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New Transmission Measuring Systems for Telephone Circuit Maintenance

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Transmission measurements on telephone circuits have long been recognized as essential aids in the furnishing of good service. Recent development work has produced new testing methods and apparatus which greatly simplify and expedite transmission measuring. This paper gives a brief description of the existing and the new arrangements.

ABOUT two decades ago pioneering work was being done in the development and introduction of methods and apparatus for the measurement of the transmission characteristics of local and toll telephone circuits, it having been realized that with the increasing complexity of the telephone plant, these measurements were necessary to insure satisfactory transmission performance. Transmission measurements now have a well established place in maintenance activity and development work is constantly in progress to improve the testing apparatus so that it can be operated more rapidly and conveniently, will cost less or do more things, and also to improve testing methods.

The principle employed in making transmission measurements has not changed. A standard testing power is supplied to one end of a telephone circuit and the power received at the other end is measured. The ratio between these powers, expressed in decibels, is a measure of the transmission loss or gain in the circuit. The magnitude of the testing powers is small, the sending power for measuring being one-thousandth of one watt and the received power ranging from one ten-thousandth to one-millionth of a watt. Sensitive meters must be used, or the power amplified before measuring it. Direct-current meters are more sensitive than alternating-current meters and it is the practice to convert the weak received alternating current to direct current by means of vacuum tube or copper-oxide rectifiers and employ direct-current meters for measuring it.

Until recently the developments have been along the line of improvements in the apparatus itself, there being practically no change in the general methods and arrangements employed. For the large toll offices where much testing is done the measuring apparatus has been installed at one or more points in an office, the installations being known as transmission test boards. From these points trunks radiate to repeaters, test boards, switchboards, etc., and the circuits and equipment to be tested are connected to them by patching cords or switchboard cords. The testing has been done by a trained force of transmission testers, this force often being separate from that of the test board attendants whose work has consisted chiefly in correcting line faults, signaling troubles, etc., which do not require transmission measurements for their location.

In the local plant, testing has been done almost entirely with portable transmission measuring apparatus in the hands of a transmission testing force who travel from office to office, testing the cord circuits, switching trunks, etc., at intervals of one or two years. The measuring apparatus has been costly and its permanent installation in each office could not be justified. The apparatus used in both local and toll testing has been described in a number of articles.[1,2,3]

During the last few years new methods and apparatus have been developed and radical changes made that greatly improve the situation both from an economic and operating standpoint. The new measuring instruments are much less costly than the types heretofore available and are as stable in operation and as simple to use as ammeters and voltmeters. In the local plant the decrease in cost and complexity and improvement in operating methods has justified permanent installations in many of the larger offices while the newer forms of portable apparatus are being much more extensively distributed than earlier types. For the toll plant the improvement consists in doing away largely with the centralized transmission testing point. The regular test board force now can make transmission measurements at their test boards and the repeater attendants can measure the performance of the repeaters while working on them. The work is so simple and the maintenance forces are so well trained that a special transmission testing force is not required.

This change has been brought about by the development of new instrumentalities and improved circuits, chief among which are more sensitive meters, the copper-oxide rectifier and the negative feedback amplifier.[5] Until recently, the most sensitive meters which were suitable for general use would not measure the weak power used in transmission measuring so that amplification of this power was required. Using the alloy steels now available, meters of much greater sensitivity and equal ruggedness have been manufactured and transmission losses of 20 db can be measured without an amplifier and without using abnormal testing power. Vacuum tubes formerly used to rectify the received alternating current testing power have been largely superseded by the copper-oxide rectifier which is small, inert and requires no added power for its operation. The combination of this rectifier with sensitive meters greatly simplifies and reduces the cost of the measuring apparatus. Figure 1 shows the simplicity of the circuit of a transmission measuring set which will measure losses up to 20 db.

While indicating meters have been used in transmission measuring for many years, it is only recently that they have been calibrated directly in db. This is the preferable way of measuring and its adoption has been delayed only because of the limitations of available apparatus and circuits which prevented a stable device from being developed. The earlier copper-oxide rectifiers were too unstable for

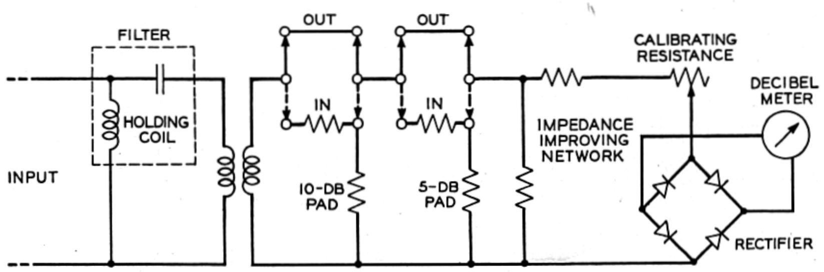

Fig. 1—Simplified circuit of transmission measuring set having a range of 20 db without an amplifier.

