# Practises in Telephone Transmission Maintenance Work[1]

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Synopsis: This paper describes the practical applications of transmission maintenance methods in a telephone system. The methods applicable to toll circuits of various types are first discussed, information being included in this connection on the maintenance of the amplifier circuits involved in telephone repeaters and carrier. Testing methods applicable to the local or exchange area plant are next described, the description including both manual and machine switching systems. The results accomplished in toll and local transmission maintenance work are considered from the standpoint of the kinds of trouble which can be eliminated and the effect which these troubles have on service.

The methods described in the main body of the paper relate particularly to testing volume efficiency. Certain other transmission maintenance testing methods directly associated with volume efficiency tests are briefly described in Appendix A of the paper.

IT is the purpose of this paper to present a general picture of the practical applications of methods of measuring transmission efficiency in the Bell System which have been developed by study and experience under plant operating conditions. The rapid growth of the telephone industry has made it necessary that these methods be such as to allow them to be applied on a large scale in a systematic and economical manner thereby providing for a quick periodic check of the efficiency of the various types of circuits as they are used in service.

Transmission maintenance can be broadly defined as that maintenance work which is directed primarily towards insuring that the talking efficiencies of the telephone circuits are those for which the circuits are designed. There are, of course, many elements which affect the talking efficiency and various d-c. and a-c. tests are available for checking the electrical characteristics of circuits and equipment to insure that these characteristics are being maintained in accordance with the proper standards. In the final analysis, however, an overall test of the transmission efficiency of the circuit in the condition it is used in service will show at once whether it is giving the loss, or in the case of amplifier circuits, the gain which it should give. Transmission tests, therefore, offer a means whereby many of the electrical characteristics of circuits can be quickly and accurately checked.

In referring to transmission testing apparatus in this paper, four standard types described in previous papers are involved. The first three types listed below were described by Best and the fourth by

[1] Paper presented at the Pacific Coast Convention, *A. I. E. E.*, October, 1924; abstracted in the *Journal*, *A. I. E. E.*, Vol. 43, p. 1124, 1924.

Clark.[2] Reference in these papers was also made to the standard oscillators used in supplying the measuring currents for the sets.

1—*A Transmission Measuring Set.* This is an "ear balance" portable set suitable for loop transmission testing only and designed primarily for testing equipment and circuits in the smaller central offices.

3—*A Transmission Measuring Set.* This is a "meter balance" portable set suitable for both loop and straightaway transmission testing and designed primarily for testing circuits and equipment in the larger central offices.

4—*A Transmission Measuring Set.* This is a "meter balance" set suitable for both loop and straightaway transmission testing and designed for permanent installation at the larger toll c[illegible]s primarily for testing toll circuits.

2—*A Gain Set.* This is a "meter balance" set designed for measuring amplifier gains.

Certain other testing methods in addition to volume efficiency tests are also extensively used in transmission maintenance work and some of the more important of these are briefly discussed in Appendix A of this paper.

Since the routine procedures in testing toll circuits using the above apparatus differ considerably from those followed in the local or exchange area plant, the toll and local practices have been considered separately in the following discussions:

## Transmission Tests on Toll Circuits

The importance of having available means for quickly checking the transmission efficiency of toll circuits and of economically maintaining the proper standard of transmission is evident when it is considered that in a plant such as that operated by the Bell System there are at the present time more than 20,000 toll circuits in service. The circuits making up this system are of various types and construction, depending on the service requirements and length, and also upon certain other factors determined by engineering and economical design considerations.

From the standpoint of maintaining transmission efficiency between toll offices, the various types of toll circuits can be divided into three general classes: one, non-repeatered circuits, two, circuits equipped

[2] F. H. Best, "Measuring Methods for Maintaining the Transmission Efficiency of Telephone Circuits," *Journal of the A. I. E. E.*, February, 1924. A. B. Clark, "Telephone Transmission over Long Cable Circuits," *Journal of the A. I. E. E.*, January, 1923.

with telephone repeaters and three, circuits equipped for carrier operation. The latter two classes are alike in many respects as far as the maintenance methods are concerned and both require somewhat more attention than the circuits not equipped with amplifying apparatus. The length and number of repeaters involved are also important factors which must be taken account of in tandem repeater and carrier circuit maintenance. Very long tandem repeater circuits

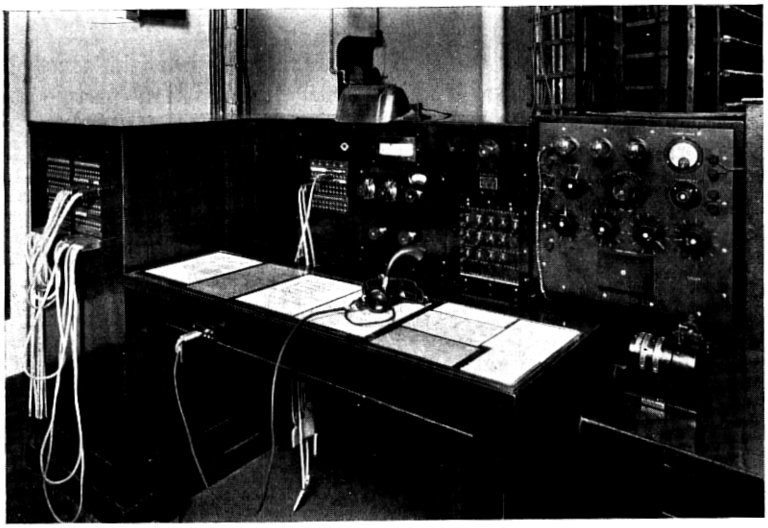


Fig. 1—Illustration of 4-A Transmission Measuring Set and 4-B Oscillator Installed in a Toll Test Room

such, for example, as the long toll cable circuits described by Clark[2] require special maintenance procedures similar in many respects to those required in carrier maintenance.

The 4-A type of transmission measuring set generally used for testing toll circuits may be considered as a toll transmission test desk. Fig. 1 shows a picture of one of the latest models together with an oscillator for supplying the measuring current, installed at a toll office for use in routine testing. The set is provided with trunks to both the toll testboard and toll switchboard, and also with call circuits to toll operators' positions for use in ordering up circuits for test. The electrical measuring circuit is designed so that tests may be made on two toll circuits looped at the distant end, or straightaway on one toll circuit the distant terminal of which terminates in an office also equipped with a transmission measuring set of the same type.

