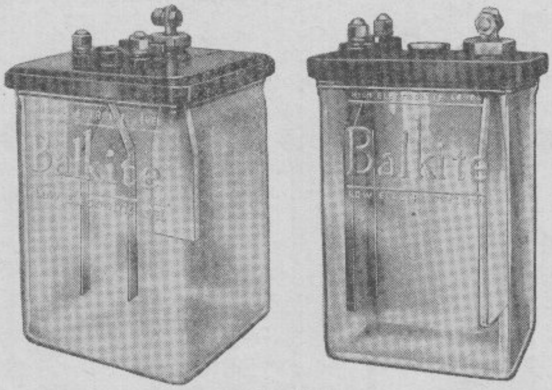

Fig. 15.
Full-Wave Electrolytic Cells Type C-10 (left), Type C-12 (right).

The curve shown in Fig. 16 was plotted from readings taken at a location where a taper rectifier is used to charge a 5-cell lead battery for a highway crossing signal. In this case, the signal operated for 30 minutes. Note that the rectifier output rose immediately, assuming a substantial portion of the load. Twenty minutes after the flasher operation ceased, battery voltage and rectifier output were both back to normal.

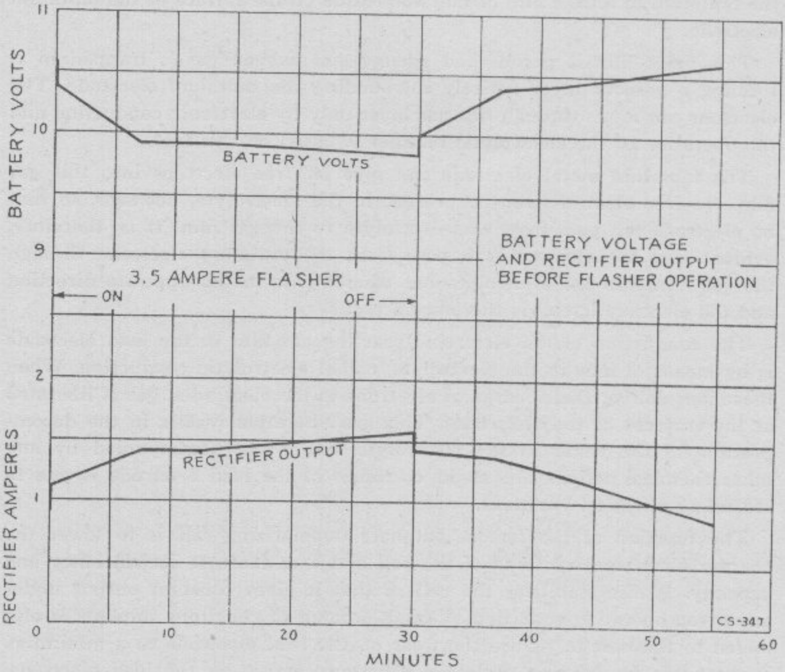

Fig. 16.

The overload capacity of these rectifier cells is not determined by overheating, as is the case with metallic rectifiers. The current limitations are set by transformers and other associated equipment rather than the cell itself. Current overload only increases consumption of water in the cell. Moreover, these cells are not damaged by high voltage surges which merely cause the tantalum oxide film on the tantalum electrode to rupture momentarily, after which the film re-forms and the rectifier continues to function normally. Sustained excess voltage will cause sparking within the cell which in time may burn the tantalum electrode.

Resistance units or transformer taps are used to control the charging rates. The standard range is from 20 per cent to full charging rate.

Theory of operation.

The theory of operation of the electrolytic rectifier is based on this fact: If an electrode of certain metals is immersed in an acid solution the metal will permit electrons to flow into the solution but not out of it, the metal thus acting as a valve which rectifies the current involving electrolytic conduction and electronic rectification. When one electrode of unformed tantalum and one of lead are placed in an electrolyte of sulphuric acid and an alternating electromotive force impressed across the cell thus formed alternating current will flow. During the half of the wave when electrons are passing out of the cell through the tantalum electrode oxygen will be liberated at the surface of the tantalum. This immediately combines with the tantalum to form a film of tantalum oxide on the surface of the tantalum electrode.

This oxide film is porous and spongy and oxygen gas is trapped in it forming a gaseous layer entirely surrounding the tantalum electrode. The electrons can move through this gas layer only by electronic conduction and the operation of the electrolytic rectifier is based on this fact.

The tantalum metal electrode can give off free electrons into this gas film. No free electrons can be present in the electrolyte, however, so that no electrons can pass from the electrolyte to the gas film. It is, therefore, evident that the electrons can pass from the tantalum electrode through the gas film into the electrolyte but cannot pass in the opposite direction and the electrolytic cell is therefore a rectifier.

The conduction of the electrons from the gas film to the lead electrode is by means of ions in the electrolyte, called electrolytic conduction. When these ions deliver their charge of electrons to the electrodes, gas is liberated at the surfaces of the electrodes. This gas liberation results in the decomposition of the water in the electrolyte and is not accompanied by any other chemical action. The slight corrosion of the lead electrode is due to secondary chemical reactions.

The function of the ferrous sulphate depolarizing salt is to lower the counter electromotive force of the cell and thus increase its efficiency and capacity. It also stabilizes the cell so that it gives constant output under any given operating condition. A small amount of cobaltous sulphate is also added to this salt to reduce the wear on the lead electrode to a minimum. It does this by forming a closely adherent coating on the lead electrode, which coating is not attacked by the electrolyte.

In considering the foregoing theory it should be remembered that the actual movement of electrons in any circuit is in the direction opposite to the commonly assumed direction of current flow. In other words, the electrons flow into the rectifier cell through the tantalum electrode, but the current is assumed to flow out of the cell through the tantalum electrode to the battery. The tantalum electrode of the rectifier, therefore, is connected to the positive terminal of the battery.

Applications.

Figure 17 illustrates connections for charging a track and a signal battery from one transformer using two rectifier cells.

Figure 18 illustrates connections for charging batteries up to 14 volts using one rectifier unit. Figure 19 illustrates connections for charging signal battery subject to heavy or irregular load with full-wave rectifier and tapped transformer. This arrangement delivers a taper charge as shown in Fig. 16.

Under certain conditions, the battery may be eliminated and the apparatus operated directly from a rectifier connected as shown in Fig. 20.

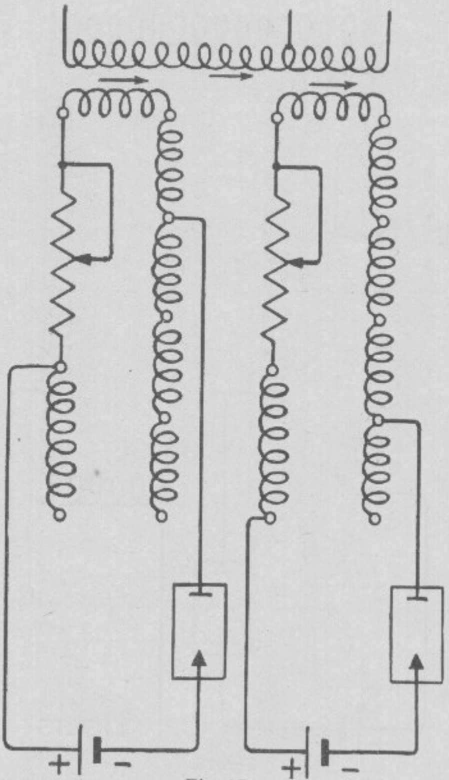

Fig. 17.

Circuit Connections for Charging Track and Signal Batteries from One Transformer and Two Rectifier Cells.

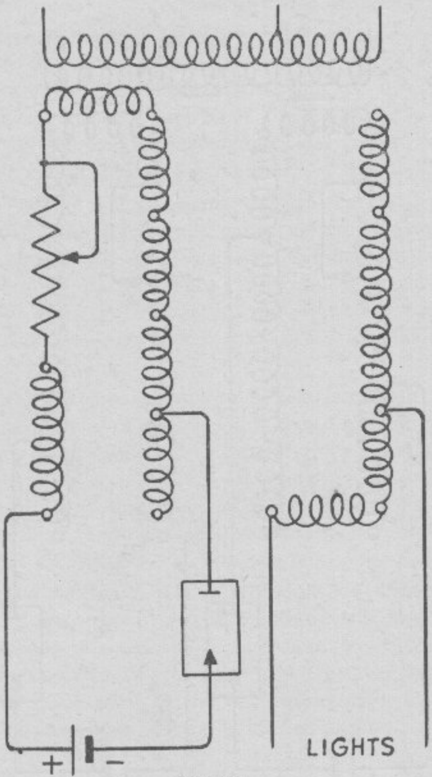

Fig. 18.

