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Electrical Tests and Their Applications in the Maintenance of Telephone Transmission

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Introduction

THE installation and maintenance of the circuits in a telephone plant employed for the transmission of speech require the use of various testing schemes to insure a high grade of commercial service. Circuits are engineered and installed to meet the established standards of transmission in the most economical manner and this having been done the next step is to provide an adequate testing program. A number of the electrical tests required in this program include well known laboratory methods adapted so that they can be readily applied in the field, while others have been developed for particular use in telephone maintenance work.

Standard types of test boards and portable testing arrangements are as a rule made up of simple circuits designed electrically and mechanically in a manner to facilitate ready connection to the operating circuits in the plant. It has been found by experience that many of the transmission maintenance requirements can be taken care of by direct current testing methods and the simpler alternating current tests. With the advent of vacuum tubes, some of the more complex circuits such as repeaters and carrier called for the development of testing apparatus to meet the additional maintenance requirements. Fortunately, the vacuum tube furnished the means whereby new testing devices have been provided which can be applied as quickly and readily to maintenance work as the simpler methods.

In what follows is given a discussion of the more important electrical testing methods together with the application of these methods in maintaining the transmission efficiency of the various types of telephone circuits now in general use. Direct current testing methods are covered first and later alternating current methods are considered. A typical toll connection is used to illustrate the general scheme of applying the various electrical tests in everyday installation and maintenance work.

Direct Current Tests

The tests involving the use of direct currents and voltages provide means for checking some of the electrical characteristics of telephone circuits and insuring to a certain extent that these circuits will give satisfactory speech transmission. The application of these tests to the telephone plant reduces to a minimum the amount of alternating current testing required and lengthens the interval at which alternating current tests need be made.

Wheatstone Bridge Measurements. The various arrangements of the Wheatstone bridge for direct current measurements and the principles involved are well known and are therefore not discussed in any detail in this paper. However, due to the importance of such measurements in the maintenance of telephone circuits and in trouble location work a brief discussion of the general applications of the bridge is given.

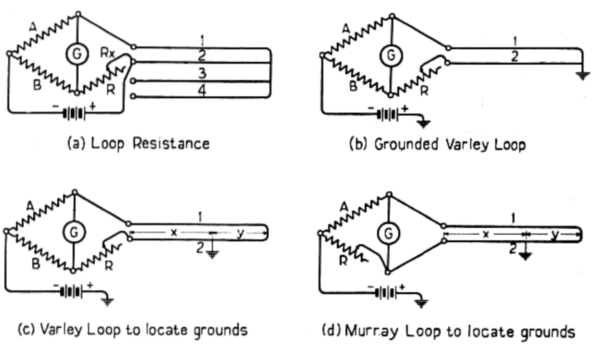


Fig. 1

Fig. 1 shows four arrangements commonly employed in routine testing and trouble location. Diagram (a) of this figure gives the bridge circuit for obtaining loop and single wire resistance measurements. Diagram (b) shows the circuit for Varley loop measurements to determine resistance unbalances in a pair when a third wire is not available, while Diagrams (c) and (d) show the Varley and Murray bridge circuits used in locating grounds. Various other arrangements of the bridge circuit are, of course, used where such arrangements will facilitate the testing work. For a condition of bridge balance indicated by no deflection of the galvanometer the value of the resistance being measured is given by the well known bridge ratio formulae. In diagram (a) of Fig. 1, for example, $R_x = \frac{A}{B} R$.

The testing circuits shown in Fig. 1 are commonly used in the day by day maintenance of the telephone plant. Resistance and resistance balance measurements are made periodically on toll circuits to guard against series resistance unbalances such as might be caused by high resistance joints. The Varley and Murray tests are constantly employed in directing linemen in clearing trouble such as crosses and grounds. The Wheatstone bridge is therefore an important feature of toll test boards where keys are provided to furnish a means for quickly setting up the different bridge test circuit arrangements desired.

The Varley or Murray tests used in connection with pole line diagrams in locating troubles provide a means whereby the test board men can direct the movements of linemen to the best advantage. Unit resistance values with temperature corrections are available for different types of circuits. If a good circuit of the same type and gauge over the same route is available, the unit resistance can be determined directly by a loop measurement of this circuit. The resistance values obtained by measurements on circuits having crosses or grounds can then be used to determine the distance to the trouble and the lineman sent to this point. By making measurements carefully and using the most accurate unit resistances available, troubles can be located and cleared in the minimum amount of time. In trouble location work on cables where the cable needs to be opened to repair the trouble, bridge measurements are made to give the approximate distance to the fault. More exact locations can then often be made by using an exploring coil test set by means of which the cable repairman listens by induction to a tone sent out from the cable terminal and determines in this way when he passes the point of trouble.

Leakage or Insulation Resistance Measurements. An important factor in the maintenance of telephone circuits is to insure that there are no resistance leaks between conductors or between conductors and ground. It is also important to insure that insulated conductors will not have the insulation broken down by the voltages which are met with under service conditions. Two types of tests now used extensively in the plant are described below:

(1) *Voltmeter Method.* This method is the one commonly used in determining the leakage between wires and to ground particularly on toll circuits involving open wire and on subscribers' circuits. As shown in Fig. 2 the testing arrangement consists of a voltmeter in series with a battery connected to the conductors under test. Diagram (a) shows the connection for testing the leakage between wires and

Diagram (b) the connection for ground leakage tests. Since the leakage resistance measured is relatively high, the most accurate results are obtained by using a high resistance voltmeter and a fairly high test voltage. In practice, a 100,000-ohm voltmeter is generally used with a test battery of from 100 to 150 volts. A test voltage of 200 is also provided in circuit with a milli-ammeter and protective resistance for use in checking the strength of insulation of central office wiring and subscriber's lines.

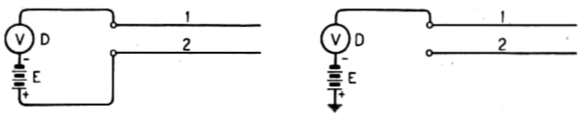


Fig. 2

Considering the circuits shown in Fig. 2, the voltage of the battery E is equal to the IR drop over the voltmeter plus the IR drop or the drop due to leakage over the remainder of the circuit back to the battery. Designating the insulation resistance being measured by X, the voltage of the test battery by E, the deflection in volts of the 100,000-ohm voltmeter by D and the current flowing by I, then

$$E = D + XI,$$

$$D = 100{,}000\ I,$$

and

$$X = 100{,}000 \left(\frac{E-D}{D}\right).$$

In practice, tables are provided from which the insulation resistance or leakage can be read directly for various deflections of the voltmeter. When expressed in terms of insulation resistance, the most convenient unit of measurement is the megohm. If expressed in terms of leakage, the unit used is a reciprocal function of the megohm known as the milli-micromho. The results of measurements for complete circuits are generally reduced to apply to a unit length of circuit such as a mile so that the testing results on circuits of different lengths will be comparable.

The open wire toll circuits in the telephone plant are tested periodically by the method just described. The leakage of circuits is materially increased by defective or broken insulators and by contact of the wires with foreign objects such as trees, particularly under damp weather conditions. Troubles of this kind are detected by careful leakage measurements and routine tests, therefore, become very useful in indicating when remedial measures, such as line inspections and tree trimming work, should be undertaken.

If open wire telephone circuits are so situated that contact with foliage growth will occur during the growing season low values of insulation resistance are certain to result even under dry weather conditions. This is illustrated by the curve of Fig. 3 which shows

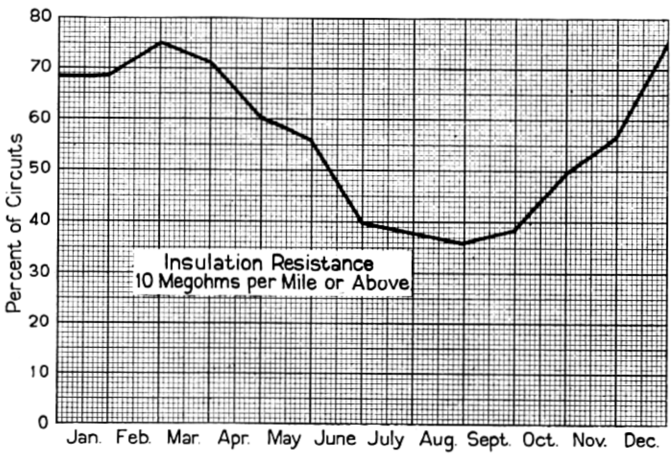


Fig. 3

results of monthly day time dry weather insulation measurements on a number of toll circuits over a period of a year under conditions of this kind. The monthly testing periods are plotted as the abscissa while the ordinates show the percentage of circuits which measure 10 megohms per mile or more during these monthly testing periods. This curve indicates the need for periodic insulation resistance tests and the use which can be made of such tests in instigating clean-up work.

(2) *Megger Method.* The voltmeter method is not applicable for accurately testing the higher values of insulation resistance such as are encountered in telephone cables. Conductors in cables require a very high insulation and in practice values of 500 megohms or more per mile are specified. The laboratory galvanometer method of testing very high resistances, which is the same in principle as the voltmeter method, can, of course, be used, but is not sufficiently rugged for field testing. To take care of cable testing work in the plant a method known as the Megger method is employed. Fig. 4 gives the

schematic circuit arrangement of the "Evershed" megger which is the commercial form of instrument now used for this work. This circuit is contained in a small portable box so that it can be readily used at office frames or carried out on the line.