measuring and until the development of the negative feedback amplifier, all vacuum tube amplifiers varied in amplification with changes in filament and plate voltage and the aging of tubes. The voltage of available power plants, while sufficiently stable for commercial use, caused the pointer of the meter in a transmission measuring set to fluctuate and over intervals of a few hours the change might be as much as one db. Smaller changes occurred frequently. These changes were slow enough so that measurements could be made, but they required frequent adjustment of amplifier gain to compensate. With such instability, the most rapid and accurate measurements can be made by using the comparison method of testing where a known "standard" power is attenuated by calibrated potentiometers or networks until it equals the unknown received testing power. A meter in this case serves merely as a means for telling when the two are equal and the result is read from calibrated dials on the attenuator. A majority of the measuring sets now in the plant operate on this "flip flop" principle. The use of these dials generally requires that the measuring instrument be built as a unit and that measurements be made at its location. The latter requirement often prevents its installation at the most desirable point because space is not available.

For toll circuit testing in the larger offices where a considerable number of routine and trouble locating tests are made, the required frequency range and loss range are beyond the scope of a simple copper-oxide rectifier and meter. The ability to make level measurements is also a desirable feature. To meet these requirements, an amplifier is provided in the receiving circuit. By applying the negative feedback principle to the amplifier and rectifier of the latest toll transmission measuring system a remarkably stable circuit has been obtained so that the meter can be calibrated directly in db and oper-

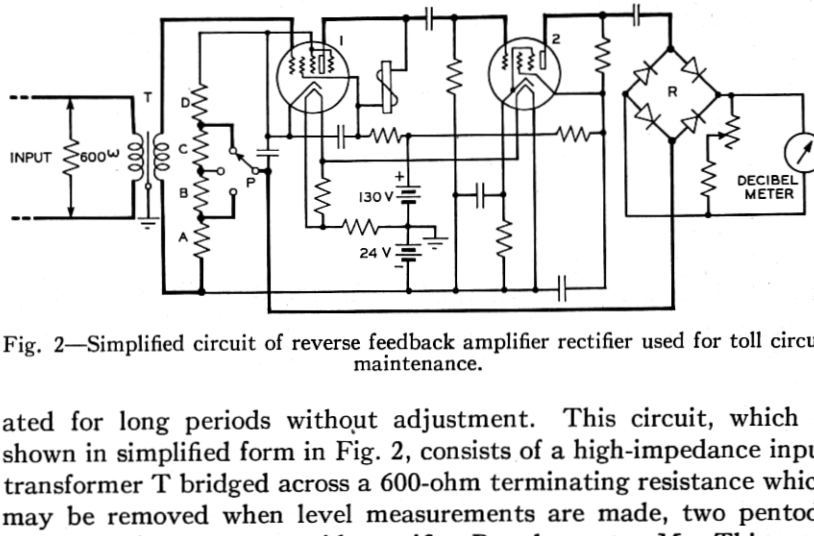

Fig. 2—Simplified circuit of reverse feedback amplifier rectifier used for toll circuit maintenance.

ated for long periods without adjustment. This circuit, which is shown in simplified form in Fig. 2, consists of a high-impedance input transformer T bridged across a 600-ohm terminating resistance which may be removed when level measurements are made, two pentode tubes 1 and 2, a copper-oxide rectifier *R* and a meter *M*. This combination has much more amplification than is required, so the excess is used to improve stability by introducing part of the output voltage into the input circuit of the first tube in such phase relation with respect to the applied input voltage that the net input voltage is reduced. This reverse or negative feedback voltage is introduced into the grid circuit of the first tube through resistances *A*, *B* and *C* by connecting one of the rectifier terminals to the movable arm of the potentiometer *P*. These resistances, and resistance *D* form the cathode drop resistance of the grid circuit and any potential applied across them affects the potential on the grid of the tube. In the position shown, the reverse feedback is a maximum and the net amplification of the amplifier is a minimum. Moving the potentiometer arm to the lowest step gives less feedback and the amplifier net gain is greater.