Circuit Connections for Charging Batteries up to 14 Volts, Using One Rectifier Cell.

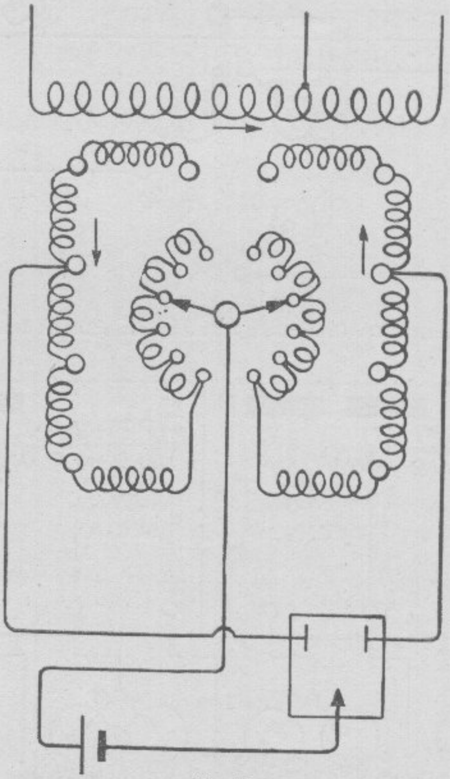

Fig. 19.

Circuit Connections for Charging Signal Battery with Full-Wave Rectifier Cell.

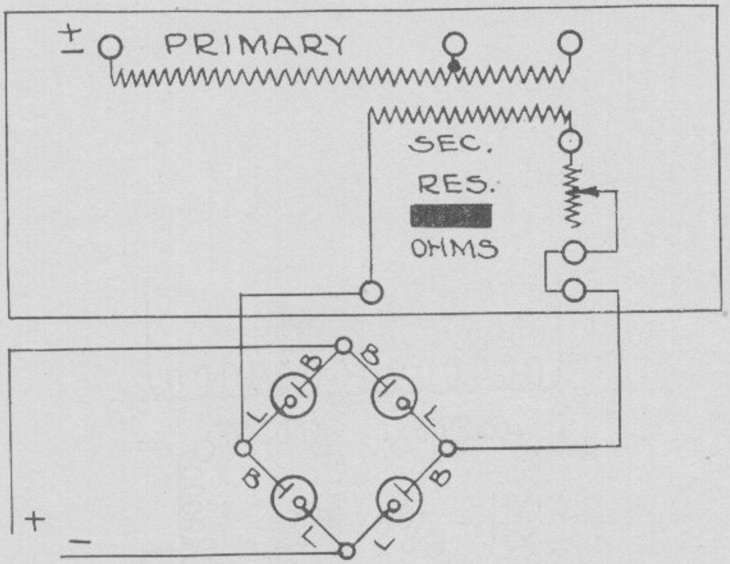

Fig. 20.

Circuit Connections for Controlling D.C. Apparatus Direct from a Rectifier.

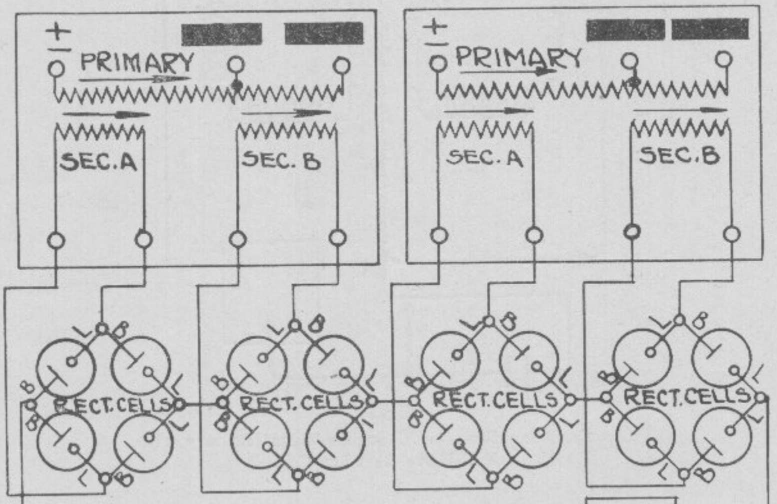

Fig. 21.

Circuit Connections for Charging Battery of 110 Volts.

A battery of 110 volts may be charged by a unit consisting of a group of electrolytic cells connected as shown in Fig. 21. Such chargers have normal charging rates of 0.5, 1, 2 or 6 amperes depending on the size of rectifier cell used. High output power units can also be used to operate 110-volt apparatus without the use of a battery.

Electrolytic rectifier cells are used in power units designed to operate direct current relays from alternating current track circuits or from alternating current power supply. The type C-8 cell is a full-wave cell designed for such service, and is connected as shown in Fig. 22. Currents up to 0.25 ampere at 15 volts can be obtained from this cell. A combination unit is supplied for lighting a flashing light signal on alternating current and also delivering direct current through the rectifier to operate a standard direct current flashing relay.

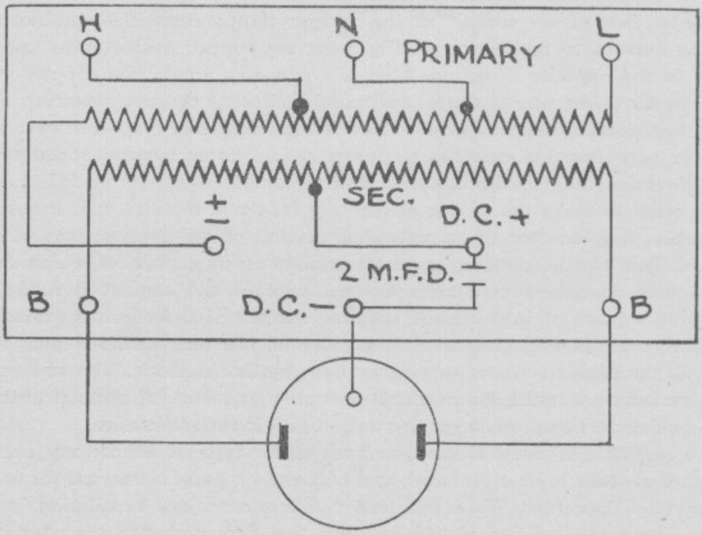

Fig. 22.
Circuit Connections for Operating Direct Current Relays from Alternating Current Track Circuits.

DRY PLATE

Copper-Oxide

Historical.

In 1920, Dr. Lars O. Grondahl, while working on the development of a light sensitive and thermal sensitive relay, discovered the asymmetric properties (ability to pass current more readily in one direction) of copper oxide. Due to the need of a reliable and efficient rectifier for the charging of radio batteries, experimentation for the development of a copper-oxide rectifier was started late in 1921. This development was diligently continued until very satisfactory rectifiers were produced. The first major commercial application for railway signaling service was a full-wave rectifier used for operating relays controlling locomotive cab signals in a two-element continuous automatic train control system on December 1, 1924. The first large commercial application of a battery charging rectifier was placed in service in December 1926. As a result of continuous development, the applications of copper-oxide rectifiers have expanded until these rectifiers are now generally used as valves, arc suppressors, snubbing devices, and for operating direct current apparatus direct from an alternating current source, as well as for charging batteries. Rectifiers have been built over a range of less than 1 watt to 100,000 watts, with current output of 12,000 amperes; for voltages up to 200,000; for frequencies up to 10,000 cycles per second. The 12,000 amperes installation was for electroplating; the 200,000 volt unit was for dust precipitation. On January 12, 1938, Dr. Grondahl was presented the Potts medal "For The Promotion Of Mechanical Arts" by the Franklin Institute as a result of his contribution in inventing and developing the copper-oxide rectifier.

The copper-oxide rectifier is based on the discovery that when cuprous oxide is formed on copper at the proper temperature the combination allows current to flow more readily from the copper oxide to the copper than in the opposite direction. This is a property not of the copper or of the copper oxide, but of the special combination of the two materials that is obtained when cuprous oxide is formed on copper in a special way. The copper cuprous-oxide unit has a greater resistance across the boundary in one direction than in the opposite direction.