To illustrate the application of this toll transmission test desk, Fig. 2 shows schematically an arrangement of four toll offices having circuits between them of the three general classes—non-repeatered, repeatered and carrier. Offices A and D are equipped with transmission measuring sets of the type shown in Fig. 1. A logical testing

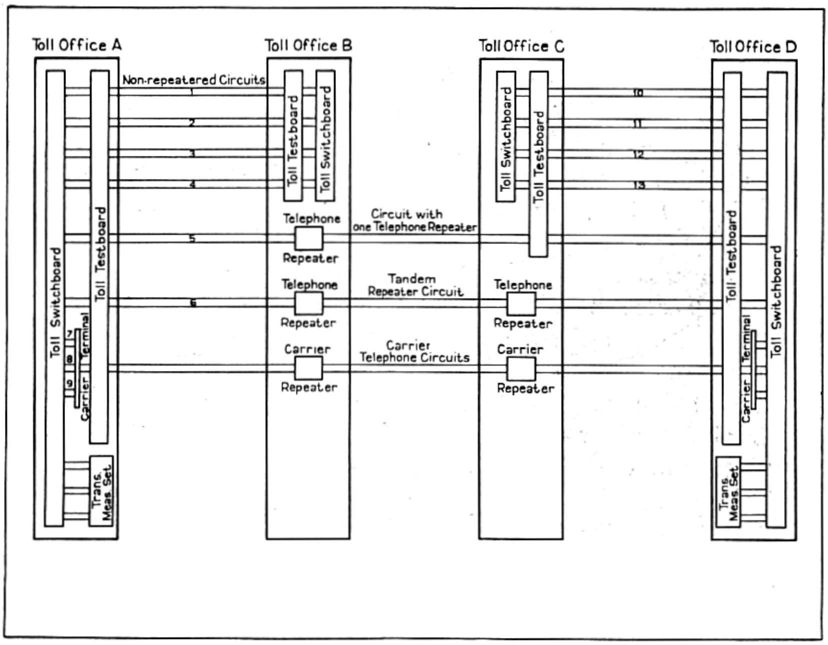



Fig. 2—Schematic Diagram of Typical Toll Circuit Layout to Illustrate General Method of Testing Non-Repeatered, Repeatered and Carrier Circuits

procedure for the arrangement in Fig. 2 is for offices A and D to test the non-repeatered circuits 1 to 4 and 10 to 13 by having them looped two at a time at the distant terminal offices B and C. By "triangulation measurements" on any three circuits in each group, the equivalent of each individual circuit can be readily computed.

For the circuits 5 to 9 extending between offices A and D equipped with telephone repeaters or carrier, straightaway measurements can be made in each direction with the two transmission measuring sets provided. Loop tests could, of course, also be made on the circuits from either office A or D, but this would require cutting the telephone repeaters out of one circuit or having available a non-repeatered or non-carrier circuit, since the gains of the repeaters in the two directions introduce variable factors in the overall equivalents which do not permit triangulation computations to be made. The overall tests on the carrier circuits do not differ in any way from the tests on repeatered or non-repeatered circuits, each carrier channel being tested as a separate circuit through the switchboards. The

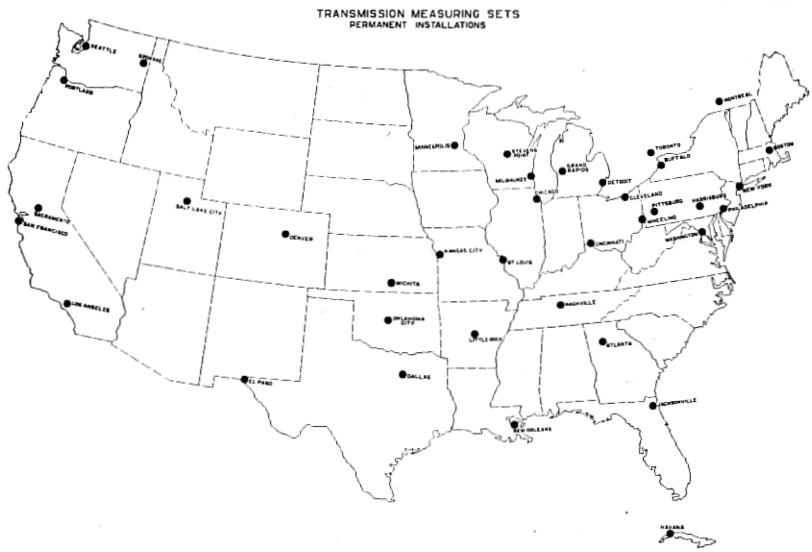
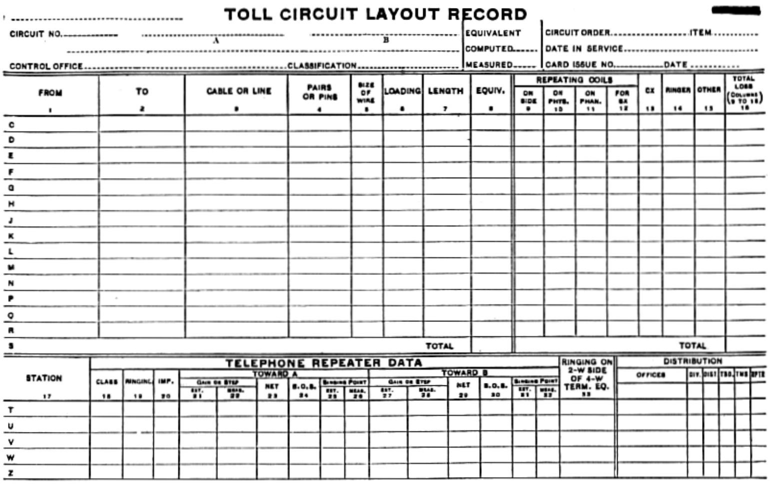



Fig. 3—Map Showing Locations in Bell System of Permanent Transmission Measuring Sets

measuring current is modulated and demodulated in the same manner as voice currents under regular operating conditions and the measured equivalent, therefore, indicates the overall transmission efficiency.

The map of Fig. 3 shows the locations in the Bell System of transmission measuring sets of the general type described above. At a number of the larger toll centers, such as New York and Chicago, where the number of toll circuits to be tested require it, several transmission measuring sets are installed. There are now in operation between 40 and 50 of these sets, making it possible to test all of the longer and more important toll routes in the system. The shorter toll circuits radiating out from the large toll centers are also tested with these same sets. At the smaller offices where fixed transmission measuring sets are not warranted, the toll circuits which cannot be picked up by the larger offices are tested by portable transmission measuring sets of the 1-A or 3-A types in connection with other maintenance work.

One very essential requirement in carrying on a systematic testing program is to have records of the detailed makeup of the toll circuits which give both the circuit layouts and the equipment associated with the circuits. Such a record is valuable, not only in giving the maintenance forces a picture of the circuits and equipment which they are



TOLL CIRCUIT LAYOUT RECORD [redacted]

CIRCUIT NO. ........ A ........ B ........ EQUIVALENT / COMPUTED ..... / MEASURED .....

CIRCUIT ORDER ........ ITEM ........ DATE IN SERVICE ........ CARD ISSUE NO. ........ DATE ........