The principle of stabilization is as follows: If a constant potential is applied to the input terminals of the amplifier a constant potential will also be applied to the grid of the first tube. As long as the tubes or the rectifier do not change in characteristics the output of the rectifier will likewise be constant. Now if through any cause, such as a change in tube characteristics or in the rectifier, the gain of the amplifier-rectifier should increase, the output will increase and the neutralizing voltage fed back into the input circuit will also increase. This will reduce the voltage on the grid so that the net output voltage of the amplifier-rectifier will not be changed noticeably. Conversely, if a change in the tubes or the rectifier should cause a reduction in gain, the voltage fed back into the input circuit will decrease, there will be less feedback voltage and the output voltage will be substantially the same as before. The reverse feedback amplifier-rectifier is so stable that once it is adjusted to have the proper characteristics it will remain constant for long periods.

The meters used with this amplifier-rectifier have a range of 15 db. This is less than the required measuring range so that it is necessary to increase it by changing the amplifier gain in steps of 10 db. The reverse feedback amplifier lends itself readily to this as the variation of a single resistance in the feedback circuit is sufficient and no expensive balanced attenuators are required. In Fig. 2 this is done by potentiometer *P*. In practice this resistance is controlled by relays which form a part of the amplifier, these relays in turn being remotely controlled by keys, jacks or dials at various points in the office.

The db meters can be located where desired without reference to the location of the amplifier-rectifier. They may also be placed in lantern slide projectors which throw a greatly enlarged meter scale on a screen so that it can be read from distances up to 50 feet or more. The new arrangements are extremely flexible, one set of equipment supplying measuring facilities for several different points in an office where previously several sets would be necessary. Where the use of the equipment is intermittent more than one meter may be used with a single amplifier-rectifier. The meters from which the results are read may be of the conventional indicating type which can be mounted on keyshelfs or on vertical panels, they may be of the projector type or they may be of the recording type which records on paper the characteristics which are being measured. All meters are interchangeable, being similar electrically.

These new instrumentalities have removed many of the limitations to the design of measuring systems and the recently developed arrangements are therefore better coordinated with other facilities than those which they replace. A few examples will be given to illustrate the recent advances in transmission measuring work.

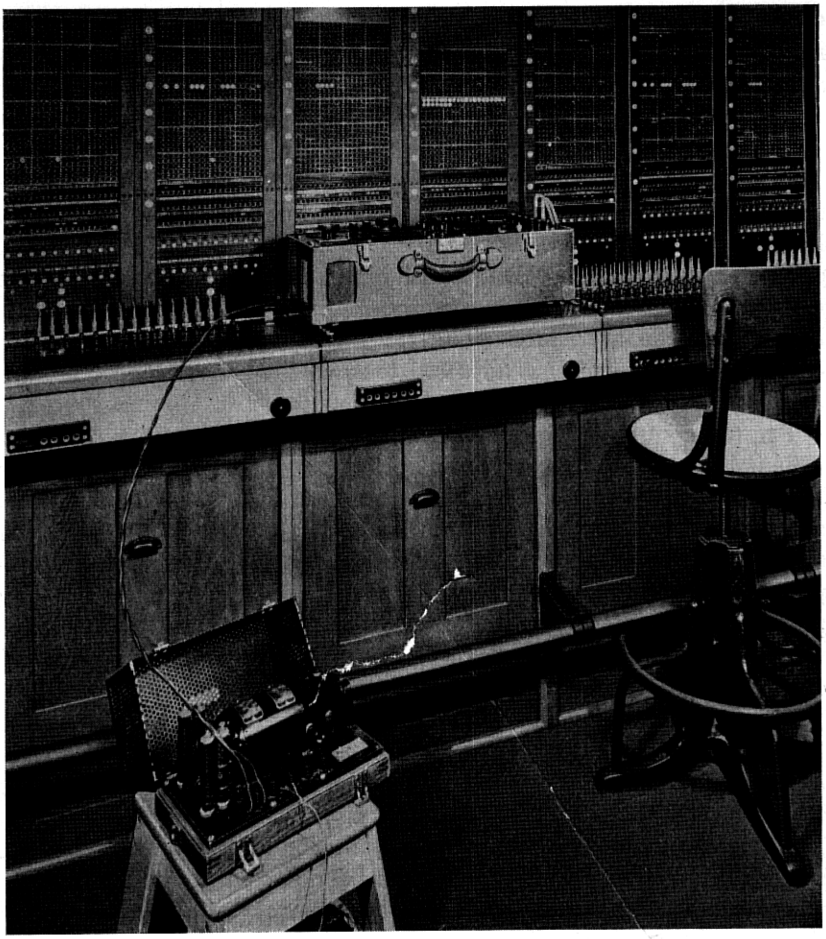

Fig. 3—Transmission measuring set developed about 1920 and associated generator as used at a switchboard in testing cord circuits or interoffice trunks. Both units are required for either sending or receiving.