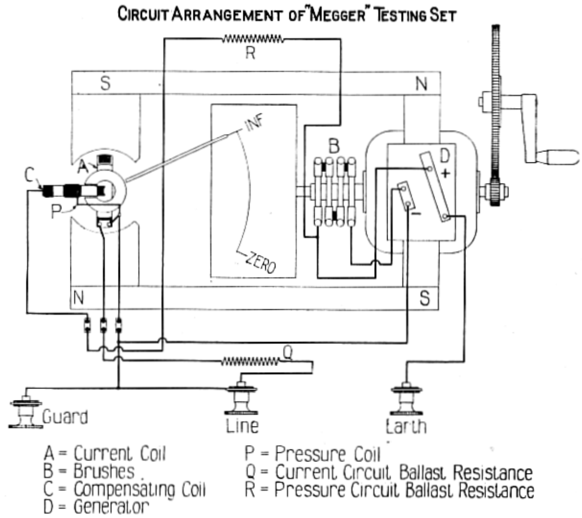


Fig. 4

The circuit of Fig. 4 consists of a high potential direct current generator, hand driven by means of a crank handle. This generator is arranged to provide a maximum potential of 400 volts which is the potential now employed in measuring insulation resistance on cable conductors. The potential furnished by the generator is impressed on two coils in an indicating device, one of these coils being in series with a fixed resistance and the other in series with the circuit under test. When the circuit under test is not connected to the megger the full current from the generator flows thru the first coil of the indicating device which for this condition causes the pointer to go to the "Infinite" position. When a circuit is connected to the megger "Line" and "Earth" terminals some current flows through this circuit due to its leakage and through the second coil of the indicating device. This causes the indicating device to move the pointer toward the "Zero" position, the amount of the movement depending on the leakage in the circuit under test. The indicating device is calibrated in megohms so that the results of insulation tests can be read directly.

Current Flow and Voltage Measurements. Tests to determine the amount of direct current flowing in telephone circuits involve the simple arrangement of an ammeter or milli-ammeter in series with a d.c. generator or battery and the circuit under test. The amount of current flowing is, of course, a function of the resistance of the circuit and the voltage applied. In testing arrangements where it is neces-

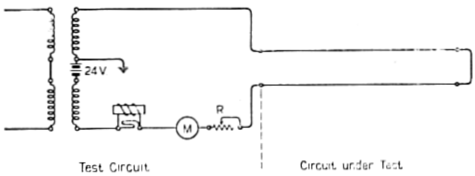


Fig. 5

sary to know the battery or generator potential, voltage readings are made by using ordinary voltmeters having the proper range and resistance. Direct current and voltage measurements can best be described by considering two of their applications in the telephone plant.

Fig. 5 shows a simple test circuit provided in the local test desk whereby central office battery is supplied through a regulating rheostat, a standard cord circuit and a meter. Knowing the voltage of the central office battery and the resistance in the test circuit, the reading of the meter when circuits such as a subscriber's loop or trunk conductors are connected and shorted at the distant end gives a means for determining the direct current resistance of these. Tables are generally provided for use at the test desks by means of which different readings of the meter for different conditions of measurement can be converted directly into resistance values. The rheostat in the test circuit is provided primarily for adjusting the current supplied to subscribers' loops and instruments to the same value for different lengths of loop. Talking tests as mentioned later in connection with substation maintenance can then be made from the instruments to the test man in the central office under the same current supply conditions for different lengths of loop at the time substations are installed or when these are reported in trouble. The arrangement shown in Fig. 5 is useful in detecting high resistances in circuits when a Wheatstone bridge is not available. High resistances in the main frame protector springs and heat coils of both subscribers' lines and toll circuits are also determined by a current flow method, a special portable testing set, however, being designed particularly for this purpose.

Direct currents and voltages are very important factors in the operation and maintenance of amplifier circuits such as telephone repeater and carrier apparatus. The battery supply arrangements for a single tube amplifier are shown in Fig. 6.

It is necessary in order to insure efficient amplification without distortion to regulate the currents and voltages to fairly close limits. In practice provision is made for quickly reading the voltages of grid, filament and plate batteries as shown by the voltmeter connection (V) in the figure. The plate current is read by the milli-ammeter M and the filament current by the ammeter A. The filament current

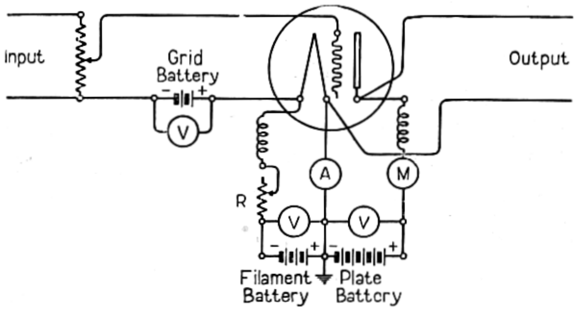


Fig. 6

is regulated to meet the operating limits by cutting resistance in or out of the circuit with the rheostat R. The same applications of current and voltage readings apply to the more complicated amplifier circuits, although wherever practicable automatic regulating devices are provided which reduce the amount of manual testing work to a minimum.

Capacity Measurements. There is little occasion in transmission maintenance work to make accurate direct current measurements of capacity. A simple d.c. test, however, has been provided for use primarily on subscribers' loops for checking the condensers in the sets.

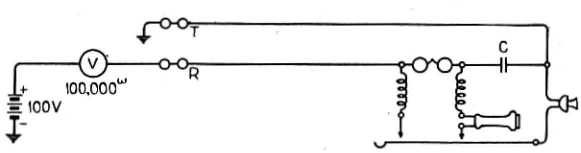


Fig. 7

As shown in Fig. 7 the circuit consists of a 100,000-ohm voltmeter in series with a grounded 100-volt battery connected to one conductor of a subscribers' loop, the other conductor of the loop being grounded.

When the battery is connected a current will flow momentarily in the circuit charging the condenser C. This will produce a throw of the voltmeter needle, the amount of the deflection depending upon the capacity of the condenser C and the capacity between conductors. If the tip and ring connections of the loop are reversed the volt-

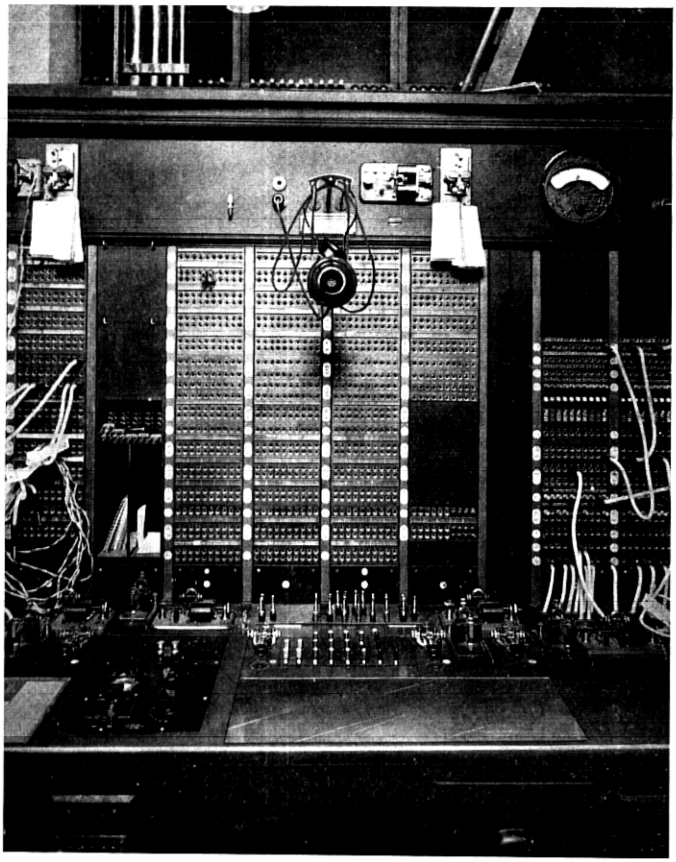


Fig. 8

meter needle throw will be in the opposite direction from that obtained in the first condition. The capacity of the conductors in the loop is relatively small as compared to that of the condenser C so that by knowing the throw which should be obtained under the test conditions for known values of capacity a fairly good check of the condensers in subscribers' sets is provided by this method of measurement. Different deflections of the voltmeter needle will, of course, be obtained depending on whether the loop tested is a single party, two-party or four-party line and also on whether 1 μ f. or 2 μ f. condensers are provided in the substation sets. These conditions must be known by the testman if he is to properly interpret the testing results and detect missing or defective condensers.

Standard Types of Testboards. Pictures of two of the latest types of toll and local testboards are shown in Figs. 8 and 9. These boards provide circuit arrangements for making most of the direct current

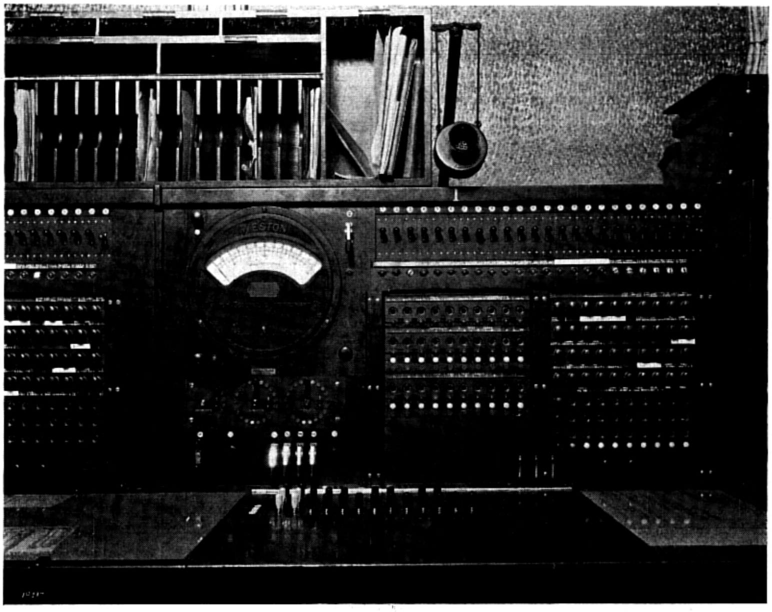


Fig. 9

tests which have just been described and also some of the alternating current tests described below. The wiring of the test circuits to keys, jacks and plugs and the provisions made for picking up various telephone circuits for test greatly facilitate routine maintenance work and the location of troubles which occur in service. Modifications and various arrangements of the tests described above have been provided for in these boards to meet different operating conditions which may arise.

The test board shown in Fig. 8 is designed primarily for testing toll circuits. The vertical section of the board provides jacks for terminating the toll circuits and the apparatus associated with them, such as phantom and simplex coils, composite sets, etc. The 100,000-ohm voltmeter and the Wheatstone bridge and keys for obtaining various testing arrangements are mounted in the horizontal shelf and connections are made to the toll circuit and equipment jacks by means of the cords and plugs located at the back of the shelf. The telegraph instruments are used on order wires to distant test boards and the meter shown in the vertical section of the board is for measuring the voltage and current in telegraph circuits.