In order to make use of this elementary unit as a rectifier, it is necessary to make good contact to an extended portion of the free surface of the oxide. This can be done in a great number of ways, two of which have been used in commercial units. By one method the contact is made by pressing a piece of lead against the free surface of the cuprous oxide. By another method both surfaces of a plate or disc are oxidized and then plated, the plated surfaces serving as the negative contacts. The two negative surfaces are multipled in a unit assembly by means of a metal bushing and two spiders to provide greater output and lower resistance.

To assemble a practical rectifier from either type of elementary unit, a number of these units are placed on a bolt and properly connected for series or parallel operation. When the lead contacts are used, ventilation is obtained by means of fins placed between the discs and also used for connectors. When the plated oxide unit assembly is used, the plates or discs themselves can be used as ventilated surfaces. These plates, however, are sometimes placed in special assemblies, in which a copper or brass ventilating fin is included, in order to increase their output rating. In both cases, separators are used when necessary to increase the amount of available ventilation.

Copper-oxide rectifiers used today in the signal field are made in accordance with one or the other method previously described. The principal difference between rectifiers manufactured by these methods is that the first method depends upon maintaining substantial pressure of the lead washer on the copper-oxide surface, and the second method requires that the contact fingers only exert a comparatively low pressure on the plated surface. Both types of assemblies require adequate protection against atmospheric oxidation or deterioration. Rectification takes place without any electrolytic action or other observable physical or chemical changes.

Description.

A rectifying unit, formed in accordance with the first method is shown in Fig. 23. The various parts comprising this unit are shown in this illustration.

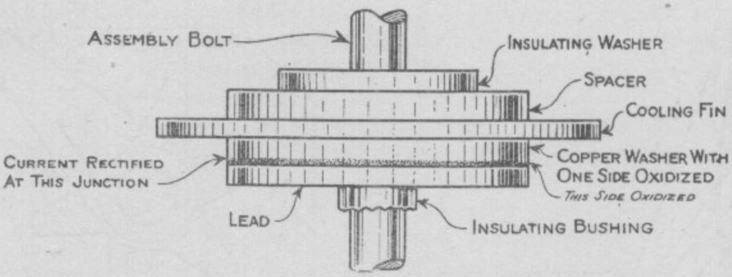

Fig. 23.
Typical Rectifying Unit.

The oxidized copper washers are mounted in units on a steel rod from which they are insulated as illustrated in Fig. 23. A connecting rod is soldered to the rim of the cooling fins thus permanently connecting the required number of rectifying units for series, multiple, or series-multiple operation.

A rectifying plate assembly formed in accordance with the second method is shown in Fig. 24 in which "A" is the copper-oxide plate, "B" the contact springs, "C" metal collar, "D" insulating collar, "E" positive connector, and "H" insulating washer.

The copper-oxide plate has a lug extension on one side to which the positive connector "E" is soldered; the positive connector is insulated from the contact springs of its own plate assembly by the insulation washer "H." The parts of the unit assembly are insulated from the steel bolt in the same manner as the standard disc and lead washer assembly. This plate type assembly is furnished for track rectifiers both battery charging and for energizing the track circuits direct (constant potential) and in a few constant potential line rectifiers in which good voltage regulation is of utmost importance.

Any number of individual elements may be assembled in series and in multiple into rectifier groups for any desired value of current and voltage. The two standard methods of connecting rectifiers for full-wave rectification are shown in Figs. 25 and 26.

Theory of operation.

The theory of operation of the copper-oxide rectifier is not yet fully understood. This much has been established experimentally: The rectification takes place at the boundary between the copper and the cuprous oxide, that is, the condition at the boundary is such that current flows very much more readily from the oxide to the copper than it does in the opposite direction. To say that the current flows from the oxide to the copper corresponds to saying that electrons move more readily from the copper into the oxide. It is as if there were at the boundary a check valve, which allowed the electrons to pass freely from the copper into the oxide, but which closes when the electrons try to pass from the oxide into the copper.

In terms of resistance we can say that the boundary has a high resistance in the direction from copper to oxide and a low resistance in the opposite direction. Physically this means that more work is required to move an

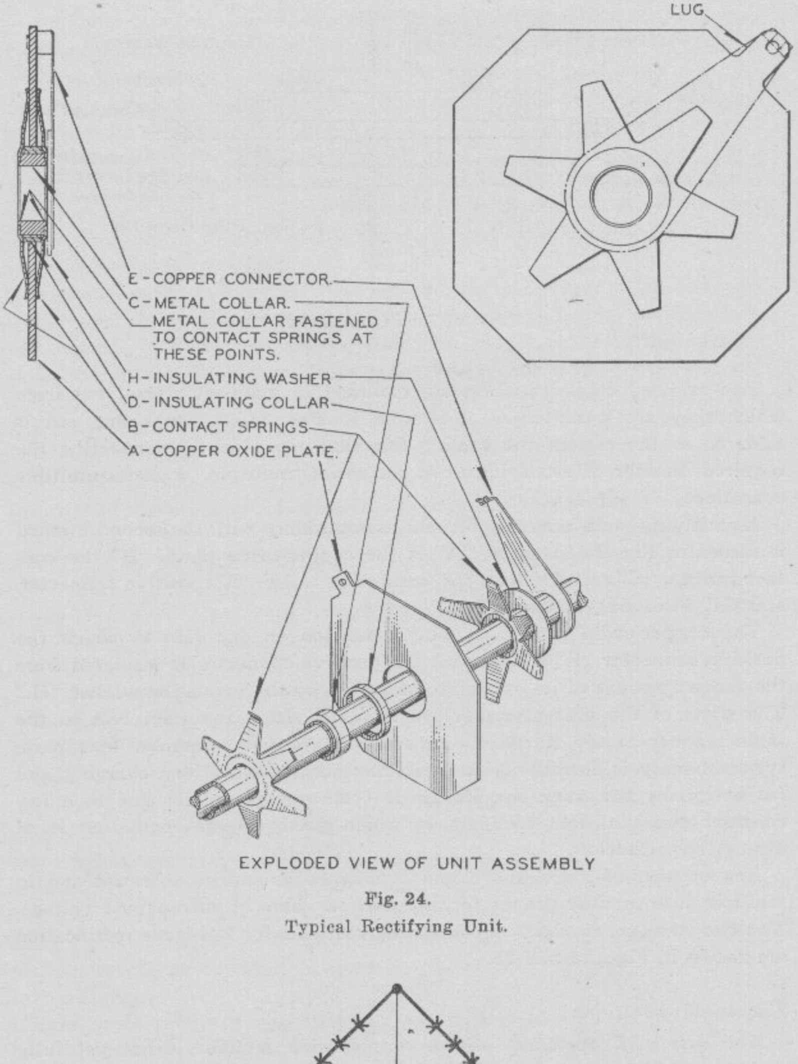

Fig. 24.
Typical Rectifying Unit.

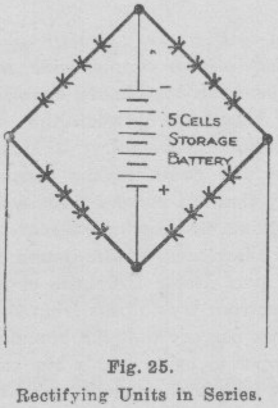

Fig. 25.
Rectifying Units in Series.

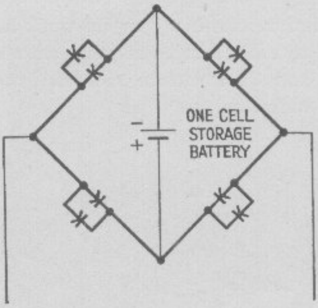

Fig. 26.
Rectifying Units in Multiple.

electron across the boundary from oxide into copper than it takes to move it across the boundary in the opposite direction. The details of the mechanism at the boundary which results in a free passage of electrons in one direction and not in the other is not yet understood. However, the results obtained with the rectifier both in the laboratory and in service have shown conclusively the action is entirely electronic and does not involve any chemical changes which result in the decomposition of the rectifier elements.

The current input to the battery is in the form of positive pulsations which are somewhat distorted from the shape of the charging wave because of the battery's potential. If, however, the charging circuit is connected to a resistance load and not to a load with a natural electromotive force, the form of the wave would be similar to that of the alternating current wave, with the exception that it would be continuously positive and not alternately positive and negative. Figure 27 shows the relation in wave form between direct current output and alternating current input.

