Recent Developments in the Measurement of Telegraph Transmission

By R. B. SHANCK, F. A. COWAN and S. I. CORY

This paper describes the progress which has been made in recent years in the development of methods and apparatus for the measurement of telegraph transmission in the Bell System. Such measurements play an important part in transmission maintenance work in the field and are also necessary in development work. The changes which have occurred in service requirements, particularly the large commercial development of start-stop teletypewriter service and the effect of these changes on the technique of telegraph transmission measurement, are first discussed; then a description is given of several new measuring devices and their use.

IN keeping with advances in the telegraph transmission art, noteworthy improvement has been made in measuring devices and methods in the past few years. The faster, more accurate, and generally more dependable telegraph service now available has been made practicable not only by improvements in the telegraph systems but also by the use of improved measuring apparatus and techniques.

In the early stages of development most transmission-measuring systems were arranged to measure transmission on "looped" circuits, that is, with sending and receiving terminals at the same point, so that a comparison between the sent and received signals could be made. Although such an arrangement is quite useful for laboratory testing, it imposes serious limitations on field testing. Therefore, it is generally desirable to make tests on a straightaway basis.

For straightaway tests it is necessary to have at the receiving end certain information regarding the sent signals. This requires either the use of signals of certain known characteristics or the determination of the important characteristics of the sent signals and the transmission of this knowledge to the receiving end. The latter of these alternatives is not frequently used since it requires another communication channel, although in some instances, where tests on working circuits are desired, it represents the only practicable approach. Straightaway measurements of telegraph transmission have for this reason been generally confined to measurements in which the important characteristics of the transmitted signals were known.

Fortunately, either synchronous or stop-start teletypewriter signals fall into the last-mentioned classification and the increased use in the Bell System of stop-start teletypewriter transmission has afforded the opportunity of making telegraph transmission tests on working circuits without the need of transmitting information regarding the character of the sent signals. Of course, when sectionalized transmission measurements are desired it is necessary for proper interpretation to transmit the results of the measurements to a single point for analysis, but the communication of this information is not at all burdensome.

Aside from the ability to measure on a straightaway basis, which is primarily a field-maintenance requirement, testing equipment should preferably be direct-reading without the need of measuring adjustments on the part of the tester. Direct-reading devices in general effect considerable reduction in the time required for measurement. This feature is especially important in the field where a rapid test of possible trouble conditions is desirable and in the laboratory where the large numbers of tests which are necessary for thoroughly checking a telegraph transmission system under all of the likely operating conditions become even at best tedious and time-consuming.

The major development in telegraph transmission testing within the past few years has been the provision of instrumentalities which possess the desirable properties indicated above. They permit the rapid and direct reading of signal distortion on working teletypewriter circuits. The same instrumentalities when used with selected or miscellaneous teletypewriter test signals also permit the rapid determination of the capabilities of a telegraph circuit in the field or in the laboratory.

A paper published in 1927 [1] discussed fundamental concepts relating to signal distortion and described a number of measuring devices which had been employed in the Bell System. Another paper [2] treated the design of telegraph circuits for distortionless transmission from the standpoint of the steady-state characteristics. The fundamental ideas set forth in these papers have continued to form the basis for development of the technique of measuring telegraph transmission. However, it has been necessary better to adapt these ideas to start-stop teletypewriter operation and changing field requirements.

Operation of telegraph circuits by means of start-stop teletypewriters [3, 4] using 7.4-unit code has become of much greater importance in the Bell System in the past dozen years. The majority of private-line service is now furnished on a teletypewriter basis; also teletypewriter exchange (TWX) service,[5] inaugurated in 1931, has become an

[1] References are listed at end of paper.

important factor, having already grown to the point where the trunk-circuit mileage employed is a large part of the total telegraph mileage. Incidentally, there has been at the same time a general increase in operating speeds, so that the majority of the circuits now operate at a nominal speed of 60 words per minute (23 dots per second or 46 bauds).