The test board shown in Fig. 9 is designed primarily for testing the local plant, although tests on toll circuits can also be made from this board. One transmission feature provided in the board is an artificial line which when cut in circuit with a 500 ohm subscriber's loop, gives an overall equivalent of approximately 30 TU. This line is terminated on keys by means of which it can be connected as a trunk circuit and used in talking tests on subscribers' loops at the time of their installation or when subscribers' stations are visited in connection with trouble complaints. Jacks are provided in the vertical section of the board for terminating certain test trunks and other test trunks are terminated on keys. A Wheatstone bridge is not normally mounted in this type of test board, but where required, a portable bridge is supplied which is generally kept in one of the drawers of the board when not in use.

Alternating Current Tests

While the direct current tests just described tell a great deal about the physical and electrical condition of telephone circuits, it is very necessary in maintenance work to consider also the alternating current characteristics. The transmission of speech is, of course, fundamentally a problem of the transmission of alternating currents of very small values. The inductance and capacity as well as the resistance and leakage of circuits, therefore, become important items in determining the efficiency of telephone circuits and means must be provided for testing these characteristics under operating conditions. In principle, alternating current testing methods do not differ materially from direct current methods and their application in the telephone plant is not difficult.

Alternating Current Bridge Measurements. These measurements employ Wheatstone bridge arrangements, the direct current source of power being replaced by an alternating current source and the condition of bridge balance being obtained by some alternating current detecting device, generally an ordinary telephone receiver. Four important bridge measuring methods are used extensively in telephone testing work as described below:

(1) *Alternating Current Capacity Tests.* The bridge circuit arrangement for measuring a.c. capacity is shown in Fig. 10.

Two arms of the bridge consist of fixed and equal resistances A and B connected by a slide wire resistance, the position of the contactor on this slide wire determining the total amount of resistance

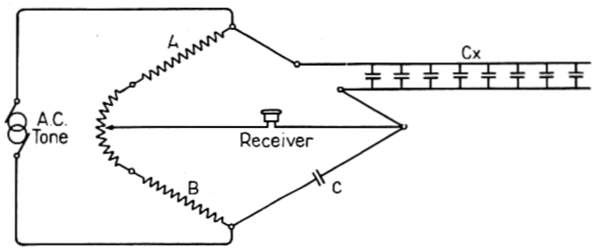


Fig. 10

in each of the two arms. The fixed resistances in A and B are simply extensions of the slide wire and can be cut out of the circuit when not required. The third arm of the bridge consists of standard condensers C, and the fourth arm the circuit whose capacity C_x is to be measured. A source of alternating current generally an 800 or 1,000 cycle oscillator is connected to the terminals of the arms A and B while the telephone receiver is connected to the slide wire contactor and to the junction of the standard condenser and circuit under test. A balance of the bridge is obtained when there is minimum tone in the receiver, for which condition the common bridge formula $C_x = \frac{B}{A} C$ applies. The slide wire is calibrated to read the ratio B/A directly.

For field testing work the above circuit arrangement is made up in a portable box and a portable oscillator is used so that the apparatus can be readily carried about as required. The commercial form of bridge provides three values of standard condensers which can be used to cover measurements from about 500 micro-microfarads up to 1.5 microfarads. This bridge finds its application in the plant in measuring the capacity of short lengths of non-loaded cable, bridle wire, switchboard wire, etc. Such measurements are of particular importance in connection with the installation of 22 type telephone repeaters to determine the proper values of building out condensers to use in the line and balancing circuits.

Another use which is made of alternating current capacity measurements is in connection with the open location test provided at toll test boards. The essential features of the circuit arrangement are shown in Fig. 11.

The ordinary Murray connection of the test board bridge is used, the four arms of the bridge consisting of one fixed 1,000-ohm resistance A, a variable resistance R, a standard 1 μf. condenser C and the open

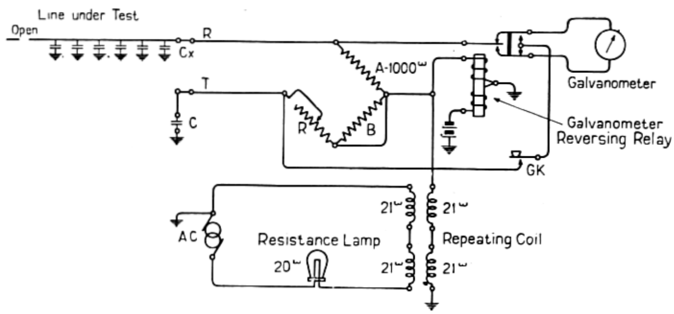


Fig. 11

condenser under test C_x. Ordinary 20 cycle ringing current is used as the measuring current and the galvanometer or voltmeter connected through a reversing relay so that it will always read in one direction. For the balanced condition of the bridge as indicated on the galvanometer the relation $C_x = \frac{R}{A} C$ holds. Substituting the numerical values for A and C in the above formula C_x then equals $\frac{R}{1000}$.

The above test provides a means for determining the approximate distributed capacity of a circuit up to the point where it is open. With previous measurements on known lengths and similar types of circuits available and assuming the distributed capacity proportional to the length of circuit, this test provides a simple means for determining the approximate distance out to the open. In practice fairly good results are obtained on loaded or non-loaded open wire circuits up to 200 miles in length and on loaded or non-loaded cable up to 40 miles in length. The degree of accuracy with which opens can be located by this method depends, of course, on having good unit capacity measurements for the different types of circuits involved in the testing work.

(2) *Capacity Unbalance Tests.* If the electrostatic capacities between wires and between wires and ground in telephone circuits are not

properly balanced crosstalk between circuits will result. The effects of capacity unbalances of this kind are particularly serious in producing side to side and phantom to side crosstalk in quadded cable circuits unless great care is taken in splicing the various pairs and quads in consecutive lengths so that the resultant unbalances will be a minimum. This is to be expected since in cables the electrostatic capacities between conductors and between conductors and sheath

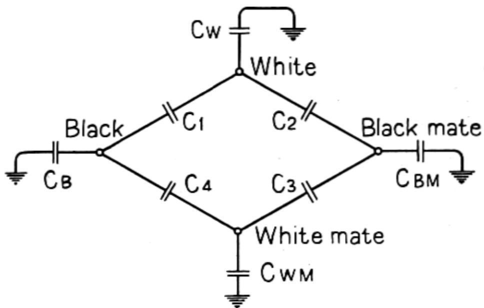


Fig. 12

are high as compared to open wire circuits and any irregularities in construction may produce very appreciable unbalance conditions between these capacities.

Fig. 12 shows the direct electrostatic capacities in a quad which, if they do not have the proper balance relations will produce excessive crosstalk. The conductors of one pair are designated "white" and "white mate" and of the other pair "black" and "black mate." The particular arrangement of the conductors in the figure to form the arms of a Wheatstone bridge is used since this arrangement is employed in the capacity unbalance measuring circuit described later.

Neglecting second order effects, side to side crosstalk is produced by unbalances in the direct capacities between conductors in accordance with the following relation.

$$\text{Capacity unbalance} = C_1 + C_3 - (C_2 + C_4).$$

In phantom to side crosstalk the unbalance relations of the direct capacities of the conductors to ground (sheath and "bunch") in addition to the direct capacities between conductors become important. Again neglecting second order effects, the unbalance relations producing crosstalk between the phantom and the "white" side is

$$\text{Capacity unbalance} = 2\,[C_1 + C_2 - (C_3 + C_4) + \tfrac{1}{2}(C_W - C_{WM})].$$

Similarly the unbalance relations producing crosstalk between the phantom and the "black" side is

$$\text{Capacity unbalance} = 2\,[C_1 + C_4 - (C_2 + C_3) + \tfrac{1}{2}(C_B - C_{BM})].$$

The factor 2 enters into the last two formulæ since the difference in direct capacities have about twice the effect on phantom to side crosstalk as they do on side to side crosstalk.

The capacity unbalances given above are measured on each quad in every loading section and give a measure of the side to side and phantom to side crosstalk due to capacity unbalance in the cable. Such measurements are usually made at three points in every loading section and the quads are spliced at these points in such a way that the capacity unbalances in the two directions will tend to neutralize. In this connection particular care is taken to neutralize the phantom to side unbalances since these are usually higher.

For making capacity unbalance tests a special portable bridge known as the capacity unbalance test set was developed which has been in general use since the introduction of quadded cables in the telephone plant. Fig. 13 shows the schematic circuit arrangement of this bridge for measuring the capacity unbalance as indicated above between sides of a quad.

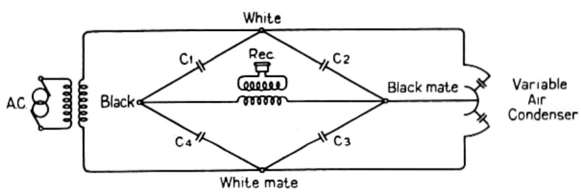


Fig. 13

The two conductors of each side circuit of the quad are connected to opposite corners of the bridge, these being designated as "white and "white mate" and "black" and "black mate." The direct capacities between these conductors then become the arms of the bridge. An oscillator is connected through a transformer to the "white" and "white mate" terminals of the bridge and a variable air condenser is connected to these same terminals. A telephone receiver is connected through a transformer to the "black" and "black mate" terminals. The variable air condenser is adjusted until a minimum tone is observed in the receiver, this adjustment adding capacity to one side or the other of the bridge. The variable condenser is calibrated to read the unbalances directly in micro microfarads, the direction of the unbalances being indicated by red and black scales and arbitrarily designated as (+) and (−).

