TELEPHONE REPEATERS

AND

ASSOCIATED APPARATUS

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PREFACE

This pamphlet is issued for the benefit of the Western Electric Installer and describes in a general way the fundamental principles and characteristics of telephone repeaters and their associated equipment.

The contents are based on various books and articles on the subject and upon information issued by the American Telephone and Telegraph Company and the Bell Telephone Laboratories, Inc.

While particular types of apparatus are discussed, this publication will not be reissued in the event of a change in this apparatus. If a change is of sufficient importance or general interest, a new pamphlet will be written.

The contents of this pamphlet are of a purely descriptive nature and are not designed to prescribe methods or instructions for the installation of central office equipment.

CONTENTS

PREFACE TO THE THIRD REPRINT

Since this pamphlet was issued, early in 1926, there have been continued developments and improvements in telephone equipment. A number of these have affected telephone repeaters and as a result some of the equipment described in the pamphlet is now becoming obsolete. No attempt will be made to issue a new edition at this time, but the more important improvements are here noted.

The development which probably effects the greatest saving in operating costs is the one-half ampere vacuum tube filament. It is used at present in 101 and 102 type tubes and aside from the reduction in "A" battery consumption has not materially affected their characteristics.

The 5D potentiometer which is described as the gain regulating device for 22-A-1 repeaters has been replaced by a resistance network and a slide wire potentiometer in the input circuit. The resistances of the network are all wound on one spool and the networks are stocked in such sizes that by their use the repeater gain may be adjusted in steps of 5 TU. The intermediate adjustments are made by means of the potentiometer which has a range of about 6 TU.

A new voice frequency ringer having two vacuum tubes has been developed to replace the one described in the text. The voice frequency parts of the two circuits are quite similar except that the additional tube in the new circuit permits it to utilize a lower signaling level so that the ringer system will cause less crosstalk. The 20 cycle part of the new detector circuit is also tuned more sharply than the old one so that the ringer is much less liable to false operation by voice currents. The new ringer in addition to being arranged for terminal and toll signaling operation can be arranged either as a 20 or 135 cycle intermediate ringer.

A ringing machine for generating the 1000 cycle current interrupted at 20 cycles without the use of commutators has also been developed. The armature windings are placed on the stator and the rotor, which revolves approximately 20 times per second, and has teeth cut only halfway around its periphery. While the teeth are passing the armature windings a 1000 cycle current is generated and no current is generated while the smooth portion passes, resulting in a 1000 cycle current interrupted at about 20 cycles.

New two and four wire echo-suppressors have also been developed to replace the one described in the text. They are essentially the same as the former circuit except that the use of 209 type relays has reduced the time required for their operation so that they will more readily suppress echos from nearby points and the introduction of a resistance-condenser timing device has insured a more reliable releasing time so that they will suppress the echo from the most remote point in the circuit without holding the circuit inoperative longer than is necessary.

A new standard gain measuring device for telephone repeaters is the 6A Transmission Measuring Set which can also be used to measure losses and to indicate transmission levels. It is generally used with the 6010-B Oscillator and is capable of covering the frequency range from 50 to 5000 cycles with good precision. Its operation is quite different from that of the 2A and 2D sets, but is too complicated for discussion here.

The tendency toward chain hook-ups of broadcasting stations has resulted in the development of program supply equipment capable of operating over a greater frequency range than equipment intended for regular telephone service and special repeaters have been developed for use with picture transmission apparatus. Neither type of apparatus, however, will be installed extensively enough to warrant a detailed description here.

These new developments and others have in some instances altered the requirements and limits that will be found throughout the text. It is therefore necesary to again draw attention to the fact, mentioned in the original Preface, that this pamphlet is of a purely descriptive nature and that the requirements and limits are given only to aid in the demonstration of the nature of the equipment described.

TELEPHONE REPEATERS AND ASSOCIATED APPARATUS

By A. M. Elliott

of the

General Installation Engineer's Staff

SECTION 1
TELEPHONE REPEATERS

TWO WIRE REPEATERS

In going from one end of any circuit to the other, telegraph or telephone signals are weakened because of the losses introduced by switches and jacks, repeating coils, resistance and leakage of the line itself, etc. These losses, of course, will vary with the equipment and are expressed in Transmission Units (abbreviated TU), which is merely a way of expressing the ratio of the power entering to the power leaving the circuit.

Circuits having losses totaling less than about 25 TU from sub-set to sub-set (corresponding to a power ratio of about 1. to .003) are generally considered satisfactory for service. To make serviceable a circuit having greater losses than are allowable, enough "gain" must be introduced into the circuit to offset at least a part of these losses and so bring the overall equivalent of the circuit (sum of all gains and losses) within the desired limits. As the word implies, "gain" occurs in a circuit in which the output power is greater than the input.

Before the invention of the telephone, long telegraph circuits were made possible by using line relays in which the weak incoming signal would make or break a local battery circuit sending a strong signal into the outgoing line (Figure 1).

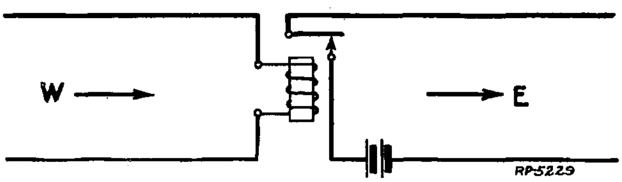


Fig. 1. One Way Telegraph Repeater (Line Relay)

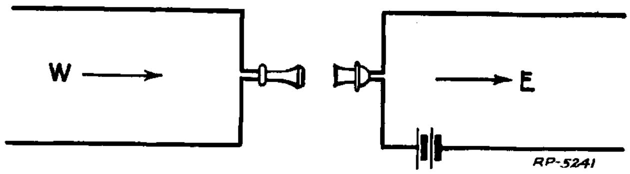


Fig. 2. One Way Telephone Repeater (Mechanical)

With the advent of the telephone, the same problem arose and was solved in much the same way (Figure 2), by using the weak incoming signal as a sort of lever with which to control the output from a local battery. This arrangement, however, permitted communication over the line in one direction only, so the next step was the mechanical two-way one-element repeater (Figure 3). In this device,

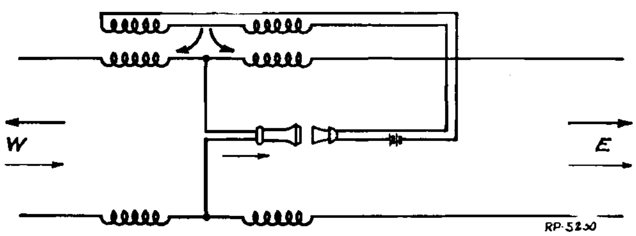


Fig. 3. Two Wire, One Element (21) Type Telephone Repeater (Mechanical)

part of the incoming signal from the west (indicated by light arrows) actuates the receiver-transmitter amplifier, releasing power from the local transmitter battery. This output is fed back into the line windings at their center point; therefore, the energy divides equally into E. and W. Line. Since this energy travels in one direction in the

W. half, and the opposite direction in the E. half of the line windings of this transformer, the voltages in the respective halves are of opposite sign and cancel out. So long as this transformer is balanced then there is no tendency for the repeater to oscillate or sing. This fact may be more easily seen perhaps by reference to Figure 4. In Figure 4a

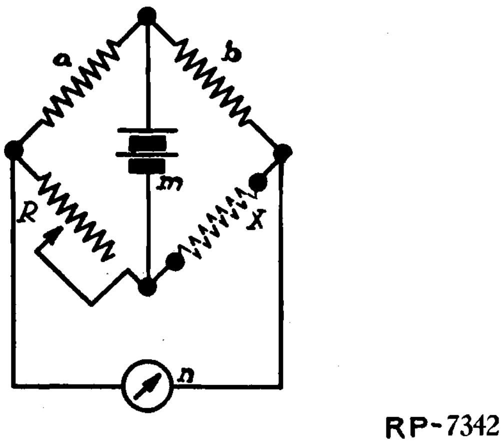


Fig. 4a. Simple Wheatstone Bridge Circuit

is shown the conventional "Wheatstone Bridge" circuit. Similar to this and operating on exactly the same principle is the circuit shown in 4b. So long as the arms are balanced no tone from "m" will be heard in the headphones at "n." Furthermore, "m" and "n" could be interchanged in the circuit and still no tone would be heard in the headphones since the two points to which "n" would

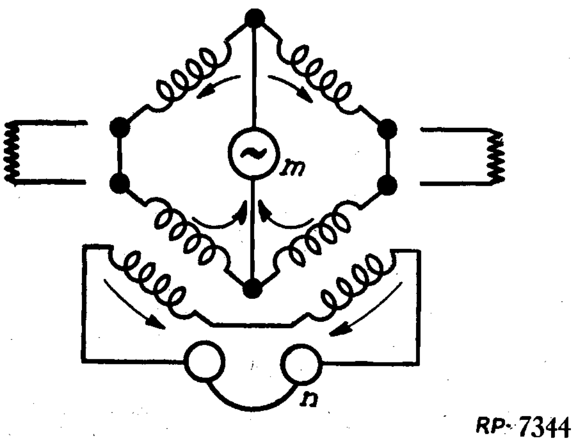


Fig. 4b. Modified Wheatstone Bridge Circuit

be connected would be at equal potentials. This balanced condition would still hold if we were to insert the two resistances (or lines) shown, so long as they were of equal value. In 4c and 4d is shown this same circuit adapted to use in repeaters and usually called "bridge circuit transformer" or "hybrid coil." With the advent of the vacuum

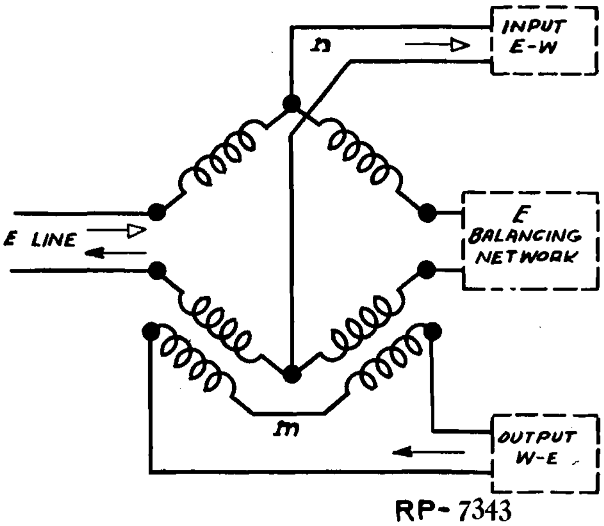


Fig. 4c. Wheatstone Bridge Circuit Applied to Two Wire, Four Wire Circuit (Also Bridge Circuit Transformer or Hybrid Coil)

tube it was a simple step to substitute a tube for the mechanical repeater. Figure 5 is the simple schematic of the 21 (2-Wire, 1-Element) type vacuum tube repeater of which some are still in use.

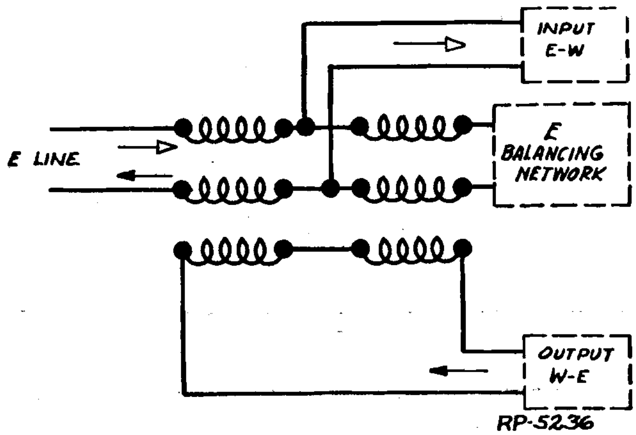


Fig. 4d. Connections to Output Transformer of 22 Type Repeater

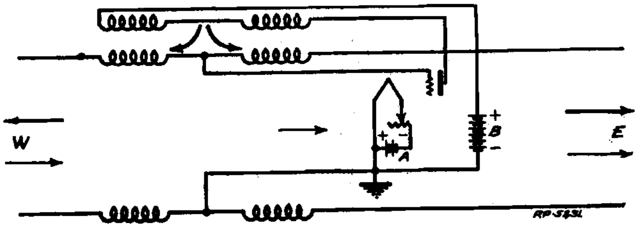


Fig. 5. Two Wire, One Element (21) Type Repeater (Vacuum Tube)

The necessary balance in this type repeater depends on the lines in both directions having nearly equal impedances. This, of course, means that the repeater must be located at about the electrical center of the circuit. Another undesirable feature of the 21 type repeater is that it sends as much energy back to the talker as it does on to the listener. This prevents the use of several in tandem on long circuits as this returning energy would result in a series of echoes which would ruin transmission. It will thus be seen that the place of the 21 type repeater is at the center of a fairly uniform circuit in which the losses are not so great that the gain from a single repeater is sufficient.

The 22 (2-Wire, 2-Element) type is nothing more than an ingenious, yet simple, combination of two 21 type repeaters (Figure 6a), one amplifying element handling the signal only in one direction, and

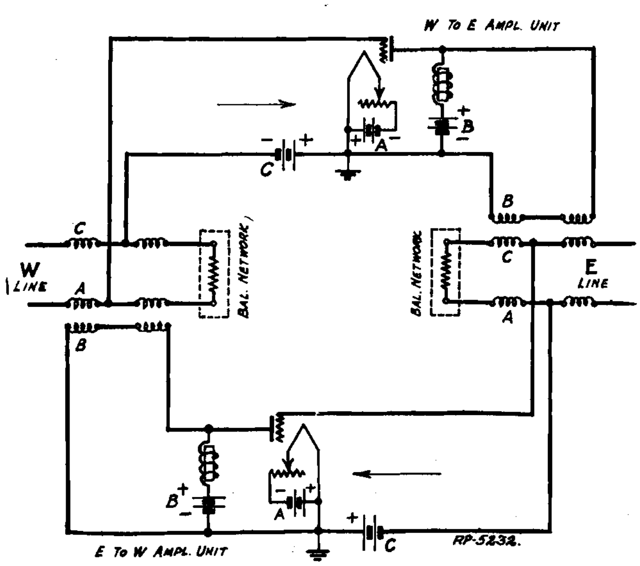


Fig. 6a. Two Wire, Two Element (22) Type Repeater

the other in the opposite direction. In this repeater, the balance on each side of the two individual repeating elements is maintained by having an artificial line or balancing network on the side of the transformer opposite the line and having the same electrical characteristics as the line. The action is then briefly as follows: A signal from the West line goes through the line windings A and C of the East output transformer, the center point of these two windings being connected to the grid circuit of the W. to E. amplifier unit. The output of this unit (a single stage amplifier using an "L" tube) goes to winding B of the W. output transformer where half is wasted in the E. balancing network and the other half goes on the E. line. So long as the balance of the lines and the networks is maintained, there will be no "feed back" and consequently no "singing." Since the amplification is only in one direction in each of the repeater elements, this type repeater can be used in tandem with other repeaters, that is, a number can be used at successive points on a very long line to repeatedly renew the signal energy.

The 22-A-1 Type

The original installation of 22 type repeaters were of the floor rack mounting type, the repeating elements with the associated battery supply circuits and signaling equipment all being together in the one rack. This arrangement made necessary the stocking of repeaters arranged for any circuit, battery or signaling conditions likely to be specified. A little later came the Reading type, which was the first attempt at dividing a repeater installation into units which could be specified and cabled together as desired. In the 22-A-1 type many improvements have been made and the repeater element itself arranged for relay rack mounting. The auxiliary apparatus such as battery supply, ringing equipment, etc., is also in panels adapted to relay rack mounting. By this arrangement the particular units adapted to a given job are specified and wired together as desired, lessening the equipment required to stock and giving a very flexible system generally. The 22-A-1 repeater is probably the most widely used piece of vacuum tube apparatus in the telephone plant and we will now proceed with a more detailed discussion of its features.

The 22-A-1 Repeater Set is a panel 7" x 19" on which is mounted all the apparatus shown in the diagram of Figure 6b, excepting the two balancing

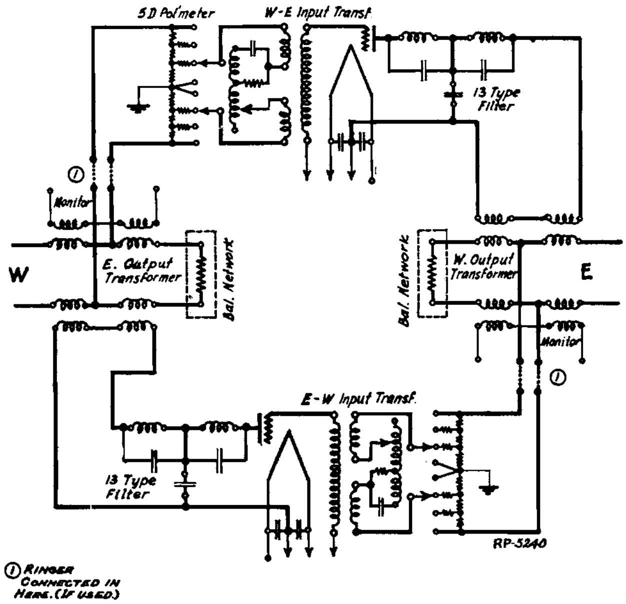


Fig. 6b. 22-A-1 Repeater—Simplified Schematic

networks. Figure 7 on the opposite page shows a number of repeater sets in a typical installation. Let us follow the path of a signal through the repeater set from the incoming W. line to the outgoing E. line, discussing the apparatus in the order in which the signal meets it. The signal enters the repeater set from the W. line and goes to the E. output transformer (which could just as well be called the W. input transformer). The side of the transformer opposite the line is connected to the W. balancing network. This network is designed to have electrical characteristics as nearly as possible identical with those of the line it balances. The center point of the E. output transformer is then the electrical center point of the line-transformer-network circuit. This center point is connected with the W.-E. 5-D potentiometer. This, of course, is the volume controlling device of the repeater having steps numbered from 0 to 9, giving zero output on step zero and on step 9 giving a gain of 18.5 ± 2 TU when equipped with 13-B or 13-C filters, and 17.8 ± 2 TU when equipped with 13-A filters. The use of an intermediate ringer cuts this gain about .3 of a TU at 1000 cycles. Each of the steps from 9 down decreases the gain by 1.9 TU (one TU equals 1.0563 miles of standard cable). This potentiometer has several special features. It will be noted that the central point is grounded and two contact arms are provided, moving simultaneously toward or away from this grounded center point, thus always maintaining a balance with respect to ground. It will also be noted that there are resistances in series with the potentiometer resistance proper and the points with which the movable arms make contact. These resistances are such that the impedance between the line output transformers and the tube input transformers is constant and therefore the characteristics of the circuit are not changed when the potentiometer is varied.

From the potentiometer a certain proportion of the signal, as determined by the potentiometer setting, goes to the primary of the W-E input transformer (type 208-U). In the center of the primary of this transformer is connected a tapped inductance (82-G retardation coil) in series with a 4 mf. condenser, this condenser being shunted by a 200 ohm resistance. This tuning circuit is for the purpose of raising the gain at about 200 cycles through resonance of the 4 mf. condenser with the inductance of the primary of the transformer, the 200 ohm resistance damping this effect down to a fairly flat curve. By varying the tap on the 82-G retardation coil which is connected to the transformer, the gain above 800 cycles can be varied through resonance of the inductance of the coil with the capacity of the high side of the transformer. The purpose of this tuning network is to compensate the repeater for use on different types of lines and to give better transmission characteristics generally. The secondary of the 208-U transformer is of very high impedance to match the grid circuit of the W-E amplifier tube to which it is connected. One terminal of the transformer goes directly to the grid and the other terminal to the C battery, which gives the grid its proper bias for amplifier action.

The amplifier tube is a type L (101-D) using .97 ± .03 ampere in the filament, —9. ± 1 volt on the grid, and 130. ± 5 volts on the plate. The voltage drop across the filament of this type tube is normally only 4 to 5 volts, so for the sake of economy the two tubes on a 22-A-1 panel (one for each direction) have their filaments connected in series, and these in series with the two tubes of another repeater panel. Since the regular office battery is 24 volts, a drop of about 4 volts is left for wiring and regulation. The electrical center point of the filament of the amplifier tube is obtained by connecting two condensers of equal capacity in series across the tube terminals, the plate battery lead being connected to the common point of the two condensers. This arrangement reduces considerably the cross-talk between repeaters.