As regards the requirements for measuring apparatus for field transmission maintenance, the desired precision and convenience have increased considerably in the last few years. This is due to several causes, chief of which are the continuing desire to give better service with greater freedom from interruptions and isolated errors, increase in speeds of operation, and the use of more complicated circuit layouts with more sections in tandem, particularly in Press and TWX service. For complicated circuits it is very advantageous to employ maintenance procedures in which each section is measured and adjusted separately to close limits, to avoid the more costly and otherwise less desirable overall line-up. Furthermore, a need has arisen for accurate transmission measuring devices for other uses such as checking the condition of receiving teletypewriters, transmitting keyboards and regenerative repeaters,[4] and use in "equalizing" of telegraph circuits, that is, the application of wave-shaping arrangements for reducing distortion. Finally, in line with improvements in main-line circuits greater emphasis has been placed on maintaining loops and circuits to outlying points so that they introduce but little distortion.

Adaptation of Measuring Technique to Teletypewriter Basis

The earlier types of measuring sets were arranged to measure the total change in the duration of signal pulses, that is, the combination of the displacements at the beginning and end of any given pulse. This method of measuring gives results which are directly indicative of the impairment for Morse operation since the interpretation of the signals depends on the total duration of pulses. This method also gives a moderately good indication of the effect of distortion for teletypewriter operation.

In start-stop teletypewriter operation there are two ways in which circuit imperfections may cause the transmission to be impaired. In the first place, imperfections other than constant delay (known as line lag), which may be neglected, may cause the start transition of any character to be displaced with respect to the time at which it should occur. This causes the starting of the receiving mechanism to be advanced or retarded and effectively displaces the succeeding transitions of the character. Secondly, other imperfections may also cause any of the succeeding transitions to be displaced in either direction. The combination of these two effects determines the effective distortion.

It is of interest to consider the case of bias alone. With uniform bias the displacement of mark-to-space transitions is in one direction and that of the space-to-mark transitions is in the other direction with respect to their positions in undistorted signals. Since the start transition is mark-to-space the result is that the effective displacement of subsequent mark-to-space transitions is zero and the effective displacement of space-to-mark transitions is numerically equal to the bias. In practice bias is seldom uniform and may vary with the signal combinations. In these cases there is an effective displacement of mark-to-space as well as space-to-mark transitions.

From the foregoing, it will be seen that it is of considerable practical value to be able to measure teletypewriter circuits on a start-stop basis in terms of displacement of transitions with respect to the start transition. (For a more complete explanation of the effect of distortion on teletypewriter operation, reference should be made to published discussions.[4, 5, 7]) In testing with miscellaneous signals, bias may for convenience be taken as the average effective displacement of space-to-mark transitions relative to mark-to-space transitions; characteristic distortion will have the appearance of a combination of fortuitous and bias effects; and the maximum total distortion will be the sum of the average effect and the variation therefrom which causes the greatest displacement.

Other Changes in Measuring Technique

In measuring with normal and inverted signals[1] on circuits of the types commonly employed, the result obtained for the bias varies somewhat from pulse to pulse of the test signal. A case in which this variation is appreciable is that of carrier telegraph having level compensators (automatic devices which correct for changes in the magnitude of the received current). With these compensators, the response is fairly rapid, the result being that the bias is to some extent a function of the signal combinations of the transmitted material. This bias variation is also noticeable with open-and-close d-c. telegraph circuits having large bridged capacitance or series inductance.

On account of this bias variation, it is desirable to measure the algebraic average of distortion of the individual pulses of miscellaneous signals and take this as the bias. This may be conveniently done by measuring on the start-stop basis mentioned above. In such measurements the differences between the distortions of the individual pulses and the average distortion may be considered as due to the combination of characteristic and fortuitous effects; further measurement is necessary in order to separate these effects. A measure of characteristic distortion may be obtained by determining the difference between the systematic distortion measured with selected recurring signals and the average distortion with miscellaneous signals. Fortuitous distortions may be taken as the difference between the total and systematic distortions obtained with recurring signals. In order to distinguish between the variable bias and the true characteristic distortion in the case of level-compensated circuits measurements may be made with the compensator disabled and with it functioning.

