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Copper-Oxide Rectifiers in Telephone Circuits*

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THE commercial development of the copper-oxide rectifier in very small sizes, has opened up a new field for the circuit designer. The use of the metal rectifier in circuit technique is still comparatively new, and therefore it is probable that the full possibilities of this particular component have not yet been exploited.

Principle of the Metal Rectifier

When cuprous oxide is formed on copper at a high temperature, the junction between the two materials has the property of asymmetrical conductivity. This effect is distributed in practically a uniform manner over the whole area common to both materials. So far as is known, no material in itself has been found to be asymmetrically conducting; if a given material has a certain resistivity in one direction, it has the same resistivity in the opposite direction, and both copper and cuprous oxide are like all other substances in this respect. The asymmetrical nature of the two substances when formed as described, must therefore be a boundary phenomenon.

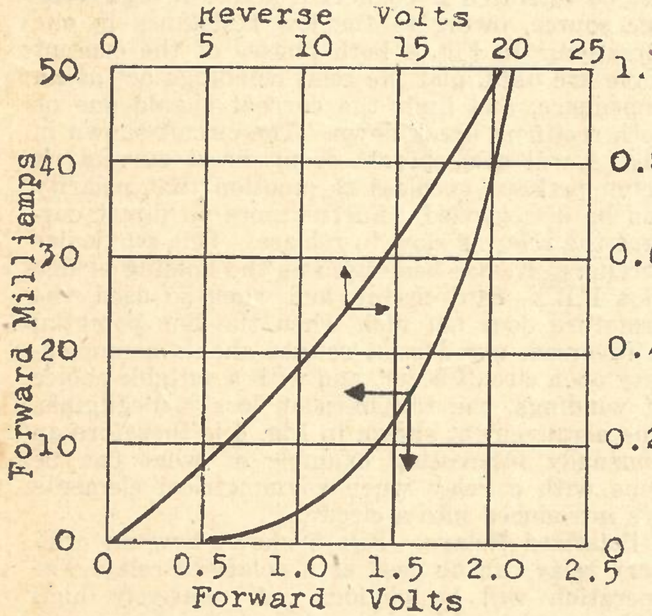

Fig. 1. Typical Voltage-Current Curves.

The transverse resistance through the combination is relatively low from oxide to metal and very high from copper to oxide. In the larger sizes of rectifiers the resistance ratio is approximately 1 to 1,000, but for small sizes the average ratio is lower. Cuprous oxide has a negative temperature coefficient, i.e., the resistance decreases with increase in temperature, which is a point not to be overlooked in circuit work.

There is reason to believe that the action in this type of rectifier is electronic, and if so, it is interesting because the electrons are emitted by a cold cathode; although on the other hand there appears to be no action analogous to the gradual destruction of the cathode such as occurs in an electronic tube.

Voltage-Current Characteristics

Typical voltage-current curves are given in Fig. 1. One curve is for the forward or low resistance direction whilst the other curve applies to the reverse or high resistance direction. It will be seen that both curves are non-linear, that is, there is no fixed ratio between the applied

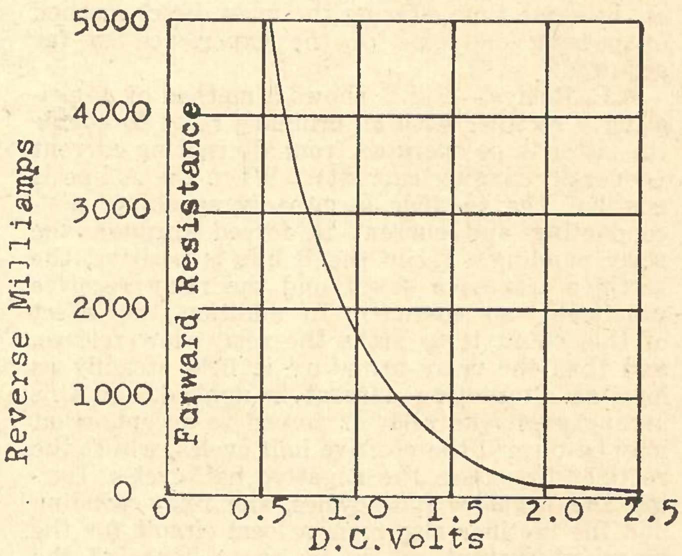

Fig. 2. Typical Resistance-Voltage Curve

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volts and the resultant current, or in other words the resistance of the rectifier in either direction is not constant.