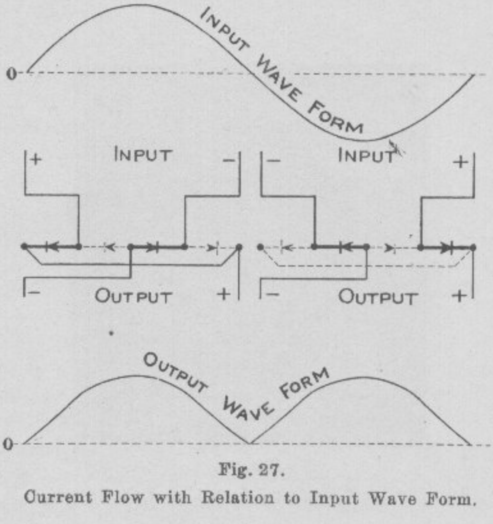

Fig. 27.
Current Flow with Relation to Input Wave Form.

Application.

Rectifiers for application in railway signal work have voltage and charging ranges engineered to meet service requirements of the railroads.

Figures 28, 29, 30 and 31 illustrate rectifiers used for charging track, signal, or interlocking batteries.

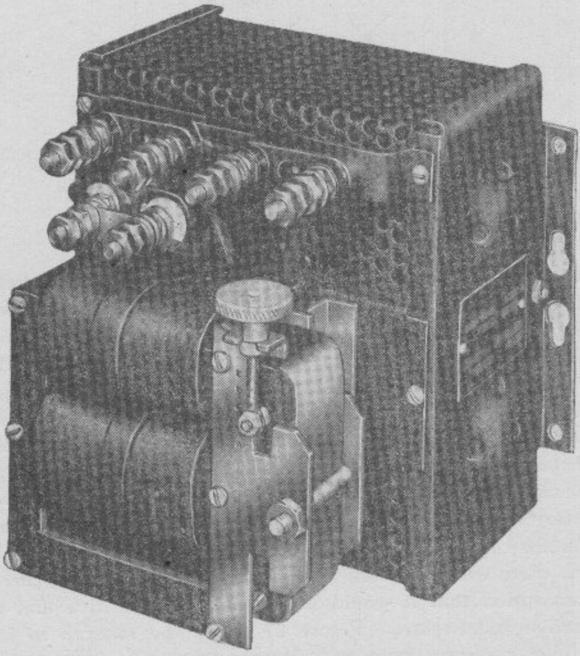

Fig. 28.

Rectifier for Charging 3 to 13.5 Volt Batteries.

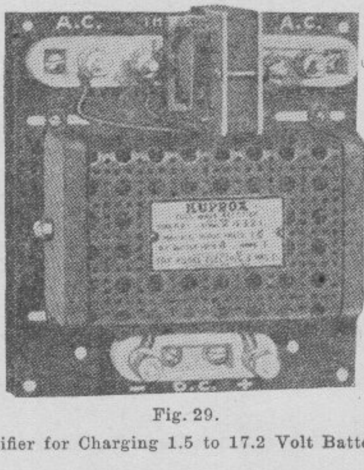

Fig. 29.

Rectifier for Charging 1.5 to 17.2 Volt Batteries.

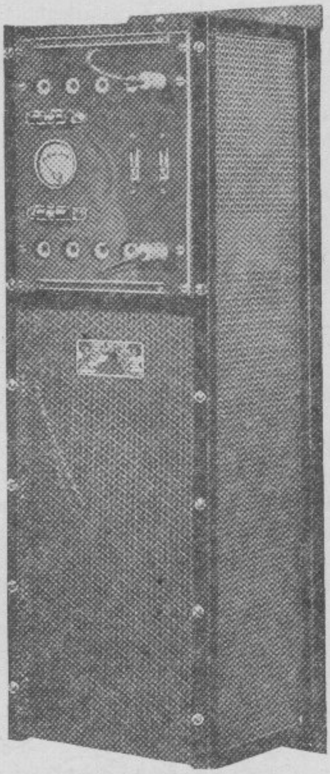

Fig. 30.
Rectifier for Charging 80 to 120 Volt Batteries.

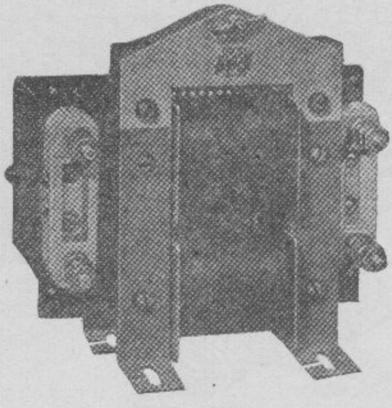

Fig. 31.
Rectifier for Charging 1.5 to 25.8 Volt Batteries.

Rating.

The rating of rectifiers designed for use inside buildings shall be based on continuous operation in freely circulating air whose temperature does not exceed 120 degrees Fahrenheit.

The rating of rectifiers designed for use in relay boxes, metal housings, etc., should be based on continuous operation in freely circulating air whose temperature does not exceed 160 degrees Fahrenheit.

The fundamental construction of the copper-oxide rectifier lends itself to flexibility of application with but slight modification in the assembly of parts, should it be desirable to use rectifiers for charging batteries of other voltages.

Automatic Rectifier

The automatic rectifier, Fig. 32, is usually used in multiple with primary battery to assume the major portion of the direct current ampere output required by the load, the remaining small drain on the battery being sufficient to keep it in active condition. The design of the transformer used in the assembly is such as to cause the rectifier to automatically assume practically all of an increasing load current within the rated current limits of the rectifier.

The taps on the transformer, or a combination of transformer taps and

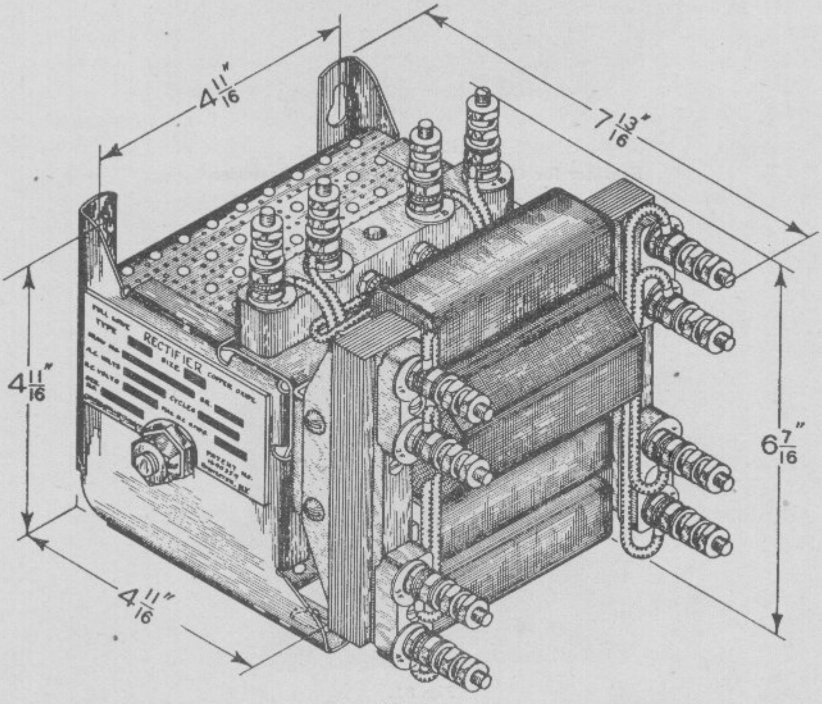

Fig. 32.
Automatic Rectifier.

a sliding core, permit adjustment to be made so as to obtain the desired division of load between the battery and the automatic rectifier.

Wiring diagram, Fig. 33, shows a typical circuit arrangement for application of the automatic rectifier to primary track battery.

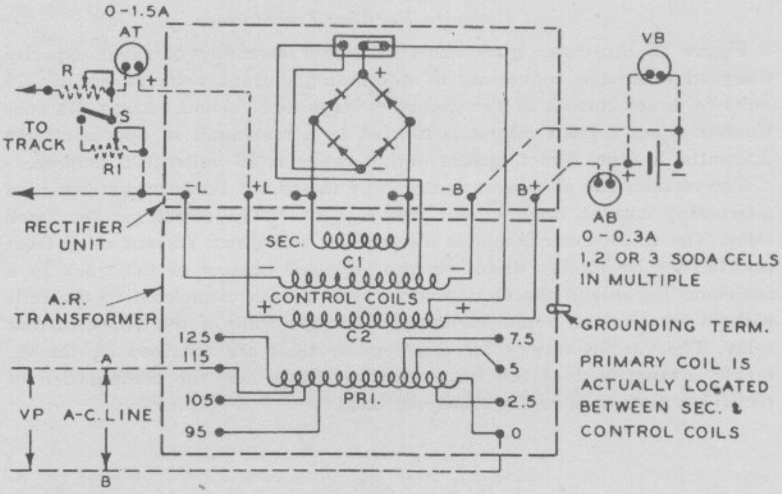

Fig. 33.
Typical Application Circuit for Automatic Rectifier.