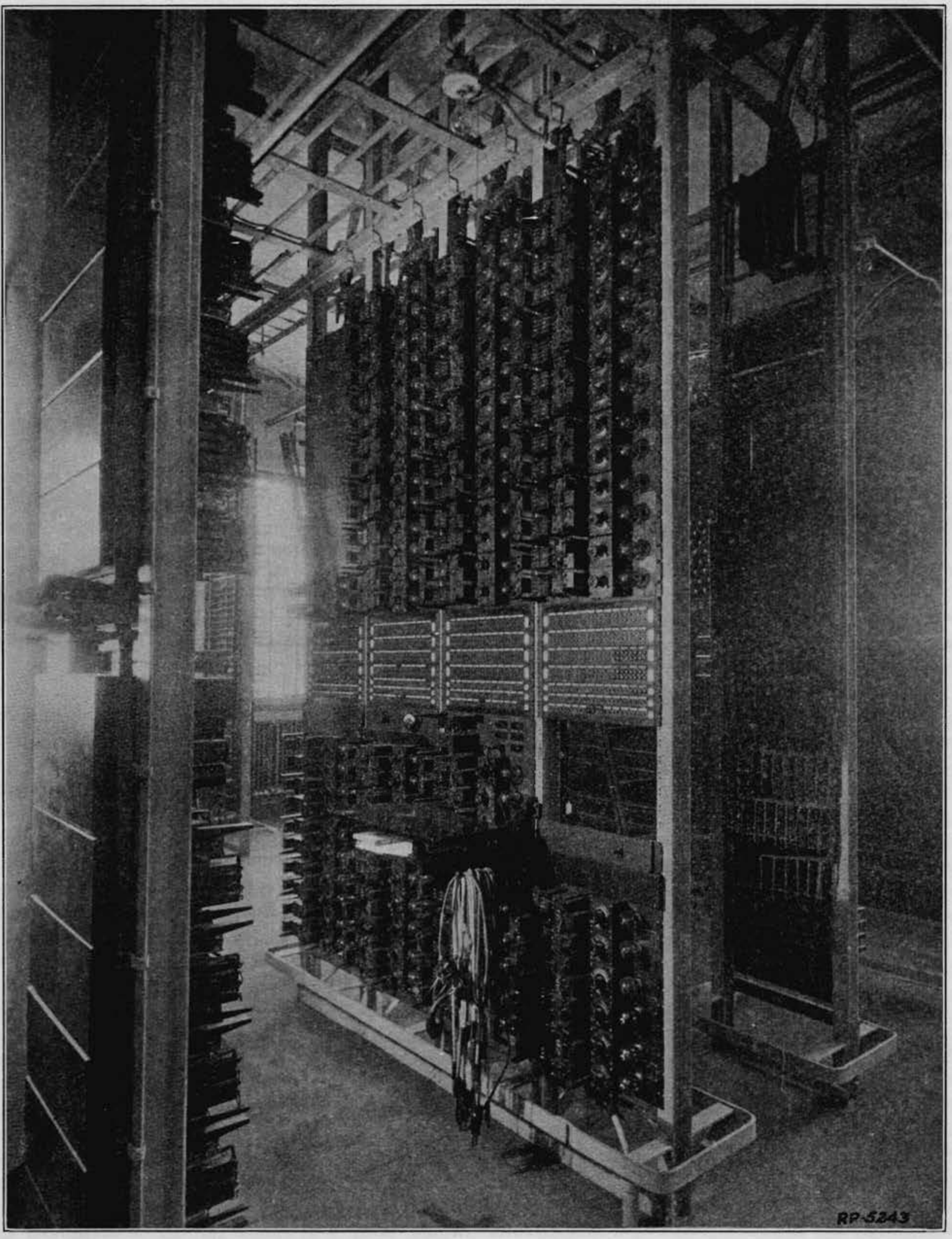


Fig. 7. Bay of 22-A-1 Repeaters

From the vacuum tube the amplified signal goes through a filter, type 13-A, B or C. These filters have normal cut off points of 2200, 2600 and 3000 cycles respectively; that is, they pass almost none of the signal having a frequency higher than their cut off points. The 2200 cycle filters are used with heavy loaded open wire and cable circuits and with cord circuit repeaters when circuits of different types are connected together through the cord circuits. The 2600 cycle filters are used on medium heavy loaded 16 and 19 gauge cable circuits usually. The 3000 cycle filters are used on non-loaded open wire and light loaded high grade cable circuits when extra good quality is desired. These filters keep out higher frequency disturbances and cut off the voice frequencies which are too high for the line to transmit without distortion. They are mounted on a small sub-base of their own and may be easily and quickly interchanged with any other 13 type filter.

From the filter, the signal goes to the W. output transformer and so through phantom and compositing equipment, if used, toll test board jacks, etc., out on the E. line. The balanced arrangement of the output terminals with respect to the input prevents feed back and consequent "singing" of the tube as was discussed in a previous paragraph. We have followed the path of the signal from the W. line, through the W.-E. potentiometer, input transformer, amplifier tube, filter and W. output transformer—a complete path for the W. to E. signal. For the E. to W. signal traveling on the same telephone circuit on either side of the repeater, a separate but exactly similar path is provided in the repeater, the two oppositely directed signals separating at the output transformers. It will be noted that each output transformer has a special winding for monitoring purposes. This winding consists of only a comparatively few turns and so introduces very little loss in the circuit.

Figure 8 is intended to show how 22 type repeaters are associated with the equipment for the other circuits carried over the same pair of wires. The two lines shown are equipped to supply a phantom circuit. Of course, the signals in the phantom circuit are attenuated just like those in the side circuit and consequently a phantom circuit repeater is used. To do this the phantom circuit must be taken from the side circuits, put through the repeater, and then returned to the side circuits for further transmission on the line. Such an

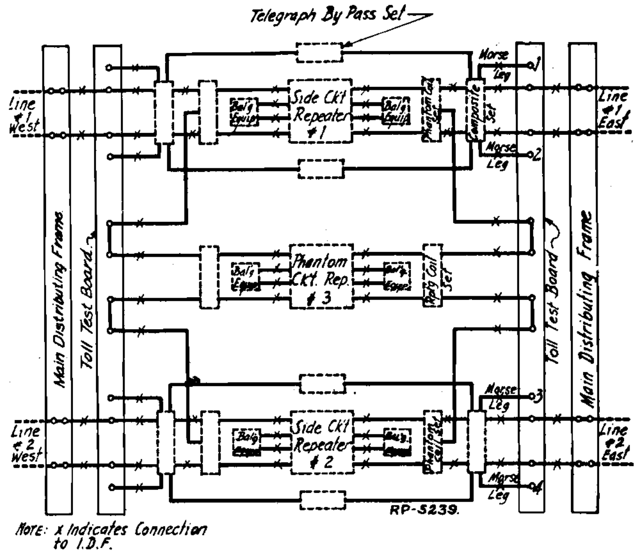


Fig. 8. Typical Arrangement of Toll Equipment—Intermediate Office

arrangement is shown in this figure. The position in the circuit of the composite sets, by-pass sets, etc., is also indicated.

A picture of how a number of repeaters may be used on a long toll circuit for repeatedly renewing the signal may be had from Figure 9, which shows the "energy level" diagram of a circuit between Boston and San Francisco. At Boston, 10,000 microwatts (.01 watt) is sent out on the line, but in going as far as New York the signal is so much attenuated that the energy must be renewed by the use of a repeater. This happens again at Harrisburg, Pittsburgh and all the other repeater stations shown on this diagram. The energy level is never allowed to drop below about 350 microwatts (.00035 watt) as disturbing noises, cross-talk, etc., would then be undesirably prominent in comparison with the signal itself. It may be noted that the rate at which the energy drops between two given stations, New York and Harrisburg, for example, is greater than between two other stations such as North Platte and Denver. This is due, of course, to the fact that between the two first mentioned stations, the necessary cabling and switching arrangements, due to the number and size of the cities through which the line passes, introduces much greater losses than between the two latter repeater stations, which are themselves smaller cities located in less densely populated territory where open wire lines can be used almost exclusively.

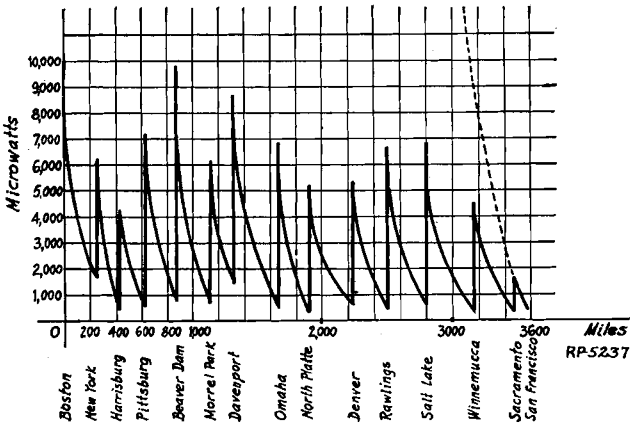


Fig. 9. Energy Level Diagram—Typical Long Circuit

The dotted line extending upward, the curve between Sacramento-San Francisco, will give some idea of the power that would have to be put into the line at Boston to receive the same amount of power at San Francisco if no repeaters were used in the circuit. The power necessary would be indicated at the point where this dotted line intersects the vertical axis. Actually this would be several million kilowatts—more than is delivered to the entire earth by the sun! By the use of repeaters we get the desired amount of power at San Francisco without the power at any point in the circuit exceeding a small fraction of a watt.

Associated Circuits

The foregoing description has included only the repeater set panel itself. With it are usually associated a battery supply panel with rheostats and meters, fuse panels with automatic alarm feature for the plate battery circuit, jack panels for plugging in at various points of the circuit for patching and testing, testing equipment (usually an oscillator and gain measuring set), and ringing panels. Figure 12 shows a typical small installation of 22-A-1 type repeaters with the battery supply bay in the foreground. Back of this are the bays of repeater sets proper.

The repeater as a whole, when provided with the proper auxiliary equipment, may be adapted to three different classes of service—terminal, thru line and cord circuit. As the names imply, the terminal repeater is located at one terminal of the circuit and is used to bring up the energy level of the incoming signal to a satisfactory level, and boost the outgoing signal; the thru line repeater is located at some point between the two terminals and is left permanently connected in a given circuit. The cord circuit repeater is controlled by the toll switchboard operator and may be connected between any two circuits requiring a repeater.

Terminal and thru line repeaters are installed and used as a regular part of a given circuit and therefore work under practically the same conditions at all times. A cord circuit repeater is used between any two lines which happen to need a repeater; consequently, circuit arrangements must be provided with this class of repeater to allow its use between lines of widely varying characteristics. These circuits are so arranged that when a repeater is not connected to the cord circuit they operate just like any ordinary toll cord at the switchboard.

In a given installation the cords used for switching may terminate in either single plugs, such as the 110 type, or in double plugs, such as the 241 type. Where single plug operation is required "compromise" networks which are connected to the repeater are used for balancing the lines in the case of thru connections only; or lines and toll switching trunks in the case of through and terminating connections. In the case of cord circuits arranged for thru and terminating connections, special arrangements are used to change from the compromise network required for toll switching trunks to that required for toll lines.

In the case of twin plug operation, as the term implies, connection to a given toll line is made by using a twin plug which is inserted into two jacks mounted in the toll board one just below the other. The line is connected to the upper jack and the correct balancing network for that particular line to the jack just below it. By this arrangement the proper network for each toll line is connected to the repeater by the same operation as connects the toll line. When using twin plug operation for terminating connections the necesary toll switching trunks and their associated balancing networks are connected in a special twin jack multiple in the toll board along with the toll line jacks.

The gain of the cord circuit repeater may be manually regulated by the operator each time the repeater is used, or automatic gain selection may be provided by resistances in the sleeve circuits of the various toll circuits. In the latter case, each of the toll circuits has in its sleeve circuit, a certain fixed resistance, the value of which depends on the transmission characteristics of the circuit. When the repeater cord circuit is plugged into the toll line

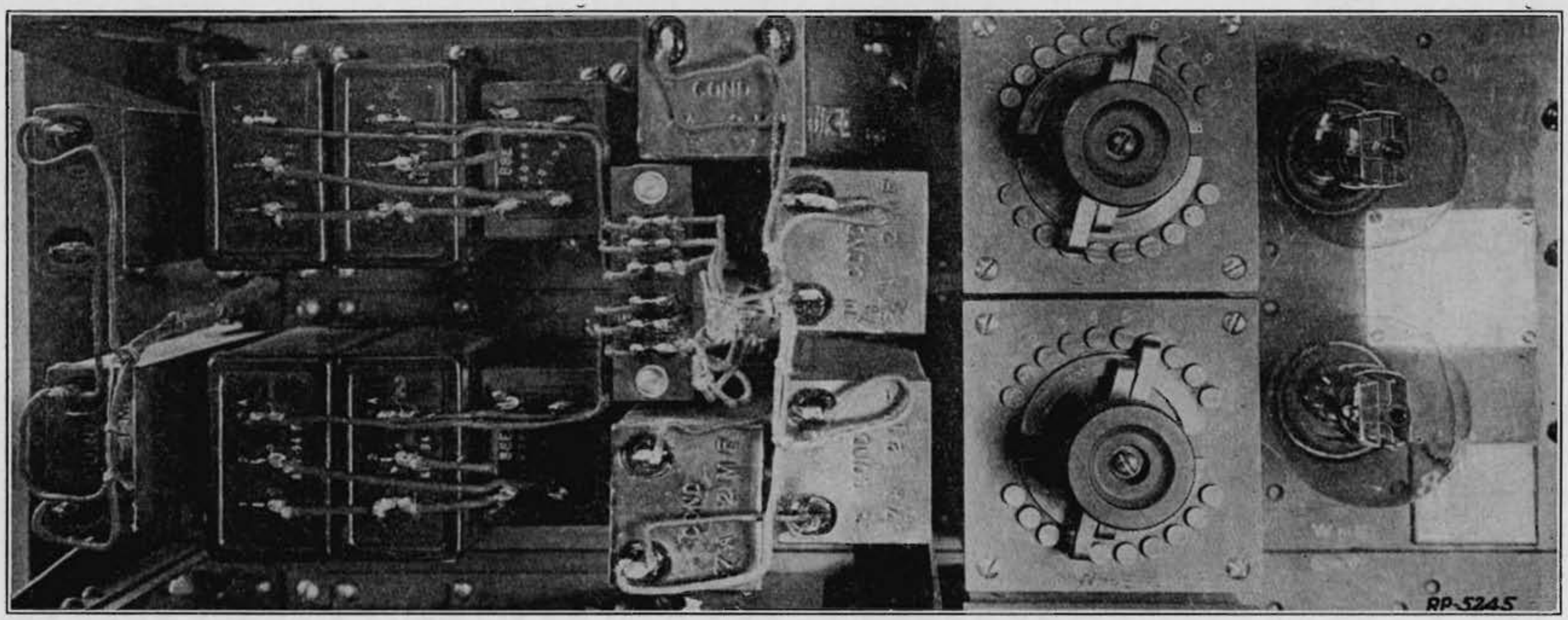


Fig. 10. 22-A-1 Repeater—Front View—Cover Removed

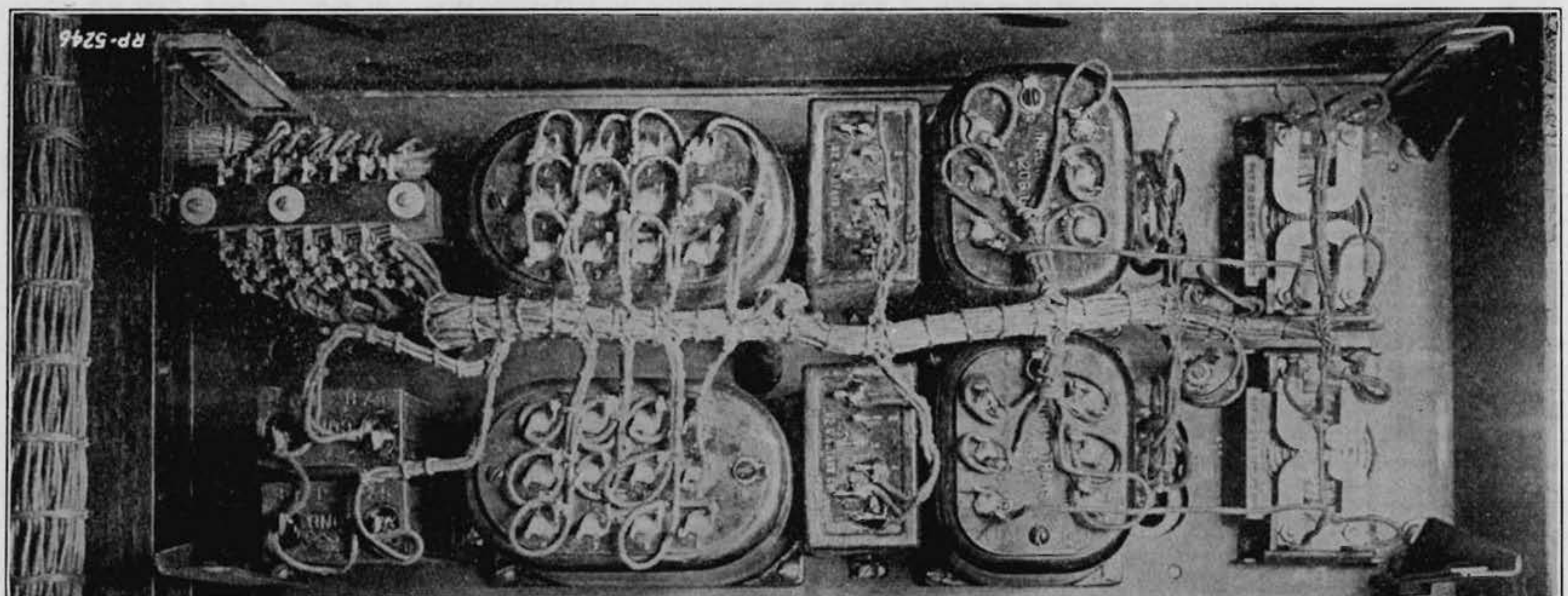


Fig. 11. 22-A-1 Repeater—Back View, Cover Removed

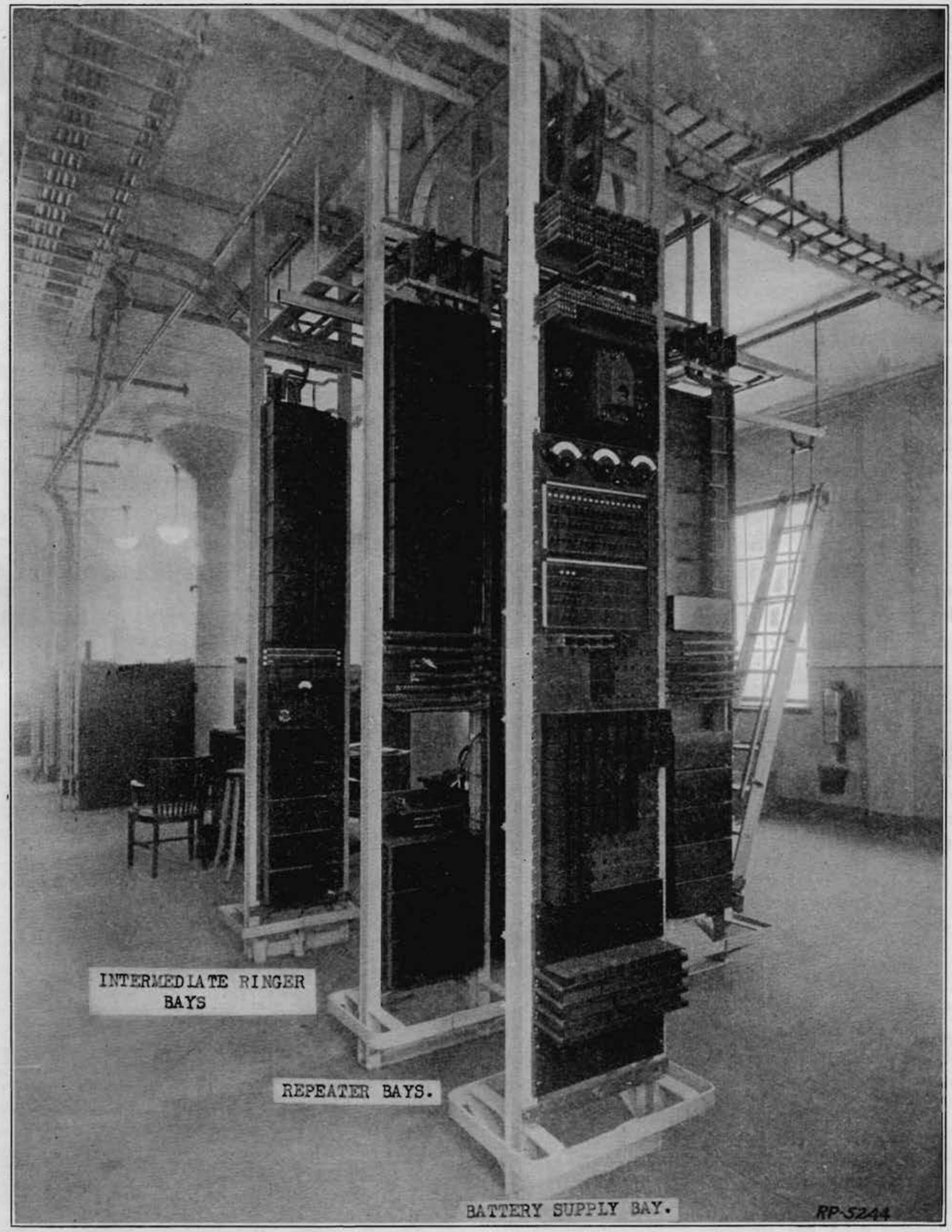


Fig. 12. Typical Small Installation of 22-A-1 Repeaters

jacks, the sleeve circuit is closed and a certain current (depending on the sleeve resistance) is connected to a group of relays. These relays have different operating current values, and certain ones will operate, depending on the current in the sleeve circuit. They connect artificial lines across the repeater input, thus decreasing the gain by a certain amount. By the foregoing arrangement it will be seen that the gain of the cord circuit repeater will be automatically reduced to a level previously determined correct for a given toll circuit, immediately that circuit is connected to the repeater cord circuit. In addition, a special "reduce gain" key is under control of the toll operator for reducing the gain of the repeater by 1.9 TU if this is desirable in any instance.

Transfer circuits may be used at the toll switchboard in connection with the repeater cord circuits. These circuits are provided so that when the toll operator at a repeater position is too busy to handle all of the repeater toll cords at her position efficiently, the control of some of the repeater cord circuits may be transferred to the adjacent operator by operation of the transfer key associated with those cords which it is desirable to transfer. Also when the position adjacent to the repeater cords is a night position the control of the repeater cords is transferred to the night operator by operating the transfer key.

Message registers are associated with each cord circuit repeater to show the number of times the repeater has been used. This information is of value to the traffic department in determining the load on the repeater and for estimating probable future needs.

Additional discussion of the ringers as well as of other closely associated circuits will be found in Section 2.

FOUR WIRE REPEATERS

Cable circuits have a much higher attenuation than open wire lines, consequently on toll cable circuits frequent repeaters having high gains must be used. It is for this class of service that the 44 (4-wire, 4-element) type of repeater has been developed. Four wires, forming two independent circuits, are used, one for transmission in each direction, for reasons that will appear later. The four elements of the repeater are the two two-stage amplifiers used, one in each of the oppositely directed channels.