For tests in the field where it is desired to measure systematic distortion effects, as for instance in connection with equalizing, several simple signals corresponding to certain especially selected teletypewriter characters are employed. In each of these signal combinations there are only two transitions; therefore it is convenient to observe the effect of the remnants of one transition upon the next transition. As discussed in the Appendix, the characteristic distortion obtained for miscellaneous signals is a function of the distortion obtained with the simplest characters; if there were no distortion on the simple characters no characteristic distortion effects would be expected when miscellaneous signals were transmitted. The process of equalization, therefore, consists in adjusting the transmission characteristics of the line circuit to reduce the characteristic distortion measured on six special characters to a minimum. The teletypewriter characters which are used for this purpose are Blank, *T*, *O*, *M*, *V* and Letters; the corresponding signals are shown in Fig. 1. The distortions of these signals are observed at the receiving end on a measuring set operating on the start-stop principle or a portable systematic-distortion measuring set having an integrating meter, as will be described more fully below.

In equalization testing, each of the six signals is sent repeatedly for the time required to determine the total systematic distortion—generally about 50 repetitions. In analyzing the results the bias component is assumed to be substantially the same for all of these signals and whatever difference is observed from one signal to another is taken as being due to characteristic distortion. It is found generally that the result for the *O* signals, which are practically unbiased six-cycle reversals (see Fig. 1), is not radically different from the result obtained for bias with reversals at 6 or 23 d.p.s. (shown in the lower part of Fig. 1), the results being expressed, of course, in the same terms, as for instance in per cent of a 23-cycle dot. The largest distortion is usually found on either the Blank or Letters character, this being reasonable because usually the remnants of transients practically disappear within a few dot lengths. Sometimes it is

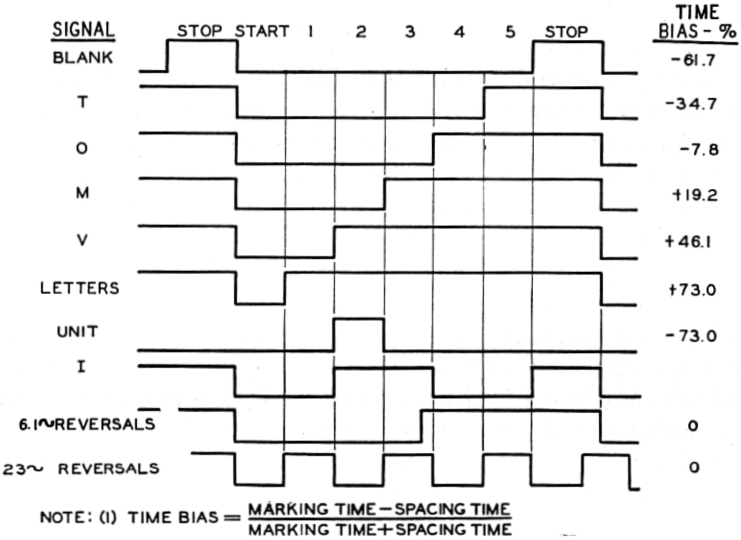


Fig. 1—Signals used in measuring systematic distortion. The first six signals and the eighth signal are teletypewriter characters.

desirable to extend the test to include biased test signals, as described below.

As an example, curves are given in Fig. 2 showing the results of tests with the six characters on a d-c. metallic telegraph [6] circuit operating on 112 miles (180 km.) of composited 19-gauge cable pair. Curves 1 and 2 show the results before and after equalization respectively; it will be noted that considerable improvement was effected. On the basis of both experiment and theory, the slope of Curve 1 is known to indicate that the received direct current is larger than it