Snubbing Rectifier

The snubbing rectifier, Fig. 34, has to a considerable extent replaced the snubbing resistor used in direct current semaphore signals. It is a half-wave rectifier or valve permitting free flow of current in one direction

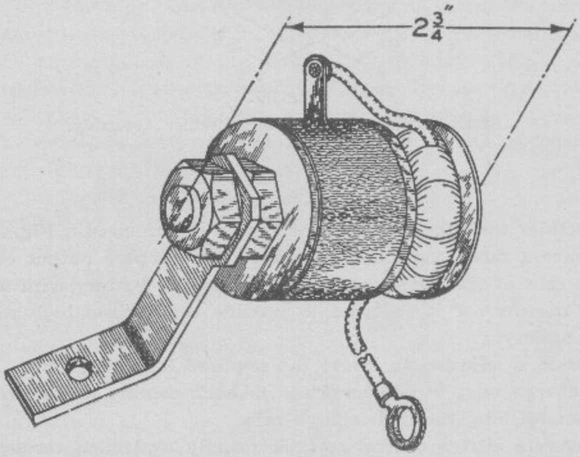

Fig. 34.
Snubbing Rectifier,

only. Its use eliminates the directional snubbing contact on the signal circuit breaker and since it permits snubbing through the entire downward movement of the spectacle and blade, smoother retardation is obtained with less strain on the mechanism than when the resistor is used.

Small Capacity Rectifier-Transformer

Figure 35 illustrates a rectifier-transformer assembly of small capacity designed to enable conversion of alternating current voltages up to 220 volts to direct current of the desired voltage and current ratings. Its continuous direct current output is limited to a maximum of approximately 2.5 watts. A usual direct current output rating is 12 volts, 0.20 ampere.

The rectifier can also be designed to be interposed between a steam road alternating current track circuit and a 2 or 4-ohm direct current track relay. The transformer insulates the rectifier and direct current relay from interference by foreign direct current which if present in the track to a sufficient degree and the rectifier unit were directly connected to the rails without transformer, could adversely affect operation of the direct current relay. The various ratings for this type rectifier are obtained by the required arrangement of the transformer windings and the combination of rectifying discs used in the rectifying unit.

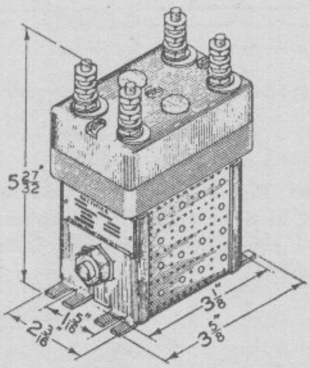

Fig. 35.
Small Capacity Rectifier-Transformer Assembly.

Two-Rate Charge Rectifier

The rectifier used for the two-rate charge in the circuit, Fig. 36, should usually have a rated continuous direct current ampere output of from 10 to 20 per cent of the 8-hour ampere rating of the battery with which it is used. Its transformer is adjusted to provide the desired high rate charge from the battery.

Resistor R is adjusted to insure the required low charge rate. When the two-rate charge relay is de-energized, its back contact shunts the resistor, thereby establishing the high charge rate.

The two-rate charge control relay is usually controlled through a front contact on a track or line relay, selected to drop when a high load is thrown on the battery. The high rate charge continues even after the front contact

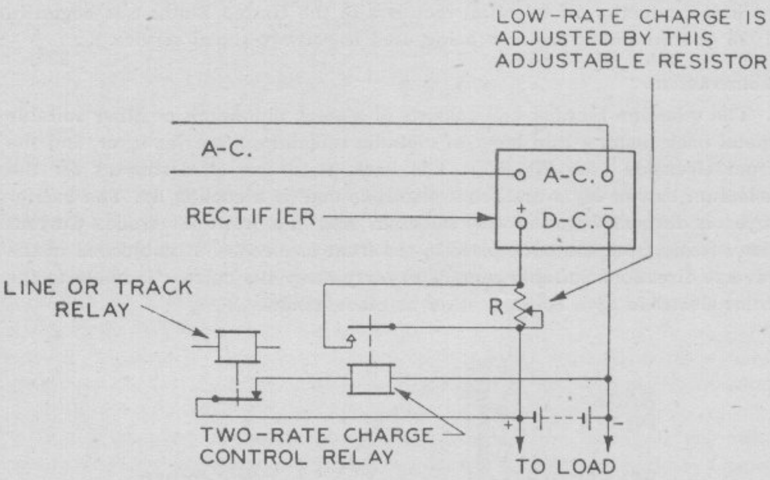

Fig. 36.
Typical Application Circuit for Two-Rate Charge Control Relay.

on the control relay closes, until the battery voltage has assumed a value corresponding to a practically fully charged battery at the existing ambient temperature, thereby causing the two-rate charge relay to pick up, which again cuts resistor R in circuit, re-establishing the low charge rate.

The two-rate charge control relay is designed so that its pick-up voltage temperature characteristics are similar to the voltage characteristic of a battery on charge and approaching a fully charged condition at the existing ambient temperature. The relay and battery should be located near each other so both will be subjected to the same ambient temperature.

The relay is provided with means to permit its pick-up to be adjusted in accordance with the high charge rate desired and the ambient temperature existing when it is first installed. An instruction tag accompanying the relay gives complete information on the method of adjusting when installing.

An alternative circuit arrangement is to locate the resistor between the rectifier transformer secondary and the input terminals of the rectifier stack. This results in lower alternating current voltage applied to the rectifier stack during the low charge rate period.

Selenium

Historical.

Selenium, which shows considerable resemblance to sulphur, was discovered by Berzelius in 1817. Its photo-electric properties were noted in 1873. It is not known when its rectifying properties were discovered, but production of selenium rectifiers on a commercial scale was begun in Nuernberg, Germany, in about 1927, and by 1932 selenium rectifiers were widely used throughout Europe. It is interesting to note that selenium rectifiers went through their early development stages in Europe at about the same time that copper-oxide rectifiers were being developed in the United States. Little use of selenium rectifiers was made in the United States during this period. Production of selenium rectifiers in the United States was begun in 1938 and a number are now being used in railway signal service.

Construction.

The selenium rectifier cell consists of a steel, aluminum or other suitable metal back plate, a thin layer of metallic selenium, a barrier layer, and the front electrode (see Fig. 37). The back plate acts as a support for the selenium barrier layer and front electrode and as a cooling fin. The barrier layer is formed between the selenium and the front electrode. Current flows freely from the back plate to the front electrode but is blocked in the reverse direction. Suitable contact to carry away the current is made to the front electrode by a spring washer or other means.

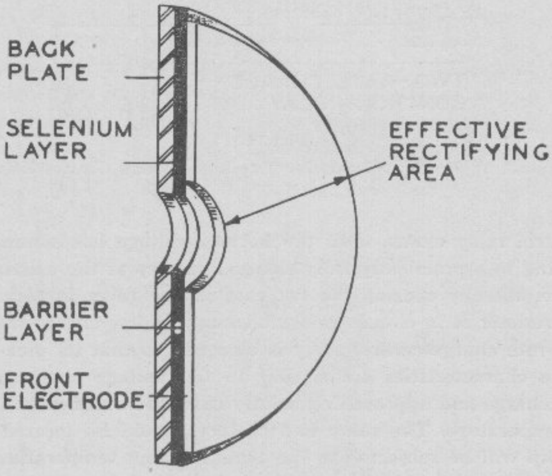

Fig. 37.
Construction of Selenium Rectifier Cell.

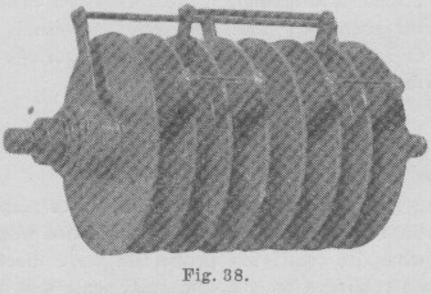

Fig. 38.
Typical Selenium Rectifier Stack.

The selenium rectifier is a one-piece rectifier requiring no high pressure contact for rectification. In fact, high pressure on the barrier layer is detrimental to the reverse resistance. In normal construction no front electrode is applied to the center of the plate and no barrier layer is formed.