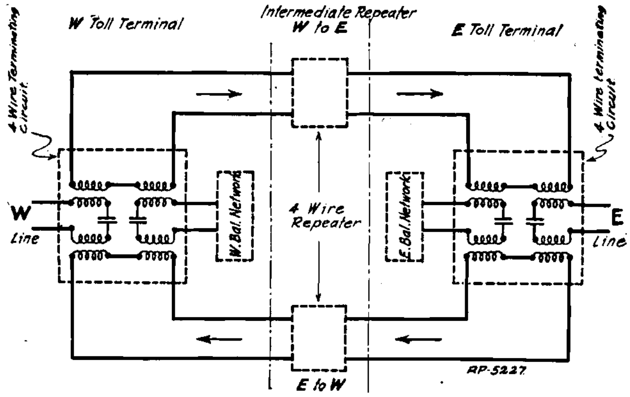


Fig. 13. Four Wire Repeater System—One Intermediate Repeater

Figure 13 shows schematically the simplest possible four wire repeater installation. The similarity between this circuit and that of the 22 type repeater is very marked. A similar bridge circuit transformer arrangement is used for separating the oppositely directed signals, but in this case it is a unit by itself and is called a four wire terminating circuit, and there is one at each terminal of the four wire section of a given line. Networks are used in the side of the terminal circuits opposite the two wire line to maintain the balance of the circuit and prevent feed back between the input and output circuits. Between the two terminating circuits is shown a single four wire repeater consisting of two electrically separate amplifying elements, one for each direction. This same arrangement is used in the two wire repeater, but whereas in the 22 type the distance from the W. input transformer through the W.-E. amplifier to the W. output transformer is a matter of inches only, in the 44 type this distance is several times as many miles. In Figure 14 is shown schematically a more nearly typical

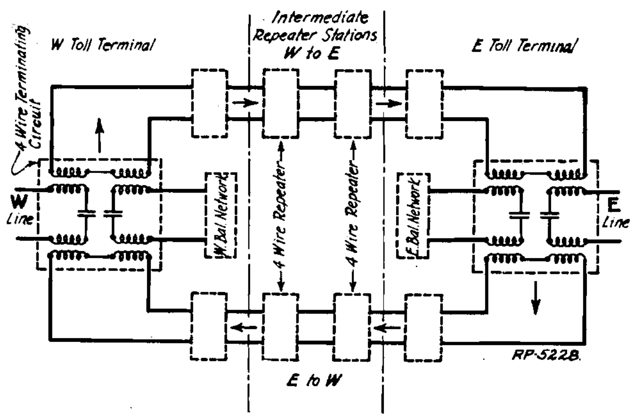


Fig. 14. Four Wire Repeater System—Intermediate and Terminal Repeaters

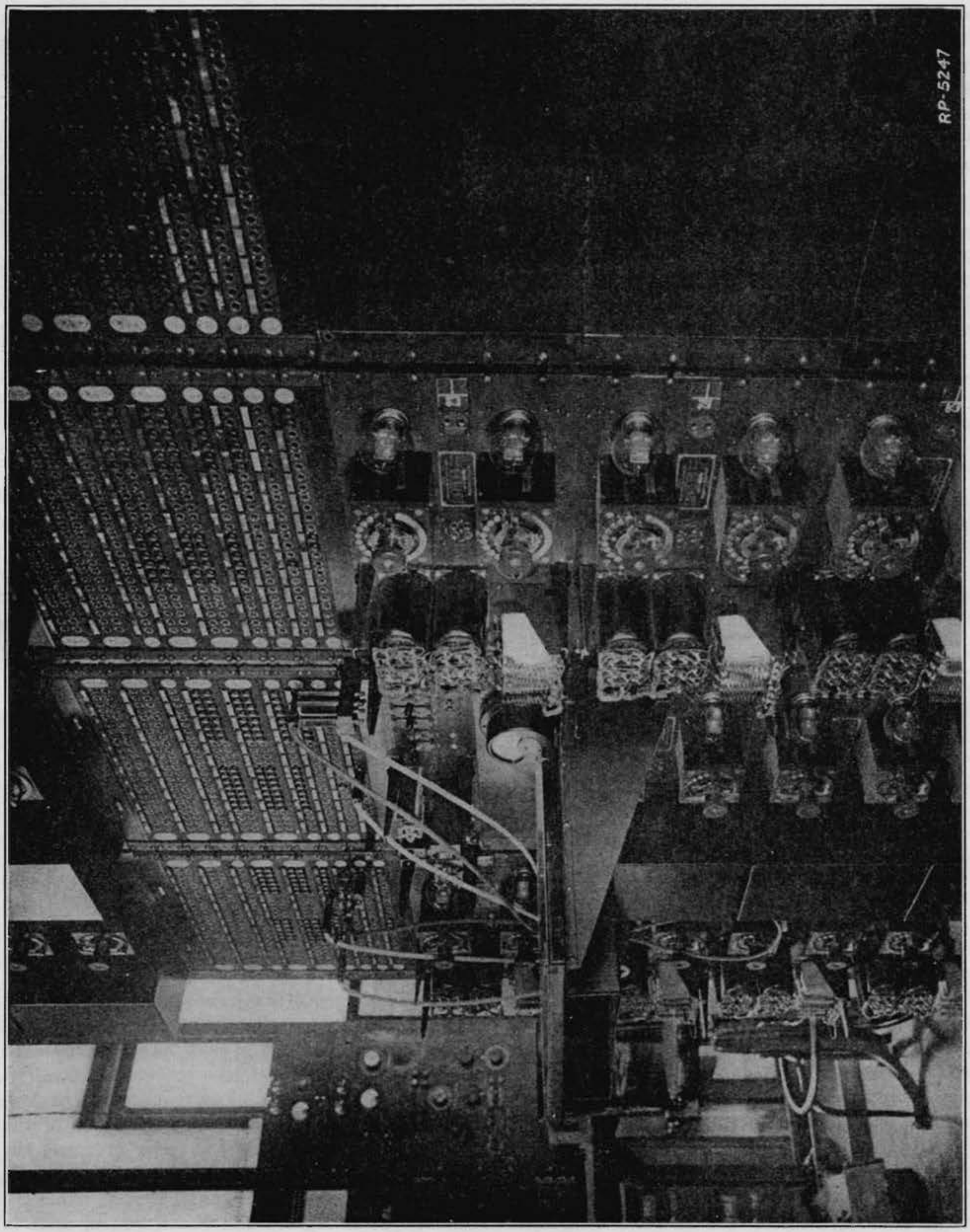


Fig. 15. Portion of Bay of 44-A-1 Repeaters

44 type repeater installation. It will be noticed that a terminal repeater is located at each of the toll terminals in addition to the four wire terminating circuits, and the other usual toll apparatus. Two intermediate repeater stations are shown with two separate blocks for each to bring out the fact that a 44 type repeater panel really consists of two individual amplifiers, one for each direction.

The important difference between the 44 and 22 type repeater is that, as shown in Figures 13 and 14, a four wire repeater circuit is changed to a two wire (and vice versa) only twice, once at each end of the circuit, irrespective of the number of 44 type repeaters in the circuit. On the other hand, in a two wire circuit using 22 type repeaters, this change takes place **twice at each repeater.** It is this fact that limits the gain allowable in a 22 type repeater, for each time the change from two wire to four wire circuit is made, the degree of balance commercially practicable between the two halves of the hybrid coil, and between the line and the balancing network, will not allow gains of more than about twenty TU without danger of singing. In a repeater circuit having 44 type repeaters, much higher gain per repeater is possible because the feed back currents between the two oppositely directed amplifier elements (which tend to cause singing) must travel to the end of the four wire circuit and back to the repeater before they can be effective. In this long path, of course, they are much attenuated and cannot cause much trouble unless the unbalance in the four wire terminating circuit is relatively large. It is for this reason that the networks used in a four wire terminating circuit for balancing the two wire circuit need not be made to balance the individual two wire circuit so exactly. In fact, what is called a "compromise network," consisting merely of a 700 ohm resistance in series with a 2 mf. condenser, is usually used.

The principal use of the 44-A-1 repeater is in four wire cable systems, using No. 19 gauge medium heavy loaded or extra light loaded cable circuits. The use of a V type and L type vacuum tube in tandem gives a very high gain, 42 ± 2 TU at 1000 cycles. However, the attenuation in cable circuits being several times that in open wire circuits, the repeaters are usually spaced 50 to 100 miles apart along the circuit. The greatly different energy levels of the input and output circuits makes it important to keep these circuits well separated to prevent cross-talk.

It will thus be seen that the high attenuation of cable circuits makes it more economical to make a complete two way communication channel by using four wires and a few high gain repeaters (44 type) than two wires and many low gain repeaters (22 type).

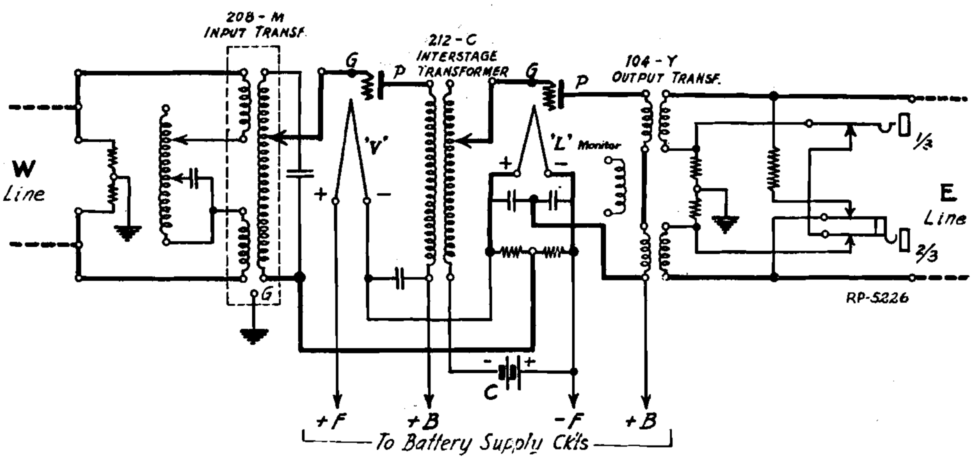


Fig. 16. 44-A-1 Repeater—Simplified Schematic of One (W-E) Half

The advantages of cable construction lie in its cheaper construction and maintenance costs and greater dependability in storms, as compared with an equivalent number of open wire circuits. The difference in the gauge of wire used in the two types of lines is also very much in favor of the smaller gauge used in cables. For instance, the weight per 1000 ft. of No. 19 gauge copper wire such as is used in cables is only 3.9 lbs., while the same length of No. 12 and No. 8 gauge, used in open wire construction, weighs 19.8 and 50 lbs., respectively. Thus a four wire cable circuit, although using twice the number of conductors, uses only about one-third and one-seventh, respectively, the amount of copper of No. 12 and No. 8 gauge two conductor open wire lines.

In Figure 16 is shown the schematic of two of the amplifier elements of a 44-A-1 repeater. The complete repeater, of course, has four of these elements divided into halves of two elements each which are used for amplifying in the two opposite directions. The one shown in this figure we shall assume to be used for amplifying a W. to E. bound signal and will follow the path of the signal from the incoming west line to the outgoing east line.

Across the input is a 700 ohm resistance with its center point grounded. This is one of several means taken in the 44-A-1 repeater to keep the two sides of the circuit carefully balanced to ground. The input transformer (type 208-M) has a tuning circuit in the center of its primary for compensating the repeater for use on various types of lines and for giving better transmission characteristics. It may be noted that a very similar arrangement is used in the 22-A-1 type repeater. The secondary of this transformer is tapped for gain control, as will be noted later in more detail. This transformer being in the input circuit of the first tube is in a very sensitive portion of the circuit and care is taken to prevent undesirable signals getting into its windings by shielding it and grounding the shield.

From the secondary of the 208-M transformer the signal goes to a V type (102-D) vacuum tube, a high impedance tube having a high voltage amplification factor (about 30) and low plate current. This tube works as a voltage amplifier and from it the signal goes through the 212-C interstage transformer to the second tube which is an L type (101-D) working as a power amplifier.

The 212-C transformer has high impedance in both primary and secondary to match the plate impedance of the V tube and the input impedance of the L tube. To one end of its primary is connected the plate of the V tube and to the other end the 130 volt B battery. Between the latter point and the B battery, however, is an 11. henry retardation coil, and between this point and the tube filament is a 2 mf. condenser, both devices for keeping any voice frequency signal getting through to the low potential end of the primary out of the plate battery circuit where it would cause cross-talk. The secondary of the 212-C transformer is also tapped for gain control.

The L tube further amplifies the E. bound signal and sends it out to the primary of a 104-Y output transformer. From the secondary of this transformer, the amplified signal goes out to the line. A further measure to prevent cross-talk is seen in the connection of the end of the primary of this transformer opposite the plate to the center point of a condenser circuit bridged across the filament of the L tube. The secondary is in two equal parts and between them is a resistance network controlled by two jacks, the center of the network being grounded. This transformer is also provided with a separate winding for monitoring.

Three means of gain control are provided in the 44-A-1 repeater. First the tapped secondary of the input transformer to the V tube gives variations between each tap of about 5 TU. The taps on the secondary of the interstage transformer give an adjustment of 1 TU per step. The two jacks controlling the resistance network in the secondary of the 104-Y output transformer make possible a 1/3 TU adjustment. Thus the entire range in gain of this type repeater from 6 ± 2 TU to 42 ± 2 TU can be covered in 1/3 TU steps.

We have followed the W.-E. path through the repeater. The other half of the repeater is a similar but oppositely directed path for the E.-W. signal. Each 44-A-1 repeater uses four vacuum tubes, two V type and two L type, and for the sake of economy the filaments of all are connected in series, the proper current adjustment being made in the associated battery supply panel. Small 9 volt C batteries supply the grid bias of the L tubes, but for the V tubes part of the voltage drop across the filament of the associated L tube is used.

Figure 15 shows a portion of a typical installation of 44-A-1 repeaters. Figure 17 is a front view of a repeater panel with cover removed. The two upper vacuum tubes are part of the E.-W. amplifier and the two lower ones of the W.-E. amplifier. The tubes to the left are V type and those to the right L type. Between them is the 212-C input transformer showing taps for gain control. The two transformers in the upper left hand corner are type 104-Y. Below them is the battery box containing C batteries for the L tubes. Figure 18 shows the back view of the same repeater set with cover removed.

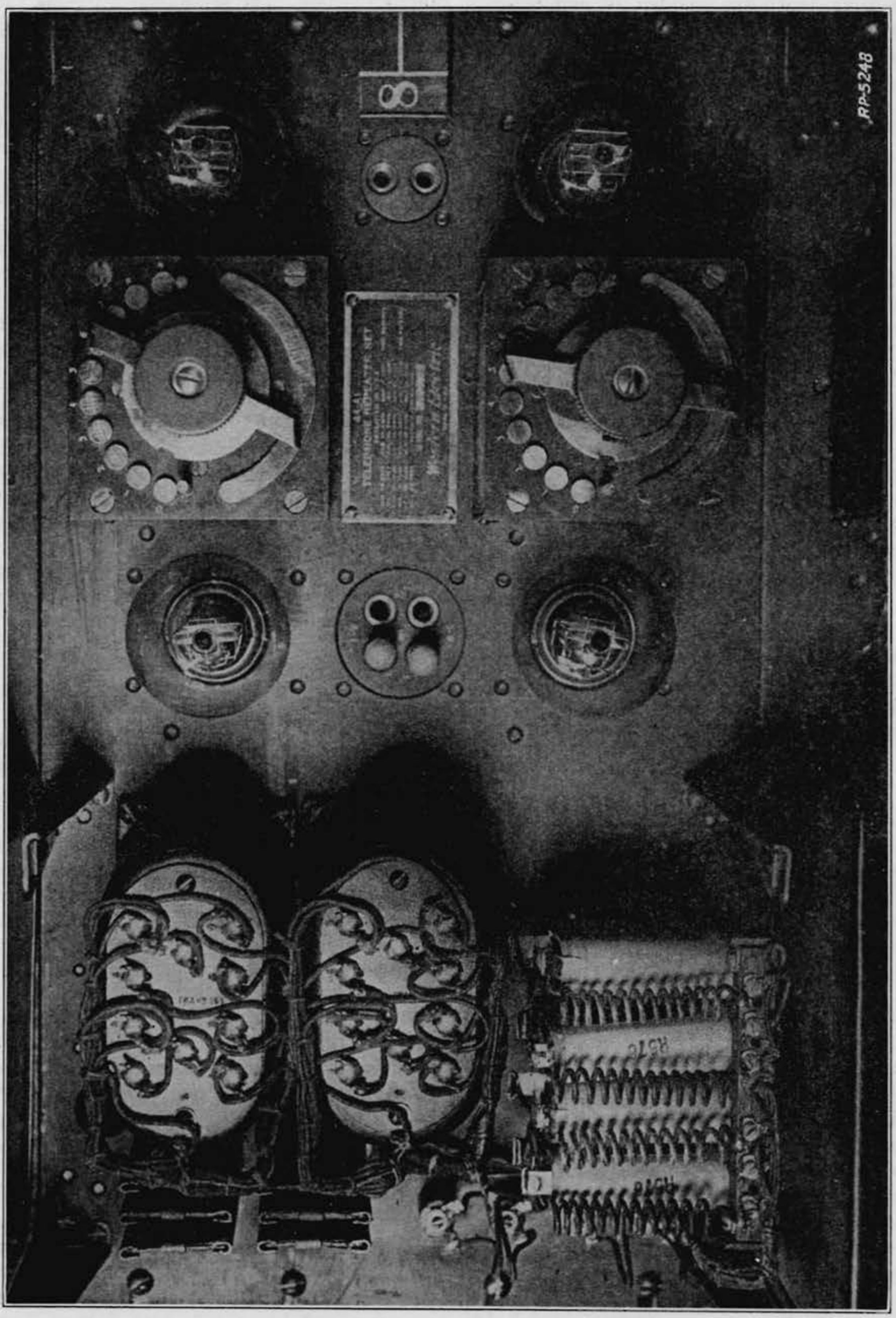


Fig. 17. 41-A-1 Repeater—Front View, Cover Removed

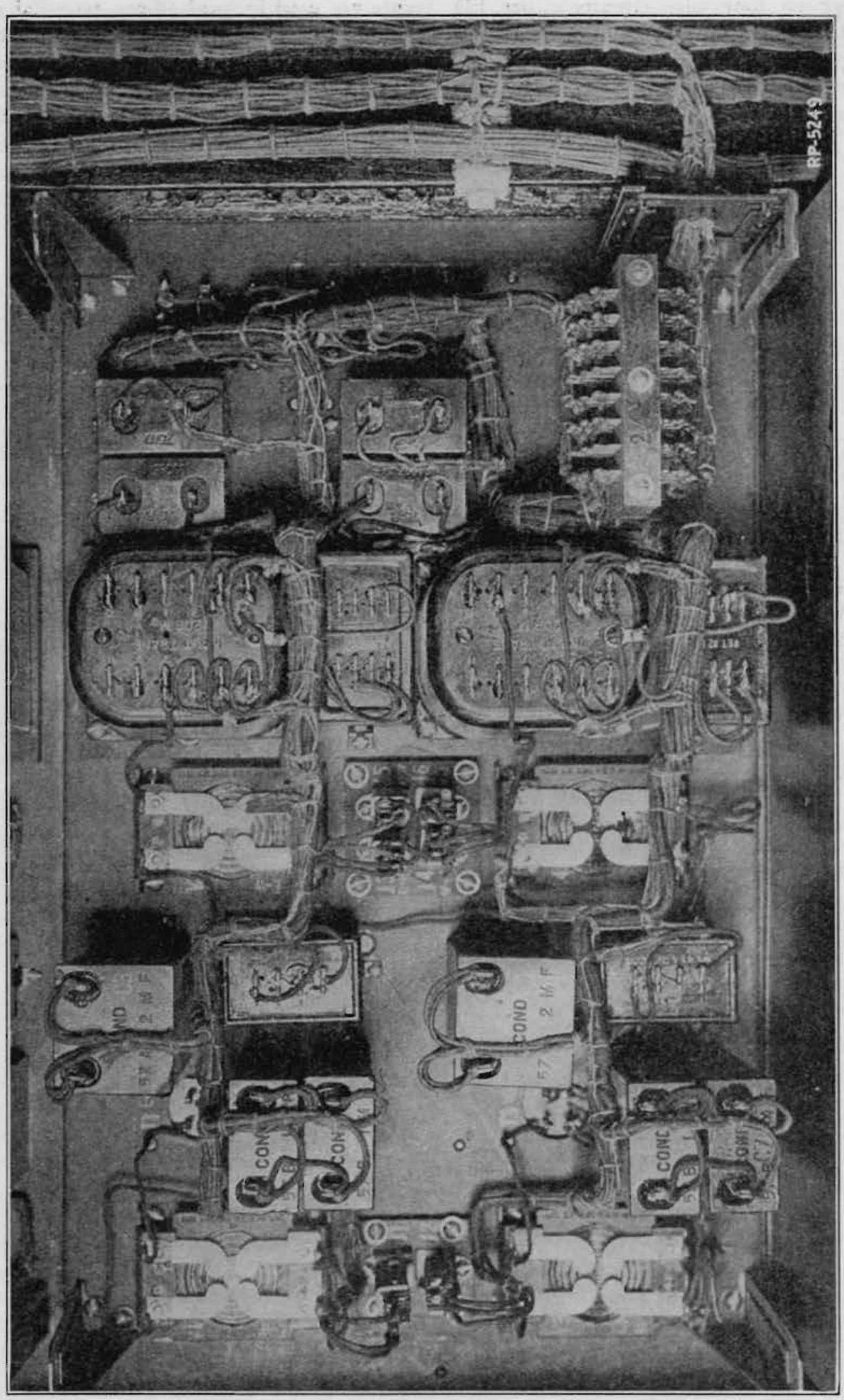


Fig. 18. 44-A-1 Repeater—Back View, Cover Removed

For signaling on four wire circuits either 135 cycle or 1000 cycle currents are used. At 1000 cycles the amplification of the repeater makes intermediate ringing equipment unnecessary. It is expected that the 1000 cycle signaling will be installed in most new jobs. Since 20 cycle signaling currents are used in local offices, terminal ringers are provided on all types of repeaters for actuating the 20 cycle ringing circuits through relays operated by the ringing currents on the toll lines whether they be 20, 135 or 1000 cycles as in the 22-A-1 type or 135 or 1000 cycles as in the 44-A-1 type repeaters.

SECTION 2

AUXILIARY CIRCUITS

RINGERS

There are three principal signaling systems in use for obtaining ring-down supervision over toll circuits. They are the 20 cycle, 135 cycle and 1000 cycle (voice frequency) systems and, as their names imply, use currents of the frequencies mentioned to accomplish this signaling.

20 Cycle Signaling System

The 20 cycle signaling system is used on non-composited two wire toll lines, toll lines not equipped with inequality ratio repeating coils and on the drop side of all ringing apparatus. The latter is its most extensive use since all signaling to and from the toll switchboard is done at 20 cycles, even though signaling on the toll line itself may be 20, 135 or 1000 cycles.