CONTROL OFFICE ........ CLASSIFICATION ........

| | FROM 1 | TO 2 | CABLE OR LINE 3 | PAIRS OR PINS 4 | SIZE OF WIRE 5 | LOADING 6 | LENGTH 7 | EQUIV. 8 | REPEATING COILS: ON SIDE 9 | ON PHTS. 10 | ON PHAN. 11 | FOR SX 12 | CX 13 | RINGER 14 | OTHER 15 | TOTAL LOSS (COLUMNS 9 TO 15) 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | | | | | | | | | | | | | | | | |
| D | | | | | | | | | | | | | | | | |
| E | | | | | | | | | | | | | | | | |
| F | | | | | | | | | | | | | | | | |
| G | | | | | | | | | | | | | | | | |
| H | | | | | | | | | | | | | | | | |
| J | | | | | | | | | | | | | | | | |
| K | | | | | | | | | | | | | | | | |
| L | | | | | | | | | | | | | | | | |
| M | | | | | | | | | | | | | | | | |
| N | | | | | | | | | | | | | | | | |
| P | | | | | | | | | | | | | | | | |
| Q | | | | | | | | | | | | | | | | |
| R | | | | | | | | | | | | | | | | |
| S | | | | | | | TOTAL | | | | | | | | TOTAL | |

TELEPHONE REPEATER DATA

| | STATION 17 | CLASS 18 | RINGING 19 | IMP. 20 | TOWARD A: GAIN OR STEP EST. 21 | MEAS. 22 | NET 23 | S.O.S. 24 | SINGING POINT EST. 25 | MEAS. 26 | TOWARD B: GAIN OR STEP EST. 27 | MEAS. 28 | NET 29 | S.O.S. 30 | SINGING POINT EST. 31 | MEAS. 32 | RINGING ON 2-W SIDE OF 4-W TERM. EQ. 33 | DISTRIBUTION: OFFICES | DIV. | DIST. | TSO. | TMS | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | | | | | | | | | | | | | | | | | | | | | | | |
| U | | | | | | | | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | |
| Z | | | | | | | | | | | | | | | | | | | | | | | |

Fig. 4—Sample of a Toll Circuit Layout Record Card

testing, but it also furnishes a means for establishing the transmission standards to which they should work. When transmission tests indicate trouble, this record becomes of particular service in locating and clearing the cause.

Fig. 4 shows a sample of the type of toll circuit layout record card which has proven very satisfactory and is now generally used in the Bell System.

*Telephone Repeater and Carrier Maintenance.* Voice frequency telephone repeaters were discussed in a paper by Messrs. Gherardi and Jewett[3] and carrier systems in a paper by Messrs. Colpitts and Blackwell.[4] The various arrangements of amplifiers to provide for telephone repeater and for carrier operation as described in these papers make up integral parts of toll circuits and introduce elements

[3] Gherardi and Jewett, "Telephone Repeaters," *Transactions of A. I. E. E.*, 1919, Vol. XXVIII, part 2, pps. 1287 to 1345.

[4] Colpitts and Blackwell, "Carrier Current Telephony and Telegraphy," *Transactions of A. I. E. E.*, 1921, Vol. XL, pps. 205 to 300.

in the circuits which have to be given particular local attention in maintaining the overall transmission efficiency. Since both telephone repeaters and carrier employ the same types of vacuum tubes with very similar arrangements for power supply, the maintenance requirements for the two are much the same. The chief items to be observed in both carrier and repeater maintenance are that the gains specified to give a desired overall transmission equivalent be

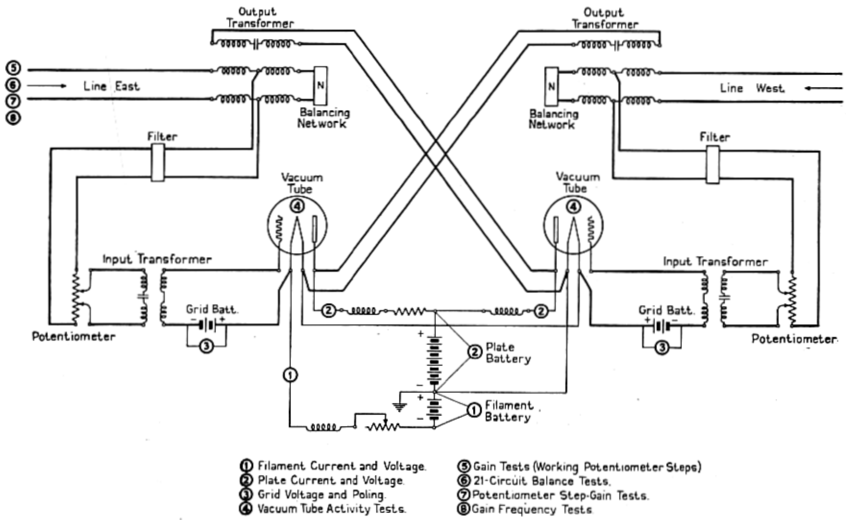
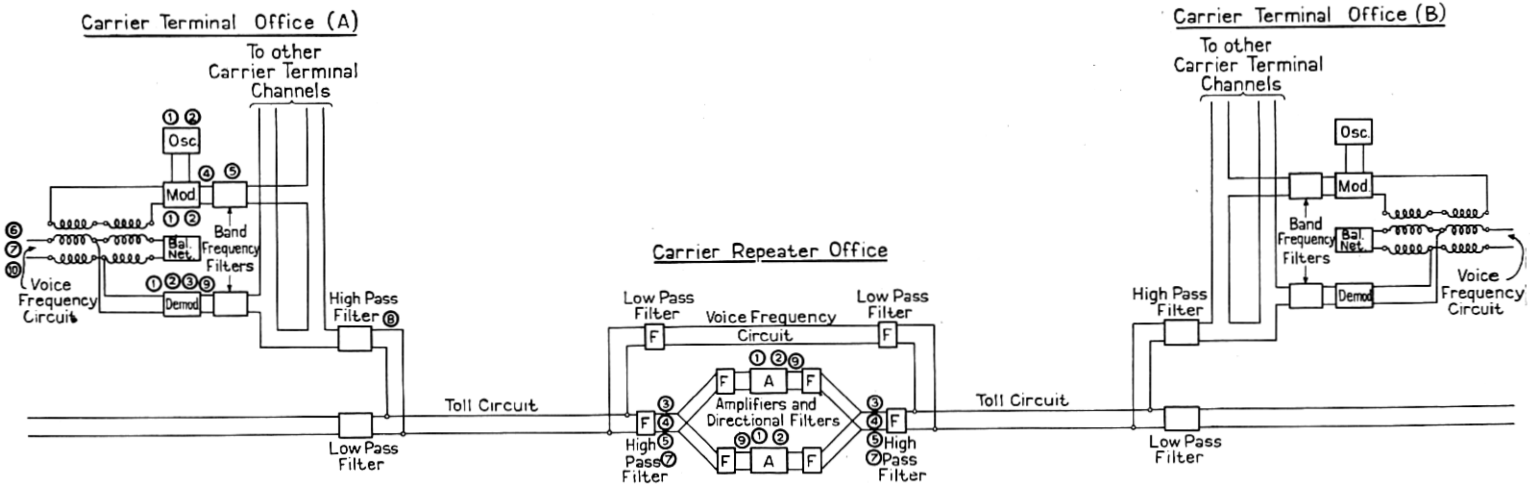



Fig. 5—Schematic Diagram of a 22-Type Telephone Repeater Showing Important Local Transmission Maintenance Tests

kept as constant as possible, that these gains remain fairly uniform within the range of frequencies involved, and that conditions do not exist which will disturb the overall balance between the circuits and networks sufficiently to cause poor quality of transmission.

Considering telephone repeater maintenance, Fig. 5 shows a schematic diagram of a 22 type repeater and indicates the important tests which are made locally to insure that the apparatus is functioning in a satisfactory manner as a part of a toll circuit. The numbers applied to the different tests listed in the figure show approximately the points in the repeater circuit at which the tests are made, the purposes of the tests being evident from their names.