This permits pressure to be applied to the spacing and limiting washers without affecting the reverse resistance.

Rectifier cells are assembled on center bolts in various combinations according to the rectifier application. Figure 38 is a typical railway signal rectifier stack.

Theory of operation.

Even at this late date there is still question about the theory of operation of metallic rectifiers, whether they be selenium or copper-oxide. One of the most logical explanations of the operation of selenium rectifiers was given by Mr. E. A. Richards in an article published in the Journal of the Institute of Electrical Engineers, London, England, Volume 88, October 1941, Part 2. It is substantially as follows:

Any dry-plate or metallic rectifier must consist essentially of a semi-conductor, a barrier layer, and a good conductor, the barrier layer being an insulator through which electrons can pass in either direction.

In the selenium rectifier, the semi-conductor is the selenium, the front electrode is the good conductor, and the barrier or insulator layer is formed between the two. If the selenium rectifier is compared to a cold-cathode-emitter rectifier, the front electrode is the cathode, the back plate the anode, and the selenium and barrier layers the insulator between the two.

Considering the electron theory, the action can be described as follows: In the good conductor (front electrode) there is an abundance of free electrons (see Fig. 39). In the semi-conductor, selenium, the number of free electrons is very small. When negative-electron potential is applied to the good conductor (front electrode) and opposite polarity to the back plate, an electric field is set up across the barrier layer. Because of the fact that the barrier layer is extremely thin, a small electromotive force will produce a steep potential gradient. With this negative potential ap-

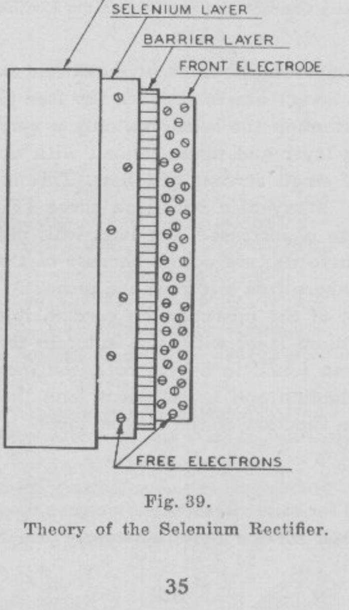

Fig. 39.
Theory of the Selenium Rectifier.

plied to the front electrode, the free electrons are acceleratd to sufficient velocity to penetrate the barrier layer and the selenium layer, establishing a conduction path for the flow of current in the opposite direction, that is, from the back plate to the front electrode. To support this theory, the selenium rectifier has high resistance in the forward direction at very low voltages. The more potential applied, the more electrons are accelerated sufficiently to reach the back plate, and more current will flow through the rectifier. There is, of course, a limit to the voltage which may be applied (see Fig. 40).

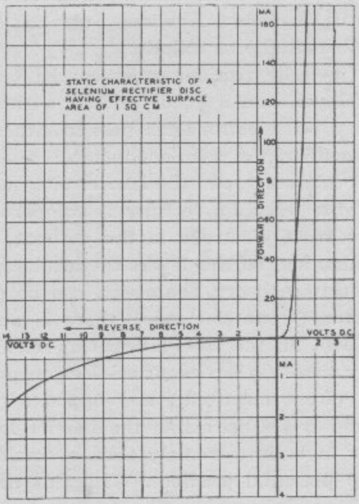

Fig. 40.

Static Characteristics of Selenium Rectifiers.

If the polarity is reversed, a different condition exists. Then the semiconductor (selenium layer) has to produce the free electrons. There being only a few free electrons in the selenium, only a very few will be able to penetrate the barrier layer and make contact with the front electrode. As a result, only a very small current will flow. This is called "reverse current" or "back leak." Study of a back-leak curve (Fig. 40) discloses that as the reverse voltage is increased, the back-leak increases. This may be carried to a point where rupture occurs because of the tremendous voltage gradient at a point where free electrons are present.

If this explanation of the operation be correct, it can be assumed that thickness of the selenium layer will be a factor in the performance of the rectifier. This has been found to be the case, the forward resistance being a function of the selenium and barrier layer and the front electrode, the reverse resistance the function of the barrier layer.

Application.

Selenium rectifiers for railway signal service are designed, rated and built to meet the recognized service requirements of the Signal Section, Association of American Railroads. Rectifiers for track or signal batteries are designed for shelf or wall mounting in signal cases, and are supplied in the following styles: (a) with adjustable reactive transformer, (b) with adjustable reactor, (c) with tapped transformer and adjustable reactor, (d) with tapped transformer, (e) with input and output terminals for operation with existing transformers and controls. Heavy duty selenium rectifiers for interlocking plants, terminals, switch machines, automatic gates, etc., are supplied with tapped transformer, controls, ammeter and circuit breakers, and are designed for indoor installation.

Detailed specifications of selenium rectifiers for railway signal service are published in manufacturer's literature.

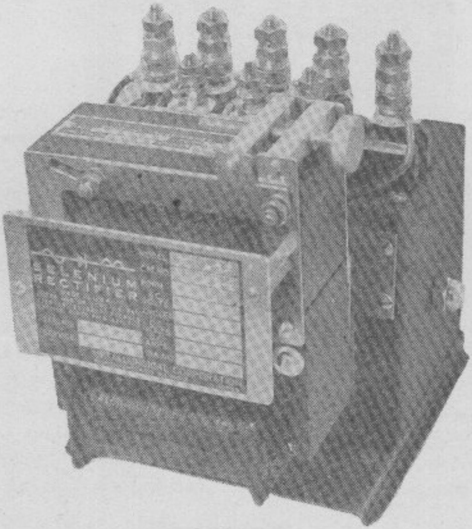

Fig. 41.
Full-Wave Selenium Rectifiers with Reactive Transformer for Charging 1 to 20 Cells of Lead Battery (2 to 30 Ni-Fe Cells).

Instructions.

Rectifiers

1. Rectifiers must be kept clean and in good condition. They must not be exposed unnecessarily to smoke, dust, grit, or battery acids. Bolts, nuts, screws, pins and binding posts must be kept tight.

2. Rectifiers must be of sufficient capacity for the service required and must be used only with the voltage and frequency for which they are designed. They should not be adjusted to charge at more than their rated capacity.

3. Fuses of the proper type and capacity must be used.

4. Adjustments must be made in accordance with instructions issued by proper authority.

5. Test must be made periodically, as instructed, to determine that rectifier is delivering the required amount of current.

6. Rectifiers found to be defective must be removed from service as

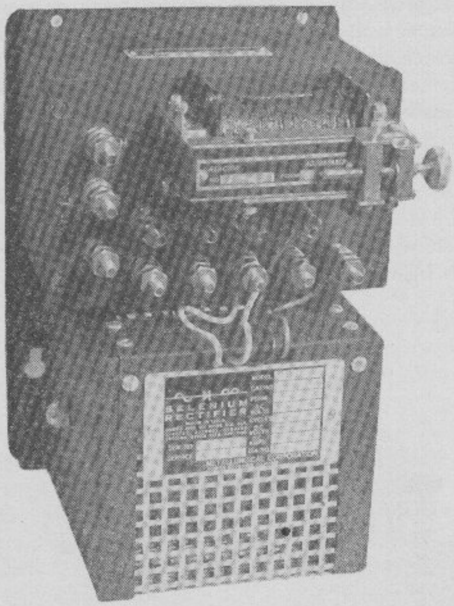

Fig. 42.

Full-Wave Selenium Rectifiers with Tapped Transformer and Adjustable Reactor for Charging 2 to 60 Cells of Lead Battery (2 to 90 Ni-Fe Cells).

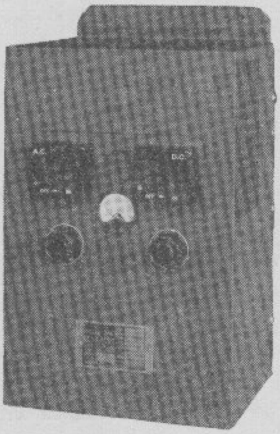

Fig. 43.

Full-Wave Selenium Rectifier Units for Interlocking Plants, Terminals, Switch Machines, Automatic Gates, Telegraph or Other Heavy Duty Service, for Charging 3 to 110 Cells of Lead Battery (4 to 160 Ni-Fe Cells).

promptly as possible and defects noted on repair tag Form 7018. (See Fig. 44.)

Mercury arc.