Fig. 2 shows a typical resistance-voltage curve, and generally speaking these two parameters are the most useful in circuit work, provided the maximum safe current of the rectifier is known. An inherent property of these rectifiers therefore, is that the resistance depends on the applied voltage, being high for small potential difference and decreasing more or less rapidly as the potential difference is increased. This particular property has proved extremely useful, and many circuits depending on this feature have been developed, several of which will be discussed later.

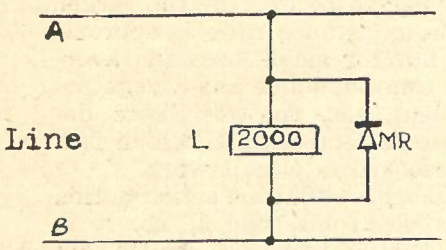


Fig. 3. A.C. Line Relay for Operation on Ringing Circuit.

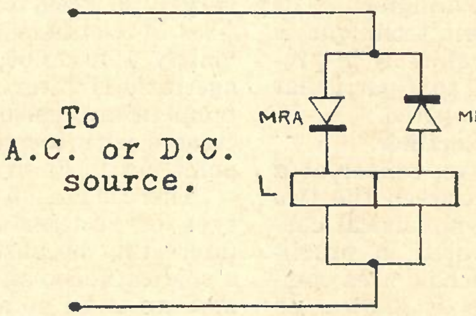


Fig. 4. Relay for Operation from A.C. or D.C.

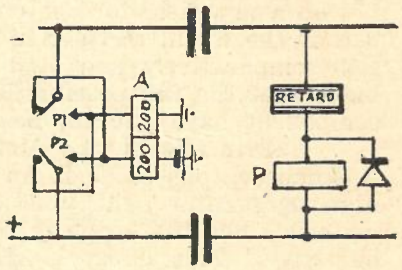


Fig. 5. Polarised Relay for Reversing Battery to Calling Line when Called Line Answers.

Applications

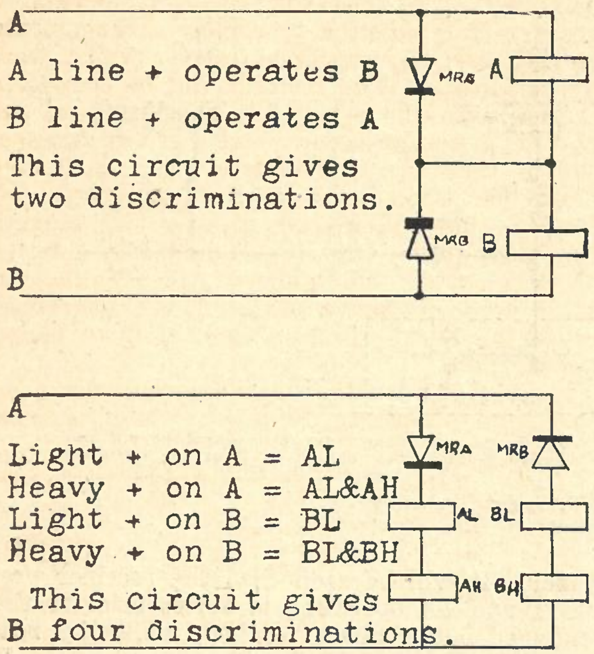
Examples will now be given showing how the metal rectifier has been applied in a variety of ways to solve circuit problems. Discussion of actual examples will demonstrate the flexibility and wide application of this circuit element, at the same time offering the most direct method of passing on some of the experience so far acquired.

A.C. Relays.—Fig. 3 shows a method of associating a rectifier with an ordinary relay to enable the latter to be operated from alternating current (generally ringing current). When the A line is positive, the rectifier is, broadly speaking, non-conducting and current is forced through the relay winding. When the B line is positive, the rectifier acts as a shunt and the relay receives practically no current. In addition the effect of this shunt is to make the relay slow release, and thus the relay armature is held steadily as long as alternating current is applied. In this arrangement the relay is forced to accept, what may be termed the positive half cycles, whilst the rectifier by-passes the negative half-cycles. During the negative half cycles, the relay winding and the rectifier also form a local circuit for the transient current set up by the collapse of the relay field. This transient current is the reason for the relay being slow to release. With suitable values for the relay winding, there is no perceptible chatter of the armature.

This method of operating relays from ringing current is far superior to earlier arrangements requiring specially designed relays, which were often expensive. The rectifier can be connected in series with the relay, but chattering of the armature generally occurs, and a series arrangement is therefore not satisfactory. Although the rectifier offers a low resistance path in one direction, there is no risk of excessive current owing to the relatively large amount of external resistance in the line, whilst if the ringing current is derived from a power driven generator, the ringing leads will be protected by a resistance or a lamp.