Figure 3 shows the testing power generator and measuring set developed about 1920 for use in the local plant to measure central office equipment and interoffice trunks with testing power of a single frequency, the frequency employed usually being 1000 cycles. When measuring circuits between offices, it is necessary either to have duplicate sets of equipment at the two ends of the circuit or to connect two circuits together at one end, testing them at the other end as one circuit. This latter arrangement, while not wholly satisfactory, has been the one generally employed because of the greater expense of the

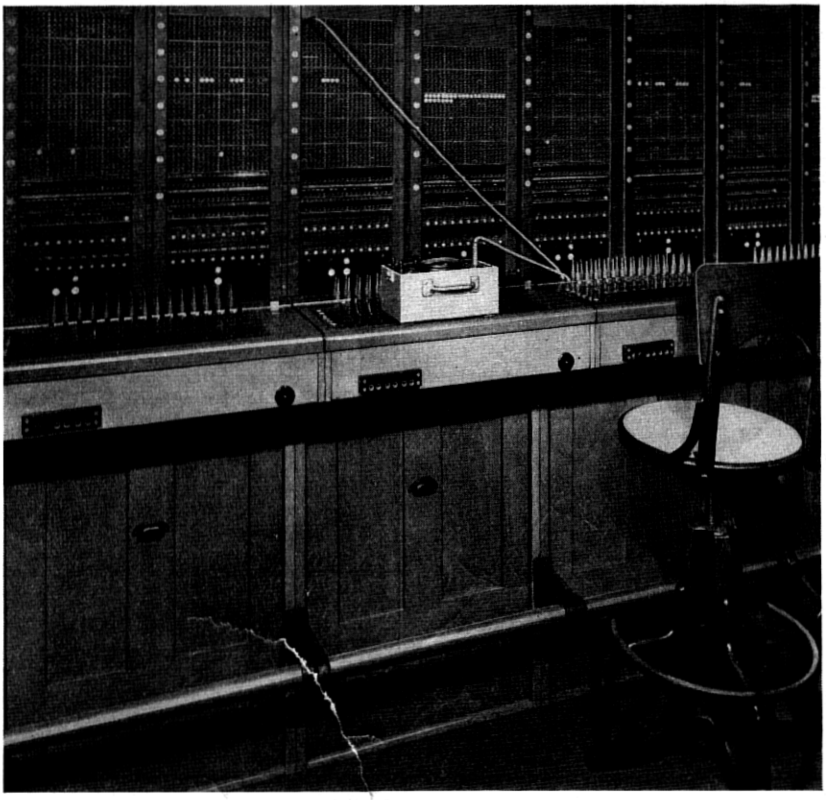

Fig. 4—Latest type of transmission measuring set as used at a switchboard. The associated generator shown in Fig. 5 is usually permanently mounted in the office and testing power is obtained through the multiple as shown. For one-way measurements on circuits between offices, the generator is connected to one end of the circuit and the transmission measuring set at the other, both units not being required at each end.

other method which has involved not only two sets of expensive testing apparatus but two testers, these being necessary because the testing apparatus required frequent adjustment. If circuits between a group of offices in a city are to be tested between circuit terminals rather than by the looping back method, considerable time is consumed in traveling between offices when using this apparatus.

The new apparatus shown in Figs. 4 and 5 not only costs but one-tenth as much and weighs one-quarter as much as the older apparatus but also has electrical advantages which enable a new and improved measuring technique to be employed. The generator is a magneto inductor alternator driven by a 50-cycle or 60-cycle induction motor and gives a constant output without attention. The output is adjusted at the factory or on installation. Some of these machines have