7. Tubes must be handled carefully and when not in service must be kept in shipping crate. They must be protected from sudden changes in temperature to avoid fracture.

8. Starting switch must not be held in starting position so that starting resistance is over-heated. If rectifier does not start readily, starting operations must be spaced to avoid excessive heating.

9. Switch adjusting arm for regulating compensator must be moved quickly from one contact to another to prevent arcing, and must not remain in a position to bridge two contacts.

Electrolytic.

10. Connections must be coated and cups filled with petrolatum to prevent acid creepage and consequent corrosion.

11. Electrolyte of between 1.200 and 1.220 specific gravity must be used.

12. Depolarizer salt, in quantity furnished by the manufacturer for each cell, must be added to the electrolyte before oil is poured over the surface.

13. Oil poured over the surface of the electrolyte must be of the quality and quantity as recommended by the manufacturer.

14. A film of oil ⅛ to ¼ inch in depth must be maintained over the surface of the electrolyte. Liquid petrolatum (United States Pharmacopoeia) heavy, may be used when necessary to add oil.

15. Hydrometer used to test rectifier electrolyte must not be used for testing battery electrolyte.

16. Cover of rectifier cell must be kept in proper position.

17. Approved water only must be used to replace that lost by hydrolysis and evaporation. Acid should be added only to replace any that may have been spilled.

18. Electrolyte must be maintained between the minimum low and maximum high levels shown in manufacturer's instructions. Electrolyte should be permitted to reach the low level before adding water. Electrolyte should be renewed in accordance with manufacturer's instructions.

Dry Plate.

19. Rectifiers should be so mounted that their cooling fins are in a vertical plane and in a location allowing free circulation of air. The temperature of surrounding air must not exceed the maximum value specified by manufacturer. Where resistors, reactors and transformers are furnished as a part of rectifier unit, the mounting must be so arranged that such devices are not placed below the rectifier unit.

Motor-Generators

20. Motor-generators must be kept clean and dry. They must not be exposed unnecessarily to smoke, dust, grit, acid fumes or battery gases. Bolts, nuts, screws, pins, binding posts, nut locks and jam nuts must be kept tight.

21. They should, when not in use, be protected by a suitable covering.

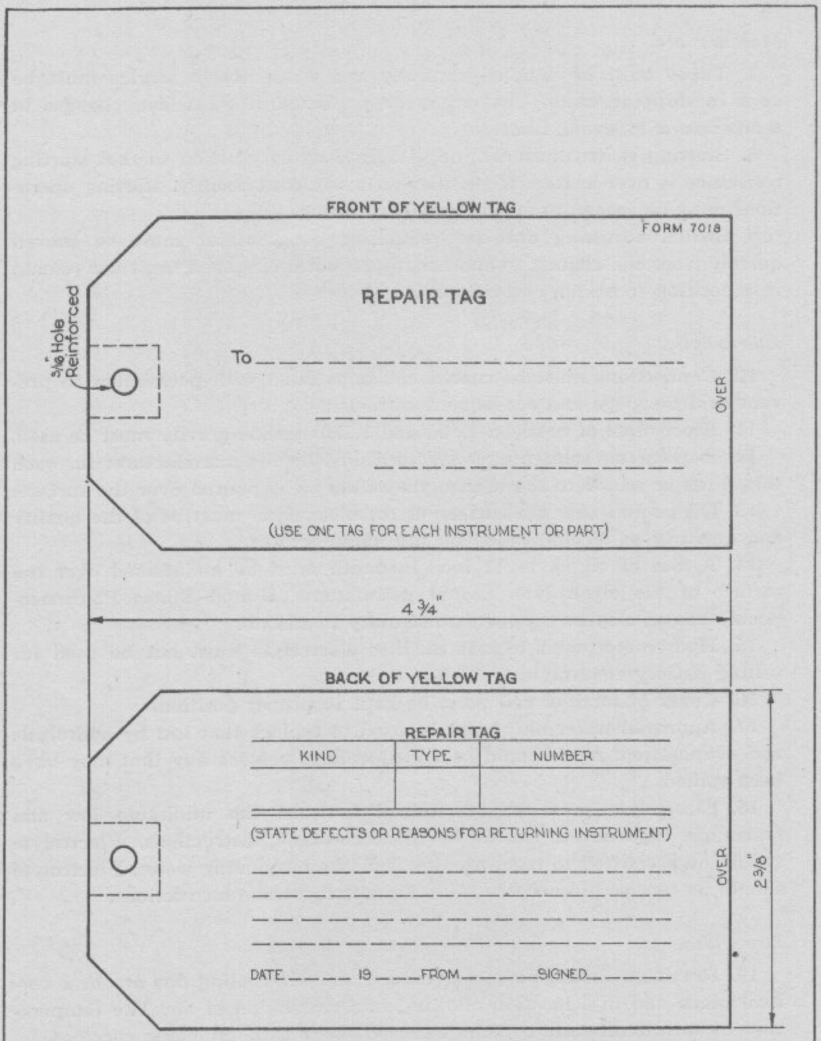
FRONT OF YELLOW TAG
FORM 7018
REPAIR TAG
3/16" Hole Reinforced
To
OVER
(USE ONE TAG FOR EACH INSTRUMENT OR PART)
4 3/4"
BACK OF YELLOW TAG
REPAIR TAG
KIND
TYPE
NUMBER
(STATE DEFECTS OR REASONS FOR RETURNING INSTRUMENT)
OVER
2 3/8"
DATE
19
FROM
SIGNED
160 LB. 20TH CENTURY BRISTOL
AAR
SIG. SEC.
7018
MAR 1922
M-1923
MAR 1935
M-1935

Fig. 44.

22. Voltage and current rating shown on name plate should not be exceeded.

23. Fuses of specified capacity and type must be used.

24. Oil-wells must be kept filled to the proper level with an approved lubricating oil. Wells must be drained periodically by removing drain plug, washed with gasoline and refilled.

25. Oil rings must be checked frequently when machine is running to see that they revolve freely and carry oil to the shaft.

26. Commutator must be smooth, clean and have a glossy appearance. To clean, lift brushes from commutator and use chamois or cloth free from lint and abrasives, moistened, if necessary, with Specification 102 or 103 oil, and then wipe commutator dry with dry chamois or cloth. Abrasives or files must not be used on commutators.

27. Brushes must be kept clean, fitted to commutator, free in brush holder, or brush holder free on stud. Springs must be in place and so maintained that brushes will have proper bearing and pressure. When installing new brushes they should be placed in position and carefully seated on the commutator by placing No. 000 or finer sandpaper under the brush with smooth side against the commutator and while pressing brush oscillate sandpaper with commutator. Burrs must be removed from the brush. When finished, all sand and dust must be removed.

28. Motor-generators found to be defective must be removed from service as promptly as possible and defects noted on repair tag Form 7018. (See Fig. 44.)

Alternating Current Floating Storage Battery System

The Signal Section, Association of American Railroads, defines Alternating Current Floating Storage Battery System as: A combination of alternating current power supply, storage battery and rectifying devices so constructed as to continuously charge storage battery and at the same time furnish power for the operation of signal devices.

For the generation and distribution of electrical power the alternating current system is the most feasible and economical due almost solely to the fact that this form of power can be transformed from one voltage to another by the simple use of a transformer. For power consumption or utilization direct current is generally accorded an equally high position and in some cases is even superior to alternating current.

The alternating current floating battery system of signal power supply is a combination of the alternating current system of power distribution and the direct current system of power consumption. At each signal location rectifiers and batteries form the connecting links between the alternating current power supply and the signal and track circuits. Figure 45 is a typical layout from the generating station to the signal circuits and Fig. 46 is an elementary wiring diagram.

One of the most popular methods of explaining the flow of electrical power in an electrical conductor or wire is by comparison or analogy to the flow of water in a pipe line, wherein the pressure exerted by a column of water is compared to the pressure in volts of the electric circuit and the flow of water through the pipe is compared to the flow of current in amperes in the electrical circuit.

This hydraulic similarity or analogy can be applied to explain the prin-

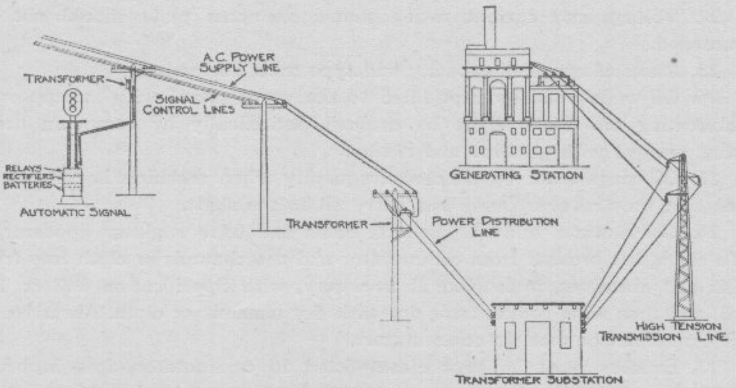

Fig. 45.