Terminal equipment used in connection with the 20 cycle system is associated with each toll line and each toll cord circuit at the toll switchboard. A relay sensitive to 20 cycle current is normally connected to the terminal of each toll line and arranged so that when 20 cycle current is applied to the distant end of the toll line, this relay operates and lights the lamp associated with the jack connected to that line. The toll cord circuits at the switchboard are arranged so that when a toll cord is connected to a toll line, the 20 cycle relay associated with the line circuit is disconnected and a second 20 cycle relay is across the cord circuit. When a 20 cycle current is sent from the other end of the toll circuit under these conditions a supervisory lamp associated with that cord will be lighted.

In order to transmit 20 cycle signaling current from the toll switchboard to a toll line, a ringing key which is under control of the toll operator is furnished in connection with each toll cord circuit at the switchboard, this key being arranged so that its operation connects a source of 20 cycle current across the toll line to which the cord circuit is connected.

On toll lines equipped with 22 type repeaters and arranged for 20 cycle signaling over the line, the signaling currents must be relayed around each repeater since this frequency is too low to pass through the repeaters. These relay circuits are termed intermediate ringers and one is shown in block schematic form in Figure 19. The operation of this ringer is briefly as follows: A 20 cycle ringing signal coming in from the E line will go from the center points of the transformer to the input of the E-W amplifier through the normally made contacts of the relay S_1. This amplifier input circuit, however, has a high impedance to such low frequency currents, but a parallel relay circuit is tuned to this particular frequency so the ringing current flows through this lower impedance path resulting in the operation of a train of relays and ultimately of S_2 which connects the local 20 cycle ringing current source to the outgoing W line. For W to E bound signals, of course, an exactly similar path is provided as shown.

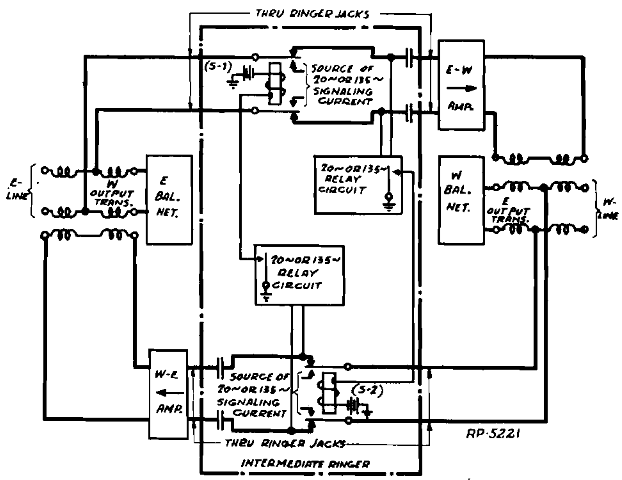


Fig. 19. Intermediate Ringer Used With 22 Type Repeater

A simplified schematic of this ringer circuit is shown in Figure 20. All E-W signals will come from the W output transformer, through the normally made contacts of relay S_1 and the condensers C_1 and C_2 to the E-W amplifier. If the signals happen to be 20 cycle ringing current they will find the circuit S_5, C_5 C_7 of lower impedance than the amplifier input circuit because the inductance of the relay S_5 is tuned to 20 cycles by the condensers C_5 and C_7. The flow of 20 cycle current through this circuit causes the operation of S_5, the consequent release of S_3, and operation of S_2. Operation of the latter connects the 20 cycle ringing current supply to the W line. The other half of this schematic will be seen to be identical to that just discussed, and furnishes a similar path for the W-E signals.

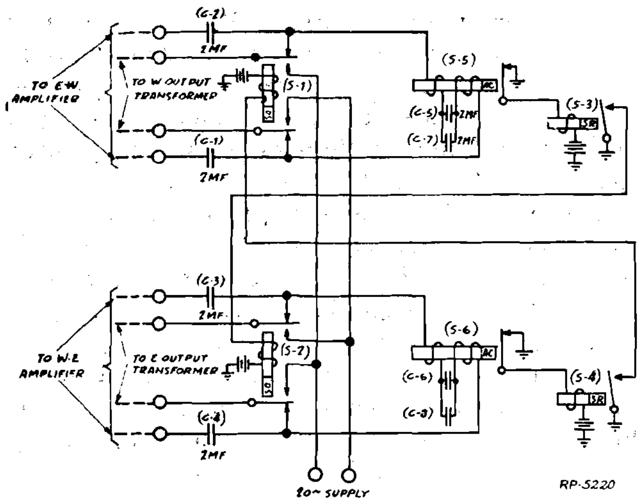


Fig. 20. 20 Cycle-20 Cycle Ringer—Simplified Schematic

The 20 cycle ringing current is usually supplied by motor generator sets, but where only a few ringers are installed vibratory generators run by dry cells may be used. For maintenance purposes, a testing circuit is provided to which the ringers may be patched. Keys and network then permit ringing through the circuit in either direction under practically the same conditions as the ringer meets in actual service.

The normal range of this system is about 300 miles of No. 12 gauge open wire line, but by special relay adjustments this range may be approximately doubled.

The great disadvantage of this system is the fact that such low frequency currents cannot be used over a line which is composited to provide telegraph service, as the signaling currents would cause the telegraph relays to chatter.

135 Cycle Signaling System

The 135 cycle signaling system is used in connection with two and four wire composited toll lines and two wire toll lines equipped with inequality ratio repeating coils.

In this system, operation of the ringing key at the toll board operates a series of relays causing 135 cycle current to be sent out on the toll line to the distant end and a second set of relays at the distant end to be operated by the received 135 cycle current and in turn cause the local source of 20 cycle current to be connected to the associated circuit at the switchboard. These relay circuits are known as terminal ringers. Block schematics showing how they are used in connection with 2 wire and 4 wire lines are shown in Figures 21 and 22.

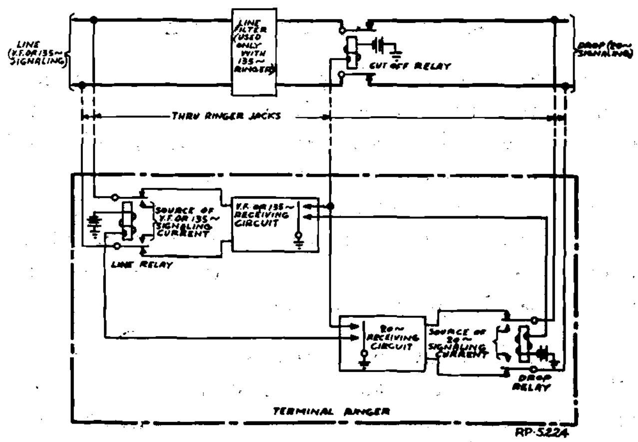


Fig. 21. Two Wire Circuit Equipped With Terminal Ringer

As noted on each of these drawings the same general circuit arrangements are used, whether 135 or 1000 cycle ringing is used on the line side. The operation of the ringer is simple as Figure 21 indicates. The 20 cycle ringing current from the switchboard goes through the normally made contacts of the drop relay to the low impedance path formed by the tuned 20 cycle receiving circuit. This operates the cut off relay and the line relay, sending ringing current out on the line but preventing the 20 cycle currents from getting out on the toll line and interfering with Morse service. 135 cycle signals from the line go to the 135 cycle receiving circuit operating the cut off and drop relays and so sending 20 cycle current to the drop circuit but not out on the line.

For 4 wire operation as shown in Figure 22 the only change so far as the ringer is concerned from the 2 wire operation above described is caused by the fact that the incoming and outgoing signals arrive and leave on two separate pairs instead of

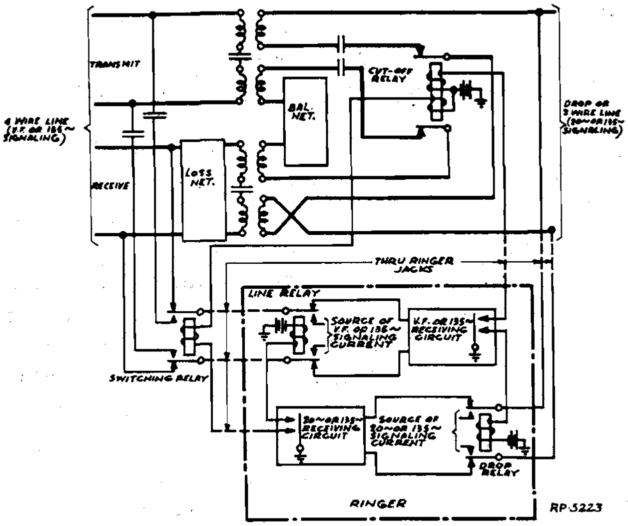


Fig. 22. Four Wire Terminating Circuit Equipped With Ringer

on the same pair. For this reason an added relay called the "switching relay" is used to change the line side of the ringer to whichever pair is needed. If the local operator is ringing out on the line this relay operates to connect the output of the local 135 cycle ringing machine to the cable pair used for transmission to the distant end. The normal position of this relay is such that 135 cycle signals from the distant end, arriving over the cable pair used for transmission in this direction, will go to the 135 cycle tuned circuit and cause the proper relays to operate connecting 20 cycle ringing current to the drop circuit.

In case the 135 cycle system is used for signaling over a circuit equipped with repeaters, arrangements will generally have to be made for relaying the signaling currents around the repeaters, due to the intentionally low gain of the repeaters at this low frequency. These relaying circuits are known as intermediate ringers and they may be used on either two wire or four wire circuits as shown in Figures 19 and 23, respectively. The operation in each case is evident from these drawings. The slightly different connections necessary for two wire and four wire use are provided for by connections brought out to the terminal strip of the ringer panel.

The operation of the 135 cycle-135 cycle intermediate ringer is identical in principle to the 20 cycle-20 cycle ringer, differing only in types of relays and values of the inductances and capacities naturally needed for tuning the relay circuit to the

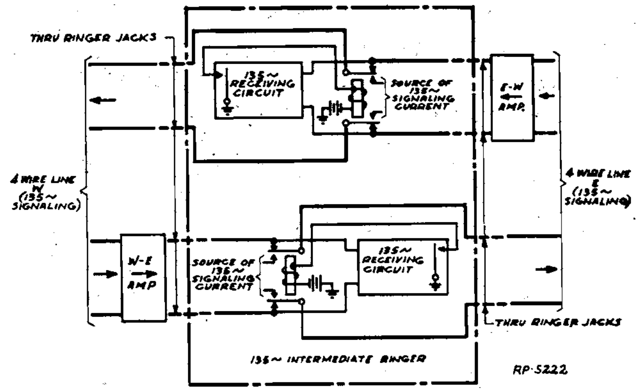


Fig. 23. Intermediate Ringer Used With 44 Type Repeater

higher frequency (see Figure 24). The operation of this ringer may be stated briefly as follows—a 135 cycle current coming in from the E line goes through the normally made contacts of relay S_1. From this point there are two possible paths, the current naturally taking the lower impedance one formed by L_1, C_1, C_3, C_5 and C_7 and relay S_3. The operation of S_3 causes S_5 to operate and hold during the operation of S_1 due to the capacity and resistance in the circuit of S_5. The operation of S_5 releases S_7, which in turn operates S_2, throwing the outgoing W line across the 135 cycle ringing supply. An exactly similar circuit is provided for the ringing signals in the opposite direction.

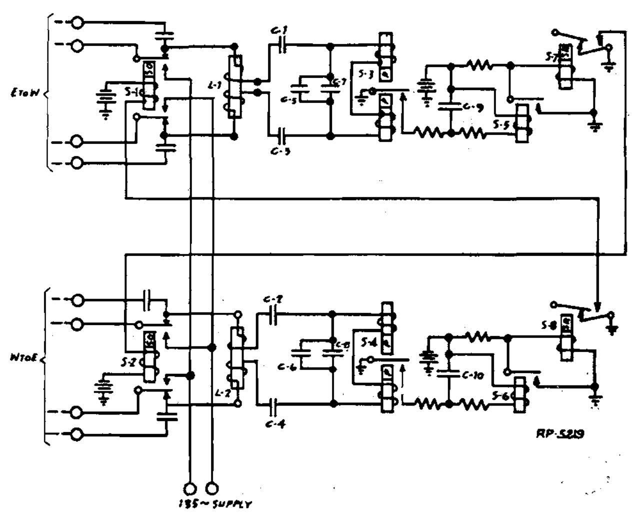


Fig. 24. 135 Cycle-135 Cycle Ringer—Simplified Schematic

A ringer operating on 20 cycles in one direction and 135 cycles in the opposite direction is needed where two sections of a toll circuit using these two signaling systems are joined, as well as between the line and drop of all circuits using 135 cycle signaling on the line. A simplified schematic of such a ringer is shown in Figure 25.

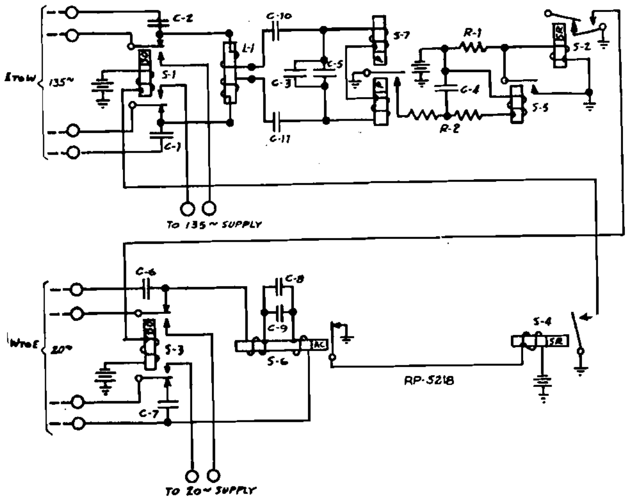


Fig. 25. 20 Cycle-135 Cycle Ringer—Simplified Schematic

Consider, for example, that the toll line to the West of this ringer uses 20 cycle signaling while to the East it uses 135 cycle. The W operator by means of a ringing key sends 20 cycle ringing current out on the line which finally reaches the 20 cycle side of the ringer on the armature contacts of the S_3 relay, passing through the normally made contacts of this relay. From this point the current can take either of two paths, the one through C_6 and C_7 or the one to S_6, C_8 and C_9. The latter circuit being tuned to 20 cycles presents the lower impedance, so the ringing current will flow in this circuit causing operation of the S_6 relay and consequent release of the relay S_4 and operation of S_1, causing 135 cycle ringing current to be sent out on the line to the E.

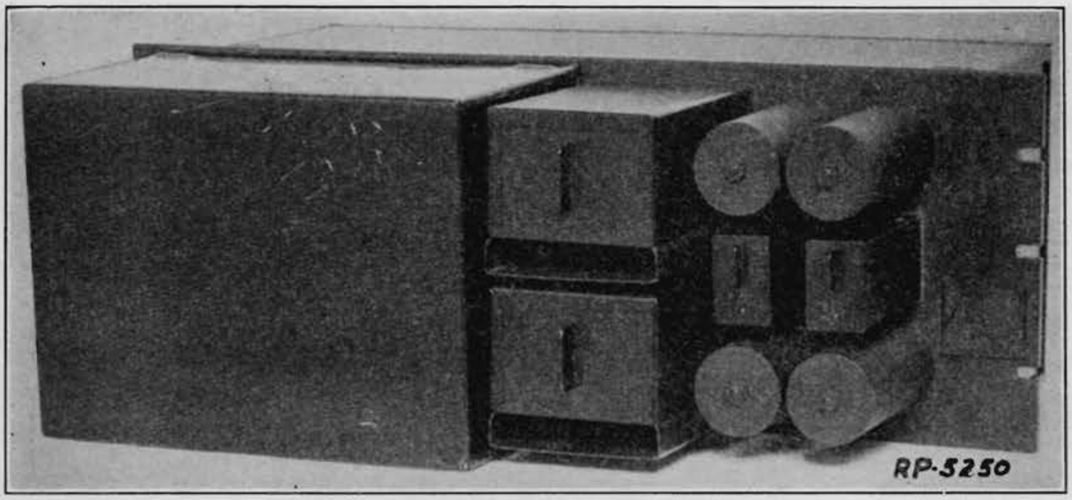
At the E terminal of this line a ringer similar to the one under discussion would be used for receiving the 135 cycle signal and using it for operation of relays sending 20 cycle current to the drop circuit. Whether used as an intermediate or terminal ringer its operation is, of course, the same. The 135 cycle signaling current comes in on the armature contacts of the S_1 relay, through the normally made contacts of this relay to the 135 cycle tuned circuit composed of L_1, C_{10}, C_{11}, C_3, C_5 and S_7. The flow of the 135 cycle ringing current causes operation of the polarized relay S_7, subsequent operation of S_5, release of S_2 and operation of S_3, the latter connecting the line W to the local 20 cycle ringing current source.

To prevent false operation of the ringers on a momentary flow of 135 cycle current from telegraph, voice or other disturbances, some of the relays in the ringer are made to have a time lag in their operation. On very long toll lines the cumulative effect of this may be too great for satisfactory operation and in such cases "amplified" ringing is used. That is, at some of the repeater points on such a line, the ringing signal is allowed to pass through the repeater and be amplified by it, thus doing away with the ringer panel at such points. By eliminating these ringers, the time lag is correspondingly reduced. Because of the time lag introduced by loading, long circuits are usually light-loaded and on such circuits the 1000 cycle ringer is generally used. The shorter, heavier-loaded circuits use the 135 cycle signaling system. The 1000 cycle ringer will be described in a later paragraph.

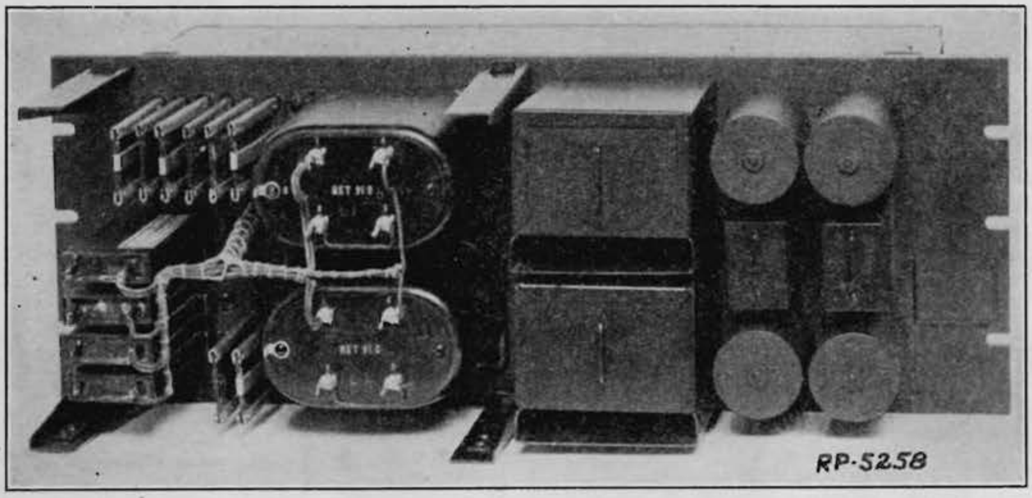
The testing circuit used in connection with 135 cycle ringers consists of an arrangement of keys and networks to which the ringer may be patched by means of testing trunks and is arranged so that the ringer may be operated in either direction under conditions approximating those met in actual service. This testing circuit is equipped with a meter, potentiometer and adjustable network which are used to control the 20 or 135 cycle current through the relay in either of the receiving circuits of the ringers to the values required in adjusting these relays. This testing circuit is also equipped with a dial circuit which is arranged to measure the time lag of the relay circuits, each of the numerals on the dial corresponding to about one-tenth second. By this means time lags of from one-tenth to one second are indicated directly.

The 135 cycle supply of ringing current is usually from small motor-generator sets. In small installations vibratory generators may be used. In either case filter circuits are provided to suppress harmonics which might interfere with telegraph or telephone communication.

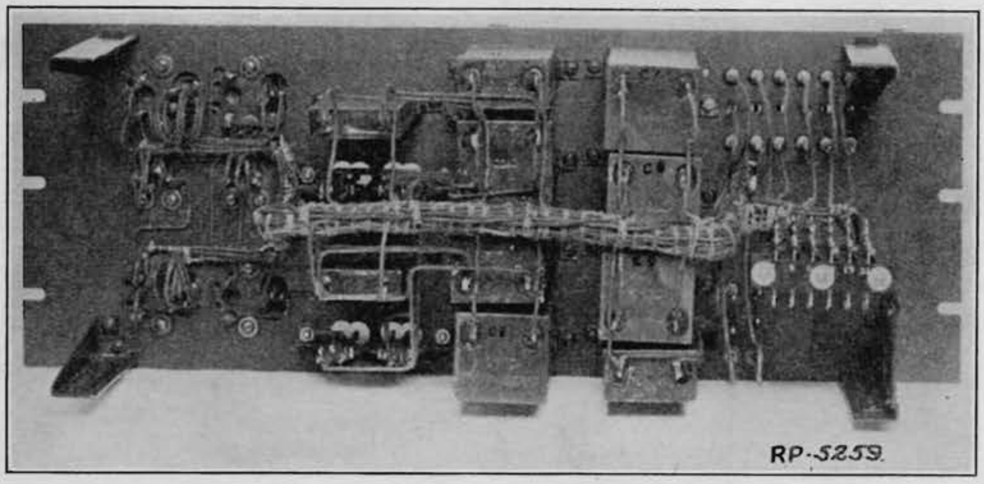
The 135 cycle signaling system will give satisfactory results in circuits having losses up to 18 TU between terminals or relaying points. If necessary this range may be increased to 22 TU by using a high pass line filter or by increasing the ringing current sent out by the ringers. The latter method cannot be used on lines equipped for telegraph service, however, as it may interfere with proper telegraph operation.