When carrier operation is applied to toll circuits, an additional transmission system is introduced involving the use of currents of higher frequencies than those in the voice range. From a main-




Carrier Terminal Tests

① Filament, Plate and Grid Battery Tests.
② Vacuum Tube Activity Tests.
③ Channel Rectified Received Current Tests.
④ Modulator Output.
⑤ Modulator Band Filter Output.
⑥ Channel Loop Gain Tests.
⑦ 21 Circuit Balance Tests on Voice Frequency Circuits.

Overall Tests of Complete Carrier System

⑧ Tests of total Carrier Output Current into Toll Circuit.
⑨ Tests of Carrier Current at Repeater Outputs and finally Rectified Received Current at Distant Terminal.
⑩ Overall Transmission Tests.

Carrier Repeater Tests

① Filament, Plate and Grid Battery Tests
② Vacuum Tube Activity Tests
③ Gain Tests.
④ Potentiometer Step-Gain Tests.
⑤ Gain-Frequency Tests.
⑥ Check of Frequency of Test Oscillator (not shown in figure.)
⑦ High Frequency Singing Tests.

⑨ Output Current on Overall Test of System.

Carrier Terminal Tests similar to those listed for Office (A)

Fig. 6—Schematic Diagram of a Carrier Telephone System Showing Important Transmission Maintenance Tests for Carrier Repeaters, Carrier Terminals and Overall

tenance standpoint this means that certain additional testing methods must be employed which will insure the proper generation and transmission of the carrier currents and that the modulation and demodulation of the voice frequency currents is accomplished without distortion or excess loss in overall transmission.

To give a general picture of the more important features involved in the transmission maintenance of carrier systems, Fig. 6 shows a schematic diagram of a carrier layout having one carrier repeater. The particular arrangement shown is for the type *B* system described by Messrs. Colpitts and Blackwell,[4] although the same general maintenance considerations apply to any of the present systems. It will be noted that three series of tests are required, one for the carrier repeaters, one for the carrier terminals and one for the system as a whole. The nature of these various tests and the approximate points in the carrier system where they are applied will be evident from the names and numbers used in the figure.

For both telephone repeaters and carrier systems, provision is made in the regular testing equipment so that the tests can be very quickly applied both as a routine proposition and also when required for trouble location.

## Transmission Tests on Exchange Area Circuits

The transmission conditions in the exchange area plant are important not only from the standpoint of insuring good local service but also to insure good toll service, since the local plant forms the terminals of toll connections. The exchange or local plant offers a somewhat different transmission maintenance problem than the toll plant, particularly with respect to the routine testing procedures which must be followed to insure satisfactory transmission. This will be evident when it is considered that in each city and town a complete telephone system is in operation which involves the use of a large number of circuits of various types. There are also in use three general types of telephone switching equipments; manual, panel machine switching, and step-by-step machine switching, and in certain cities combinations of these equipments. It is estimated that at the present time in the Bell System there are in the neighborhood of two and one-half million exchange area circuits, exclusive of subscribers' lines, involving equipment other than contacts and wiring which may directly affect the transmission of speech.

The general classes of exchange area circuits in both manual and machine switching offices, important from a transmission maintenance standpoint, are listed in Table I. The operating features of manual telephone systems are generally well known as are also the features of step-by-step machine switching systems, both having been in use for many years. The panel machine switching system which is a relatively recent development was described in a paper by Messrs. Craft, Morehouse and Charlesworth.[5]

TABLE I

*Classification of Circuits in the Exchange Area Plant Important from a Transmission Maintenance Standpoint*

MANUAL OFFICES

| Local Switchboards | P. B. X. Switchboards | Toll Switchboards | Toll Testboards |
|---|---|---|---|
| Cord circuits | Cord circuits | Cord circuits | Composite set circuits |
| Operators' circuits | Operators' circuits | Operators' circuits | Composite ringer circuits |
| Trunk circuits | Trunk circuits | Trunk circuits | Phantom & simplex circuits |
| Miscl. circuits | Miscl. circuits | Miscl. circuits | Miscl. circuits |

Subscribers' loops and sets
Operators' telephone sets

MACHINE SWITCHING OFFICES

| Panel | Step by Step |
|---|---|
| District selectors | Connectors |
| Incoming selectors | Toll selectors |
| Trunk circuits | Trunk circuits |
| Miscl. circuits | Miscl. circuits |

Subscribers' loops and sets
Operators' telephone sets for
Special service positions

General classes of exchange area circuits involving equipment other than contacts and wiring which affect telephone transmission.

While it may appear at first hand from the above discussion that transmission testing in the exchange plant is a complicated and expensive matter, this has not proven to be the case. It has been found by experience that the systematic use of transmission measuring sets, following the testing methods which have been developed provides a means for periodically checking transmission conditions with a relatively small amount of testing apparatus and with a small maintenance force. All of the transmission circuits exclusive of subscribers' lines in a 10,000-line central office, either manual or machine switching, can, for example, be completely tested by two men in a

[5] Craft, Morehouse and Charlesworth, "Machine Switching Telephone System for Large Metropolitan Areas," *Journal of the A. I. E. E.*, April, 1923.

period of from two to four weeks, (five and one-half 8-hour days per week assumed) any trouble found being cleared as the testing work is done. The maintenance of the subscribers' lines is not included in this work since it is taken care of by other methods as outlined later.

In order to give a general picture of the application of transmission testing in the exchange telephone plant, a brief discussion of the methods employed in both manual and machine switching systems is given below. In either system the loop method of testing proves

Fig. 7—Illustration of a 3-A Transmission Measuring Set Being Operated in a Manual Office

most satisfactory, that is, one measuring set is used and where both terminals of a circuit are available as in cord circuits, a loop test through the circuit is made. In testing trunk circuits two trunks are looped together at their distant terminals and a measurement made on the two combined.

*Transmission Tests on Manual Exchange Area Circuits.* In central office, P. B. X. and toll switchboards, the cord circuits and associated operators' circuits are tested by using a portable transmission measuring set, moving this along the boards as required to pick up the cords. Fig. 7 shows a 3-A transmission measuring set being operated at an

A switchboard position. The cords are picked up and plugged directly into the set as shown and measurements made of the loss of both the cord and operator's circuits. Trunk circuit tests are made at the switchboards in the same manner as previously described for loop transmission tests on toll circuits, portable measuring sets such as shown in Fig. 7 generally being employed for this work. Operators' sets are inspected periodically and transmitter and receiver efficiency testing methods are under field trial which provide a means for testing these instruments in central offices. The miscellaneous transmission circuits in an office are tested at the points where they can be most conveniently picked up. The tests on toll test board circuits are made at this board and involve chiefly loop tests on the equipment associated with the toll circuits in the office and tests on the toll line circuits between the toll testboard and toll switchboard.