Fig. 14 shows the circuit arrangement of the bridge for measuring the capacity unbalance between the phantom and "white" pair. The oscillator, variable condenser and receiver are connected as before, the "black" conductor and its mate however, being strapped together at one of the remaining bridge terminals and ratio arms R_1 and R_2 each consisting of 2,000 ohms resistance, being connected as shown to the fourth bridge terminal. For the condition of minimum tone the variable condenser reading then gives a measure of the capacity unbalance between the phantom and the "white" pair, that

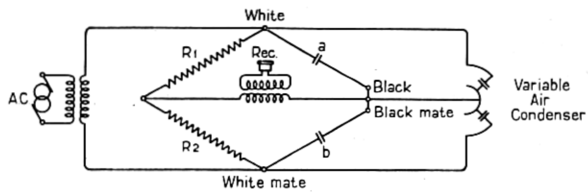


Fig. 14

is $a-b$. The capacities a and b take into account in this case the capacities of the "white" and "white mate" conductors to ground in addition to the direct capacities between wires shown in Fig. 13. The unbalance between the phantom and "black" pair is obtained in the same manner as shown by interchanging the "white" and "black" conductor connections to the bridge. The test set reads only half the capacity unbalance as defined in the above formulæ for phantom to side unbalance.

In practice the testing arrangement just described is used to test unbalances of all quads in a cable in each direction. At any splicing point where the tests are made the three unbalance measurements in each direction for each quad are carefully recorded and the splices then made by combining (+) and (−) values so as to neutralize each other as much as possible thereby reducing the resulting capacity unbalances and the crosstalk in each direction to a minimum. Both the bridge and oscillator are readily portable and designed for outdoor use. The bridge is equipped with keys, binding posts and leads to allow connections to be quickly made to the cable conductors and the various conditions of unbalance measured.

(3) *Impedance Tests.* The various bridge arrangements for capacity measurements are essentially impedance measuring devices, the im-

pedance of condensers being negative reactance. In telephone circuits and equipment where inductance is involved such as in loading coils, transformers, retardation coils, etc., the effective resistance as well as the inductance becomes a factor which must be taken account of in bridge testing work. For measuring effective resistance, inductance and impedance, bridges have been developed which are similar to capacity bridges except that standard condensers in the balancing arm are replaced by standard inductances and resistances.

There are two general types of bridges in use in the telephone plant designed to measure impedance; one type for testing equipment made up mostly of inductance, such as loading coils, and the other for testing the impedance characteristics of various types of equipment and circuits generally within the operating range of frequencies.

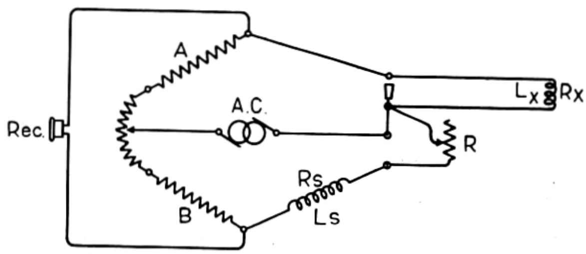


Fig. 15

The circuit arrangement shown in Fig. 15 is for an impedance bridge designed primarily for measuring impedance of equipment having positive reactance characteristics. As in the capacity bridges two arms are made up of fixed resistances *A* and *B*, connected by a slide wire resistance. The impedance to be measured makes up the third arm of the bridge and the standard impedance consisting of known values of inductance and resistance is the fourth arm. To obtain accurate measurements requires that the standard impedance be approximately the same order of magnitude as the impedance measured and the phase angles of the two must be very nearly the same. Values of standard inductance are, therefore, chosen which are known to be fairly near the values of the unknown inductances and a variable resistance *R* is provided which can be switched in series with either arm of the bridge and adjusted until the resistance components in the two arms are equal. The bridge is balanced by adjusting the slide wire resistance and the resistance *R* until a minimum tone is heard in the receiver. For the condition shown in Fig. 15 when the bridge is balanced $L_x = \frac{A}{B} L_s$ and $R_x = \frac{A}{B} (R + R_s)$. The slide wire is calibrated to read the ratio $\frac{A}{B}$ directly and tables of values for L_s and R_s at various frequencies are supplied for use with the commercial form of bridges. The value of R is read directly from the dial rheostats on the bridge.

In practice this form of bridge finds its principal application in measuring the inductance and resistance of cable loading coils when trouble is experienced which necessitates opening up the cable and loading coil pots. It is also used to measure the unbalance between windings of coils as, for example, between the line windings or the drop windings of repeating coils. For measurements of the latter kind one winding is connected in place of L_x and the other in place of L_s and the unbalance between the two windings is then given by the slide wire ratio. A further use of this scheme is in checking the correctness of loading of short cable circuits and a special bridge has been designed for this purpose. A pair which is known to be properly loaded is used as the standard and all other pairs of the same length and loading are checked by connecting them one at a time into the unknown arm of the bridge.

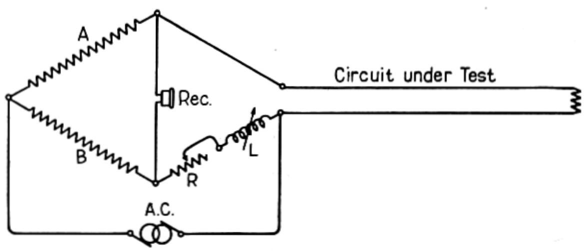


Fig. 16

The form of bridge designed to measure the impedance characteristics of circuits and equipment at any desired frequency or at a number of frequencies is shown in Fig. 16.

The fixed resistances A and B, generally of 1,000 ohms each, make up two arms of the bridge, the circuit under test the third arm and a variable resistance and a variable inductance standard the fourth arm. The variable inductance L is arranged so that it can be switched in series with the circuit under test when the characteristics of this circuit are such that its capacitive reactance predominates. For a condition of balance indicated by minimum tone in the receiver, the effective resistance of the circuit is given directly by the value of the variable resistance R, and the inductance by the value of L. For any particular frequency f at which a measurement is made, the reactance of the circuit can be computed from the value of L and expressed in ohms by the formula

$$\text{Reactance} = 2\pi fL.$$

The impedance of the circuit expressed in ohms is equal to the vectorial sum of the effective resistance R and the reactance. This relation is made use of in practice when it is desired to express the impedance of circuits in round numbers without reference to its component parts. Generally, however, in the practical applications of impedance measuring in maintenance work, the resistance and inductance components can be used directly to the best advantage without combining them or expressing the inductance readings in terms of reactance.

One of the most important applications of impedance measurements is the determination of the characteristic impedance of telephone circuits at the various frequencies involved in the transmission of telephone currents. Measurements of this kind, when applied to equipment circuits such as telephone repeaters, balancing networks, etc., and to the line circuits themselves, tell a great deal in regard to the efficiency of these circuits for the transmission of speech. They are very important, therefore, in checking up the installation of certain circuits in the plant and making sure that the proper impedance relations are obtained.

Fig. 17 shows the results of impedance measurements on a loaded 19 gauge cable circuit within a range of frequencies from 300 cycles to 2,300 cycles. The effective resistance values and the values of the reactance components are indicated by the curves. The inductance values are negative which means that the circuit tested had capacitive reactance throughout the range of frequencies used. When the measurements were made the distant terminal of the circuit was terminated by an impedance approximating the characteristic impedance of the circuit in order to give the effect of an infinite length of line. If the above circuit is used for 2-way telephone repeater operation it is necessary that the repeater balancing networks have impedance characteristics similar to the lines which they balance in order that the maximum repeater gain with good quality be obtained.

Measurements such as described above, in addition to giving a picture of the effective resistance and reactance of circuits at different frequencies, also provide a means for locating the irregularities and troubles which tend to change the normal impedance characteristics. The omission of loading coils or the reversal of one loading coil winding, the installation of intermediate apparatus or of emergency cable, etc., cause impedance irregularities which are very detrimental to telephone repeater operation. The effect of these irregularities on an alternating current is to reflect some of the current back towards the sending end, this reflected current either adding to or subtracting

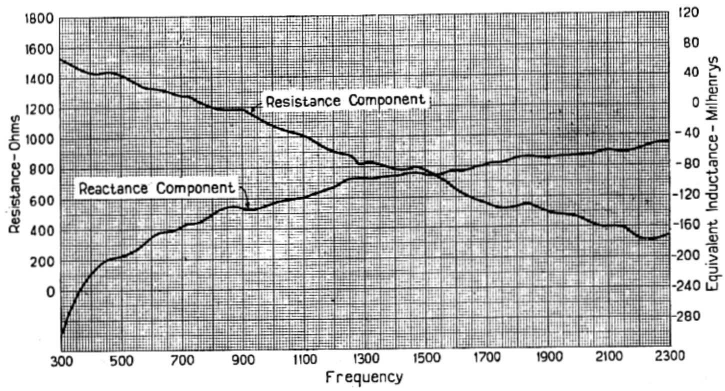


Fig. 17

from the current entering the line. This effect can be observed in impedance measurements by peaks and hollows in the effective resistance and inductance curves.

Fig. 18 shows two resistance curves of measurements made on a loaded No. 104 copper circuit (No. 12 N. B. S.), Curve *A* being for a condition where two consecutive loading coils were missing and Curve *B* for the condition after these coils were connected back in the circuit. The small irregularity in Curve *B* was due principally to the irregularity introduced by the use of a 1,500 ohm termination when making the measurement. The distance in miles from the end of the circuit at which the measurements were made to the irregularity caused by the missing loading coils is given fairly accurately by the formula:

$$\text{Distance} = \frac{V}{2(f_2 - f_1)},$$

where V is the velocity of the measuring current in miles per second for the particular type of circuit tested and $(f_2 - f_1)$ the average difference in frequencies between successive peaks of Curve *A*. For the type of circuit on which the measurements shown on Fig. 18 were made, the velocity of propagation is approximately 54,700 miles per second. The average difference in frequencies between peaks on the curve is about 380 cycles. Applying these figures in the above formula gives the distance out to the irregularity as 70 miles. In this case the ninth and tenth loading coils were missing, which gave a very close check to the computed 70 mile figure. A great deal of use is

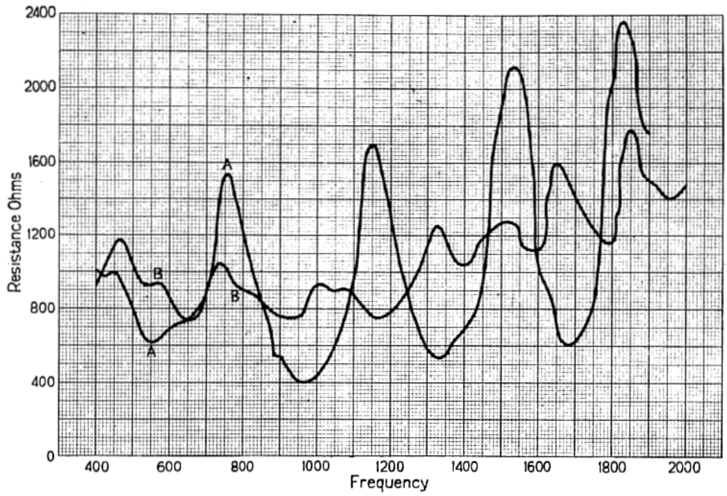


Fig. 18

made of measurements of this kind in locating troubles which affect telephone repeater operation and in directing the work of linemen in clearing these troubles.