Front View—Cover On



Front View—Cover Removed



Back View—Cover Removed

Fig. 26. 135 Cycle-135 Cycle Ringer (528-B Panel)

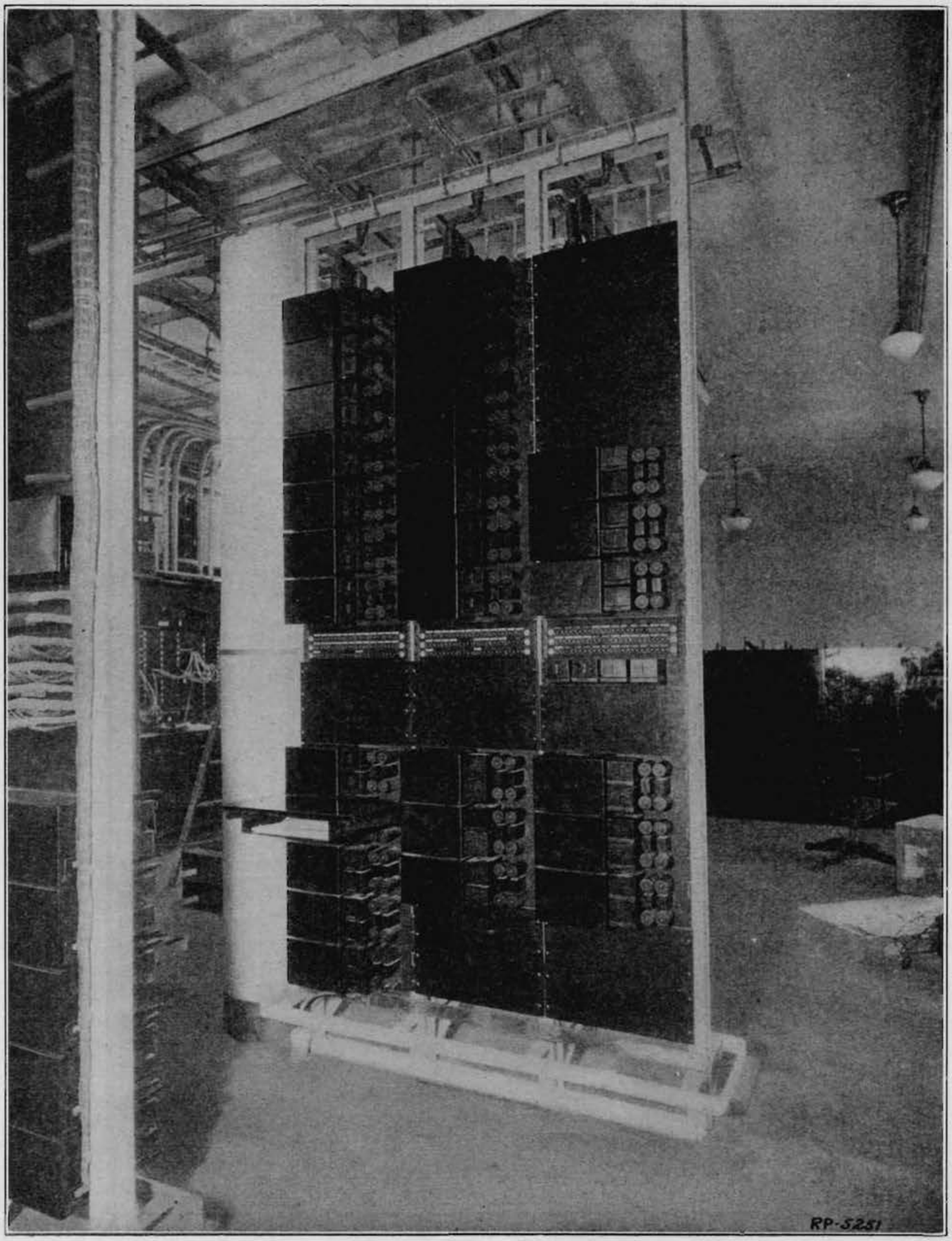


Fig. 27. Ringer Bay—Typical Installation

Voice Frequency Signaling System

The voice frequency (1000 cycle) signaling system may be used in connection with any type or combination of toll lines, carrier telephone or radio systems. Its principal use at present is on the longer toll lines and the type C carrier telephone systems where none of the other systems may well be employed.

In this system operation of the ringing key by the toll operator causes a 1000 cycle current interrupted at a 20 cycle rate (hereafter called the "1000 cycle ringing current") to be sent out over the toll line to which the toll cord has been connected. At the distant end, this current is received and made to operate a series of relays which connects a local 20 cycle source to the proper toll switchboard circuit. The relay circuits used at each end are similar to each other, being arranged for two way operation, and they are called terminal ringers. No intermediate voice frequency ringers are needed, of course, because the repeaters used on toll circuits for amplifying the voice signals serve equally well to amplify the signaling currents, since the frequency of the ringing current used in this signaling system is in the middle of the voice frequency range—hence the name "Voice Frequency Signaling System."

In Figures 21 and 22, respectively, are shown in block schematic form the arrangements for using

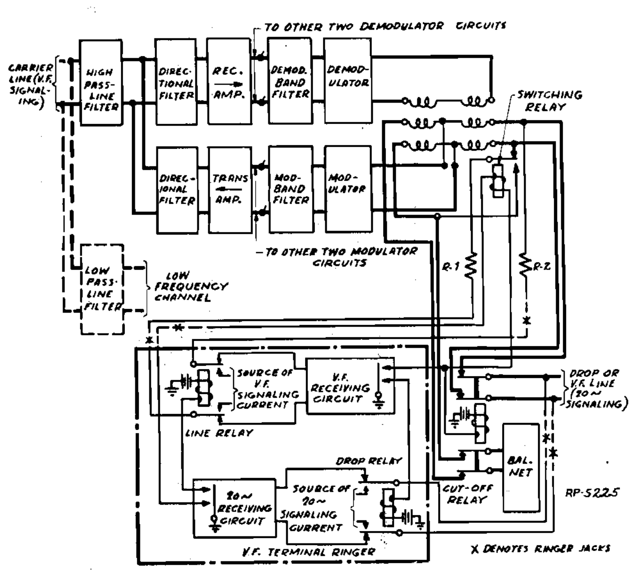


Fig. 28. One Channel of Type C Carrier Telephone Terminal Equipped With Voice Frequency Terminal Ringer

the 1000 cycle ringer on 2 wire and 4 wire terminating circuits. Both these drawings having been discussed in connection with 135 cycle ringers, a repetition is unnecessary, the operation in each case being the same. The only circuit differences are, of course, that 1000 cycle tuned circuits instead of 135 cycle receive the ringing signal, and 1000 cycle ringing current instead of 135 cycle is sent out.

In Figure 28 is shown how a 1000 cycle ringer is used at the terminal of a type C carrier current telephone installation. A type C system furnishes three telephone channels in addition to whatever other low frequency service is already on the line. On the drop side of the modulators and demodulators, of course, all channels are regular voice frequency so, as far as the ringers are concerned, they are operating on an ordinary voice frequency circuit. For ringing out in a given channel, the local toll operator's ringing key sends 20 cycle current through the 20 cycle receiving circuit causing operation of the cut off, switching, and line relays. The first mentioned removes the drop and its balancing network from either end of the hybrid coil. The drop is removed to prevent the 20 cycle ringing current from getting out on the toll line where it would interfere with the operation of telegraph apparatus which may be in use. The balancing network must, of course, be also removed from the other end of the hybrid to prevent unbalance. Operation of the switching relay puts the 1000 cycle ringing current on each end of the primary windings of the hybrid coil. Arriving at the modulator this ringing current is stepped up in frequency by an amount determined by the frequency of the carrier current used for transmission in that channel. It is then amplified by the transmitting amplifier and sent out on the line. Resistances R_1 and R_2 are used to cut down the output of the ringer to prevent overloading the modulator.

A ringing signal in this channel from the distant terminal will arrive as a high frequency wave at the demodulator of this channel only, due to the selective action of the line, directional and demodulator filters. In the demodulator the action of the distant modulator is reversed, the ringing signal is dropped down to its normal frequency of 1000 cycles and flows through the hybrid coil and line relay contacts to the 1000 cycle receiving circuit. The resulting operation of the cut off and drop relays sends 20 cycle current to the toll board and prevents it from getting out on the line.

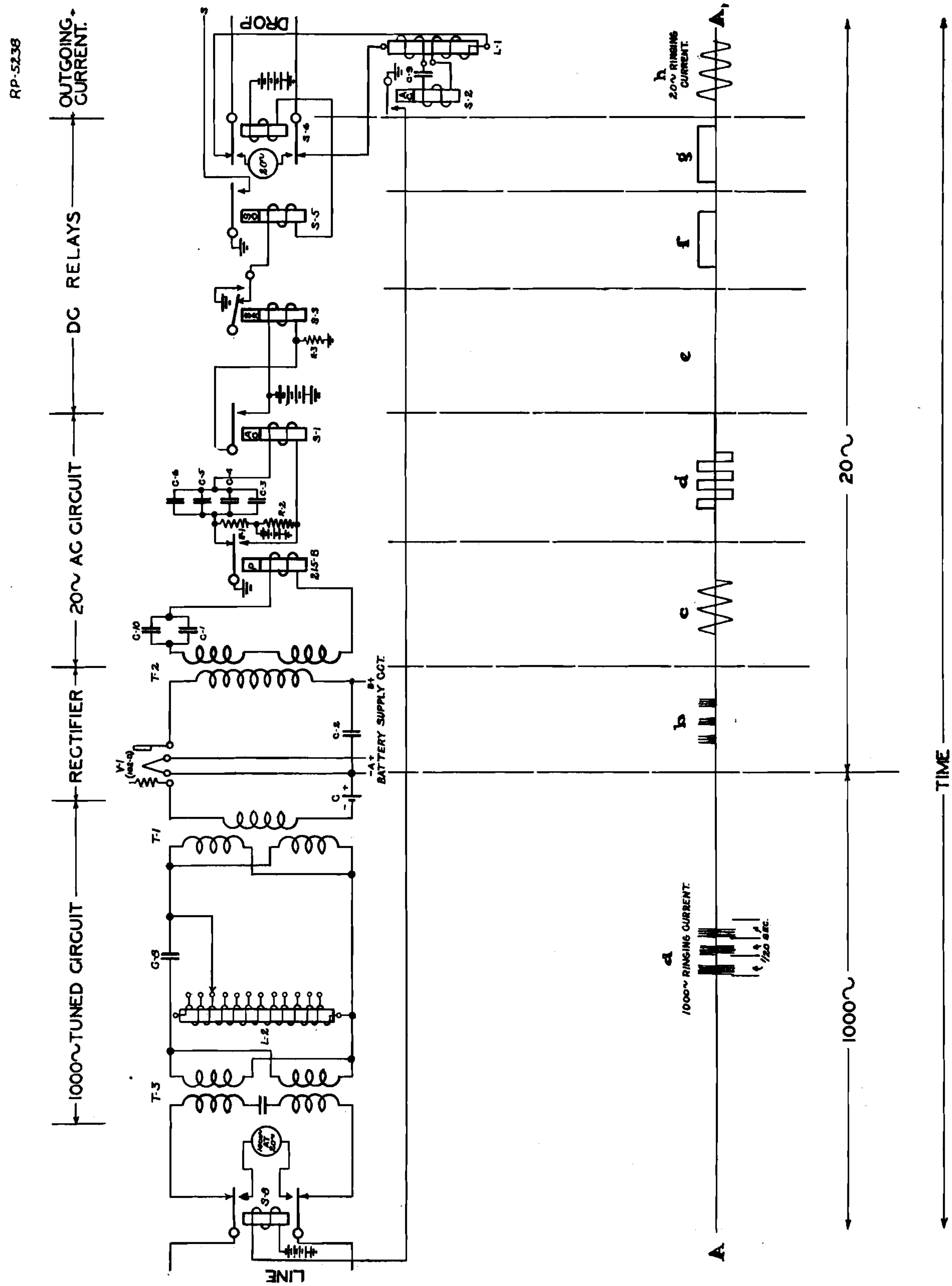


Fig. 29. Voice Frequency Terminal Ringer—Simplified Schematic

In Figure 29 is shown the simplified schematic of a 1000 cycle ringer. The circuit as a whole may be subdivided into the parts shown above the schematic proper in this figure. The effect of the original wave at the left is shown in each part of the circuit on the axis AA. A discussion of each of these parts of the circuit will be given in a later paragraph.

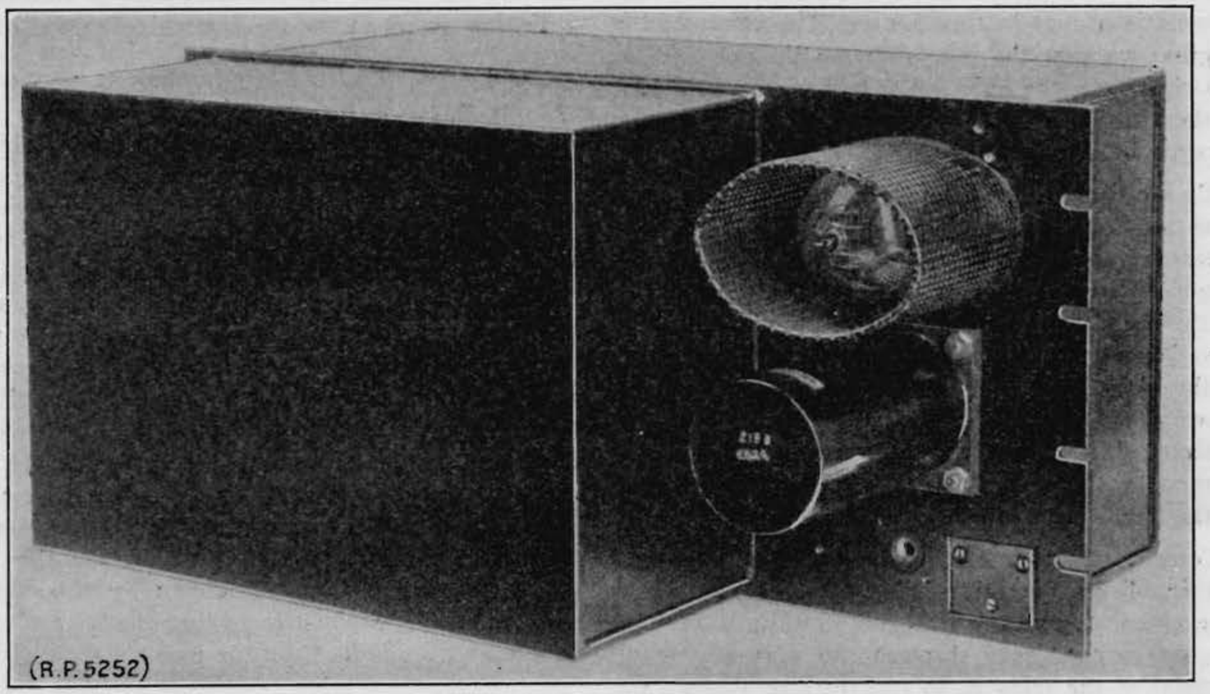
To see the action of the ringer when in use, suppose the local toll operator wishes to signal the operator at the other end of the line to which this ringer is connected. She operates the ringing key at the toll board putting 20 cycle current on the "drop" leads through the normally made contacts of the relay S_6 to the 20 cycle tuned circuit composed of L_1, C_9 and S_2, causing the relay S_2 to operate, this causing the operation of S_8 and so connecting the source of 1000 cycle ringing current to the line.

Considering now that we are at the other end of this toll line, we will see how this ringing signal is received. Coming in from the line the 1000 cycle ringing current goes through the normally made contacts of the relay S_8 to transformer T_3. T_3, C_8, L_2 and T_1 are so proportioned as to form a circuit tuned to currents of a frequency of 1000 cycles. The 1000 cycle ringing current will then be impressed on the grid of the vacuum tube V_1, which acts as a rectifier. In the plate circuit of this tube will appear the positive portions only of the original alternating current signals. In passing through the primary of the transformer T_2, these "bumps" of direct current of a frequency of 20 cycles per second result in an alternating current of the same frequency in the secondary circuit of this transformer. The inductance in this circuit (T_2 and the 215-B relay) is tuned to 20 cycles by the condensers C_1 and C_{10}. The 215-B relay is a polarized AC relay so its armature will be operated at the rate of 20 cycles per second. The armature of this relay is grounded while the two contacts are connected across a resistance which has its center point connected to 24 volt battery. One contact also goes to the winding of the AC relay S_1 while the other contact goes to the other end of the windings of this relay but through a bank of condensers C_3, C_4, C_5 and C_6. The operation of the 215-B relay thus alternately charges and discharges this condenser bank causing an alternating current to flow through the windings of relay S_1 and operating it, causing the release of S_3 and operation of S_5, grounding the sleeve of the drop side of the ringer circuit. S_6 is also operated, connecting Tip and Ring of this circuit to the 20 cycle ringing machine causing the usual signals to appear in connection with this circuit at the toll board.

On the axis AA an effort is made to picture the various stages in the operation of this ringer from the reception of the interrupted 1000 cycle ringing current to the connection of the local 20 cycle ringing machine to the drop side of the ringer circuit. At "a" we see a group of 1000 cycle wave trains coming in from the line. Since the frequency (time from beginning of one wave train to beginning of next one) is 20 cycles per second, each wave train with its succeeding space will be 1/20 second in duration. The duration of the wave train itself and of the space following it being about equal, we see that were we to monitor on a line over which this ringing current were flowing we would hear for 1/40 second a 1000 cycle note, then for 1/40 second nothing, then for another 1/40 second the 1000 cycle note, and so on. Incidentally this sounds very much like a whistler trilling the note C′ (one octave above middle C on the musical scale).

The 1000 cycle ringing current having been passed by the 1000 cycle tuned circuit, the negative portions of the waves are suppressed by the rectifying action of the vacuum tube V_1 (type 102-D), the positive halves "b" flowing in the primary of the transformer T_2 resulting in an alternating current "c" of the same frequency (20 cycles per second) flowing in the secondary of this transformer and so through the 215-B relay. The operation of the armature of this relay reverses the direction of current flow in the windings of the AC relay S_1 "d" causing it to operate, this resulting in the release of S_3 "e" and operation of S_5 "f", and S_6 "g," and causing the 20 cycle ringing current "h" to flow in the drop circuit to the toll board.

When a subscriber is talking over the toll circuit to which this ringer is connected, his voice is almost certain to be pitched at various times, at a 1000 cycle frequency, since this is in the middle of the normal voice frequency range. When this happens, part of these voice currents will be passed by the 1000 cycle tuned circuit, rectified in V_1 and appear in the secondary of T_2. They will get no further, however, since the secondary circuit of T_2 is tuned to 20 cycles. Thus it will be seen that although the frequency of the ringing current lies in the voice range, the voice current will not cause false operation of the ringer because the ringing



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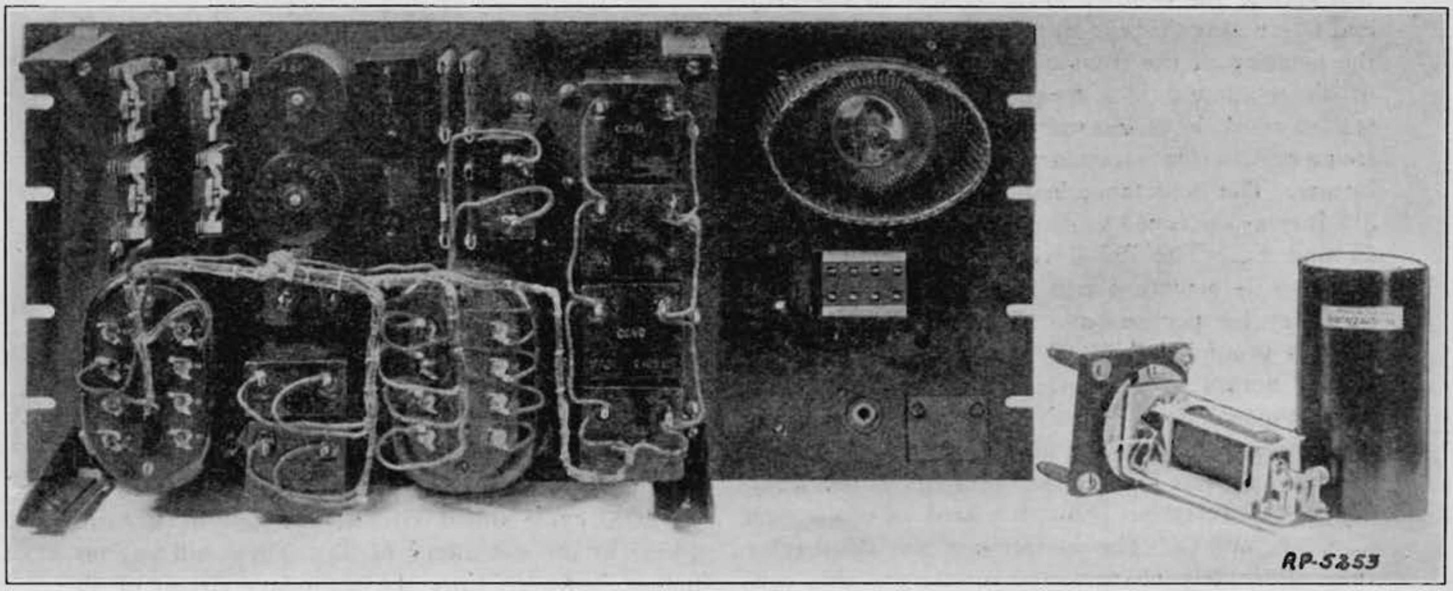

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Fig. 30. Voice Frequency Ringer (513-A Panel)

current must fulfill two conditions; i.e. (1) it must have a frequency of 1000 cycles to pass through the 1000 cycle tuned circuit and (2) the current in the secondary of T_2 must have a frequency of 20 cycles per second. This can only result from the rectification in V_1 of 1000 cycle wave trains arriving in groups at the rate of 20 per second.

Of course, the fact that we have a 1000 cycle tuned circuit normally connected across our voice circuit will cause some loss at the 1000 cycle frequency. The ringer circuit has a sufficiently high impedance, however, even at its resonant frequency, to cause a loss of only about .2 TU. At all other frequencies the loss is negligible.

The range of the voice frequency signaling system over a given circuit is, of course, the same as for the satisfactory operation of voice signals. The current sent out on the line by one of these ringers is normally about 5 milliamperes (.005 amp.) excepting where the ringer output goes directly to a vacuum tube input circuit (as a terminal repeater or carrier current system), in which case the ringer output is reduced to prevent overloading the tubes.