*Transmission Tests on Machine Switching Circuits.* The transmission circuits in panel machine switching systems are identical to those in manual systems, while these circuits in step-by-step systems are of a different design but essentially the same as far as transmission losses are concerned. Transmission tests on machine switching circuits are similar to those on manual circuits but involve special methods for picking up the circuits and holding them while the measurements are made. The standard types of transmission measuring sets are used in this work in conjunction with the regular testing equipment provided in the machine switching offices and the methods which have been developed offer a quick and convenient means for making the tests. In manual offices the circuits terminate in jacks or plugs at switchboards where they are readily accessible. In machine switching systems, provision is made for terminating the circuits in jacks at test desks or frames where they can be picked up by patching cords and tested as conveniently as the corresponding types of circuits in manual offices. Machine switching systems offer an important advantage in transmission testing work, particularly in trunk testing, in that the circuits to be tested can be looped automatically by the use of dials or selector test sets, thereby doing away with the necessity for having someone at the distant office complete the loops manually.

In panel machine switching offices the circuits involving transmission equipment corresponding to cord circuits are the "district" and "incoming" selectors. These are tested by setting up the transmission measuring set at the district or incoming frames and connecting the set to the test jacks associated with the circuits. Tests on trunks between manual and panel machine switching offices where both systems are in operation in the same exchange area are generally made from the manual office, the loops being dialed from the *A* switchboard, while trunks between two machine switching offices are tested from the outgoing end of the trunks.

Fig. 8 shows a 3-A transmission measuring set as used in a machine switching office ready for making tests on district selectors. To

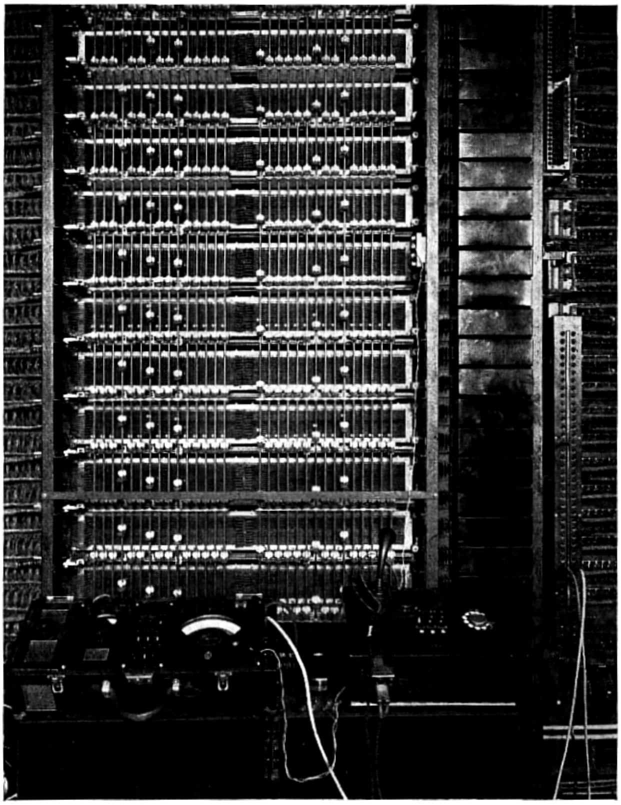


Fig. 8—Illustration of a 3-A Transmission Measuring Set, Set up in a Panel Machine Switching Office for Testing District Selectors

illustrate the general method of testing panel machine switching circuits, the upper diagram of Fig. 9 shows the schematic arrangement for measuring trunks between two panel machine switching offices. The transmission measuring set is located at office A, and connection made to the outgoing end of the trunks to office B through the test jacks at the trouble desk. A standard selector test set used in local maintenance work and a high impedance holding coil are also connected to the trunks through the measuring set, these being used to establish the loop and hold this loop while the tests are made. At office B two spare multiple circuits are cross-connected at the main distributing frame. Any two trunks in the group can then be auto-

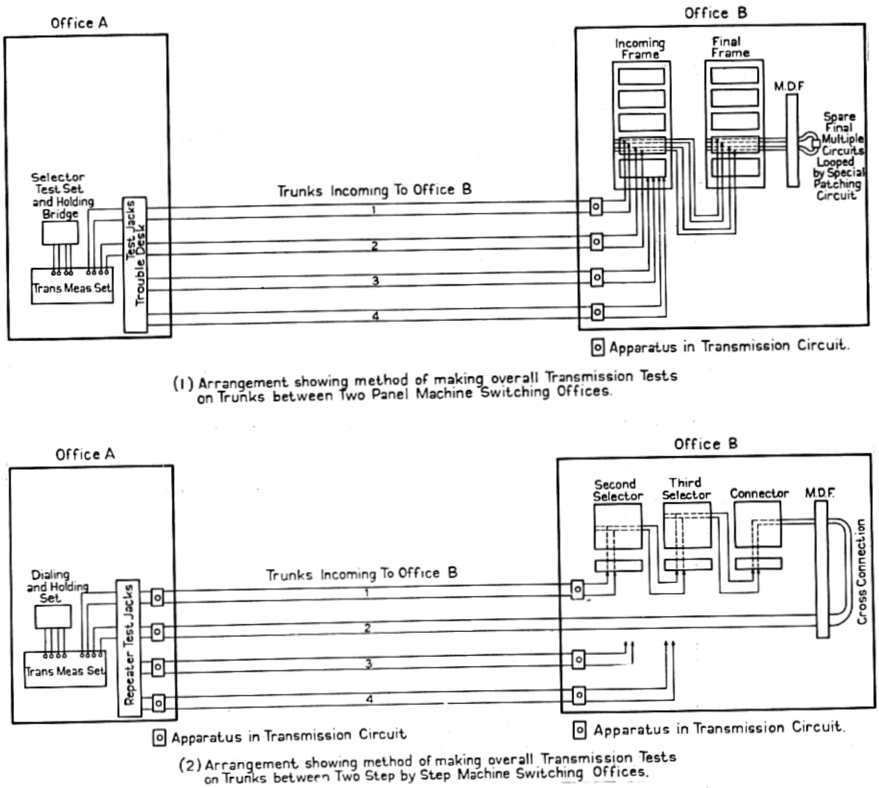



Fig. 9—Schematic Diagrams Showing Methods of Making Transmission Tests on (A) Trunks Between Panel Machine Switching Offices and (B) Between Step by Step Machine Switching Offices

matically looped together at office B by the use of the selector test set which functions to connect the trunks to the two spare multiple circuits previously cross-connected at office B.

In step-by-step machine switching offices the circuits involving transmission equipment corresponding to cord circuits are the connectors. Each connector is provided with a test jack through which connection can be made to a transmission measuring set and the loop completed over a test trunk by dialing. Local selectors do not contain any equipment other than contacts and wiring in the transmission circuits but these can be tested in the same manner as connectors if it is desired to check the wiping contacts and wiring. Toll selectors which involve equipment in the transmission circuit can also be tested in the same manner as connectors. Trunks between manual and machine switching offices can be most conveniently tested from the manual office, the trunk loops being established directly by dialing.

To illustrate the general method of testing step-by-step machine switching circuits, the lower diagram of Fig. 9 shows the schematic circuit arrangement for testing trunks between two machine switching offices. The transmission measuring set is located at office A in a position so that it can be patched to the outgoing trunk repeater test jacks and an arrangement for dialing and holding is connected to the trunks through the measuring set. At office B the apparatus in one trunk is disconnected and this trunk used as a test trunk by cross-connecting it at the main distributing frame to a spare subscriber's multiple terminal. All trunks in the group can then be tested by dialing over them, from office A, the number of this spare terminal at office B which automatically loops them back over the test trunk.