Fig. 4 shows another arrangement for operation from alternating current, which is more suitable than that shown in Fig. 3, where the relay requires to be permanently connected across an a.c. source, such as for use as a power failure relay. Although Fig. 3 is satisfactory for intermittent operation, the arrangement could not be tolerated if connected across a high voltage source, owing to the low resistance in one direction. In Fig. 4 both phases of the current wave are used, and the relay windings act as an impedance, and limit the current should one or both rectifiers break down. The circuit shown in Fig. 4 will also operate from direct current, it being perhaps needless to mention that polarity can be disregarded. Furthermore on direct current the relay is slow to release. This particular arrangement has been used as the holding bridge in a P.B.X. cord circuit, and when so used, the armature does not flick when the line potential is reversed, nor does it release should a momentary open circuit occur, and with a suitable choice of windings, the transmission loss is negligible. The arrangement shown in Fig. 4 is therefore an unusually interesting example of what can be done with a relay when asymmetrical elements are introduced into a circuit.

Polarised Relays.—Fig. 5 shows how an ordinary relay can be used as a polarised relay. The operation will be obvious. A relatively high resistance retard in conjunction with a low resistance relay ensures that the line current remains approximately the same after reversal. There



Note the alternative ways of connecting the rectifiers

Fig. 6. Discriminating Relays.

are numberless variations of this scheme. Here again, the rectifier enables an ordinary type relay to be used, and obviates the need for a specially designed relay.

Discriminating Relays.—Fig. 6 provides an example of the usefulness of rectifiers for discriminating purposes. With two relays, two distinct signals can be sent over a line according to the polarity of the applied voltage. By using two relays with each rectifier, one of each pair of relays to operate on light current, and each pair to operate on heavy current, four different signals can be sent over a line. The last mentioned scheme, by means of relay combinations enables the selection of ten different circuits to be effected, and a 10-line system has been built up on this principle.

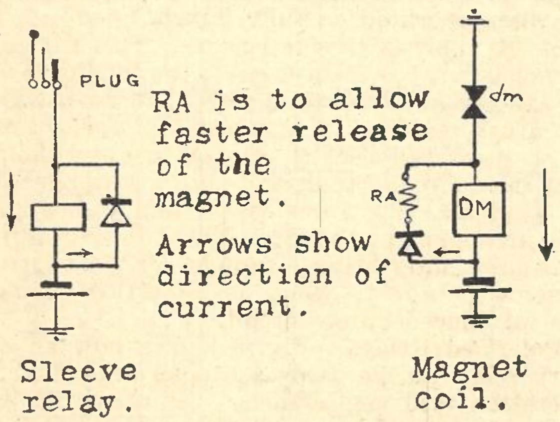
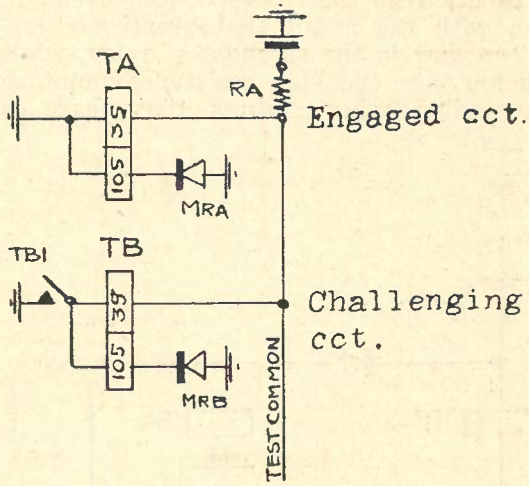


Fig. 7. Quench Circuts.

Quench Circuits.—Fig. 7 shows a rectifier acting as a quench for inductive surges. This arrangement prevents shocks being received by telephonists from sleeve relays when withdrawing plugs from jacks, and can also be used as a quench circuit on a magnet coil. The rectifier offers a high resistance to the normal flow of current, and a low resistance to any back e.m.f. generated by the coil. This method of quenching is very effective, and also has the advantage that there is no oscillatory discharge. The resistance in the magnet circuit is to reduce the slugging effect of the rectifier, and therefore allows faster release of the magnet.

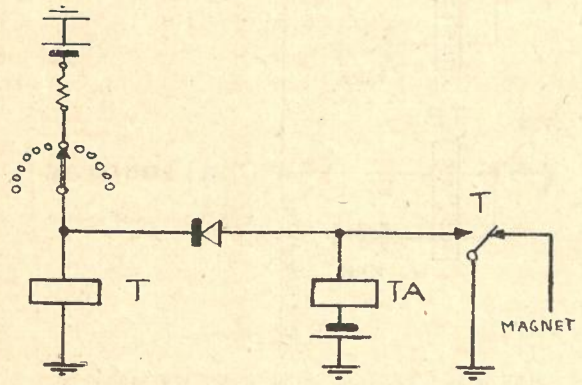


MRB is high resistance owing to the low voltage on the test-in common. TB does not receive sufficient current to operate, and TB + MRB does not appreciably shunt TA.