A further use which can be made of a bridge similar to the one just described is in the location of impedance unbalance conditions which tend to increase crosstalk and noise between circuits. This is a fairly recent development and a description of it will be included in a paper to be published later.

(4) *Tests of Balance of Apparatus.* Certain types of equipment associated with telephone circuits are made up of apparatus which has to be closely balanced with respect to the various parts in order that the equipment when connected to telephone circuits will not cause unbalances in these circuits. Any unbalances introduced in this way will increase noise and crosstalk in the same manner as impedance unbalances in the line circuits themselves. Cord circuits, phantom repeating coils, composite sets, etc., are examples of the types of equipment in which unbalances in the apparatus may affect noise and

crosstalk conditions in the telephone circuits to which they are connected. The capacity bridge and the impedance bridge previously described can be used to test apparatus unbalances.

Composite sets for superposing telegraph on telephone circuits are particularly important in respect to balance and in order to provide a means for quickly checking the balance conditions in these a special form of bridge has been designed. This testing apparatus is known as the composite set bridge and is of particular advantage in that it provides for quickly testing the balance conditions of various parts

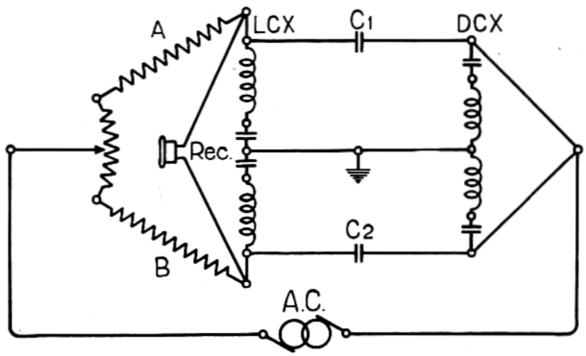


Fig. 19

of the set as well as complete sets. Tests can be made for example of the balance of the telegraph branches complete or of the condensers and coils in these branches separately. Tests can also be made of the balance of the grounded branches or of the series line condensers of the set.

To illustrate the operation of this bridge, Fig. 19 shows the arrangement for testing the balance of the series condensers in a composite set. Two arms of the bridge *A* and *B* consist of fixed resistances connected together by a slide wire resistance. The series line condensers of the composite set, C_1 and C_2, then become the other two arms of the bridge. When a source of alternating current is connected as shown, a condition of minimum tone in the receiver obtained by adjusting the position of the contactor on the slide wire indicates when the bridge is balanced. The slide wire is calibrated to read the percentage unbalance of the condensers C_1 and C_2 directly.

Crosstalk and Noise Measurements. Circuit unbalance conditions, such as described in some of the previous tests, are often very detrimental to telephone transmission in that they cause crosstalk between circuits. Also foreign currents, induced from supply lines, produce noise which has much the same effect as inserting a transmission loss. The magnitude of noise produced in this way is dependent among other things, on the balance conditions of both the supply and telephone circuits.

The determination of the magnitude of crosstalk and of noise currents can be made by relatively simple measurements. In practice crosstalk tests, which also give an indication of the balance conditions of circuits, can be made more quickly than impedance unbalance tests, although they do not give a location directly of any troubles which may exist. The usual procedure then is to make noise and crosstalk tests on circuits, and in those cases where the measurements indicate that improvement is desirable some of the direct current or alternating current methods previously described are applied to locate the cause. The simplified circuit arrangement of the test set commonly used for measuring crosstalk between two circuits is shown in Fig. 20.

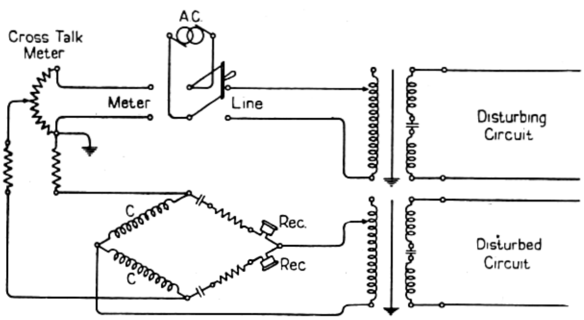


Fig. 20

An alternating current source generally of complex wave shape to simulate voice currents is connected to a switch in the set so arranged that its voltage can be impressed either on a telephone circuit known as the "Disturbing Circuit" or on a measuring shunt known as a "Crosstalk Meter." The other side of the shunt is connected through a Wheatstone bridge arrangement to a second telephone circuit known as a "Disturbed Circuit." Shielded transformers are used in the set as shown for connection to the circuits under test, these transformers being designed to give the proper impedance relations required by the different types of circuits met with in practice. The Wheatstone bridge arrangement is primarily for the purpose of allowing any noise currents which may be present in the disturbed circuit to be impressed on the observing receivers either when these are used to listen to the cross-talk through the shunt or directly to the crosstalk from the disturbed line. Errors which might be introduced should line noise be present for only one condition of the test are in this way eliminated.

Measurements are made by first impressing the alternating current tone on the disturbing circuit and then on the meter and adjusting the shunt until the annoying effect of the tone heard in the disturbed circuit is judged to be the same as that heard on the meter. The crosstalk meter is calibrated in crosstalk units, one unit being defined as the ratio of one millionth between the current at the terminal of the disturbed circuit and the current at the terminal of the disturbing circuit, providing these currents are transmitted into like impedances and distortion of the speech sounds is not involved.

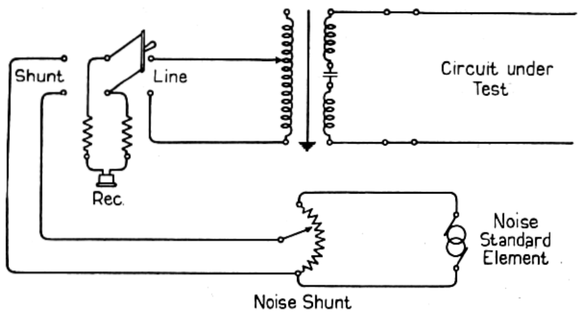


Fig. 21

Fig. 21 shows the simplified circuit of a noise measuring set arranged to measure metallic noise on a telephone circuit. As in the case of the crosstalk set, a shielded transformer is used to connect the set to the circuit under test which can be adjusted to give the proper impedance relations. With the switch thrown towards "line" the receiver is connected to the circuit under test and any noise on this circuit observed. When the switch is thrown towards "shunt" an artificial noise current produced by a vibrator is impressed on the receiver through a shunt. By alternately throwing the switch from the line under test to the shunt circuit, the shunt is adjusted until the interfering effect of the noise on the line and from the shunt are judged to be equal. The reading of the shunt which is calibrated in noise units gives a measure of the amount of noise in the circuit under test. In the commercial form of instrument used in the plant, the circuit is arranged so that both metallic noise and noise to ground can be readily measured. Where noise is present on circuits, instruments are also available for analyzing the wave shape, that is, determining which frequencies making up the noise currents predominate. For both noise and crosstalk measurements, definite rules must be followed in terminating the distant ends of the circuits under test in order to reduce terminal impedance irregularities.

21-*Circuit Balance Tests.* In describing the use of the bridge for locating impedance irregularities, mention was made of the effect of such irregularities on telephone repeater operation. Since the making of impedance runs on circuits involves a considerable amount of time and expense, a simple and quick balance test, known as the 21-circuit test, was devised in which the telephone repeater is made to function as the testing set. The gain which can be obtained from a 21 or 22 type telephone repeater with good quality depends to a large extent on the degree of balance, within the frequency range involved, between the impedances of the telephone circuits and the impedances of the corresponding balancing networks. The use of this balance relation is illustrated in the simplified circuit of Fig. 22 which shows a 22 type repeater connected to make a 21-circuit balance test between the "East" line and its balancing network.

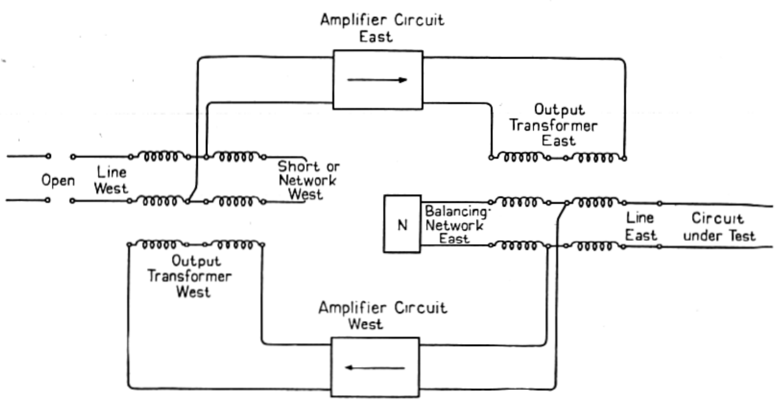


Fig. 22

The line under test and its balancing network are connected as for normal repeater operation, while the "West" line is opened. The "West" line network terminals are either shorted or the network left connected, the principle of the test being the same in either case. The 3-winding transformer, when connected for normal repeater operation, as shown for the "East" transformer in Fig. 22, simply gives a Wheatstone bridge relation, the input of the "West" amplifier being connected to the balanced points of the bridge. The proportion of the current delivered to the transformer from the "East" amplifier which gets to the input of the "West" amplifier depends, therefore, on the degree of bridge balance furnished by the line under test and its network. When the 3-winding transformer is opened on the line side with either the network terminals shorted or with the network connected, as shown for the "West" transformer its action is the same as a repeating coil.