Typical Layout from Generating Station to the Signal Circuits.

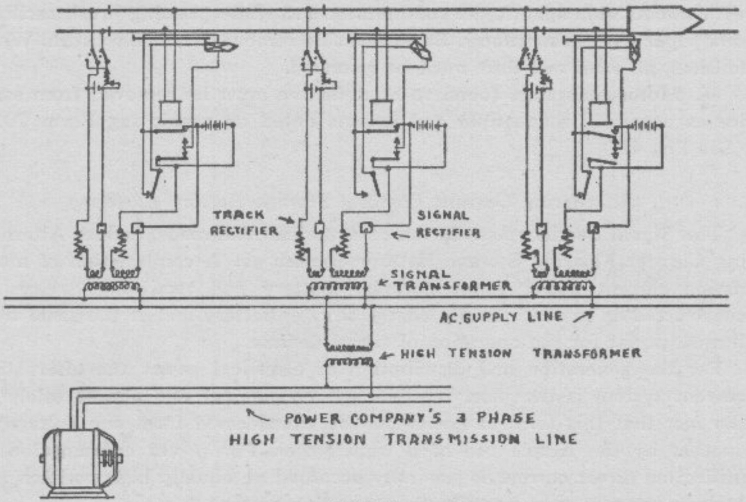

Fig. 46.

Elementary Wiring Diagram for Floating Storage Battery System.

ciple and operation of the alternating current floating battery system. Figure 47 is a simple water supply plant or system. Assume that it is utilized for some manufacturing purpose and must supply a small steady stream of water continuously, and a larger flow or stream over short periods of time, intermittently. To protect the manufacturing process against a failure of water supply, in case of breakdown of the boiler room or pump, the storage tank becomes a necessary part of the water supply plant.

The best way to operate this water supply plant would be to regulate the speed of the pump so as to keep the tank approximately full at all times, but without an excessive overflow of water from the tank; that is, the speed or output of the pump would be adjusted to meet the average demand for

water. There might be periods of time when the intermittent demand for water would be large and during this time the level of the water in the tank would drop. Again, if the intermittent demand is small, the level lost during periods of large intermittent demand would be restored; that is, when the intermittent valve is closed the tank would gain in level until it overflowed and there would be a small continuous overflowing of the tank until the intermittent valve is again opened. In fact, all of our city water supply systems of today are built and operated upon this principle.

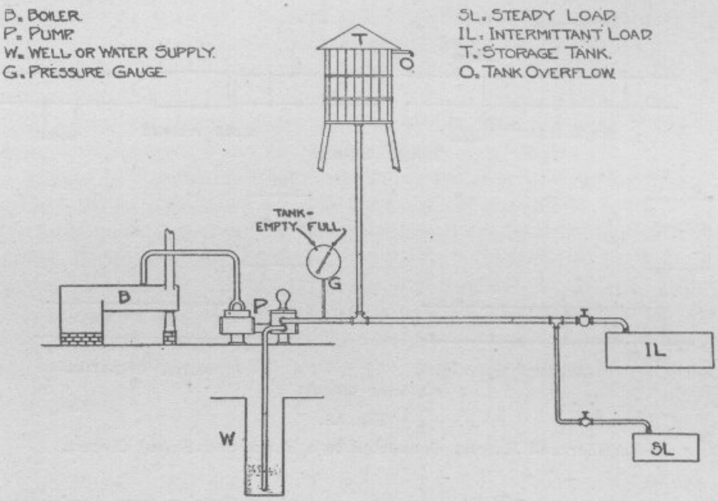

Fig. 47.
Simple Water Supply Plant System.

In this water supply plant the water and steam pressure actuating the pump corresponds to the alternating current power; the pump corresponds to the rectifier; the storage tank to the battery; the steady stream or supply of water corresponds to the steady load on the signal system such as the output to a track circuit, the holding coil of a semaphore signal, relays, or the signal light where it is continuously lighted with direct current; and the intermittent supply of water corresponds to the intermittent load on the signal system, such as the track circuit drain with a train in the block, the motor current of the semaphore signal, the signal light current in approach lighting or where alternating current power-off relays are used, which operate on an interruption in the alternating current supply, and the loss of water in the operation of the plant, due to leakage and evaporation, corresponds to the internal loss or local action within the storage cell or battery.

Figure 48 shows a rectifier and battery connected into a track circuit and a signal circuit. In the unoccupied block it will be noted that the rectifier furnishes the total output to the track circuit and is also charging the battery; that is, the battery is doing no work whatever at this time. When a train occupies the track circuit the battery discharges to furnish most of the extra current drawn because of the fact that the track circuit is short circuited. In the signal circuit, as shown, the rectifier supplies the steady connected load and charges the battery when there are no signal movements. When the signal motor operates, the battery discharges to supply practically all the current for the operation.

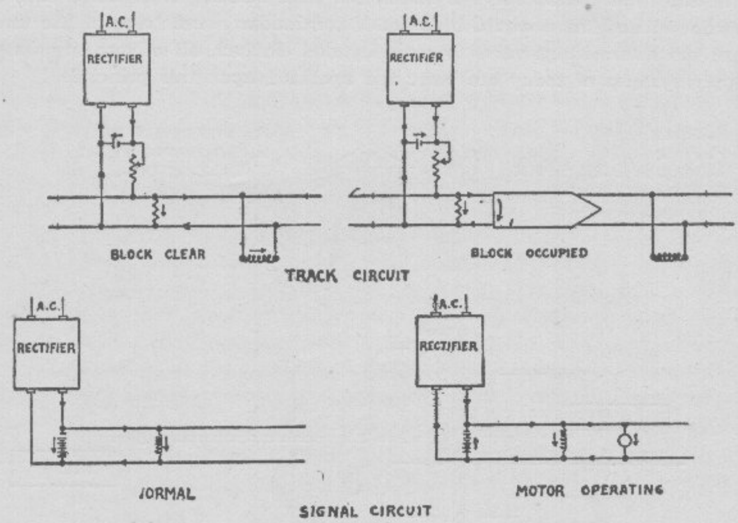

Fig. 48.

Rectifier and Battery Connected to a Track and Signal Circuit.

The rectifier must supply a steady current or floating rate equivalent to the sum of three different currents as follows:

1. A current to supply the steady connected load.
2. A current to return to the battery the amount taken out during the intermittent discharges.
3. A current to make up for the local action or loss within the battery.

The total output or the floating rate of the rectifier, whatever it may be for any particular location, should be sufficient to maintain the battery in an approximately fully charged condition. In the alternating current floating battery system the voltmeter corresponds to the pressure gage in the water supply system and is the most satisfactory method of checking the floating rate. Gassing of the electrolyte corresponds to the overflow of the water tank.

Instructions.

Alternating current floating storage battery system should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be adjusted to provide a charging rate sufficient to keep the battery fully charged.
2. Frequent tests must be made by taking a voltage reading across the terminals of each cell, while rectifier is charging, to determine that the cell is fully charged.
3. Voltage across each cell of lead type battery must be maintained at an average of 2.15 volts.

4. Voltage across each cell of nickel, iron, alkaline battery must be maintained at an average of 1.5 to 1.6 volts.

5. A battery record form must be kept for each cell, on which the date and voltage reading of each cell must be entered each time check is made.

6. Adjustment of charging rate must not be made each time it is found a cell is outside the voltage limits specified in Instruction 3 or 4. If, however, the voltage is found to be consistently low or high on three consecutive checks, adjustment must be made as necessary.

7. It is advisable that the charging rate be first set at a safe maximum and reduced as necessary. In this way the possibility of exhausted cells, during interval of adjustment, will be eliminated.

8. Voltmeter used for these tests must be kept in calibration to less than 5 per cent error.

9. If necessary to add water to batteries during freezing weather, a syringe must be used to mix the water with the electrolyte.

10. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

11. Lead acid type storage batteries should be installed, maintained and operated in accordance with the instructions covered in Chapter V—Batteries.

12. Nickel, iron, alkaline storage batteries should be installed, maintained and operated in accordance with the instructions covered in Chapter V—Batteries.