Fig. 8a. Test-in Circuit

Slow Release Relays.—The effect of connecting a rectifier across a relay winding, such as has been shown in Figs. 3, 4 and 5, is to make the relay slow to release, correct polarity being of course assumed. This method of deriving a slow release, as compared with copper sleeves and/or slugs, makes more winding space available on the relay spool, and higher resistance windings can be used. A slugged relay always has an appreciable operating lag, which is a disadvantage if quick operation is required; but the use of a rectifier overcomes this objection, as it does not interfere with the operating speed of a relay.

Test-in Circuits.—Fig. 8a shows an interesting application of a rectifier for a testing-in circuit, with a guard against intrusion by other circuits. The test-in relays TA, TB, etc., each have two windings, one of low resistance and the other of comparatively high resistance with a rectifier connected in series with the high resistance winding. On a test-in the relay operates with both windings and the rectifier in series; under these conditions the rectifier functions at the lower resistance end of its curve, and fast operation of the relay is not appreciably interfered with, as both windings are operative. When the relay has operated, it holds through its low resistance winding, and assuming that RA is say 250 ohms, the potential difference on the start common is reduced to approximately 6 volts. If now the connection is challenged by another circuit, the 35-ohm holding circuit of the engaged circuit is shunted by both windings of the challenging test relay plus the associated rectifier. Owing to the comparatively low potential on the test-in common, the rectifier in the challenging circuit will function at the high resistance end of its curve, with the result that practically no current can flow in the second test relay, whilst at the same time the high resistance shunt across the operated relay ensures that there is no

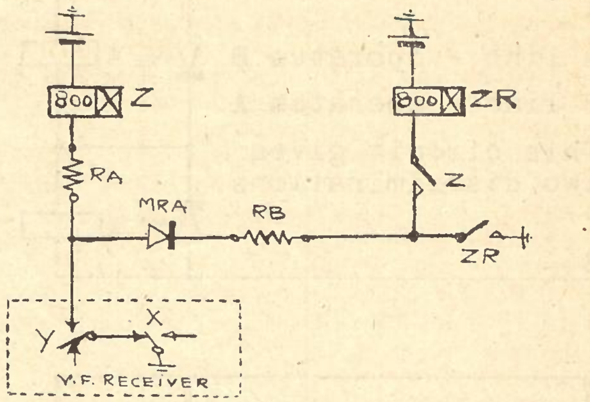


T is a high-speed relay and therefore has only one contact, which cuts the drive, busies the outlet and operates TA.

Fig. 8b. Test-in Circuit.

danger of the established connection being released. Thus, with this arrangement, the rectifier:—(a) Offers a low resistance on a normal test-in and does not appreciably reduce the voltage available for a test-in; (b) gives a high resistance test on any circuit which challenges an established connection, and thereby prevents the test relay of the challenging circuit from operating; (c) prevents the irregular release of an established connection by ensuring that the holding winding of the engaged test relay cannot be shunted by the test relays of other circuits.

Fig. 8b shows another interesting test-in circuit. Assume a test relay of the high speed type, in which case its contacts will be restricted to a single change-over. This circuit shows such a contact doing three things which without the aid of a rectifier would not be possible. When T operates, its break contact opens the magnet circuit, whilst its make contact operates the multi-contact relief relay TA and at the same time busies the circuit via the resistance of the



ZR is the controlling relay and cannot be operated unless Y holds long enough to cover the operating lags of Z + ZR.

Fig. 9. Speech Immunity Element in V.F. Receiver.

rectifier. It will be seen that the rectifier prevents T and TA operating in series prior to the disengaged outlet being reached, whilst by reason of the rectifier having some resistance, T does not short itself out.

Speech Immunity in V.F. Receivers.—Fig. 9 shows a rectifier in conjunction with two slow-operate relays arranged as a speech immunity element in a two-frequency receiver. X and Y are the anode relay contacts in the V.F. receiver and respond to 750 and 600 cycles per sec. respectively. A connection, after having been set up, is released by a long pulse of Y frequency, but release must not occur accidentally should fluttering of the anode relay be caused by X and Y components of speech. Z and ZR have long operating lags, and if a pulse is less than the combined operating lags of both these relays, any further armature travel of Z—the first in the series—due to flux collapse, must not result in the operation of ZR, but if both relays operate, ZR must depend for its release on the release of Z. Slow operation is assisted by the non-inductive resistance in series with each relay, but ZR when operated, is fully fluxed.