An internal path for currents which may produce repeater "singing" or a sustained tone, is established if the gain of the two amplifiers is just greater than the sum of the losses within the repeater circuit, that is, the losses through the transformers and any other equipment in the circuit. Theoretically, if the line and network were perfectly balanced and there were no internal unbalances in the repeater, it could not be made to sing since, due to the balance relations of the "East" 3-winding transformer, there would be infinite loss from the output of the "East" amplifier to the input of the "West" amplifier. This ideal condition is, of course, not met with in practice, since it is not practicable to design repeater circuits for perfect balance or to construct artificial networks which will exactly balance the working lines at all frequencies involved. The amplification which can be obtained in any instance without singing, then depends to a large extent on the balance between the lines and networks. In the test circuit shown in Fig. 22 the gains of the two amplifier elements are increased until singing or a sustained tone is observed and the total gain required for this gives an indication of the balance between the "East" line and its balancing network. In the same way the balance between the "West" line and its network can be determined by connecting this in the regular way to the "West" 3-winding transformer and disconnecting the "East" line. In making the tests in either direction the "poling" of the repeater circuit is reversed in order to give the lowest value of singing point which might occur under service conditions.

In practice the tests described above have become of considerable use and importance in the installation and maintenance of telephone repeaters and the circuits associated with them. Methods are available for computing the estimated singing points which circuits and equipment should give with telephone repeaters under operating conditions. These computations allow toll circuits and equipment to be engineered intelligently with respect to the gains which the repeaters may be expected to give with good quality. After installation, the 21-circuit tests furnish a means for checking computed or estimated singing points. When the estimated singing points cannot be obtained with the 21-circuit tests, this is an indication of balance trouble which must be located either by an inspection of the circuits or balancing equipment or by resorting to impedance measurements as described previously.

Another method of determining impedance irregularities which is made use of in some of the larger offices is to measure the transmission loss through the 3-winding transformer with the lines and networks connected as for normal repeater operation. As stated previously the loss through the transformer to currents from the output of one amplifier to the input of the other gives a measure of the balance conditions of the line and network, the loss increasing as the balance becomes more perfect. By this scheme the losses through the 3-winding transformers can be measured over a range of frequencies as in line impedance measurements and a loss curve obtained which can be used to locate irregularities in the same manner as described for line impedance curves.

Transmission Efficiency Measurements. If all or a part of the tests already described were applied to the various transmission circuits in the telephone plant, most troubles which might effect speech transmission could be detected and assurance given that the circuits were properly installed. Such a procedure would be costly and impracticable and for this reason it is necessary that means be provided whereby a measurement of a circuit's efficiency for the transmission of voice currents can be quickly made.

The transmission of voice currents can be measured in terms of a standard and expressed in units in much the same manner as the transmission of any electrical currents. A telephone circuit, for example, extending between any two offices is said to have an equivalent of so many units of transmission, the number of these units depending on the electrical characteristics of the component parts of the circuit.[1] Transmission measurements, as far as volume efficiency is concerned, involve determining by means of suitable testing apparatus the number of transmission units of loss or gain which a particular circuit or piece of equipment causes. As it is desired to obtain a measure of efficiency at a frequency comparable with the combined frequencies of the voice, a frequency of 1,000 cycles for the testing current has been chosen which experience has shown gives results approximating fairly closely those obtained by using a combination of the frequencies within the voice range. Measurements can also be made at other frequencies within the voice range or at

[1] See the article in this issue, The Transmission Unit and Telephone Transmission Reference Systems, by W. H. Martin.

frequencies outside of this range where desired, for example, at ringing current frequencies or carrier current frequencies.

Efficiency tests of transmitters and receivers present a somewhat different problem and for these it has been found most convenient to make direct comparisons between the instruments under test and standard instruments.

A discussion of the application of transmission testing apparatus in maintenance work for measuring losses and gains is given below.

(1) *Measurements of Transmission Losses.* In its simplest form a transmission measuring set involves an arrangement of apparatus whereby a volume comparison can be made between voice currents transmitted over a circuit of unknown efficiency and then over a standard circuit of known efficiency.

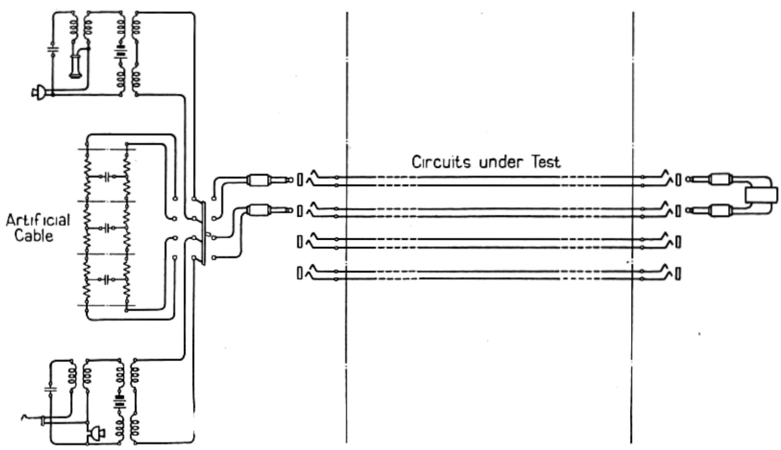


Fig. 23

Such an arrangement is illustrated in Fig. 23 in which the amount of artificial cable required to give a volume of transmission equal to that obtained over the circuit under test is a measure of the circuit's efficiency in terms of the artificial cable units. Prior to the development of the present types of transmission measuring sets the arrangement shown in Fig. 23 was used to a limited extent, principally in making measurements on important types of toll circuits and in determining fundamental transmission data such as unit equivalents, reflection losses, etc.

To meet the practical requirements of field testing work two general types of testing apparatus have been developed, one involving "ear balance" methods and the other "visual" methods, that is, an amplifier and detector arrangement.

Fig. 24 shows the schematic circuit arrangement for an ear balance test set and Fig. 25, that for a set employing visual methods.

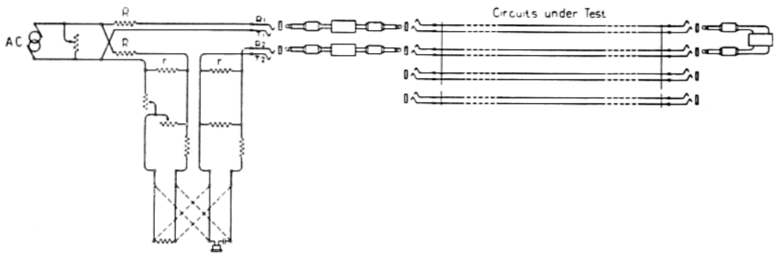


Fig. 24

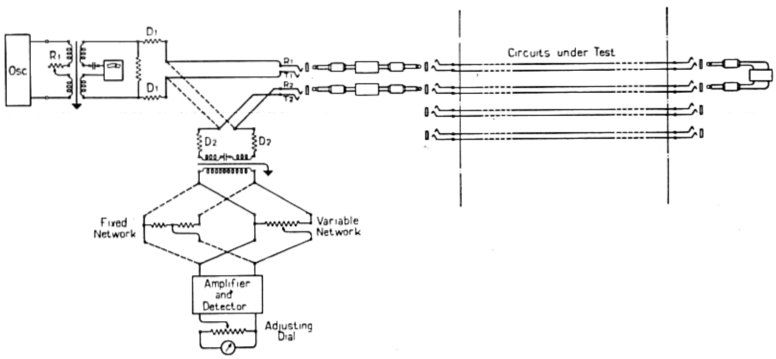


Fig. 25

A description of this apparatus and its development has been given in a paper by Best.[2] In brief, one subscriber's set of the circuit in Fig. 23 has been replaced by an oscillator while the other subscriber's set has been replaced by a receiver and resistance arrangement in the circuit of Fig. 24 and by an amplifier and detector in the circuit of Fig. 25. The artificial cable of Fig. 23 has also been replaced by distortionless resistance network standards in Figs. 24 and 25. Various resistances and coils are also provided to meet practical testing requirements such as adjusting the measuring current, and reducing reflection losses.

For field testing work, the circuits shown in Figs. 24 and 25 are mounted in compact form in portable boxes which can be readily carried from office to office or wherever required. Portable oscillators for supplying the measuring current are also provided so that com-

[2] F. H. Best, *Jour. A. I. E. E.*, Vol. XLIII, No. 2., Feb., 1924.

plete testing equipment is available, by means of which, a large volume of transmission testing in central offices and private branch exchanges can be done in the most convenient manner. Tests using these instruments can be made as readily on the transmission circuits in machine switching offices of both the step by step and panel types as in manual offices. The ear balance set of Fig. 24 requires no external source of direct current power and only a three dry cell battery is required for operating the oscillator. It is, therefore, used to the best advantage in testing private branch exchange switchboards and magneto switchboards where the power necessary to operate visual types of sets is not readily available.

The visual type of set of Fig. 25 is particularly suited for testing in the larger common battery central offices since it permits measurements to be made more quickly and accurately than in the case of the

Fig. 26

ear balance sets. These larger offices also have readily available the 24-volt batteries required to operate the visual reading sets. Fig. 26 shows a picture of one of the latest types of portable visual reading measuring sets, set up ready for operation at a central office switchboard position.

In order to give a general picture of the kinds of trouble found with this transmission testing equipment the following table shows a trouble classification which is particularly useful in analyzing testing results and instigating any required remedial measures.

Classification of Troubles Found

Physical defects.	Wrong type of equipment or circuit.
Opens.	Missing equipment.
Grounds.	High resistance.
Crosses.	Low insulation.
Cut Outs.	Wrong routing.
Electrical defects.	Bridged conductors.
Incorrect wiring.	