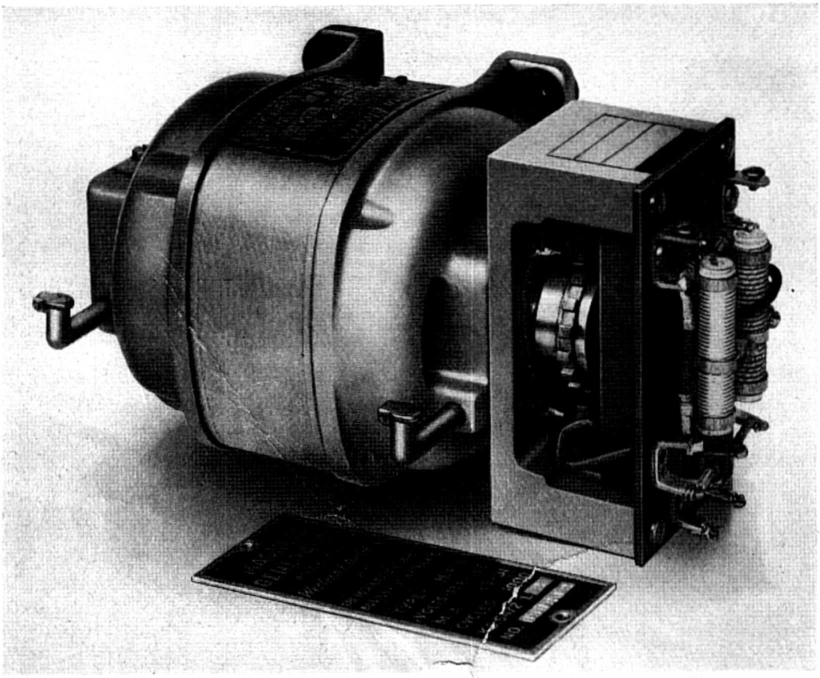

Fig. 5—One thousand-cycle magneto generator used generally for transmission testing. Cover plate removed to show the generator construction. Overall length 7 inches.

been running continuously for about a year without showing any appreciable change in output. They can, therefore, be mounted permanently in an office and the output terminals wired to convenient testing points so that the generator need not be carried around. Because of this output stability, it is not only unnecessary to have an experienced tester at the distant end of the circuit but in the larger offices auxiliary switching equipment is arranged so that testing power can be supplied automatically to one end of the circuit by direction of the tester at the other end, who simply calls or dials a designated number over the circuit to be tested.[7] The testing power is cut off at the sending end when the connection is broken at the receiving end. Tests can be made in the same manner from private branch exchanges and subscribers' stations without a charge being registered against the subscriber.

Fig. 6—Small receiving set as used to measure the transmission loss of a subscriber's line. The 1000-cycle generator has been connected to the central office end of the line by calling a designated number. When the telephone instrument has been replaced on the mounting, the meter in the measuring set will read the line loss.

The receiving set shown in Fig. 4 is based on the electrical circuit of Fig. 1. It has a transmission range of 20 db, and is provided with all the jacks and facilities required for testing cord circuits, trunks and central office equipment. A still smaller and less expensive receiving set of a similar type having a 10 db range is shown in Fig. 6. It is extremely portable and light and is useful for work where the limited range is sufficient. Jacks and other testing conveniences have been omitted to save bulk and cost.