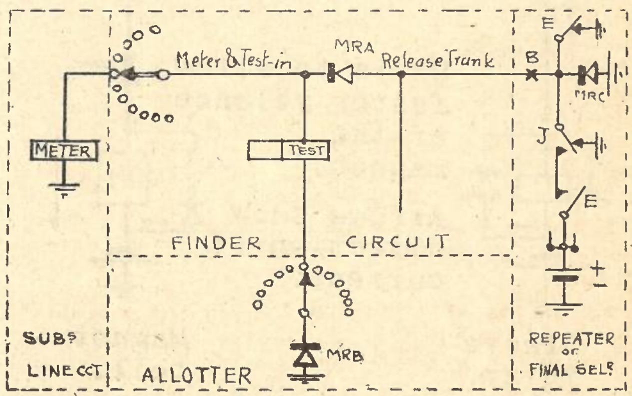
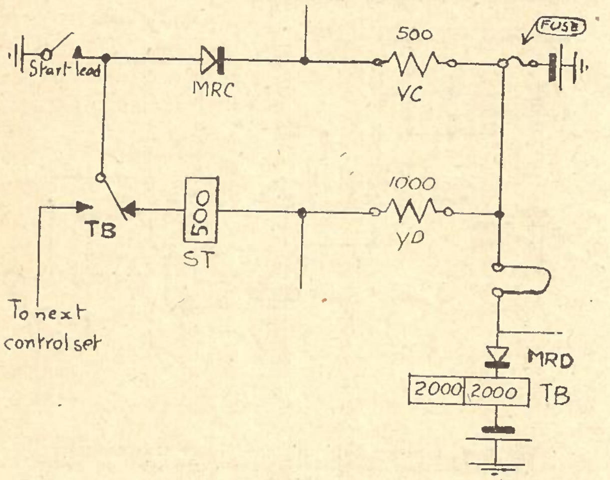


Fig. 10. Meter Circuit and Portion of Test-in Circuit for 2,000-type Exchanges

Subscriber's Meter Circuit.—Fig. 10 shows the meter circuit in a 2,000-type automatic exchange. The finder wipers rotate over a level until full negative battery is found, which operates the test relay in series with rectifier MRB. As the private bank is also used for metering, it is possible for the wipers of a searching finder to pick up positive battery on some of the contacts searched over. This positive potential is due to metering pulses, and to prevent false operation of the test relay, the rectifier MRB is included to offer a high resistance to positive battery. The rectifier MRA allows positive current to flow for operating the meter, but at the same time prevents the meter circuit from grounding the release trunk when relay B in the final selector or the repeater is released.

During the progress of a call, selectors are held by a ground on the release trunk. When metering occurs this earth is replaced by positive



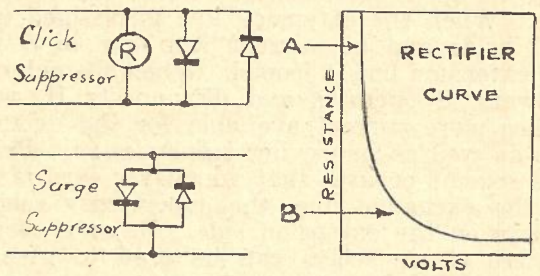
If start lead is earthed and fuse is open, TB operates and switches in the next control set.

Fig. 11. By-passing an Operated Fuse.

battery, which as well as operating the meter also holds the selectors during the metering period. To ensure that a connection will not be dropped out should an open circuit occur in the positive battery lead, a rectifier MRC is connected in the release trunk of all switches which apply a metering pulse. The rectifier MRC offers a high resistance to the metering pulse, and does not therefore shunt the meter, but provides a low resistance path for negative battery should the positive battery fail. This arrangement also renders make before break contacts unnecessary in the positive battery circuit.

Bypassing an Operated Fuse.—Fig. 11 shows the arrangements in 2,000-type exchanges for switching in a second primary finder control set if the first becomes inoperative due to a blown fuse. In the normal condition, when the start lead is grounded by a calling line, relay ST operates and a preassigned finder locates the calling line and switches through. Relay TB is inoperative at this stage because both sides are connected to battery, the direct battery connection being taken through a different fuse from that on the rectifier side. Should the control circuit fuse operate, this will of course place the circuit out of commission and the usual fuse alarm will be given, but callers can still receive service since under these conditions a calling line will operate TB and switch the start lead to another control set. Assuming that the start lead is grounded by a caller and at the same time the control circuit fuse happens to be open, it will be seen that TB operates in series with the rectifier, lamp, YC plus MRC in parallel with YD plus ST, to ground on the start lead. TB switches the start lead to the next control set and thus the faulty control set is bypassed until a new fuse is inserted.