*Maintenance of Subscribers' Lines and Stations.* The circuits making up subscribers' lines from switchboard to instruments consist simply of pairs of conductors, almost always in cable, with the necessary protective devices. These can be checked by certain d-c. tests described in a recent paper.[6] Equipment is also provided in local test boards for use in making talking transmission tests between the station and the test boards. Accurate machine methods for determining the efficiency of transmitters and receivers have been developed for testing new instruments and instruments returned from service.

*General Scheme of Testing Exchange Area Circuits.* The plan being followed in the Bell System for systematically checking the transmission conditions of exchange area circuits is to have all offices tested periodically by men equipped with portable transmission measuring sets who travel from office to office. It has been found by experience that after an office has once been tested and any transmission troubles eliminated, it is only necessary thereafter to make transmission tests at infrequent intervals, these subsequent tests serving primarily as a check on the local maintenance conditions.

[6] W. H. Harden, "Electrical Tests and Their Applications in the Maintenance of Telephone Transmission," *Bell System Technical Journal*, July, 1924.

With a testing plan of this kind large areas can be covered by a small traveling force with a small amount of testing equipment. This results in a very economical transmission testing program while at the same time insuring that transmission conditions are maintained satisfactorily.

Fig. 10 shows a typical transmission testing team layout. The team is equipped with an automobile which proves an economical means of transportation between offices and exchange areas and

Fig. 10—Illustration of a Typical Transmission Testing Team Layout

provides a convenient method for carrying the testing equipment. During transportation this equipment is packed in padded trunks which insures against injury. In this particular case the equipment includes, in addition to transmission testing sets and oscillators, other apparatus such as a wheatstone bridge, crosstalk set and noise measuring set so that other maintenance work may be done in connection with transmission testing whenever this is desired.

## Results Accomplished

The results accomplished in transmission maintenance work can best be appreciated by considering the kinds of troubles which adversely affect transmission and which can be detected and eliminated by routine testing methods. Consideration is first given to the general causes of troubles which are detrimental to both toll and local transmission, and later the features in this connection more particularly identified with telephone repeaters and carrier systems are discussed.

The different classes of circuits given in Table I are made up of various combinations of the following individual parts:

| | | |
|---|---|---|
| Repeating Coils | Plugs | |
| Retardation Coils | Jacks | |
| Relays | Keys | |
| Condensers | Heat Coils | |
| Resistances | Carbons | |
| Auto-Transformers | Wiring | Switchboard to M. D. F. |
| Induction Coils | | Cross-connection |
| Loading Coils | | Outside |
| Cords | Transmitters | |
| | Receivers | |

The above parts are combined in various ways to make up the complete operating circuits such as cord circuits, operators' circuits, trunk circuits, etc. Each complete circuit causes a definite normal loss to telephone transmission which must be taken account of in designing the plant to meet the various service requirements. If, however, any of the parts used are defective, if the wrong combinations of parts are used, or if the installation work is not correctly done, excess transmission losses will result which may very seriously affect the transmission when the particular circuits involved are employed in an overall connection.

*Classification of Common Types of Troubles.* An analysis of a large amount of transmission testing data has made it possible to develop a definite trouble classification which is particularly helpful in transmission maintenance work and which permits the most efficient use of the results in eliminating transmission troubles. Experience has shown that the troubles found can be divided into two general classes, A—troubles which can be detected either by simple d-c. or a-c. tests in connection with the regular day-by-day maintenance work or by transmission measuring sets, and B—troubles which can be detected most readily by transmission measuring sets. The most important troubles in the above classes are as follows:

| Class A | Class B |
|---|---|
| Opens | Electrical Defects |
| Grounds | Incorrect Wiring |
| Crosses | Wrong Type of Equipment |
| Cutouts | Missing Equipment |
| | High Resistance |
| | Low Insulation |

If, in making transmission tests in a central office, a high percentage of Class A troubles is found the remedy is generally to instigate more rigid local maintenance routines paying particular attention to the type of circuits in which the troubles are located. The percentage of Class B troubles is not as a rule as high as the Class A troubles and experience has shown that when Class B troubles are once eliminated by transmission testing methods only infrequent subsequent tests are required to take care of any additional troubles of this class which may get into the plant.

In determining what constitutes an excess loss, the value of the transmission as well as the practical design and manufacturing considerations to meet operating limits are taken account of. An excess gain is also considered as a trouble on circuits equipped with amplifiers, since this may produce poor quality of transmission which is likely to be more detrimental to service than an excess loss. The value of transmission based on economical design considerations varies, depending on the first cost and annual charge of the particular types of circuits involved. A gain of one TU in the toll plant is generally worth more, for example, than one in the local plant, since it costs more to provide. In transmission maintenance work the cost of making transmission tests and clearing trouble is balanced against the value of the transmission gained for the purpose of establishing economical transmission limits to work to.

*Specific Examples of Common Troubles Found and Their Effect on Transmission.* Certain kinds of troubles which are detected by transmission measuring sets do not cause excess losses which can be quantitatively measured. Such troubles are, however, readily detected by "ear balance" transmission measuring sets in that they cause noise or scratches and by the "meter balance" sets from fluctuations of the needle of the indicating meter. The most common trouble of this kind is due to cutouts or opens which may be caused by dirty connections, loose connections, improper key and relay adjustments, etc. While not causing a quantitative value of excess loss, this class of trouble is very detrimental to transmission and more serious in many instances than fixed excess losses. Indeterminate troubles of this nature are given an arbitrary excess loss value based on experience.

Considering troubles which give definite losses, the most common kinds are caused by electrical defects in equipment, incorrect wiring of equipment in circuits and wrong types of equipment. The other classes of troubles, such as crosses, high resistances, and low insulation, also generally give measurable excess losses but these are not as common in the plant, since troubles of this nature are more likely to affect the signaling and operation of the circuits and are, therefore, eliminated by the regular maintenance work. Missing equipment will in certain cases cause a gain in transmission but affects the circuits adversely in other ways.

Typical examples of common troubles, with the excess losses which they cause, are given in the following table:

| Type of Circuit and Equipment | Cause of Trouble | Approximate Excess Transmission Loss[7] |
|---|---|---|
| Repeating coils in cords, incoming trunk circuits, selectors, toll connectors | Electrical defects (Generally short circuited turns) | 1.5 to 5.0 TU |
| | Incorrect wiring (Generally reversed windings) | 2.0 to 13.0 TU |
| Supervisory relays in "A" cord circuits | Electrical defects (Open non-inductive winding) | About 2.5 TU |
| Bridged retardation coils or relays in toll cord circuits, composite sets, connectors and step-by-step repeaters | Electrical defects (Generally short circuited turns) | 1.0 to 5.0 TU |
| Repeating coils on loaded toll switching trunks | Wrong type of equipment, incorrect wiring | 1.0 to 4.0 TU |
| Induction coils in operators' telephone sets | Electrical defects. Incorrect wiring | 1.0 to 13.0 TU |

There are, of course, many other specific types of troubles detected by transmission tests which give definite quantitative losses but the above will serve to illustrate the value of this testing work in eliminating excess losses in a telephone plant.