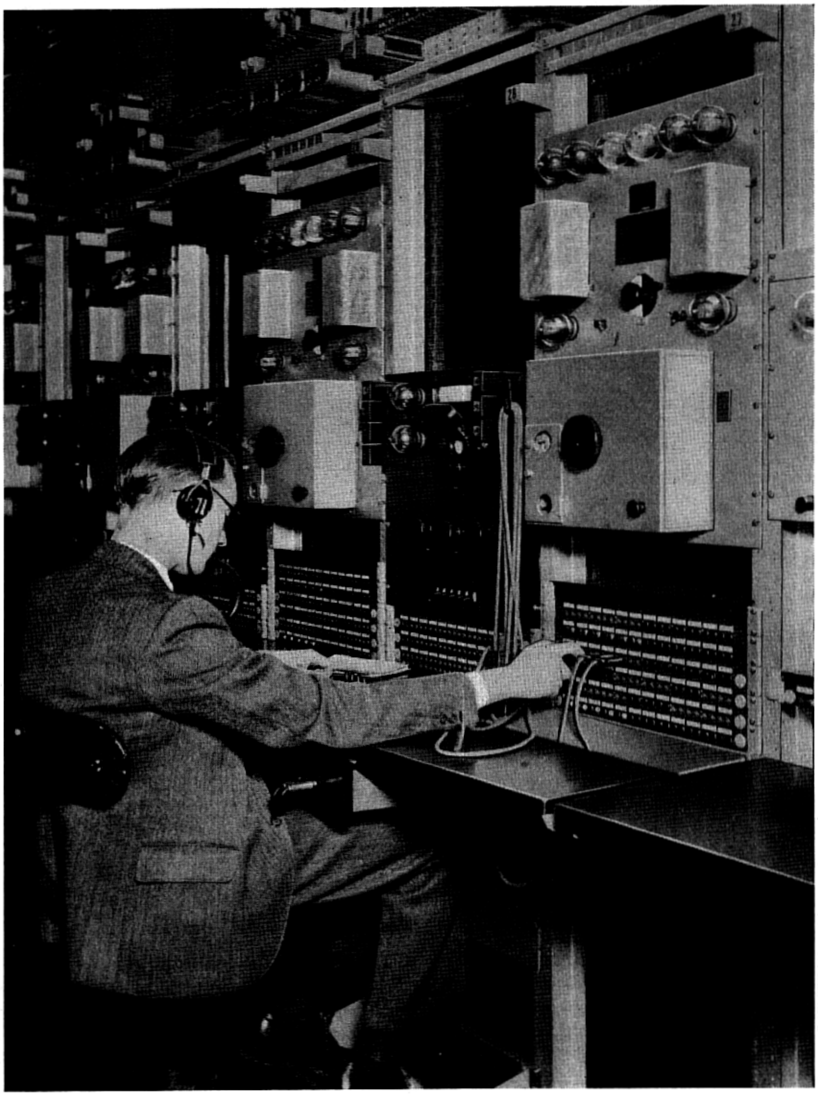

Fig. 7—Transmission testboard for maintaining long distance circuits.

The new instruments for the local plant are not limited to local testing but also have extensive application in the toll plant especially in the smaller offices which do not have many toll circuits. Because of its excellent performance the 1000-cycle generator shown in Fig. 5 will be used generally in the toll plant for 1000-cycle testing.

Figure 7 shows several positions of the transmission test board now widely used for measuring toll telephone circuits. Introduced in 1926, it preceded the development of the reverse feedback amplifier-rectifier and the transmission measuring set used in this board is therefore of the comparison type in which the results are read fron calibrated dials. Testing power is provided by a variable frequency oscillator from which frequencies in the voice range can be obtained. The size of this equipment precluded its being installed in test boards which contain the circuit terminals so that trunks between the measuring

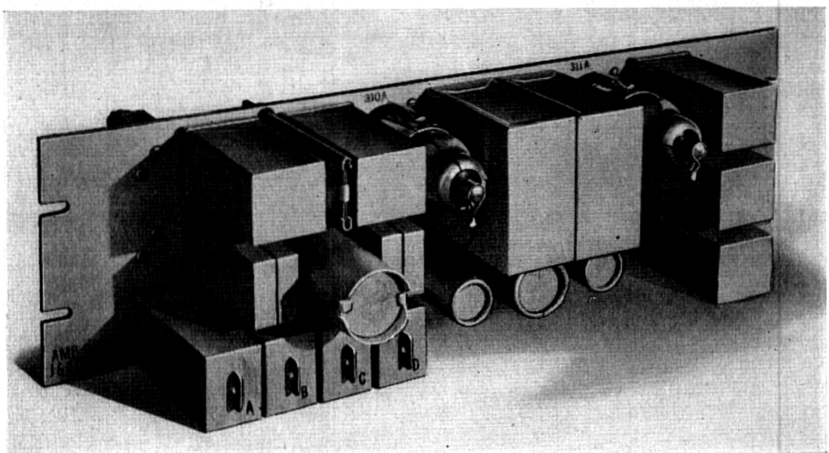

Fig. 8—New amplifier rectifier for general use in toll transmission maintenance.

equipment and these terminals are necessary. In large offices a number of these transmission test boards have been provided.

Figure 8 shows the new reverse feedback amplifier-rectifier used with the latest toll transmission measuring system. This simple panel, which is about one-fourth the size of the measuring set employed in the test board shown in Fig. 7, contains everything required at the receiving end of a circuit excepting the meter and the keys for changing the measuring range. With its associated meter and keys, it is less than one-half as expensive as corresponding elements in the transmission testboards. It can be used with the variable frequency oscillator shown in Fig. 7 or with the 1000-cycle machine shown in Fig. 5.

The meters used with this amplifier-rectifier have a specially designed magnetic circuit which gives an evenly spaced scale on the meter.[8] A conventional meter would have large db divisions at one end of the scale and small ones at the other.

When a direct reading transmission measuring set is used to make measurements over a wide frequency range, it is essential that the response be the same at all frequencies. Variation of response of the new feedback amplifier-rectifier with frequency is so small that it can be calibrated with 1000-cycle current and measurements made over a wide frequency range without recalibration.