The rectifiers MRC and MRD are not required to make the circuit function exactly as just described, but when the ramifications of the



The rectifiers operate in the vicinity of point A for normal speech, and in the vicinity of point B for high-voltage transients.

Fig. 12. Suppression of Clicks, Dialling Surges, etc., in a Speech Path.

complete control circuit are considered, the rectifiers are essential for decoupling purposes. For example without MRC, a ground on the lead taken from YC would give a false start.

Click Suppression.—Fig. 12 shows two rectifiers connected back to back for eliminating clicks in a telephone receiver. The action depends on the non-linear resistance-voltage characteristic of the rectifier combination. For low voltages, such as occur in normal speech, the rectifiers form a high resistance shunt across the receiver, but for transient high voltages which occur from relay operation, inductive surges on the line, etc., which would cause disagreeable clicks, the rectifiers form a low resistance shunt and bypass most of the surge. For high level speech the rectifiers will cause some attenuation, but this is not a disadvantage. For normal speech the transmission loss may be of the order of 0.2 db. and for high level speech approximately 1.5 db.

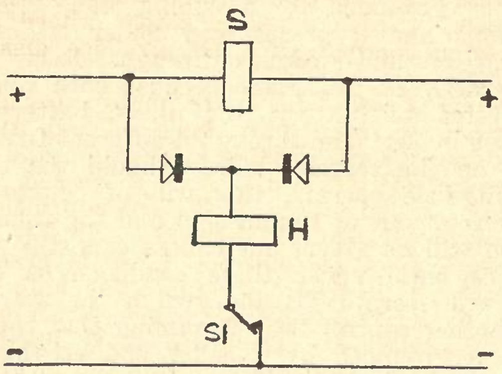


Fig. 13. To place a Supervisory Relay behind a Bridging Relay where there is no Line Reversal

To Connect a Supervisory Relay Behind a Hold Relay.—Fig. 13 shows the basic principle of an arrangement which could be used in a P.B.X. cord circuit where there is no reversal of line battery. Either cord can be used on the exchange line. When the exchange line is plugged up, H operates and holds the exchange line. When the extension line is plugged up H still holds and no current can flow in S until the extension line is looped. When the extension answers, S operates and disconnects H, which makes more current available for the extension line as well as improving transmission. Briefly, this scheme ensures that whichever cord is used on the exchange line, the supervisory relay is always on the extension side. In some circumstances sleeve relays can be used to give the required discrimination.

Blocking of Earth Currents.—Where each leg of a junction or trunk circuit is used for battery signalling, earth currents sometimes become troublesome. Bothway junction working between automatic exchanges where loop signalling is used in each direction, necessitates the same circuit conditions at each end when the circuit is idle, i.e., battery and earth via a line relay to the line. It might at first sight appear that when the circuit was idle no current would flow,

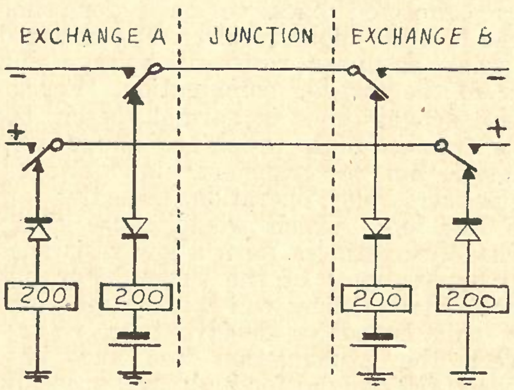
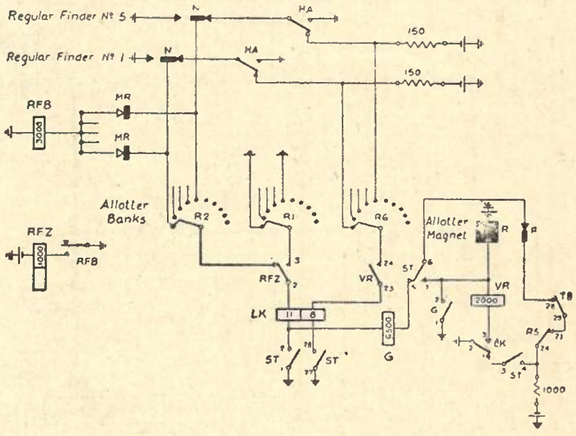


Fig. 14. Blocking of Earth Currents.

owing to the relays at each end being opposed, but this is not so, as balancing or residual currents would be present due to:—(a) A difference in the battery voltage at each exchange; (b) a difference in the earth potentials at each end of the line. Any difficulty of this nature can usually be overcome by inserting rectifiers in the direct current path, such as shown in Fig. 14. In this scheme, current through one relay cannot affect the other, and vice versa.