*Maintenance Features Peculiar to Telephone Repeaters and Carrier Systems.* The same classification of troubles discussed above applies to repeaters and carrier systems. Amplifier equipment, however, employs certain features which are not common to the more simple telephone circuits and some of the troubles which may occur if the proper maintenance procedures are not followed will seriously affect service. It is for this reason that repeater and carrier installations are provided with special testing equipment which is always available for use either in routine maintenance or in locating and clearing any troubles which may occur in service. Automatic regulating devices are also provided wherever this is practicable in order to reduce to a minimum the amount of manual regulation and maintenance.

[7] W. H. Martin, "The Transmission Unit," *Journal of the A. I. E. E.*, June, 1924; *B. S. T. J.*, Vol. III, p. 400, 1924; C. W. Smith, "Practical Application of Transmission Unit," *B. S. T. J.*, Vol. III, p. 409, 1924.

The important elements in both repeaters and carriers which may directly affect transmission or cause service troubles in other ways are as follows:

| | |
|---|---|
| Filament Batteries | Potentiometers |
| Plate Batteries | Filters |
| Grid Batteries | Transmission Equalizers |
| Vacuum Tubes | Signaling Equipment |
| Balancing Equipment | Patching Arrangements |

The tests outlined in the main body of the paper aim to insure that the above essential parts of repeater and carrier circuits are functioning properly and that the equipment as a whole is giving the desired results in overall transmission efficiency.

### Conclusion

The above discussion of testing methods and the results accomplished indicate how a comprehensive and economical transmission maintenance program can be applied to a telephone plant to check the volume efficiency of the circuits against the established standards. Consideration is continually being given to new testing methods and their applications in order that further improvements in service may be effected and increased economies in testing taken advantage of.

## APPENDIX A

### Principles of Testing Methods Closely Associated with Transmission Efficiency Tests

Tests of volume efficiency often need to be supplemented by other methods of testing in transmission maintenance work. Transmission efficiency both as regards volume and quality may be seriously affected by noise or crosstalk, and tests for any conditions of this kind are therefore important in maintenance work.. Furthermore when efficiency tests show excess losses or unsatisfactory circuit conditions other testing methods prove very valuable in locating the cause.

To illustrate this phase of transmission maintenance the principles of some of the more important testing methods are briefly described below. Two of the tests employ a method very similar to loop transmission testing while others employ the well known "null" method. A special method employing three winding transformers and amplifiers widely used to determine impedance balance conditions between lines and networks is also described. Several methods which involve simply current and voltage measurements have been mentioned in this paper but these are generally well known and therefore require no detailed description.

## 1. Measurements of Crosstalk

In the circuit shown in Fig. 11, if a-c. power is supplied to a circuit known as the "disturbing" circuit and unbalances exist between this circuit and a second known as the "disturbed" circuit, power will be transferred from one circuit to the other causing crosstalk in the second. A definite power transmission loss therefore takes place between the two circuits which can be measured by a loop transmission test similar to the efficiency tests described in the main body of the paper. An adjustable shunt called a "crosstalk meter" cali-

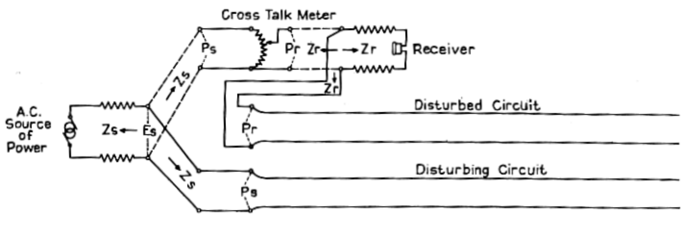



Fig. 11—Diagram Showing Principles of Crosstalk Measurements

brated in either *TU* or in crosstalk units is substituted for the two circuits. With the same power supplied alternately to both the "disturbing" circuit and the meter and with the sending and receiving end impedance conditions as shown, the meter shunt is adjusted until, in the opinion of the observer, the annoyance produced by the tone in the receiver is judged to be equal for the two conditions. The reading of the shunt if there was no distortion of the line crosstalk currents would then give the volume of crosstalk which could be expressed in *TU* as 10 $\log_{10} P_r/P_s$ similar to loop transmission testing. However, this relation only holds approximately in practise since the line crosstalk measured is produced by various currents having different phase relations and a certain amount of distortion therefore occurs. The commercial form of crosstalk set now used is equipped to give the approximate impedance relations required and also provides a feature for eliminating the effect of line noise except in the case of one type of measurement which is made on long cable circuits. For practical reasons the results are generally expressed in crosstalk units rather than *TU*.

## 2. Measurements of Noise

The common method of measuring noise in a telephone circuit is shown in the diagram of Fig. 12. In this test an artificial noise current produced by a generator of constant power $P_s$ called a "noise standard" is substituted for the line noise current. If the two noise currents were exactly alike as regards wave shape and the relative magnitude of the frequencies involved they would produce the same tone in the receiver and their volumes could be made equal by adjustment of the noise shunt. The power ratio, $P_r/P_s$, as indicated

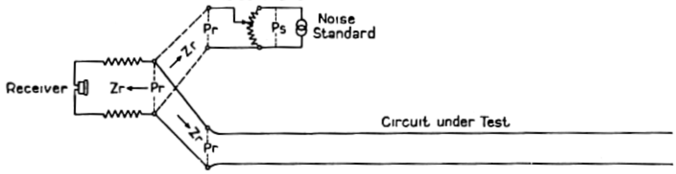
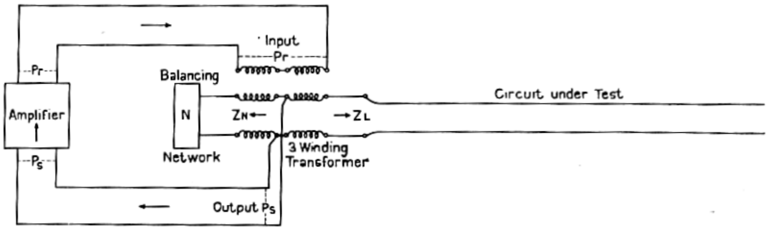



Fig. 12—Diagram Showing Principles of Noise Measurements

by the shunt, would then give a measure of the line noise in terms of the noise standard. This condition, however, is not met with in practise due to differences in wave shape of the two noise currents. For this reason noise measurements are made by adjusting the noise shunt until the interfering effects of the noise on the line and from the shunt are judged to be the same for which condition the power supplied to the receiving network by the noise standard is not necessarily the same as that supplied by the line. The receiving end impedances however, are kept as nearly alike as practicable to prevent reflection losses.