The above classification includes all of the common types of troubles which, if not kept out of the plant, will be detrimental to service. The item of physical defects is a class of trouble which is not determined directly by transmission tests but is discovered by the maintenance forces during the course of their testing work. It represents any unsatisfactory conditions found in the circuits which, while not causing trouble at the time, may very likely do so later and should, therefore, be corrected. The next four kinds of trouble shown in the table viz: opens, grounds, crosses and cut-outs while detected by transmission tests can also be found and cleared by the everyday maintenance work without the use of transmission testing apparatus. The remaining classes of trouble listed can, it has been found, be detected and eliminated most efficiently by the use of transmission testing sets. Classifying troubles and identifying them with the important circuits in the exchange area plant such as cord circuits, operators' circuits, trunks, etc., has proved very valuable in transmission maintenance work. The results of the work when analyzed in this way are a very great aid in supervision and assist materially in keeping the plant in good condition.

The visual reading circuit of Fig. 25 is also designed in a form for permanent installation particularly for use in testing toll circuits. A picture of a typical installation of one of the latest types of sets and its associated oscillator is shown in Fig. 27.

From 40 to 50 instruments of the general type shown in the picture are now located at important toll centers throughout the country. They are constantly used to check the overall transmission efficiency of toll circuits and in locating and clearing any transmission troubles which occur in service. Tests are made either by looping two circuits together at the distant terminals and measuring the loop loss or by testing single circuits straight-away between toll centers equipped with measuring instruments of this type.

In general, transmission testing apparatus quickly locates kinds of troubles which cannot be readily detected by other routine testing methods. Transmission tests also serve as a means for checking

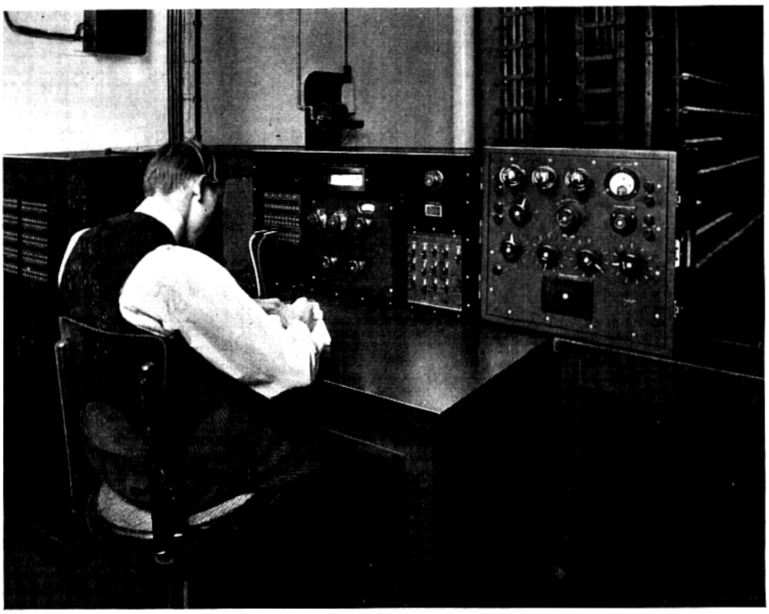


Fig. 27

general maintenance conditions and for insuring that other routine testing work is carried on in an effective manner.

As an illustration of the effect of some of the kinds of troubles which transmission tests detect, Fig. 28 shows the transmission circuit arrangement for a typical toll connection and below transmission level diagrams are given for the normal transmission condition and for conditions where common kinds of troubles are present. The level diagrams show how the normal overall transmission equivalent is increased when one or a number of transmission troubles are present in the various circuits going to make up the connection between subscribers. As indicated some troubles are more severe than others,

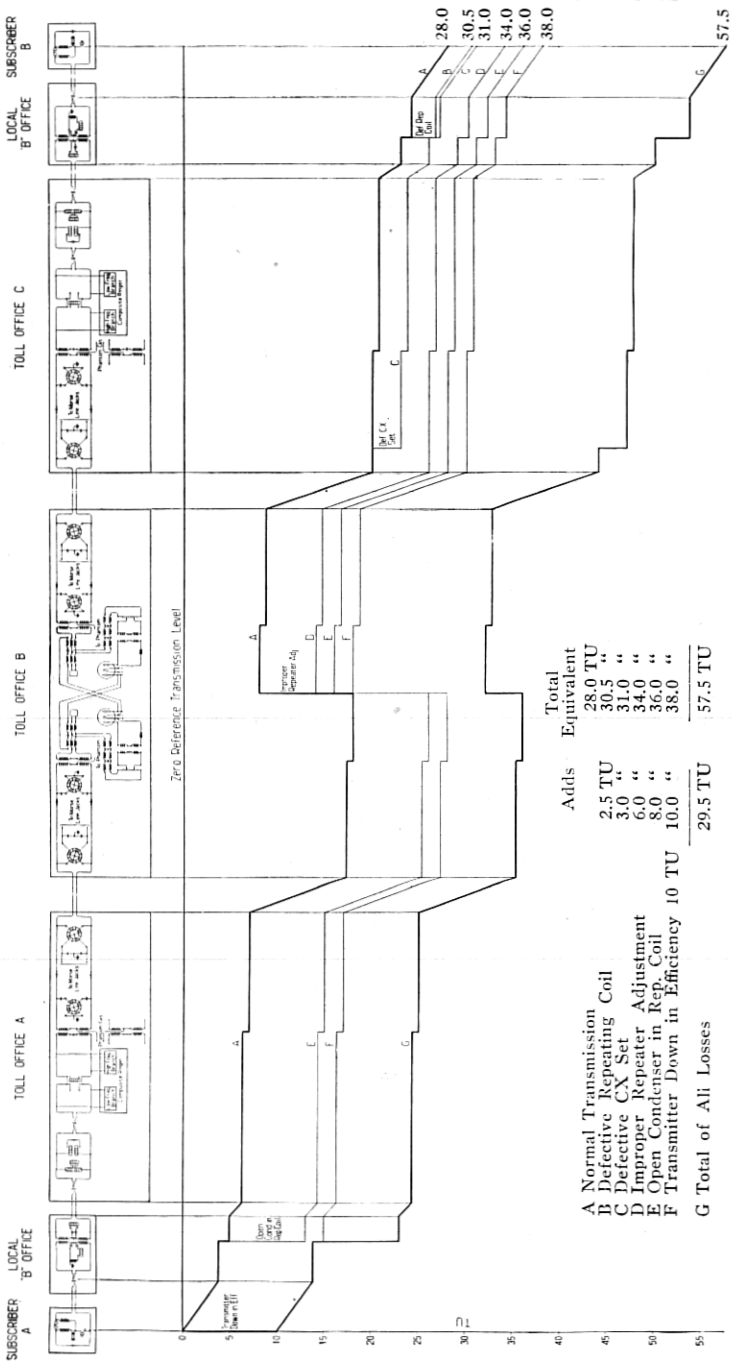

SUBSCRIBER A
LOCAL "B" OFFICE
TOLL OFFICE A
TOLL OFFICE B
TOLL OFFICE C
LOCAL "B" OFFICE
SUBSCRIBER B
Zero Reference Transmission Level
Transmitter Down in Eff
Open Cond in Rep Coil
Improper Repeater Adj
Def CX Set
Def Rep Coil
28.0
30.5
31.0
34.0
36.0
38.0
57.5
A Normal Transmission
B Defective Repeating Coil
C Defective CX Set
D Improper Repeater Adjustment
E Open Condenser in Rep. Coil
F Transmitter Down in Efficiency 10 TU
G Total of All Losses
Adds
2.5 TU
3.0 "
6.0 "
8.0 "
10.0 "
29.5 TU
Total Equivalent
28.0 TU
30.5 "
31.0 "
34.0 "
36.0 "
38.0 "
57.5 TU

Fig. 28

but any of them tend to produce conditions which may be very detrimental to service. These diagrams illustrate therefore, how important it is to maintain the telephone plant so that troubles of this nature will not be present.

(2) *Measurements of Transmission Gains.* The transmission gains of amplifier circuits are measured in much the same way as transmission losses. A gain may be considered as a negative loss and is expressed in the same transmission units. In measuring the gains of amplifier circuits designed for two way operation, it is necessary to provide the proper balancing conditions in order to prevent "singing." This is done by connecting the amplifier circuit between two artificial lines of the proper impedances and balancing these lines by networks. The simplest measuring circuit now in use consists of an arrangement whereby the repeater or amplifier under test is connected between two artificial lines with balancing networks and tone is supplied by an oscillator at the terminal of one line while the terminal of the other line is equipped with a receiver and a measuring shunt calibrated in transmission units. The repeater and the shunt are then alternately cut in and out of the circuit and the shunt adjusted until equal volume of tone is observed in the receiver, for which condition the shunt reading gives the gain of the repeater.

A visual method for measuring repeater gains is provided by substituting an amplifier detector circuit for the shunt and receiver. This is essentially what is done in the transmission measuring circuit shown in Fig. 25. The type of set designed for permanent installation which employs this circuit is arranged so that amplifier gains up to about 20 TU can be measured when a repeater is connected in place of the lines under test and the necessary repeater balancing requirements taken care of. The gains of repeaters connected in toll circuits are often checked in this way when overall transmission tests are made on these circuits.

To meet practical testing requirements at the larger repeater and carrier stations where a considerable amount of gain testing work is done, a visual reading measuring set especially designed for testing amplifier gains has been developed. The measuring circuit employed in this gain testing set has been described.[3] The equipment going to make up these sets, that is, the measuring shunts, artificial lines, amplifiers, meters, etc., is mounted in compact form on standard panels which can be installed at convenient locations near repeater and carrier equipment. A panel mounted 1,000 cycle oscillator is also

[3] A. B. Clark, *Bell System Technical Journal*, Volume II. No. 1, January, 1923.

provided to supply measuring current, although other types of oscillators giving the necessary output and proper wave shape can be used if desired.

In practice, it is necessary to maintain the gains of the amplifiers in repeater and carrier circuits to fairly close limits since these amplifiers form an integral part of toll circuits. Measurements of gains are also made in connection with the 21 circuit balance tests previously described. Another important application of gain tests is to check the gain frequency characteristics of repeaters to determine that all frequencies within the voice range are being properly amplified. By varying the filament current between limits, a test of the vacuum tubes for filament activity is obtained by gain measurements.