From the standpoint of efficiency, the best place for making trans-

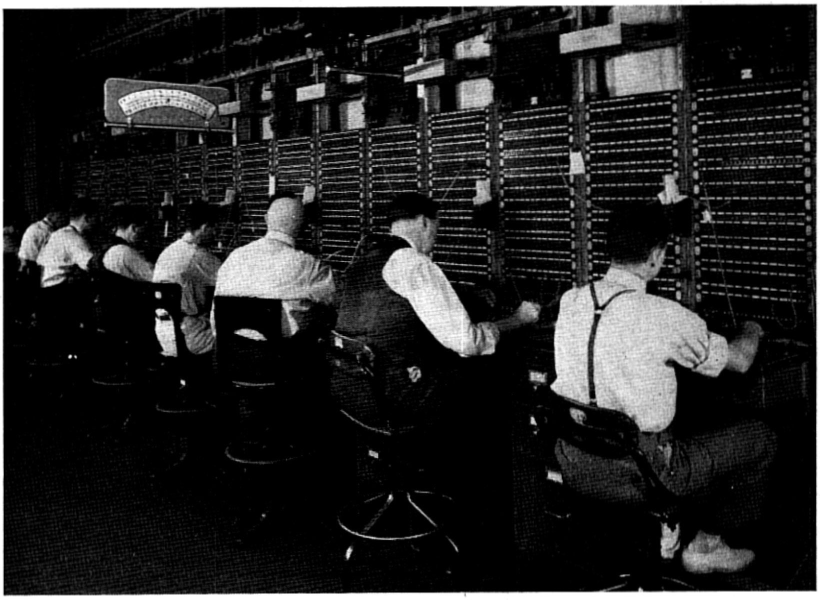

Fig. 9—Projection meter as used for measuring transmission at a secondary testboard. The meter is being read by the third man from the right.

mission measurements on complete toll circuits is at the test board to which all troubles are reported by the operator and where overall signaling and other operating tests are made. Practically all of the space in this board is taken up by jacks on which the circuits terminate so that the older types of measuring set could not be provided at this point. The new arrangement is ideal for application to this type of board since all that is required in the board are the meter and a few jacks or keys for controlling its range. This type of measuring device can be applied equally well to new and existing boards of various types. This feature is of particular value as the maximum efficiency of high-speed measuring systems can be obtained only when all test boards are equipped with them. Two arrangements are available for test board use. One employs a conventional type of meter mounted in the keyshelf or on a panel and the other employs the projection type of meter which is illustrated in Fig. 9.[6] The method of operation is simple. When a transmission test is to be made the tester listens until he hears the tone caused by testing power coming over the circuit from the distant generator, then connects the circuit to a jack in which the measuring set input terminates. The meter indicates immediately the net loss of the circuit at the testing frequency. With the projection meter arrangement the lamp in the projector is turned on automatically when a connection is made to the test jack.

The new amplifier-rectifier will measure transmission losses and

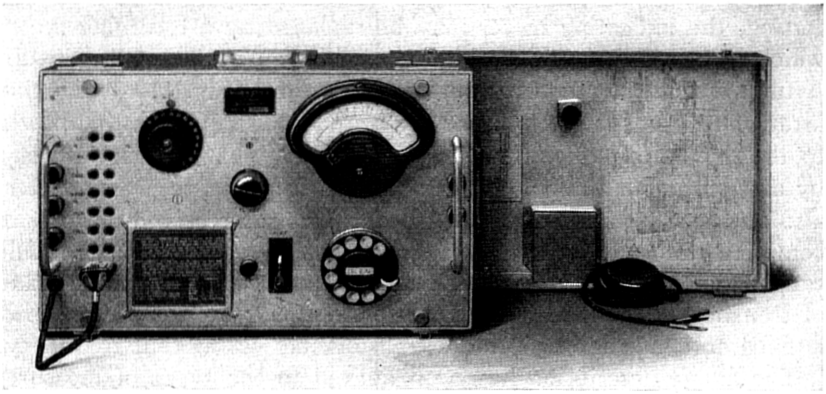

Fig. 10—Noise measuring set.

gains and also transmission level. For the latter type of measurement the input impedance of the amplifier is raised to a high value so that it is, in effect, a voltmeter. This change in impedance can be made from a remote point, a relay for making the change being a part of the amplifier.

In addition to the measurement of transmission losses, gains and levels on telephone circuits, it is also necessary at times to make measurements of noise on the circuit. This noise may be caused by currents induced by power systems or from power plants in the telephone offices or it may be in the form of crosstalk, sometimes unintelligible, from other telephone circuits. Noise measurements are now made with meter indicating devices, the latest type of self-contained portable noise measuring set being shown in Fig. 10.[9] Where enough noise measurements are made to justify a permanent installation, an arrangement similar to that described for transmission measurements can be used. While a different amplifier-rectifier is required for noise measurements the same meters and methods of control can be employed as for transmission measurements.