Decoupling Commons.—In dealing with commons, it is often necessary to decouple the individual leads whilst still keeping them connected to a common relay. A rectifier offers a simple and reliable method of meeting this requirement, the principle being shown by Fig. 15a, which shows portion of the circuit involved in the change-over to the indirect finders in a 2,000-type exchange. The indirect finders are

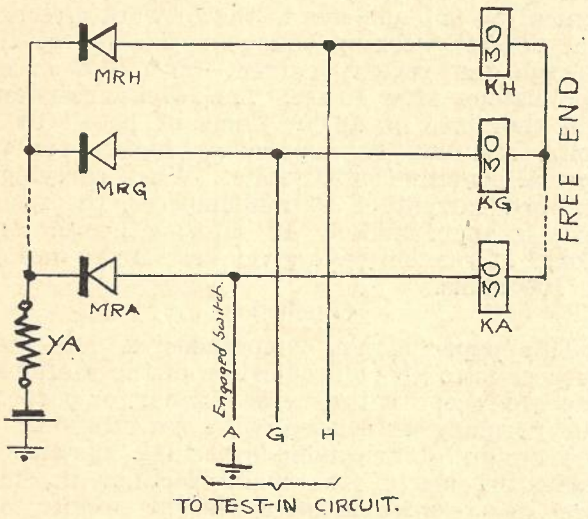


The leads between bank R2 and N are independent of each other, but nevertheless also commoned on relay RFB.

Fig. 15a. Decoupling a Common

not introduced until all the direct finders are engaged. The direct finders are connected to the early contacts of allotter bank R2, and a lead is taken from each direct finder through a metal type rectifier, all these leads being commoned on a relay RFB. As each direct finder is taken into use, the corresponding R2 bank is earthed by the off-normal spring N. As long as one direct finder remains idle, RFB holds, but when all these finders are in use RFB releases and switches in the indirect finders. The function of the rectifiers is to decouple the leads commoned on RFB, otherwise a ground on any R2 bank would short-circuit this relay. Whilst Fig. 15a shows the principle of using rectifiers for isolating the leads of a common, the particular application shown is open to criticism on three points:—(a) The same functions could have been performed without rectifiers by rearranging the circuit; (b) as each direct finder goes into use, the back resistance of the associated rectifier is shunted across RFB. In a large group of finders, the combined shunting effect of busy finders may reach a figure comparable with the resistance of RFB; (c) a reverse voltage equal to the drop across RFB is placed across the rectifiers of all busy direct finders, which increases the chances of a rectifier breaking down.

Fig. 15b shows another use of rectifiers in a common. Some systems operate the selector switches on a common control basis, i.e., instead of providing each selector with a full complement of equipment necessary to carry out all the functions of a selector, the more complicated functions are relegated to common control equipment. It might be arranged for example that one control serves eight selectors, and it will be obvious therefore that on a selector seizing the common control circuit, all other switches having access to the same control must be instantly



KA is operated through the seven parallel paths made up of relays B to H and their respective rectifiers. Leads B to H are busied through KA and the respective relay.

Fig. 15b. Example of a Double-ended Common, with One End Free.

busied out. Moreover, it is necessary to establish certain local connections between each selector and the control, one customary method being the operation of a coupling relay. The circuit in Fig. 15b shows three of the eight coupling relays for such a scheme, viz., the first, seventh and eighth. Assume that the first inlet is seized. The testing path is via MRA and resistance YA to battery, the switch end being similar to 8a or 8b. The other inlets are immediately busied by reason of the earth on inlet A simultaneously earthing the other inlets via the low resistance K relays. KA is operated from the earth on inlet A to battery via the parallel resistance of KB to KH inclusive and the associated rectifiers, the last mentioned relays receiving one-seventh of the current flowing in KA. The rectifiers in this circuit are necessary to prevent the K relays being short circuited. This is one example where a disconnected common does not produce disastrous results.