## 3. Measurements of Line-Network Balance (21-Circuit Balance Test)

The testing arrangement of Fig. 13 shows the principle of the 21-circuit balance test referred to in the main body of the paper in connection with telephone repeater and carrier maintenance. In this test the gain of an amplifier calibrated in *TU* is used to compensate for the loss through a three winding transformer or output coil of a telephone repeater. If the impedances of the balancing network and line were exactly alike at all frequencies, *i.e.*, $Z_n = Z_L$, and no other unbalances existed in the circuit none of the power supplied by the amplifier to the input of the three-winding transformer would be transferred to the output, *i.e.*, the power ratio $P_s/P_r$ would be infinity. However, this ideal condition cannot be produced in practise so that there is always a finite power loss between the input and output of the transformer which can be measured approximately by the gain of an amplifier calibrated in *TU*. An internal




Measurements of Impedance Balance Between Lines and Networks
(21-Circuit Tests on Telephone Repeaters and Carrier)

Fig. 13—Diagram Showing Principles of 21 Circuit Balance Tests

path for currents which may produce "singing" or a sustained tone is established if the gain of the amplifier $P_r/P_s$ is greater than the loss $P_s/P_r$ through the three-winding transformer. As unbalances between network and line become greater the loss through the three-winding transformer becomes less thereby requiring less gain in the amplifier to produce a "singing" condition. It should be noted in this connection that to produce the condition described above exactly, the current received around the "singing" path must be in phase with the starting current. In practise this condition obtains sufficiently accurately so that the gain of the amplifier required to produce "singing" gives an approximate measure of the impedance balance between line and network.

## 4. Measurements of Resistance, Reactance and Impedance

Diagram (a) of Fig. 14 shows the wheatstone bridge circuit for d-c. resistance measurements. It is unnecessary to describe the well known principles of this bridge but mention is made of it here in view of its importance and use in telephone maintenance work. It supplies an indispensable method of measurement for certain trouble locations, such as crosses and grounds and embodies the fundamental principles of all null tests.

Diagram (b) of Fig. 14 gives a bridge circuit for measuring impedance, the particular arrangement shown being for measurements of impedances having inductive reactance. The bridge measurements express impedance in terms of its resistance component and equivalent inductance or capacity. In measuring an impedance having inductive reactance at any frequency, $f$, for example, a balance gives $R=R_x$ and $L=L_x$. At the frequency $f$, the effective resistance is given directly by the value of $R$ and the reactance by the relation, $2\pi f L$.

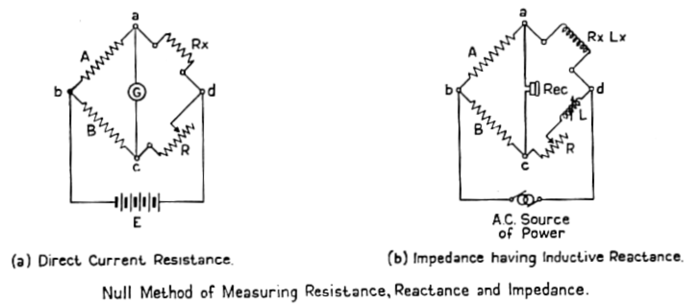


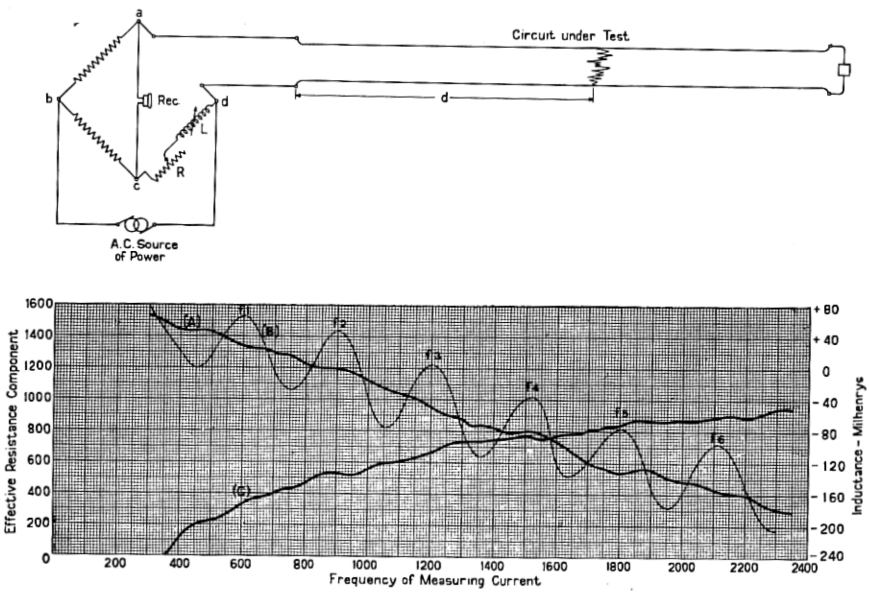

Fig. 14—Diagrams Showing Principles of Null Methods for Measuring Resistance, Reactance and Impedance

The impedance is the vectorial sum of these two or $\sqrt{R^2+(2\pi f L)^2}$. In maintenance work involving impedance measurements as will be noted in the next testing method described, the effective resistance component and the equivalent inductance are generally used directly without combining.

## 5. Measurements of Line Impedance and Location of Impedance Irregularities

Fig. 15 shows a telephone circuit connected to a bridge and terminated at its distant end in characteristic impedance. If the circuit has approximately uniform impedance throughout its length the resistance and equivalent inductance curves of this impedance within a range of frequencies will be fairly smooth as indicated by $A$ and $C$ of the figure. The curves are not perfectly smooth since it is not practicable to construct the line for perfect impedance uniformity. If at some point in the circuit an irregularity is present such as an omitted loading coil, an inserted length of line of different construction, etc., which changes the impedance, this will produce a periodic change in the resistance and inductance curves $A$ and $C$ such as shown by Curve $B$. Curve $C$ will be changed in the same way as Curve $A$ but for simplification this is not shown on the diagram.

The change in impedance in the circuit reflects some of the current sent out back to the sending end where it adds to or subtracts from the sending current depending on the phase relations of the two currents at any particular frequency. Since impedance equals $E/I$ its value changes as the value of $I$ changes. This is made use of in line impedance measuring work to give a location of impedance irregularities which may exist somewhere in the line.




Null Method of Measuring Line Impedance and Locating Impedance Irregularities

Fig. 15—Diagram and Impedance Curves Showing Principles of Line Impedance Measurements by Null Method and Location of Impedance Irregularities

Referring to Fig. 15, let $d$ equal the distance in miles to an impedance irregularity and $f$, one frequency at which the resistance component of the impedance is a maximum. The next maximum point will occur at a frequency $f_2$ such that as the frequency has been increased, one complete wave length is added in the distance traveled by the reflected current. Maximum points at $f_3$, $f_4$, etc., occur in the same way as the frequency is increased. Considering the two values $f_1$ and $f_2$ let

$V$ = velocity of current in miles per second

$W_1$ = wave length at frequency $f_1$

$W_2$ = wave length at frequency $f_2$

$N$ = number of wave lengths in distance traveled by reflected current or $2\,d$.

At frequency $f_1$ then,

$$N = \frac{2d}{W_1}$$

and at $f_2$,
$$N + 1 = \frac{2d}{W_2}$$

also at $f_1$,
$$W_1 = V/f_1$$

and at $f_2$,
$$W_2 = V/f_2$$

Substituting above

$$N = \frac{2df_1}{V} \text{ and}$$

$$N + 1 = \frac{2df_2}{V}$$

Subtracting,
$$1 = \frac{2df_2}{V} - \frac{2df_1}{V} \text{ or}$$

$$d = \frac{V}{2(f_2 - f_1)}$$

which is the distance in miles from the sending end of the circuit to the point of impedance irregularity. The velocity of propogation $V$ is not exactly constant within the entire frequency range but does not vary sufficiently to materially effect the accuracy of impedance trouble locations by this method.