(3) *Measurements of Transmitter and Receiver Efficiencies.* Transmitters and receivers are used in the telephone plant principally in operators' sets and subscribers' sets. In the former, the transmitters, receivers and operators' circuits are readily available to the maintenance forces and therefore can be inspected and tested in a routine manner. In the case of subscribers' sets, however, the equipment in service is not accessible and tests must be made on the instruments before installation or at times when they are removed from service. Talking tests can also be made from the instruments at the time installations are made and any particularly unsatisfactory conditions found in this way.

The difficulties incident to testing transmitters and receivers are due to the fact that in transmitters, the efficiency depends on the ability to convert sound energy into electrical energy and in receivers, the ability to convert electrical energy into sound energy. Obviously, a simple form of transmitter test and one which has until recently been generally used is to talk alternately into the transmitter under test and then into a standard transmitter and observe the difference in volumes at a receiving set. In the same manner, a simple receiver test is to listen alternately to a receiver under test and then to a standard receiver connected to a talking station. This method is slow and also of limited accuracy due to inherent changes in a speaker's voice and to the possibility of the distance of the speaker's lips from the transmitter varying. To take the place of this method transmitter and receiver testing machines have been developed which will be described in a paper to be published later.

Oscillators. Practically all alternating current testing work requires the provision of an external source of measuring current. For this purpose oscillators of various types have been developed which are designed electrically and mechanically to meet various test circuit requirements as to wave shape, volume of current, etc. One of the earliest forms of oscillators known as the "substation howler" was made by coupling the receiver and transmitter of a subscriber's set together mechanically and taking off the alternating current generated by means of an induction coil in the howling circuit. This type of oscillator, which was subject to large variations in volume and produced a very poor wave form, has now been replaced by other and improved types.

Oscillators now in use in the field can be divided into three general classes, those employing vibrators, those employing motor generator equipment and those employing vacuum tubes. The principles of these oscillators are briefly described below by considering one commercial type in each class:

(1) *Oscillators Employing Vibrators.* Fig. 29 shows the circuit arrangement of an oscillator of this type which is designed for producing a single frequency alternating current.

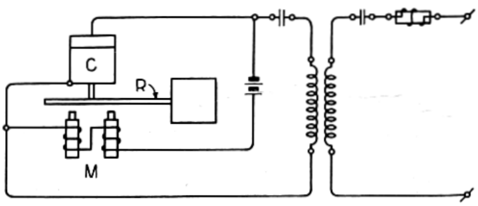


Fig. 29

The current generating element consists of a metal reed *R*, resting against the diaphragm associated with the carbon button *C*. The receiver spools *M*, are so arranged that when they are energized by the battery an attractive force is exerted upon the reed which draws it away from the carbon button. This action decreases the pressure in the carbon button with a corresponding decrease in the current from the battery, which in turn decreases the attractive force of the receiver so that the pressure of the reed against the carbon button is again increased. This cycle of change in current and pressure is repeated at the natural frequency of vibration of the reed so long as direct current flows from the battery. The alternating currents set up in this way are passed through a circuit resonant at the natural period of vibration of the reed, thereby giving a current of good wave form.

This particular form of vibrator oscillator is used principally in transmission testing work where portable "ear balance" methods are employed. It may, however, be used for other kinds of measurements where single frequency currents of fairly good wave form are required. Other forms of vibrator oscillators are available, particularly for use in capacity and capacity unbalance tests and cross-talk and noise tests.

(2) *Oscillators Employing Motor Generator Equipment.* This type of oscillator is illustrated by ordinary ringing and trouble tone machines and the low frequency alternating currents generated by these machines are often used in testboard work. The circuit for an oscillator of this type, particularly designed for producing 1,000-cycle alternating current with good wave form, is shown in Fig. 30.

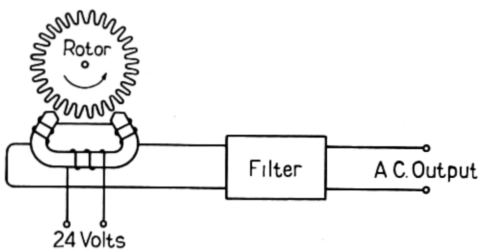


Fig. 30

In this circuit the field of an electromagnet is varied by a laminated core or rotor resembling a spur gear driven by a small 24-volt d.c. motor. The speed of the motor is automatically regulated and the electromagnet and rotor so designed that a 1,000-cycle current is generated. Harmonics which are inherent in the oscillator are eliminated by the use of a filter. This oscillator can be operated on the regular 24-volt central office battery and is compactly mounted to make it readily portable. It is particularly adaptable, therefore, for supplying the measuring current required to operate portable visual transmission measuring sets and is now generally used for this purpose in the telephone plant.

(3) *Oscillators Employing Vacuum Tubes.* Fig. 31 shows the simplified circuit arrangement of a vacuum tube oscillator.

The oscillating vacuum tube in this generator has its plate and grid inductively connected together in a tuned circuit. Closing the filament battery circuit starts this tube oscillating, the frequency of the oscillations being controlled by the inductance of the plate and grid coupling and the variable condenser *C*. The current thus generated is amplified by other vacuum tubes to the values which are required in the alternating current testing work. The circuit of Fig. 31 shows only one amplifying vacuum tube, but additional amplifiers may be added to meet the requirements of particular kinds of testing work. One of the latest forms of oscillators of this type is shown in Fig. 27 set up for use with one of the permanent types of transmission measuring sets.

Vacuum tube oscillators have been developed which will generate measuring currents of any desired frequency within the range of 100 cycles to 50,000 cycles, thus covering both the voice and carrier

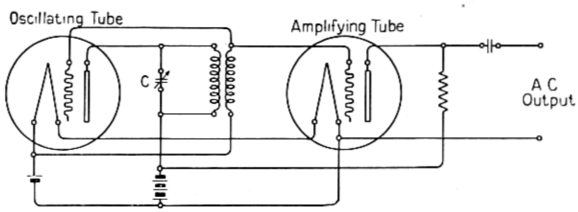
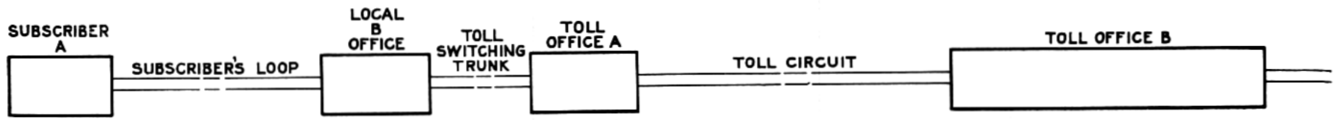


Fig. 31

range. These oscillators have become indispensable in testing and maintenance work. They are used extensively in making both single frequency transmission tests and transmission loss and gain tests within the range of frequencies mentioned above. They are also used in making line impedance and impedance unbalance tests and in determining the characteristics of telephone repeater and carrier circuits.

Specific Applications of Electrical Testing Methods. In describing the various electrical tests above, considerable has been said regarding the applications which are made of them to insure satisfactory telephone transmission. In order to give an overall picture of these applications the toll connection for which transmission level diagrams are given in Fig. 28, is shown in simplified form in Fig. 32, with various tests listed underneath the different sections of the circuit layout. Only the sections of the circuit making up the first part of the connection are shown since corresponding tests will apply to the circuits making up the second.

The tests listed in Fig. 32 are not intended to give a testing program but rather to show the various electrical testing means which are available for use in installation and maintenance work. Just what tests should be made, the frequency of making the tests and the limits to work to, to insure a high grade of transmission depend on the types of circuits and equipment involved and their relative im-



Subscriber A / Subscriber's Loop

1. Transmission efficiency tests of transmitters, receivers and instrument circuits before installation.

2. Talking transmission tests at time of installation.

3. D.C. current flow and resistance tests.

4. Insulation tests.

5. D.C. capacity, voltmeter "kick" tests.

Trouble Location Tests

Wheatstone bridge measurements and any of above tests required.

Local B Office / Toll Switching Trunk / Toll Office A

1. Transmission tests of toll switching trunks, toll cord circuits, operators' circuits, composite sets, coils, etc.

2. Tests and inspections of operators' transmitters, receivers and cords.

3. D.C. resistance tests of heat coils and protector springs.

4. Impedance balance tests of composite sets.

5. Insulation tests of central office wiring.

6. Insulation tests of cable conductors used for trunks.

Trouble Location Tests

Wheatstone bridge measurements and any of above tests required.

Toll Circuit

1. Insulation resistance or leakage tests.

2. D.C. loop resistance and resistance balance tests.

3. Overall transmission efficiency tests.

4. Overall noise and crosstalk tests.

5. Capacity unbalance tests during installation of quadded toll cables.

Trouble Location Tests

1. Wheatstone bridge measurements for opens, crosses, and grounds.

2. Impedance measurements for unbalances affecting telephone repeater operation not evident by D.C. tests and inspections.

3. Impedance unbalance measurements for location of unbalances causing noise and crosstalk.

4. Current flow continuity tests to check open wire pin positions and transportations.

5. Use of special test sets by lineman to obtain exact location of troubles which have been approximately located by above tests.

Toll Office B

1. Transmission efficiency tests of circuits and equipment.

2. Inspections and tests of operators' transmitters, receivers and cords

3. Impedance balance tests of composite sets.

4. Insulation tests of central office wiring.

5. D.C. resistance tests of heat coils and protector springs.

(Telephone Repeater Tests Only)

1. A.C. Capacity tests of office wiring on circuits involved, before repeater is installed.

2. Direct current and voltage tests.

3. 21-circuit balance tests.

4. Filament activity tests of vacuum tubes.

5. Transmission gain tests on operating steps.

6. Transmission gain-frequency tests.

7. Transmission step-gain tests.

Trouble Location Tests

Same tests as above. In addition characteristic impedance tests of repeaters and networks where necessary.

Fig. 32

portance in the system as a whole. These matters are covered in routine instructions which are developed by experience and which take into account local conditions and service requirements.

In conclusion, it may be stated that telephone systems in their present development have at their disposal means for carrying on an adequate transmission maintenance program in an economical manner. Furthermore, studies and trials of new methods are continually being carried on with a view to obtaining further improvements and increased economies in transmission testing and maintenance work.