Voice frequency ringing current is usually supplied by small generator units, producing 1000 cycle current at 6 volts, which is interrupted at a frequency of 20 cycles per second by a mechanical interrupter mounted on the generator shaft. Circuits for measuring and regulating the output are provided. In offices equipped for automatic filament current regulation, the generator control can be made automatic. Each motor generator unit is equipped with a ring type regulator set to maintain the proper speed to ± 2% of normal value. In the case of an installation of only a few ringers, the 1000 cycle current may be supplied by a 6-B or 6-C oscillator and interrupted by a relay operating from the 20 cycle source in the office. In such cases a spare oscillator is regularly furnished and in all cases at least one spare ringer is supplied to insure continuity of service. Since a 102-D vacuum tube is a part of each ringer, 24 volt filament and 130 volt plate circuits are a part of the ringer installation.

The testing circuit used in connection with voice frequency ringers consists of an arrangement of keys and networks which may be patched to the ringer under test by means of testing trunks. These networks are so arranged that the ringer may be operated to relay a signal in either direction under conditions similar to those which the ringer must meet in service. This testing circuit is also equipped with a meter, potentiometer and network which are used to control the current flowing through the windings of either the AC relay S_2 in the 20 cycle receiving circuit, or the polarized relay (type 215-B) in the voice frequency circuit, while adjusting these relays. A dial and relay circuit is provided to measure the time required to operate the train of relays in the 1000 cycle circuit.

AUTOMATIC FILAMENT CURRENT REGULATING CIRCUIT AND AUTOMATIC PLATE VOLTAGE REGULATING CIRCUIT

Such a sensitive device as a vacuum tube requires rather constant operating conditions if it is to give the desired high standard of service. Due to variations in the load, necessity for periodic charging, and other reasons, the 24 volt battery supplying the filament circuit is subject to considerable variation. To maintain the filament current within the specified limits of .97 ± .03 ampere, a circuit known as the Automatic Filament Current Regulating Circuit has been developed.

The desired regulation is accomplished by having a number of stepping relays cut in or out resistances in the filament circuits under control of a voltmeter relay which is arranged to make contact at 20 and 21 volts, this voltage variation resulting in a current variation within the limits above given. The voltmeter relay is connected across the filament battery supply, so if the voltage changes sufficiently to cause the relay to make contact at either of these points, the chain of relays operating or releasing will cut in or out resistance in the filament circuits. At the same time one unit of a resistor furnished with the voltmeter relay will also be cut in or out causing the needle to return to its floating position between the contacts.

The circuit will maintain the current in any number of filament circuits up to 140, between the limits of .94 and 1.0 ampere with a battery voltage variation of 20 to 28 volts, or 21 to 29 volts, as desired. A greater number of filament circuits than 140 can be controlled by using an additional set of intermediate control relays.

In most cases where vacuum tube repeaters are installed the necessary 130 volt plate potential will be supplied by a separate 130 volt battery or by a booster battery in conjunction with a 120 volt

Morse battery. Variations in load due to the repeaters themselves are very small so that little difficulty is had in maintaining the plate battery voltage within the specified limits of 130 ± 5 volts where a separate battery is used. The telegraph battery is subject to much wider variations than ± 5 volts, however, and an automatic plate voltage regulating circuit is sometimes used in conjunction with a booster battery, in order to maintain the plate potential within the limits specified.

The circuit arrangement for the plate voltage regulating circuit is very similar to the automatic filament current regulating circuit, the voltmeter relay and the resistor being connected across the telegraph battery and operating on a change in voltage to cut in or out resistances in the plate leads. The voltage drop in these resistances due to the passage of the plate current will thus be cut in or out of the circuit, giving the desired regulation. Due to variations in tubes and the grid biasing potentials the plate current in the tube will differ to some extent, causing some variations in the plate battery regulation, but this is not sufficient to cause trouble in the repeaters.

While the principle of operation of both these regulating systems is very simple, the number of relays required to get the desired close regulation makes it impracticable to present a schematic of these circuits in the present booklet. For those interested the information contained in the circuit descriptions (CD sheets) is recommended.

COMMON GRID BATTERY SUPPLY CIRCUIT

The 22 type repeater is one of the most widely used pieces of apparatus in the telephone plant. Each repeater uses two 101-D vacuum tubes (one for amplifying in each direction), consequently in large offices the number of these tubes used in repeaters may number in the hundreds. For operation as an amplifier each tube must have its grid maintained at a normal potential of negative nine volts with respect to the negative side of the filament. No current flows in the grid circuit of a vacuum tube working as an amplifier, consequently no power will be drawn from this nine volt source. In comparatively small installations this nine volt potential is usually supplied by small 4½ volt C batteries, two for each tube. Regular voltmeter checks must be made, of course, on the pair of batteries used in each grid circuit and they must be replaced as soon as their combined voltage drops to 8. While this method is satisfactory and economical in small installations, the cost of the labor required in checking the battery voltages and replacing them when necessary, as well as the cost of the batteries themselves, makes the use of the Common Grid Battery Supply Circuit advisable in larger installations.

As shown in the schematics of Figure 31, the filaments of the two tubes of a 22 type repeater are connected in series, and these in series with the two of another repeater. This is done for the sake of economy, the office battery supply being 24 volts and the drop across the individual tube filaments being 4½ volts. The four tubes in series forming a given filament circuit thus utilize about 18 volts, leaving the rest for regulation, drop in wiring, drop in battery terminal voltage due to heavy load, etc. In accordance with standard practice the positive side of this 24 volt A battery is shown grounded, the "Fil. Batt. Busbar" being connected to the negative. The negative filament terminal of tube No. 1 will then be connected to the negative filament battery busbar. To care for the different wiring resistance (and consequent voltage drop) in various installations, a number of resistances are connected between these two points, the resistances being of graduated sizes, so that by strapping out certain of them the total voltage drop between the busbar and the tube will be the same for all installations—1.5 volts at .97 ampere. Thus the filament busbar will always be at a potential of –1.5 volts to tube No. 1 and, because of the drop of 4.5 volts in the filament of tube No. 1 of –6 volts to tube No. 2 (referring always to the negative end of the filament). Since we require –9 volts on the grid of each tube, we need only to add –7.5 volts and –3 volts, respectively, to the potentials above mentioned. This is done by utilizing the constant voltage drop resulting from a constant current flowing through a fixed resistance. The constant current is supplied by a 10 volt grid battery, and the constant resistance is one of 750 ohms. This resistance is connected, in series with a variable one, across the grid battery, the variable resistance being adjusted until a current of 10 millamperes (.010 amp.) flows through the circuit. This current flowing through 750 ohms will cause a drop of .01 times 750 or 7.5 volts—just what is needed for the grid circuit of tube No. 1. The 3 volts for tube No. 2 is obtained by using the drop across 300 of the same 750 ohms resistance. The positive side of the grid battery being connected to the filament busbar, these voltages will be negative with respect to it, so when the grid of tube No. 1 is connected to the end of the 750 ohm resistance its grid will be –1.5 plus –7.5 or –9 volts with respect to its filament. The grid of tube No. 2 will similarly be –1.5 plus –4.5 plus –3, or –9 volts negative with respect to its filament. Tubes No. 3 and No. 4 use the drop across the filaments of the two tubes preceding them.

connected across the 300 and 750 ohm resistances to eliminate from the repeater grid circuits any noises in the battery circuits.

The foregoing description has been of a common grid supply for 22 type repeaters and it is in connection with this apparatus that common grid battery supply circuits are most generally used. A circuit similar to it may be supplied on installations of echo suppressors also.

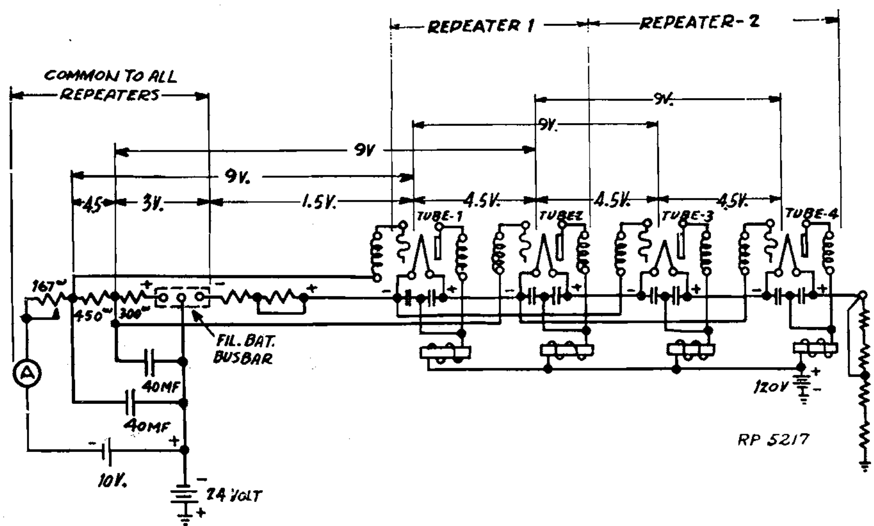


Fig. 31. Common Grid Battery Supply Circuit—Simplified Schematic

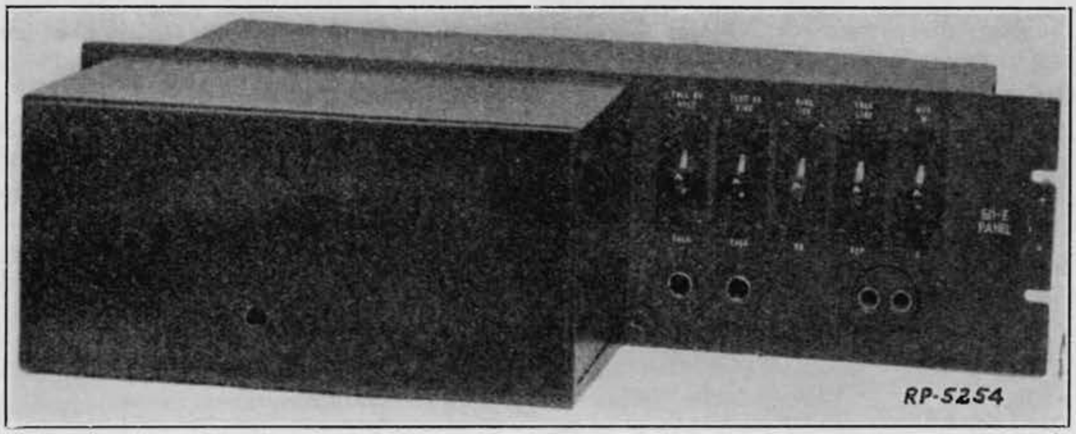
Figure 31 is a simplified schematic of the common grid battery supply circuit supplying the proper grid potentials to two 22 type repeaters. The various voltage drops which are used as grid bias are indicated in this drawing.

For proper operation, of course, it is important that a current of 10 milliamperes flows through the 750 ohm resistance and for this reason a milliammeter relay is in this circuit and adjusted to close an alarm circuit at 9.5 and 10.5 milliamperes (.0095 and .0105 amp.). This alarm can be cut off only by a key which simultaneously cuts into the circuit a milliammeter so that the current may be correctly adjusted. The above current regulation of ± .5 milliampere gives a voltage regulation in this circuit of ± .375 volt. So long as the specified current flows in this resistance circuit and in the tube filament circuit then, a grid potential within the limits of — 9 ± 1 volts will be applied to all tubes. Heavy condenser banks of 40-mf. each are

REPEATER ATTENDANT'S TELEPHONE SET CIRCUIT

For testing and observing the service on a repeater circuit, the repeater attendant is provided with means for monitoring, talking and signaling on the line, talking and monitoring on the repeater, and for signaling and talking to the Toll Switchboard or Toll Test Board. These facilities are provided by the Repeater Attendant's Telephone Set Circuit coded as the 511-E Panel and shown in Figure 32.

This circuit is intended for use with repeaters which have monitoring windings in their output transformers. These monitoring windings are balanced with respect to the other windings of the transformer and are of relatively high impedance so they cause no unbalance and but very little loss to the circuit to which they are connected. Figures 6b and 16 show these monitoring windings in the



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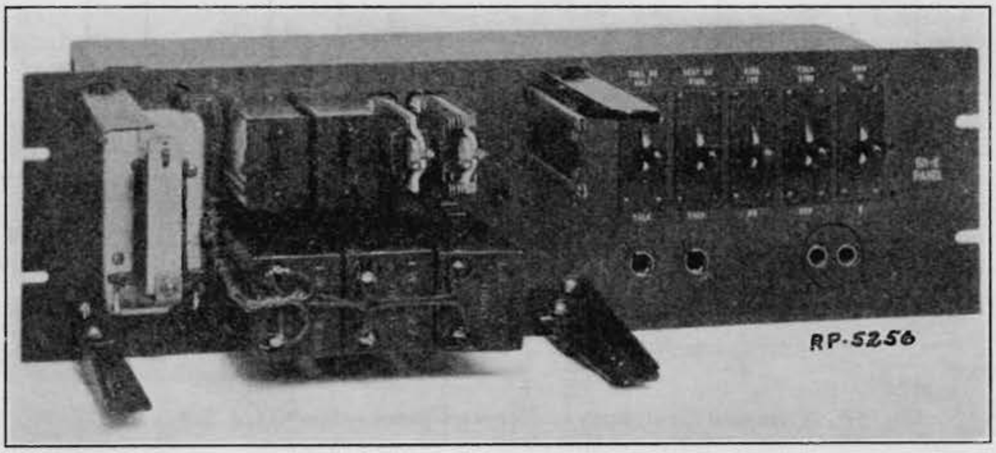

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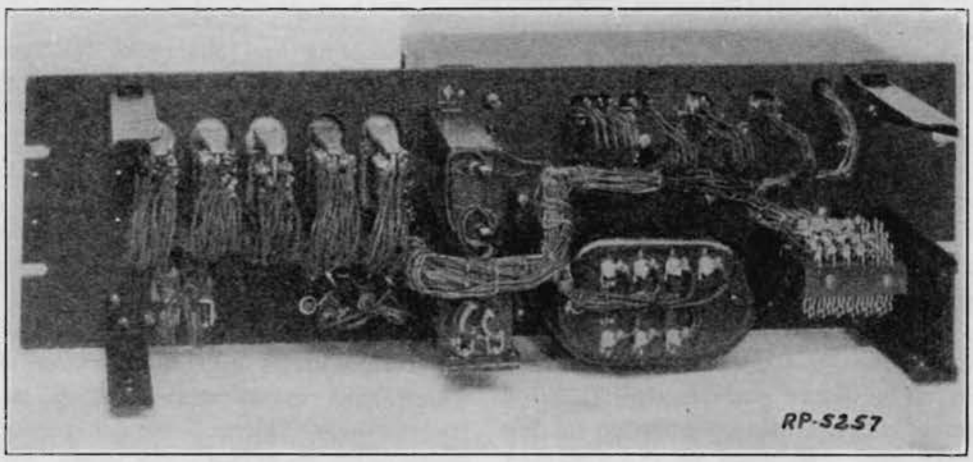

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Fig. 32. Repeater Attendant's Telephone Set (511-E Panel)

output transformers of the 22-A-1 and 44-A-1 repeaters, respectively. They are connected to jacks on the jack strip in the repeater bay as are the jacks to the Attendant's Telephone Set Circuit. The circuit can thus be connected by a patching cord to the monitoring windings of the repeater or to the lines. A ring down trunk from the Toll Test Board and a two-way automatic trunk from the Toll Switchboard are connected to keys on the panel, which permit two-way signaling and talking to either board. Both visual and audible alarms on the telephone set panel operate when the repeater attendant is being called from the Toll Switchboard or Toll Test Board. A "hold" position of the "Toll Bd." key allows the repeater attendant, in case he is using the trunk to the Toll Switchboard, to disconnect his telephone set from this trunk without giving the toll operator a supervisory disconnect signal.

The three other keys shown in the photograph adapt the circuit to its several other uses. By patching the Telephone Set Circuit to the repeater and properly operating the keys on the set panel, monitoring may be had in both directions or amplified monitoring in either direction. Keys controlling the talking circuits allow simultaneous transmission in both directions or in either direction, as desired.

The circuit may also be patched directly to the line associated with the repeater and used for communication over it. A key controlling 20 and 135 cycle ringing current is provided on the Telephone Set Panel.

On large installations where there are a number of bays of repeaters, interposition trunks are usually installed and a busy test jack circuit is provided so that the attendant will not come in on a busy trunk. This busy test circuit when patched to the Telephone Set Circuit makes possible an audible busy test on the interposition trunks.

Using a regular operator's telephone set (No. 234 Transmitter and No. 528 Receiver) with this circuit, satisfactory transmission will be had under all ordinary conditions in which it will be used by the repeater attendant.

The allowable battery variation is from 20 to 28 volts. The loss to through transmission of the repeater to which this telephone set circuit is connected is not more than .1 TU for monitoring or .4 TU for talking.

TESTING EQUIPMENT

For the proper maintenance of repeaters it is necessary that periodic tests be made on them which will show how they work under operating conditions. The function of a repeater being to supply gain to the circuit in which it is connected, it follows that the tests for determining this gain are of great importance. The equipment usually supplied for making such tests consists of two main pieces of apparatus, an oscillator and a gain measuring set. There are various types of each, but they are all similar in principle and will here be discussed in a general way. More detailed description of a given type and instructions for its operation may be found in the Test Methods Instructions (TMI) for that particular apparatus.

Probably the most widely used type of gain measuring equipment at present is the 2-A Gain Set. A later type, the 2-D is now being installed on new jobs and will, therefore, be of interest to us as installers. The two types are identical except that the 2-D set is designed to read gain in TU whereas the 2-A reads in standard miles.

Figure 34 shows a schematic of the 2-D Gain Set and its associated oscillator and jack circuits. In this particular case both the 6-B and its superseding type the 6-C are shown since they are at present, and will probably continue for some time to be, generally used in connection with this Gain Set. It will be noted from this schematic and by inspection of the photograph on the next page, that the gain set comprises two separate panels coded as the 50-D Repeater Gain Unit and the 3-A Amplifier, which in the photograph are the lower and upper panels, respectively. In the following paragraphs we will discuss the above mentioned equipment in the following order: 6-B and 6-C Oscillators, 50-D Repeater Gain Unit, and 3-A Amplifier.

Tests for gain in voice frequency repeaters are naturally made at voice frequencies. 1000 cycles being at about the middle of the voice frequency range, tests made at such a frequency will give a good indication as to whether or not the repeater is functioning normally. The duty of the 6-B or 6-C oscillator is to supply this 1000 cycle current for use in measuring the repeater gains by means of the repeater gain unit.

A study of the schematic of the 6-B oscillator shown at the left of Figure 34 shows that the vacuum tube (A) is connected in a conventional oscillator circuit. The grid and plate circuit are inductively coupled through the 91-A Retardation Coil. This inductance in the grid circuit is tuned by the tapped condenser C_2 so that the circuit has a natural period of 1000 cycles. C_2 is adjusted to the connected directly to that of (A) so these variations will cause the grid voltage of tube (B) to vary at the rate of 1000 cycles per second. This causes a corresponding increase and decrease in the plate current of (B) and since this current flows through the primary of transformer T, a 1000 cycle

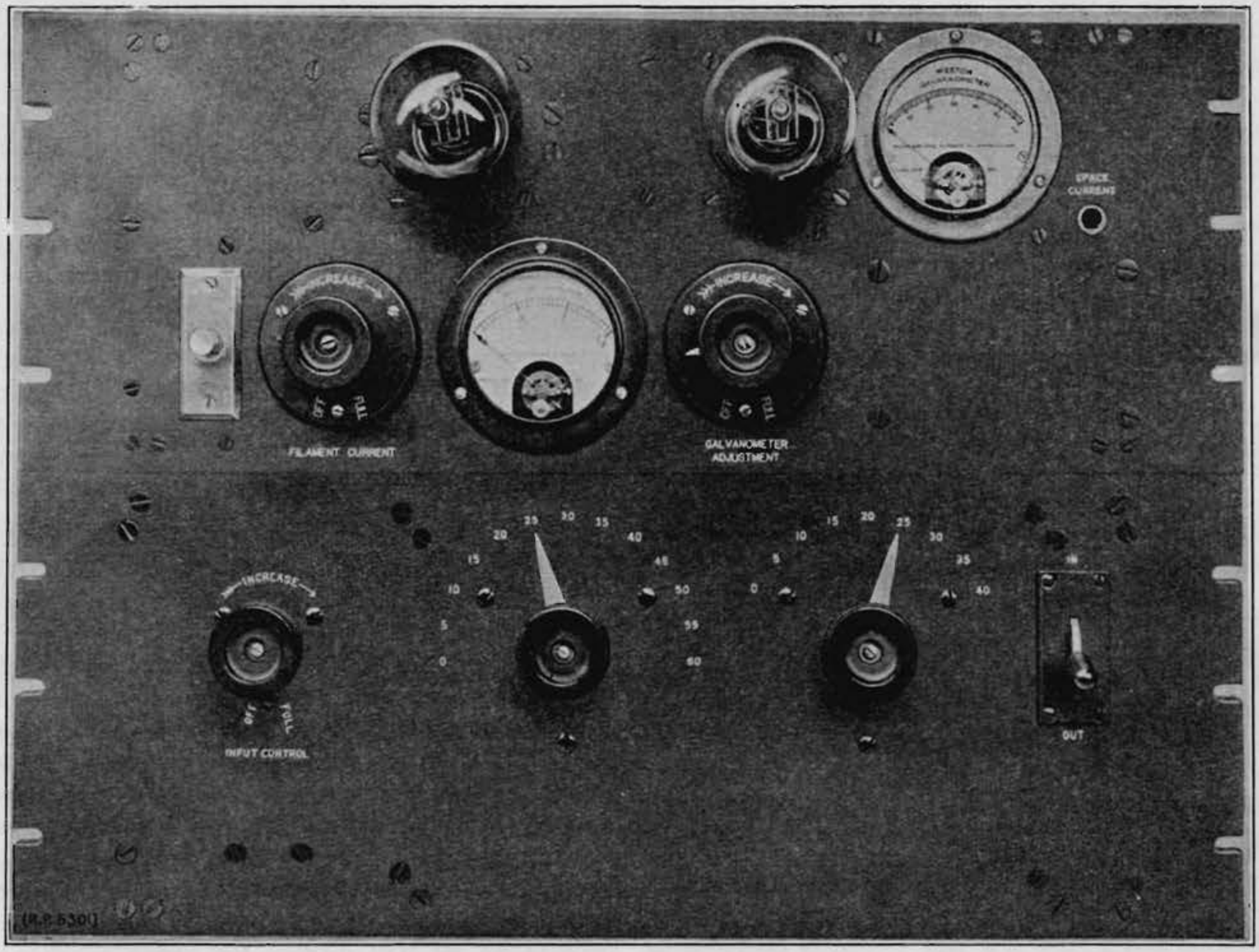

Fig. 33. 2-D Gain Measuring Set

correct value by the factory at the time of test. The resistance R_1 limits the amount of energy fed back to the grid circuit from the plate, and having a value of about 36,000 ohms, makes the impedance looking both ways from the oscillating circuit quite high as compared to the impedance of the oscillating circuit itself. This keeps the oscillator from being susceptible to small changes such as variations in filament or plate battery voltage, or variation in the vacuum tubes used as replacements. The condenser C_1 prevents the plate voltage from reaching the grid. Tube (B) is an amplifier of the 1000 cycle variations in the circuit of tube (A). Its grid is alternating voltage will appear across the secondary terminals of this transformer.