All of the methods so far described are manually operated in so far as the recording of the results is concerned. There are occasions when a fully automatic recording device is desirable.[4] Such cases are the making of transmission versus frequency runs on repeaters or circuits where measurements are desired over a wide range of frequencies. Another class of measurements are those in which the single-frequency transmission loss of a circuit is to be determined over a long period of time to obtain a measure of the stability of the circuit. For this purpose the new method of measuring transmission is well adapted. With a stable amplifier-rectifier having practically no frequency distortion, the indicating meter may be replaced by a recording meter which will record continuously the received power expressed in db. A fully automatic recording system is shown in Fig. 11. With this arrangement an oscillator at one end of the line supplies testing power to the line, the frequency of the power being changed continuously by a synchronous motor. At the receiving end the recording meter, also operated by a synchronous motor, plots the received power. A complete transmission frequency run on a message telephone circuit can be made in less than one minute. When records are to be made of transmission vs. time, the oscillator frequency at the sending end is fixed and the meter plots the transmission loss at that frequency.

The above description has been limited to the types of measurements commonly made on complete circuits or parts of circuits. In addition to these there are a number of types of measuring apparatus which are used in connection with the installation of new equipment, changes in installations and the detailed running down of trouble.

Transmission measurements have proved to be of great value in maintaining satisfactory transmission performance of telephone circuits. Periodic routine tests avoid service impairment by detecting troubles. Troubles which are thus detected or which cause service complaint are located readily. Another large field of use is in the adjustment of repeaters and complete circuits to prescribed transmission characteristics. The importance of this work to the Bell System is indicated by the fact that there are nearly 1000 of the portable transmission measuring equipments and 1500 transmission test boards now in use, with which several million measurements are made annually. The new measuring systems enable this work to be done more rapidly than in the past, and the reduced cost of the equipment is resulting in its greater distribution.

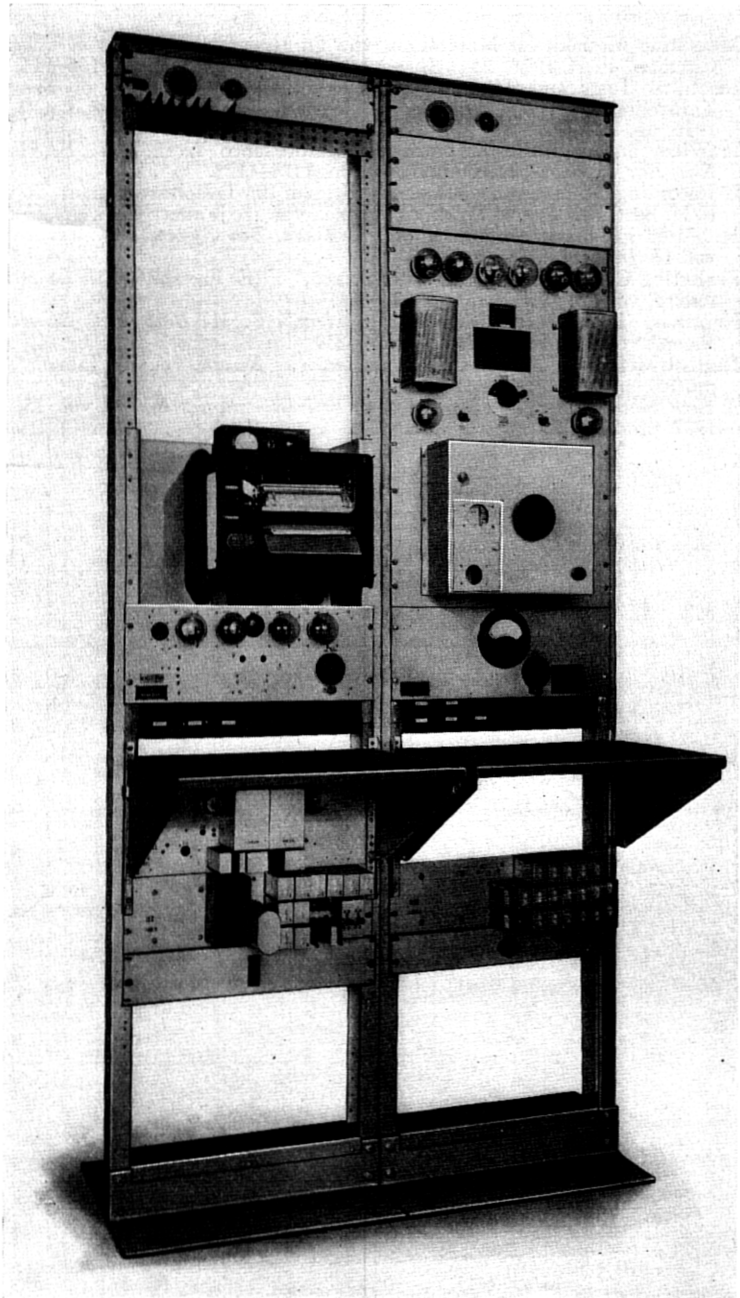

Fig. 11—Automatic recording transmission measuring system.

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