Special Uses.—There are many special uses to which rectifiers have been applied, such as echo suppressors, variable attenuators and so on. These applications will not be discussed, except to give an indication of the basic principle involved in attenuation networks. In Fig. 16 if the battery is disconnected there is practically no transfer of speech owing to the high resistance of the rectifiers, but when direct current flows through the rectifiers, it is possible to speak through the arrangement, and in practical circuits the loss between the input and the output depends on the priming current passed through the direct current path. It has been claimed that the attenuation between input and output can be adjusted over a range of 60 db in circuits depending on this principle. For explanatory purposes, let it be assumed that a sinusoidal e.m.f. is applied to the input side instead of

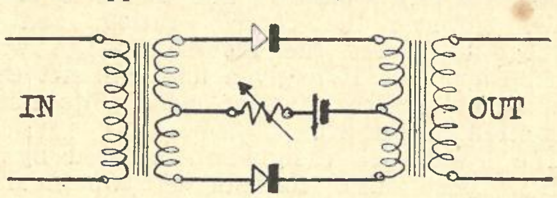


Fig. 16. Variable Speech Attenuator.

speech. The voltage acting across each rectifier will now consist of an a.c. and a d.c. component, and as the a.c. components of each rectifier will have a phase difference of 180 deg., this means that the a.c. component will increase the current in one rectifier and decrease it in the other, the nett result being that a.c. appears in the output circuit. Looked at from another standpoint, the process is analogous to modulation, the direct current in each side circuit being varied by equal and opposite amounts. The direct current through the rectifier determines the resistance offered by the rectifiers, and the resistance of the rectifiers determines the extent of the change in current due to the a.c. component. For example, if each rectifier has a resistance of say 5,000 ohms, an equal and opposite change of one volt across each rectifier would cause an effective current change of 0.4 milliamperes. If the priming current is such that the rectifier resistances are each equal to 1,000 ohms, the same voltage change would cause an effective current change of 2.0 milliamperes, this being equal to an improvement of approximately 14 db. As stated earlier, Fig. 16 is only intended to show the principle involved; workable circuits require careful design to avoid distortion of speech, and an appreciable change in the priming current should be necessary to cover the transmission range.

Points to be Observed in Using Rectifiers

The following are some of the points to be kept in mind where rectifiers are used in a circuit:—

1. Adequate cross-sectional area for the current to be carried.
2. Sufficient number of plates to safely block the reverse voltage.
3. Avoidance of heat from adjacent apparatus.
4. A reverse potential should not be permanently applied. If this cannot be avoided, the permanent reverse potential should be kept at a relatively low value.
5. For intermittent operation, a rectifier may be subjected to currents in excess of the normal rating, but the safe reverse voltage should not be exceeded at any stage of a circuit operation.

Rectifier Units

The rectifier units consist of one or more groups of metal plates. The diameter of the plates governs the current rating, and the number of plates the reverse voltage which can be applied. If a given unit will not carry the current desired, two or more units can be connected in parallel.

The system of designation adopted by the British post office consists of two numbers separated by a bar, the first indicating the number of groups in a unit and the second the number of plates in each group. This number is followed by a suffix letter which serves to indicate the type of disc. For example, a unit designated as 1/12A, would mean one unit consisting of 12 A-type discs, and so on. Normally the free ends are of opposite polarity, but in certain cases this is departed from, and the letter N or P is added to the group number to signify that both free ends are either negative or positive as the case may be.

The sizes of the discs usually employed are:—

Disc letter	Diameter, inch
A	3/4
C	1/4
D	5/64
E	1/32
G	11/64

The actual current rating depends largely on circumstances, that is, whether the circuit is a.c. or d.c., and whether reactive or non-reactive. Generally speaking, the reverse voltage which can be safely applied is not affected by the circuit conditions. One end of a unit has a red disc; this is the cathode terminal (copper) for the low resistance direction, and negative battery must be connected to this terminal to obtain forward current.

A unit largely used in circuits is the one designated 1/12A. This unit consists of 12 discs each $\frac{3}{4}$ in. diameter, and will safely carry a current of 50 milliamperes in the forward direction. The reverse working voltage is 72, and at this voltage the reverse current must not exceed 4 milliamps. after 10 sec. The reverse resistance will therefore be 18,000 ohms or better at 72 volts, and will be appreciably higher for the normal condition of 50 volts. When carrying a forward current of 50 milliamperes, the resistance is approximately 40 ohms, although units picked at random have given resistances as high as 100 ohms.

Conclusion

This paper is not comprehensive. Its main purpose is to give an indication of the usefulness and wide scope of the metal rectifier for purposes not normally associated with rectification. In the design of telephone switching systems at least, the use of the metal rectifier in small sizes has resulted in more efficient circuits; and as stated earlier, it is not unlikely that further developments will demonstrate new uses for this particular component.

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