Both oscillator and amplifier tubes are type L (101-D). Their filaments are in series and this circuit also includes a 12 ohm resistance R_3 so that the total resistance of the filament circuit is about 21 ohms. There is no provision for varying the resistance of this circuit and when connected to the office battery at least the rated current of .97 ampere will flow even at 21 volts, the lowest voltage to which this battery is usually allowed to fall. At normal voltage and higher, more current will flow, but this does not affect the frequency or power output of the oscillator appreciably, though it does shorten the life of the tubes somewhat. The condenser C_3 and the retardation coil L_1 prevent the 1000 cycle current in the plate circuits of both tubes from getting into the common 130 volt battery supply and causing cross-talk. A snap switch mounted on the panel is provided for opening or closing the filament circuit.

The oscillator is mounted on a panel adapted to relay rack mounting, size 5 7/32″ wide and 19 3/16″ long. Its rated output is 5 to 10 milliamperes into a circuit having a resistance of 1000 ohms. The condenser across the grid circuit is adjusted at the factory so that the oscillator frequency will be within ± 5% of the rated value of 1000 cycles.

The 6-C oscillator is shown just below the 6-B in Figure 34. An inspection of this schematic will show that the two 101-D vacuum tubes used are both oscillators in a "push-pull" circuit, their grid circuits being coupled through the 71-D retardation coil. Part of the energy in the plate circuit of each of the tubes is fed back to the tuned grid circuit of the tubes through 85970 ohm resistances (R_1 and R_2) which limit this energy and stabilize the circuit as mentioned in the discussion of the 6-B oscillator. The two condensers C_2 and C_3 prevent the plate battery from reaching the grids. The tapped condenser C_1 is adjusted to a value so that together with the inductance of the 71-D retardation coil, it forms a circuit having a natural period of 1000 cycles per second. To work in a push pull circuit, the grid of each tube must, of course, have the same normal voltage with respect to its filament. This grid bias, as it is called, is customarily measured from the negative filament terminal of the tube. In the case of this oscillator the grid bias is obtained by using the voltage across resistances in the filament circuit due to the filament current flowing through them. This current is approximately one ampere and therefore the grid of tube (B) will have a bias of 6 volts due to the drop in R_4 and R_5. The grid of tube (A) will have the same bias, but it is from the drop across R_4 and the filament of tube (B) instead.

As in the 6-B type, the 6-C oscillator has the filaments of the two 101-D vacuum tubes connected in series. In addition to the resistance of the tube filament, this circuit contains resistances R_3, R_4 and R_5 so that its total resistance like that of the 6-B is about 21 ohms and the remarks previously made about filament current variations and control with reference to the 6-B apply equally well to the 6-C.

The general appearance of the 6-C oscillator is much the same as the 6-B. The output circuit is designed to work into an impedance of about 600 ohms and will deliver 12 to 15 milliamperes into such a circuit. Like the 6-B it is factory adjusted to within ± 5% of the rated frequency of 1000 cycles. In addition to their extensive use in connection with gain measuring sets, the 6-B or 6-C oscillators are also often used in connection with small installations of voice frequency ringers to supply the 1000 cycle ringing current needed.

The photograph of the 2-D gain set (Figure 33) shows that it is comprised of two units, the upper one being coded as the 3-A Amplifier and the lower as the 50-D Repeater Gain Unit. The function of the Repeater Gain Unit is to supply a means for comparing the voice frequency current from the oscillator with the same current after it has been amplified by the repeater under test and attenuated by losses in the unit, these losses being adjustable and calibrated. When the portion of the circuit in which the repeater gain occurs has its losses adjusted to exactly offset this gain, the losses, being calibrated, will indicate the gain of the repeater.

A simplified schematic of the 50-D Repeater Gain Unit is shown in Figure 34. At the left is shown a potentiometer controlling the oscillator input to the gain unit. From this INPUT CONTROL the testing current goes through an electrostatically shielded transformer to the gain measuring circuit proper. One portion of this circuit consists of an 1130 ohm resistance "m" shunted by the variable resistance under control of the ½ TU dial, in series with another portion of the circuit shunted by the 5 TU dial, this latter portion containing two artificial lines between which is connected the repeater under test and beyond which is the 1130 ohm resistance "n." The resistances controlled by the ½ TU and 5 TU dial are so proportioned that when the voltage across the two resistances which they shunt ("m" and "n," respectively) are equal, the gain of the repeater under test will be indicated by the dial settings. The artificial lines across the input and output circuits of the repeater under test are for the purpose of matching the gain set with the repeater impedance. An accurate comparison of the voltages across "m" and "n" is essential in the use of this set and to aid in this comparison a quick-acting key IN-OUT is provided which con-

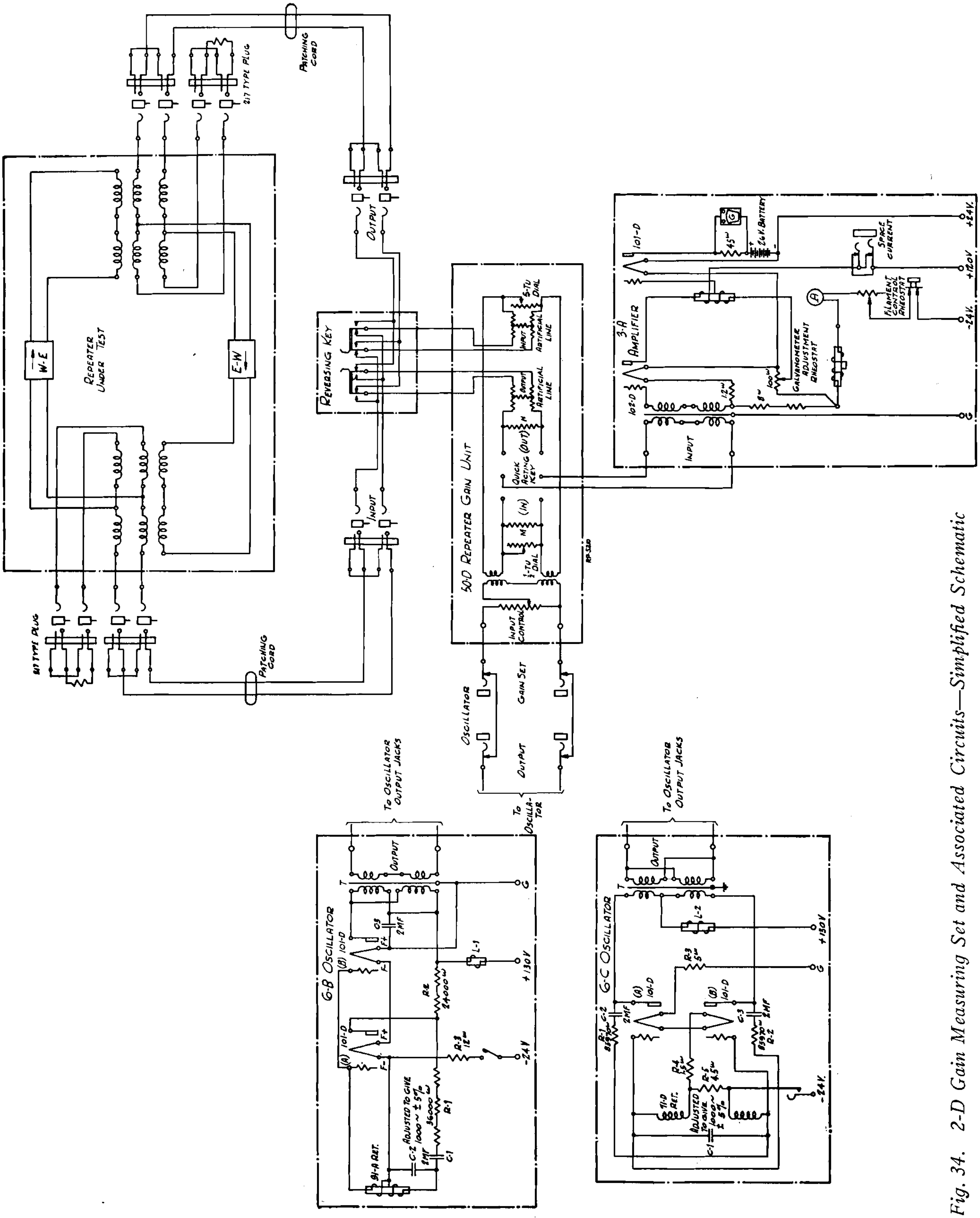

Fig. 34. 2-D Gain Measuring Set and Associated Circuits—Simplified Schematic

nects either to the input of the 3-A amplifier. Reference to the photograph of the 2-D gain set will show the above mentioned controls on the Repeater Gain Unit panel.

The 3-A amplifier is the device which makes possible the accurate comparison of the voltages across "m" and "n." Briefly, this is done by amplifying the voltage impulses in a vacuum tube amplifier, then rectifying these impulses in a second vacuum tube. The rectified current resulting is indicated by a galvanometer in the plate circuit of the latter tube.

A simplified schematic of the 3-A amplifier is shown in Figure 34. The input circuit is through a shielded transformer to the grid of a 102-D vacuum tube. This tube has an amplification factor of 30, so the impulses are considerably amplified, then passed through a coupling transformer to the grid of a 101-D tube. Here the alternating current is rectified and flows from the plate of the tube, through a 45 ohm resistance to a 26 volt B battery contained in a small battery box on the back of the panel. A sensitive galvanometer is connected across this 45 ohm resistance and, therefore, gives an accurate indication of any change in the current flowing through it. Since this current is determined by the voltage applied to the input circuit of the amplifier it follows that identical deflections of the Galvanometer when the IN-OUT key on the Repeater Gain Set is operated shows that the voltages across "m" and "n" must be equal. The proper grid bias for the 102-D tube is obtained by using the drop across a 1.2 ohm resistance. A potentiometer GALVANOMETER ADJUSTMENT controls the grid bias of the 101-D tube and consequently the current normally flowing in the plate circuit of the tube. A filament ammeter and rheostat allow the proper filament current to be maintained. A snap switch is also provided to open the filament circuit. A jack is provided so that the space current of the 102-D tube may be read on a milliammeter when desired. The position and appearance of the various controls may be seen on the photograph of the 2-D Gain Set, the amplifier panel being the upper one shown.

As has been stated before, the 3-A amplifier is used in connection with the Gain Set as an accurate voltage comparing device. It is also sometimes used for checking up on the condition of 101-D tubes by placing them in a repeater and making direct gain measurements with them at various filament currents, this method giving more reliable results than the "5-mil., 1.1 ampere test."

The reversing key shown in the input and output circuits of the repeater under test is for the purpose of reversing these two circuits to the repeater so as to make possible the measurement of the repeater gain in either direction without the necessity of changing the patching cords to the repeater. This key is usually mounted separately in a panel near the Gain Set.

The various units necessary in this complete gain measuring circuit have been discussed individually. Figure 34 shows how they are cabled and patched together to make an actual test. The output of the oscillator (6-B or 6-C) is wired through disconnect jacks "Oscillator Output" and "Gain Set." The first mentioned allow the 1000 cycle output of this oscillator to be patched out for use in some other circuit. The latter allow any other source of alternating current to be used in making the gain test. For instance, a variable frequency oscillator such as the 8-A may be used and the gain measured at a number of different frequencies. From the jacks "Gain Set-In" and "Gain Set-Out" patching cords connect to the input and output circuits of the repeater under test. The regular network may be used to balance the input circuit, but if the networks are not connected up at the time of test or if other conditions make it desirable, a non-inductive resistance across the "Repeater Net" jacks may be used. In this particular case where a 22-A-1 repeater is shown under test, a 600 ohm resistance would be used, a handy form for this purpose being the 217-D plug as shown.

ECHO SUPPRESSORS

Two wire-four wire circuits such as the terminating circuits used in connection with four wire cable circuits depend upon the principle of balance for their proper operation. If this balance is perfect, there will be no energy fed back from the pair used for transmission in one direction to that used for transmission in the opposite direction. If this balance is very poor, so much energy will be fed back that continuous oscillations or "singing" may result and service ruined. Actual operating conditions are, of course, somewhere between these two extremes. It is economically unpractical to manufacture perfectly balanced sets or to supply networks which balance the line exactly, so there is bound to be some feed back between the two oppositely directed circuits.

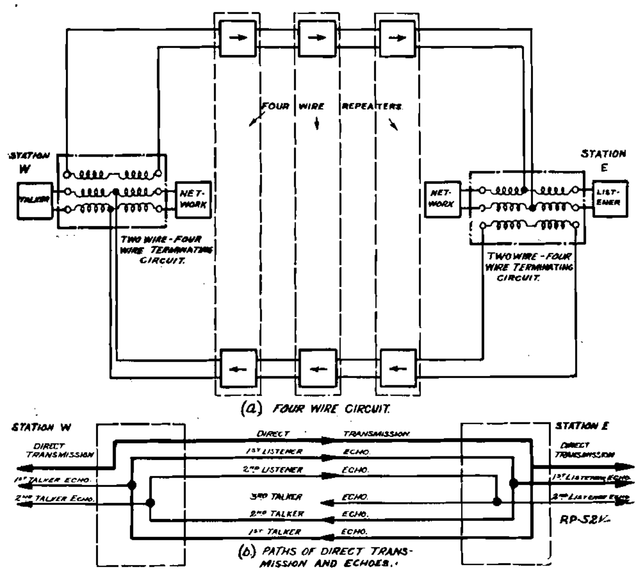

Fig. 35. Echoes in Four Wire Circuit

An example of the effect of this unbalance is shown in Figure 35. A talker at station W will have his voice currents carried to the listener at Station E over one pair of wires, the upper pair in "a" of this figure. Due to the unbalance in the two wire-four wire circuit at Station E, however, some of this direct transmission will be fed into the return circuit—the lower pair—and returned to the talker at station W, where it will appear as a delayed side tone or "echo." Again, due to unbalance in the two wire-four wire circuit at W, part of this "first talker echo" will be fed into the circuit to E, where it will appear as delayed transmission or "listener echo." The unbalance at E again results in part of this "first listener echo" being fed back to W resulting in the "second talker echo" or further delayed side tone, and similarly, part of this latter echo is fed back to E and so on, each echo becoming less than the preceding one until they are of no consequence. Generally speaking, the first two echoes are of an appreciable magnitude. If all our circuits were non-loaded open wire construction, the important talker and listener echoes would occur so soon after direct transmission in circuits of ordinary length, that the talker and listener would not be able to distinguish them from direct transmission. This is because open wire lines have a speed of transmission approaching the velocity of light—186,000 miles per second. In loaded circuits, particularly loaded cable circuits, the speed of transmission departs considerably from this value as will be seen below.

These values for any other type of circuit may be calculated from the approximate formula $V = \frac{1}{\sqrt{LC}}$, where V is the velocity of propagation in miles per second, L is the inductance per mile, and C the capacity per mile, in henries and farads, respectively.

It will be seen that in cable circuits the speed of transmission is comparatively very low indeed. Since it is in cable circuits that the four wire system is used, here is where our greatest trouble from echoes will be experienced. Since, at any given instant, transmission is required in only one direction, the obvious solution to the problem lies in blocking transmission in the opposite direction, thus preventing the first talker echo—and, therefore, all subsequent ones—from ever being effective. This is exactly the idea and function of the echo suppressor.

Figure 36 shows in simplified diagrammatic form an Echo Suppressor applied to a four wire circuit. The equipment represented by the two blocks E-W and W-E in this portion of Figure 36 will be discussed in more detail later. For the present it is

Type of Circuit	Time in Seconds for Current to Travel 1000 Miles	Miles Current Will Travel in 1 Second (V)	Ratio of Speed of Transmission of Circuit to Velocity of Light
Non-Loaded Open Wire	.0057	175 000	.942
Loaded " "	.018	55,500	.298
Extra Light Loaded Cable	.05	20,000	.108
Medium Heavy " "	.10	10,000	.054
Heavy " "	.12	8,350	.045

sufficient to explain that they comprise two similar high-impedance vacuum tube amplifier-detectors bridged across the two sides of the four wire circuit, each amplifier-detector having associated with it a relay which operates whenever alternating voltage of sufficient strength is impressed across the input. The operation of either relay places a short circuit across the side of the four wire circuit opposite to the one to which the input of its particular amplifier-detector is connected. This short circuit blocks the transmission in one side of the four wire circuit and at the same time renders the other amplifier-detector inoperative.

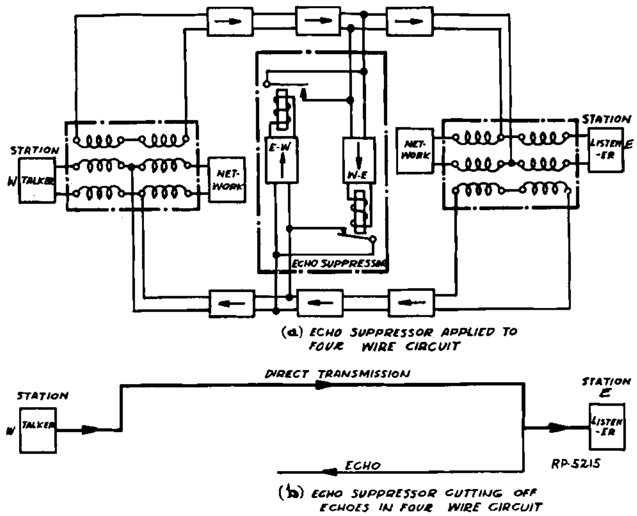

Fig. 36. Suppression of Echoes in Four Wire Circuit

Normally, of course, both relays are open, ready for signals in either direction. As soon as W begins to talk, the voice currents flowing in the W-E (upper) channel cause a short circuit to be applied to the E-W channel—the condition shown in this figure. The direct transmission from W to E, of course, is not appreciably affected since the echo suppressor input is of high impedance. The echo, however, traveling back on the E-W (lower) pair is stopped by the short circuit applied by the W-E suppressor. When W pauses in his speech, the blocking relay drops back and the circuit is then ready for E to reply if he wishes, or else W can continue. If E replies, circuit arrangements similar to the above cause the direct transmission in the E-W pair to be unaffected, while the W-E pair is short circuited.

A summary of the fundamental operating conditions which the echo suppressor must meet is: When no one is talking the circuit must be ready for transmission in either direction and each suppressing relay must operate promptly as soon as speech passes in its input circuit. So long as this speech continues, this relay should remain operated, not only blocking transmission in the opposite direction, but also preventing operation of the other half of the suppressor due either to the returning echo which might be powerful enough to operate it, or to an interruption by the listener. Also, since an appreciable time may elapse between the passage of the directly transmitted signal across the input to one-half of the suppressor and the arrival of the resulting echo across the oppositely directed circuit, this relay should remain operated long enough to block the echo from the last sound transmitted, but not long enough to interfere with the reply from the opposite end of the circuit.

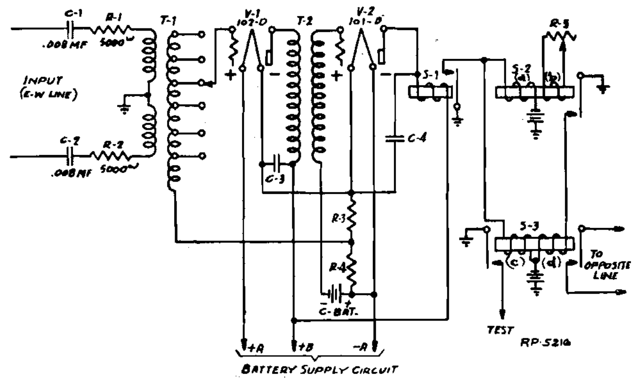

Fig. 37. One-Half of a Four Wire Echo Suppressor Simplified Schematic

That the first two conditions—preparedness for initial transmission in either direction, and the operation of one-half of the suppressor preventing the operation of the opposite half—are met, may be most easily seen from Figure 36. The latter one—holding over of the short circuiting relay—will be discussed in connection with Figure 37, which is a simplified schematic of the circuit of one-half of a four wire echo suppressor. The input circuit includes two low capacity condensers, C_1 and C_2, two 5000 ohm resistances, R_1 and R_2 and the primary of T_1—a circuit of such high impedance that, although it is directly across the transmission circuit, it causes no appreciable loss. The circuit is balanced to ground as shown. The secondary of T_1 is tapped to afford gain control over the amplifier-detector circuit, and feeds into V_1, a 102-D vacuum tube working as a voltage amplifier. This tube, having an amplification factor of 30, considerably increases the amplitude of the signal from the line, then passes it on through T_2 to V_2, a 101-D vacuum tube acting as a detector. Here the signal is rectified and the resulting direct current operates the relay S_1. The condensers C_3 and C_4 bypass to the filament circuit any undesirable AC or fluctuating DC reaching these points. The operation of S_1 causes the operation of S_2 through winding (a) and S_3 through winding (c) as shown. A second winding (b) on S_2 has its circuit completed through an adjustable resistance R_5. When voice currents in the direct transmission circuits cease and the relay S_1 releases, the collapse of the magnetic field in winding (a) of S_2 induces a voltage in winding (b). The resulting current can flow only through R_5 and as soon as it has died down, relay S_2 will then release, allowing S_3—which it controls through winding (d)—to also release. R_5 being adjustable, the time for the current in winding (b) to die out may thus be varied, giving the adjustable relay hold-over feature necessary for use in different types and lengths of lines.

The operation of S_3 closes two contacts, the one on the right in this diagram short circuiting the oppositely directed line to which the input circuit of this half of the suppressor is connected. The other contact goes to a testing circuit. The grid bias of V_1 is obtained by utilizing part of the drop across the filament of V_2 by means of R_3 and R_4.

The grid bias of the detector tube V_2 is maintained at a very negative value by the C battery shown so the plate current in this tube when no signal is being received is practically zero. The positive portion of the greatly amplified signals will overcome this bias under normal operation, thus causing a comparatively large change in plate current in V_2, resulting in reliable operation of the relay S_1.

Testing equipment which is part of each echo suppressor installation allows convenient checks of the various portions of the suppressor circuit to be made. These tests fall into five groups—current and voltage tests, vacuum tube tests, relay adjustment tests, sensitivity tests, and timing tests. The vacuum tube equipment and circuits of an echo suppressor are very similar to those of the 44-A-1 repeaters with which they are usually associated. Much the same means for making the current and voltage tests are therefore used in the two. The stability and activity of the vacuum tubes used may be tested by an arrangement whereby the plate current is measured at varying filament currents and with known input to the grid circuit. For checking the relay adjustment, the input from a 1000 cycle test oscillator to the echo suppressor is set to a certain value of plate current in V_2 at which the relay S_1 should release and the relay so adjusted, the oscillator input is then set to give the operate value of plate current from V_2 and the relay adjusted to this condition. The sensitivity of the amplifier-detector circuit of the echo suppressor is measured by means of a regular transmission measuring set. The time required for operation and release is determined by having the relay S_3 short circuit a 1000 cycle input to the suppressor. The cycle of operations of this circuit will then be: operation of relay S_3 due to 1000 cycle input; short circuit of 1000 cycle input; continuance of short circuit due to hold over circuit of S_2; release of S_2 and S_3, and repeat. This cycle of operation is allowed to continue for a certain time, the number of cycles in that time being indicated by the position of a stepping selector circuit connected to the relay circuit. The operating lag being small compared to the hold over time, the above time divided by the indicated cycles is usually considered as the hold over time unless quite accurate results are required when a different arrangement can be used.

It may already have occurred to the reader that the terminating circuit of a four wire system is not the only place where two wire-four wire circuits are used. They occur much more frequently in fact in two wire circuits equipped with repeaters, since the two output transformers in each repeater are nothing more nor less than two wire-four wire circuits. Unavoidable unbalance will exist and therefore echoes will occur just as in a four wire circuit. However, two wire circuits are usually of open wire construction and consequently have a much greater speed of transmission than do the cable circuits in which four wire operation is used. Still, on very long two wire circuits it is just as desirable to suppress echo effects, and a type of suppressor for application to two wire circuits will in all probability be developed whenever the number of long two wire circuits warrants.

Another circuit variation in which the echo suppressor is used occurs when, on long circuits, a portion of the circuit is two wire and the rest four wire. In such a case the present type of suppressor may be installed for operation in the four wire portion of the circuit and will then, of course, eliminate

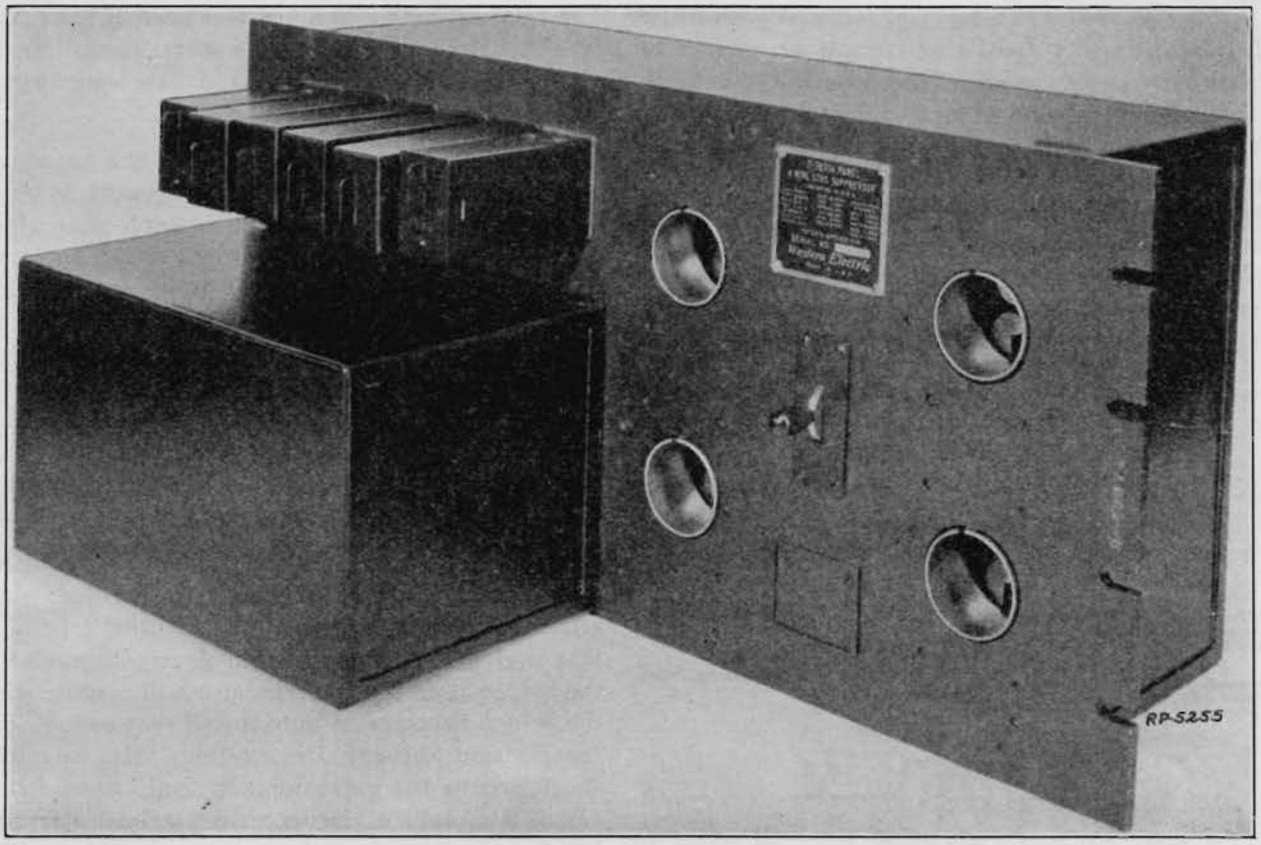

Fig. 38. Echo Suppressor (553-A Panel)

echo effects from beyond the suppressor whether they be due to the two wire or four wire portions of the circuit.

The beneficial results which may be expected from a given echo suppressor installation will depend on the individual case. On very noisy circuits it may be necessary to so reduce the sensitivity to prevent false operation, that an installation may not pay. However, it will be remembered that cable circuits whose low speed of transmission make suppressors most desirable are inherently quiet. As a typical example it was found that on a 1500 mile extra light loaded circuit, the loss in the circuit could be reduced by 7 TU when the echo effects were eliminated by the installation of an echo suppressor.

PILOT WIRE REGULATING SYSTEM

Natural changes in temperature between day and night cause corresponding changes in telephone circuits exposed to these changes, particularly as to their resistance. These changes are especially great, of course, in small gauge aerial cable circuits and where such circuits are of any considerable length these changes must be compensated for if uniform service is to be maintained. Where attention is required by a number of such circuits, as would be the case with an aerial cable, an automatic means for maintaining nearly constant circuit equivalents becomes very desirable. The transmission regulating equipment about to be described is designed to meet this need. As suggested by its name, regulation is accomplished by using changes in a "pilot wire" circuit to govern changes in all the parallel circuits to be regulated.

In applying this system the whole circuit is divided into Regulator Sections, usually from 100 to 200 miles long. At a repeater station somewhere near the center of each of these sections is installed a device known as a "Pilot Wire Regulator." It controls loss networks associated with the repeater in each circuit in the cable or cables in a given Regulator Section. The Regulator is arranged to operate a train of relays which will cut in or out, losses approximately equal to the variations in the circuit.

Figure 39 shows in simplified schematic form the Regulator and its associated circuits as applied to a four wire cable circuit. The device is essentially a galvanometer connected to indicate changes in the DC resistance of a "Pilot Wire Circuit," a special two-wire circuit extending from one end of the Regulator Section to the other, and used only for regulating purposes. The Pilot Wire Circuit will, of course, experience the same temperature and consequent resistance changes as the circuits to be regulated, so the deflections on the galva-

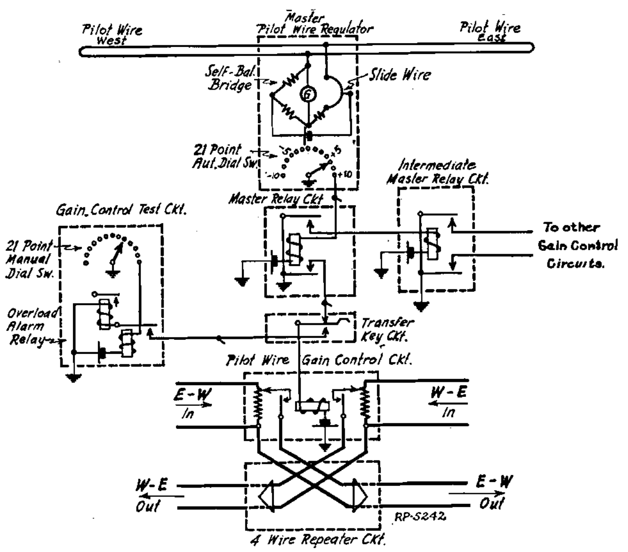

Fig. 39. Pilot Wire Regulating System—Simplified Schematic

nometer will be proportional to variations in these circuits. The galvanometer is arranged so that its deflections will operate a 21 point dial switch, the center point connecting the normal gain of the regulating repeater in the circuit by means of a Master Relay Circuit, and the ten points on either side of this center point allowing this number of steps of increased or decreased gain. It is by means of this Master Relay Circuit, and intermediate relays as needed, that all the parallel circuits in the Regulator Section are controlled by the one Regulator.

The relay circuits also allow this system to be used on either the four wire circuits where potentiometer type gain control is used, or on two wire circuits where the control is by networks.

In medium heavy loaded circuits the maximum loss introduced by the regulating network is about 11 TU and the arrangement is such that about 6 TU loss is normally in the circuit. The operation of the dial switch by the galvanometer will then insert 5 TU more or remove the original 5 as required, the changes being in steps of ½ TU. In extra light loaded circuits, similar arrangements provide for the insertion or removal of 10 TU in steps of 1 TU. These ranges are sufficient to take care of the widest transmission equivalent variation usually experienced in these circuits.

To protect various delicate parts of the regulator, alarm and protective circuits are provided which attract the repeater attendant's attention when certain trouble conditions occur. A sensitive relay in the bridge circuit of the regulator will operate when the bridge becomes so unbalanced that enough current is sent through its windings. Its operation short circuits the galavanometer and operates both visual and audible alarms. An overload alarm relay is operated when the regulator reaches either its maximum or minimum step, giving an audible alarm. Another relay circuit operates to indicate failure of the power supply.

To insure continuity of service in the case of trouble in the automatic gain regulating circuit, and to allow testing of this circuit, a manually operated dial switch is provided to which control of the regulator circuit may be transferred by operation of the "Transfer Key" circuit.

The present pilot wire regulating system is applicable to either two wire or four wire No. 19 gauge cable circuits equipped with telephone repeaters. Variations in the loss networks and the relay circuits controlling them allow its use on these types of circuits with various loadings.

SECTION 3

SUPERIMPOSED CIRCUITS

GENERAL

The desirability as well as the possibility of using the same physical circuit for simultaneously transmitting several non-interfering messages was realized many years ago In fact it was through certain experiments in Multiplex Telegraphy that Bell conceived the idea which resulted in the invention of the telephone. By the use of the "phantom circuit" it is possible to transmit three telephone messages over two pairs of wires. By the use of a similar scheme a "simplex" circuit will provide an additional telegraph channel over a pair of wires used for a telephone circuit. "Compositing" will give a telegraph circuit for each wire already in use for telephone communication. A considerable number of either telegraph or telephone messages may be simultaneously superimposed on a single pair of wires by means of high frequency "carrier currents." A number of these various arrangements may also be used on the same pair of wires. For instance, it is quite common practice to have two pairs of wires provide three telephone channels (two side circuits, one phantom), and four telegraph channels (composite legs) as well as a system of carrier telegraph (ten channels) or telephone (three channels) on either or both pairs. Phantom, simplex and composite arrangements fall into one group, being merely special circuit arrangements, while carrier current involves some new principles in its operation. The first mentioned will be briefly discussed here. It is planned later to issue a pamphlet similar to the present one on carrier current circuits.

PHANTOM CIRCUIT

In Figure 40 is shown a simple schematic of a phantom circuit. The two original circuits are shown as lines 1 and 2. When two otherwise independent circuits are used to obtain a phantom circuit, they are usually called "side circuits." The phantom circuit is obtained by connecting to the center point of the secondaries of the repeating coils of the two side circuits. The path of a signal from the W to the E terminal of the phantom circuit is shown by heavy arrows in Figure 40, while light arrows indicate the path of a W-E signal in side circuit No. 1. Suppose at a given instant that a signal is traveling in the phantom circuit from W to E. It will go to the center point of the secondary of the repeating coil in side circuit No. 1 where it divides equally, half flowing through the repeating coil in one direction, and half in the opposite direction. The two voltages thus induced are therefore equal in value and opposite in sign and neutralize each other and do not affect the side circuit. The signal having divided equally flows in the same direction over the two wires forming side circuit No. 1 to the repeating coil at the E end of the side circuit where it passes to the center point of this coil and on to the E terminal of the phantom circuit. The return path for the signal exists in side circuit No. 2 through the connections shown. It is, of course, absolutely necessary to preserve the balance between the two wires forming each side circuit if cross-talk between phantom and side circuits is to be avoided. If this balance is not preserved, more current from the phantom circuit will flow through one of the side circuit wires than the other, inducing a greater voltage in one-half of the secondary of the side circuit repeating coil than in the other, thus causing cross-talk.

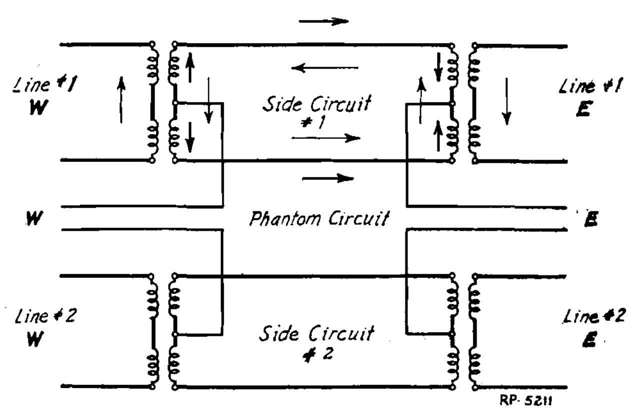

Fig. 40. Phantom Circuit—Simplified Schematic

So long as this balance is maintained, however, we have secured a third telephone channel, using but little more equipment than before. Furthermore, this channel has even better transmission characteristics than the two side circuits since it has twice as much copper in its circuit.

Theoretically it is perfectly possible to phantom two phantom circuits just as the two side circuits are themselves phantomed. This "double phantom" or "ghost" is usually found undesirable, however, because of the practical difficulty in maintaining the necessary balance in the eight wires involved.

If the pairs in a cable are designed for phantom use the cable is of a special construction and called a "quadded" cable. The two wires of the side circuits are first twisted together into pairs—one pair being given one length of twist and the other pair a different length of twist. These pairs are then themselves twisted together into "quads," using a still different length of twist. The purpose is, of course, to have each wire occupy alternately every possible position with respect to all other wires, thus preventing cross-talk. Were this not done, cross-talk would be very severe because of the close proximity of the wires throughout the length of the cable.

Phantom circuits are treated very much like side circuits. They may be loaded as desired, terminated at intermediate points if necessary, and are brought out to regular jacks on the toll switchboard and toll test board. The use of a pair of wires as the side circuit of a phantom causes a slight increase in resistance of the side circuit due to the phantom coils introduced (and phantom loading coils, if used), but this loss in efficiency is a comparatively slight disadvantage when the gain of the extra circuit is considered.

SIMPLEX CIRCUIT

The simplified schematic of a simplex circuit is shown in Figure 41. Such a circuit provides an additional telegraph channel using a phantom circuit arrangement on a pair of wires for one side of the circuit, with usually a ground return. If the line wires and the line windings of the phantom repeating coils are balanced, it is evident that the telephone and telegraph signals will pass over the line without interfering with each other.

The circuit, though very simple, is not widely used as by arrangements to be next described, a greater number of telegraph channels can be obtained over the same number of wires.

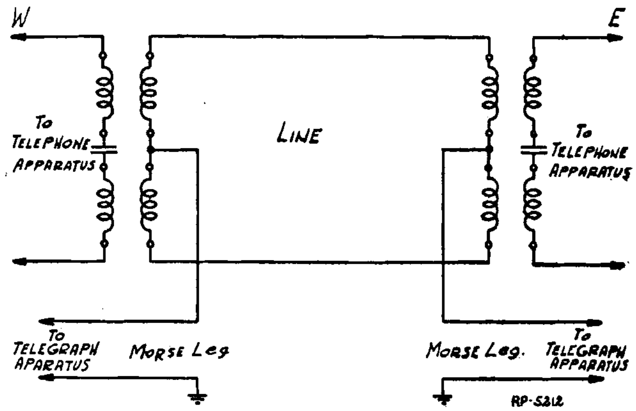

Fig. 41. Simplex Circuit—Simplified Schematic

COMPOSITE CIRCUIT

Since telegraph operation involves frequencies of from zero to approximately eighty cycles per second while the voice frequencies are above two hundred, the two groups of frequencies may be sent over the same circuit if provision is made for properly separating them at the receiving end. Figure 42 shows in simplified schematic form a typical composite set. Such a circuit arrangement provides an independent telegraph channel (usually called a "Morse leg") over each wire of the pair shown, without interference with the regular telephone channel.

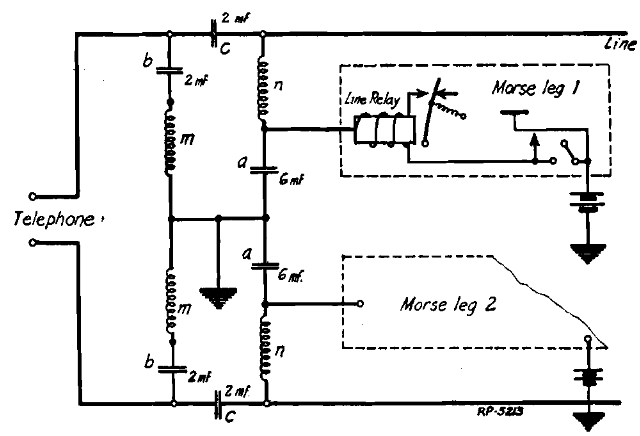

Fig. 42. Composite Circuit—Simplified Schematic

In order to show the operation of this circuit, suppose we were sending over Morse Leg No. 1. Operation of the telegraph key shown makes and breaks the telegraph battery circuit causing a series of interrupted DC signals to flow through the

Morse line relay and the retardation coil "n" on the line and so to the other terminal of the circuit where the signals are received by an exactly similar arrangement, the circuit being completed through ground. The Morse line relay at the sending end actuates the local sounder so the operator can hear his own signals. In going through this relay, and particularly through the retardation coil "n," the abrupt wave front of the signals is very much smoothed out. The condenser at "a" is of large capacity (about 6 mf.) and so acts to prevent very sudden changes of current by providing a path to ground. This smoothing out of the telegraph signals is necessary to prevent a sharp click ("Morse thump") from being heard in the telephone receiver associated with this line. If this were not done, the two telegraph channels operating on the two wires of a telephone channel would cause so much noise in the receiver as to make communication difficult or impossible. The condensers at "c" are obviously for preventing the DC telegraph impulses from getting into the telephone circuit. The telephone signals being AC of fairly high frequency have no difficulty in passing through these condensers and so out on the line. The inductance of coils "m" and "n" prevent these signals from reaching ground through the composite set.

To reduce the momentary signals known as "cross-fire" which pass from one telegraph branch to the other through the telephone branches, and to reduce the effect of these impulses upon signaling apparatus, each telephone branch of the composite set is connected directly to ground through the inductance "m," the condenser "b" preventing this ground from interfering with the proper operation of direct current supervisory signals in the telephone cord circuits or trunks.

To prevent cross-talk between a phantom circuit and its side circuits when the latter are composited, it is necessary that the composite sets introduce no inductance and capacity unbalance in the side circuits. For this reason the coils and condensers in a composite set are selected to meet very close limits. Either side circuits or phantom circuits may be composited, but, of course, if one side circuit of the phantom is to be composited, both side circuits must be composited to maintain balance, even though there is no immediate need for all four of the telegraph circuits so provided.

QUESTIONS

The following list of questions is supplied to the readers as a guide to what may be considered the important points in the description of this equipment. The answers to some will be found concisely stated in a single sentence or paragraph, while others will require a digest of several paragraphs. It is suggested that the reader test the completeness of the information gained from reading this pamphlet by answering each question and then referring to the text to see if the answers are correct.

Answers to these questions should not be sent in unless specifically requested.

(1) What is the function of a telephone repeater?

(2) Draw a simplified schematic of a 22-A-1 repeater showing as much detail as your interest in toll equipment warrants but in no case omitting the detailed connections to the output transformer (hybrid coil). Compare with Figure 6-b.

(3) Give a brief description of the functions of the equipment shown in your schematic.

(4) What is the function of the line balancing network?

(5) Why are filters used in two-wire repeaters?

(6) What limits the gain obtainable with a two-wire repeater?

(7) Draw a simplified schematic of a Four-wire Repeater System showing where the two-wire lines are changed to a four-wire line at the terminating circuits and showing as blocks two terminal and two thru line repeaters. Compare with Figure 14.

(8) What is an intermediate ringer? Where is it used?

(9) What is a terminal ringer?

(10) What is the principal advantage of the Voice Frequency Signaling System as compared with 20 and 135 Cycle Systems?

(11) What is an echo in a telephone circuit?

(12) What is the function of a pilot wire regulator?

(13) Outline briefly the functions of the 50-D Repeater Gain Unit.

(14) Make a simplified sketch showing the repeating coil arrangement which permits three voice circuits to be carried on two pairs of wires.

Indicate at the terminals which of the circuits is the phantom. Compare with Figure 40.

(15) What is a composite circuit?