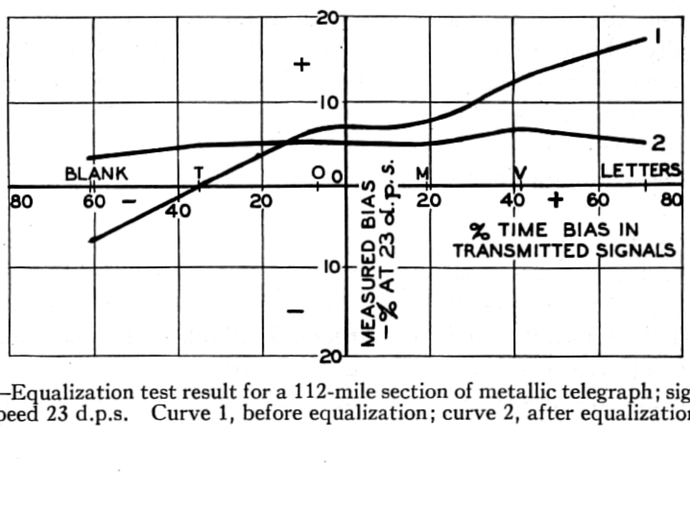


Fig. 2—Equalization test result for a 112-mile section of metallic telegraph; signalling speed 23 d.p.s. Curve 1, before equalization; curve 2, after equalization.

should be as compared to the higher-frequency components of the received current waves. The required type of equalizer in this case is one which adds loss at frequencies in the vicinity of zero, without a corresponding loss at the higher frequencies. If, however, the slope had been in the opposite direction, an equalizer which would discriminate against the higher frequencies would have been required. As a check of the equalizer setting, the total distortion and bias are usually measured using miscellaneous teletypewriter signals.

In addition to measuring with undistorted signals applied at the sending end of a circuit, the measuring technique has been expanded to include measuring with distorted signals and a device has been made available for field use by means of which reversals or teletypewriter characters may be distorted by known amounts. This kind of test furnishes additional information in that it affords an examination of the effect of signal combinations which are not included in perfect telegraph signals. It is of value because in actual operation a given telegraph section may not have perfect signals impressed at the sending end due to distortion occurring in previous sections or at the transmitter. Although such a test furnishes valuable information for line testing, it has been used in the field up to the present mainly in testing the distortion-tolerance of subscriber-station teletypewriters with signals from the adjacent central office and in maintaining regenerative repeaters.

It is necessary, of course, to make transmission measurements on the manual Morse circuits which still constitute a considerable part of the total mileage. Testing such circuits by the same methods as used for teletypewriter circuits has been found to give good results. However, due to improvement of telegraph circuits, the transmission-maintenance problem in this case consists mainly of keeping the bias within reasonable limits for which purpose simple tests with reversals can be used.

New Measuring Devices

In the following is given a description of a number of testing methods and arrangements which have been found useful in recent years both in the field and in development work.

A. Start-Stop Distortion-Measuring Set for Central-Office Use

A start-stop type of measuring set for testing teletypewriter circuits has been developed and is now used generally in maintenance work and special testing in the field and in laboratory work. This represents an outstanding advance in that it provides a quick and convenient means for reading, directly from conventional-type milliameters as illustrated by Fig. 3, the distortion of miscellaneous teletypewriter signals on working circuits. It has the distinct advantage of giving immediate indication of the occasional isolated peaks as well as the average distortion. In using this set, it is unnecessary to have a knowledge of the transmitted text.

This set employs the condenser-charging principle in the measurement of small time intervals corresponding to the distortion of the

Fig. 3—Meters and control apparatus at telegraph board.

signals. The outstanding feature of this device is that the beginnings of the condenser-charging intervals are timed with relation to the start transition by a start-stop distributor which forms an integral part of the set. The charging intervals are terminated by the occurrence of transitions in the characters, at which times the operation of a receiving relay causes the condenser voltages to be compared to a reference voltage. The circuit is arranged to charge the condenser at a constant rate; hence the voltage attained is determined by the duration of the charging interval. In this way the displacements of the transitions in the received teletypewriter characters from their proper positions are measured in terms of condenser voltages. Indications are afforded of the average distortion and the peak value of the total distortion, the latter being the sum of the bias, characteristic and fortuitous effects.

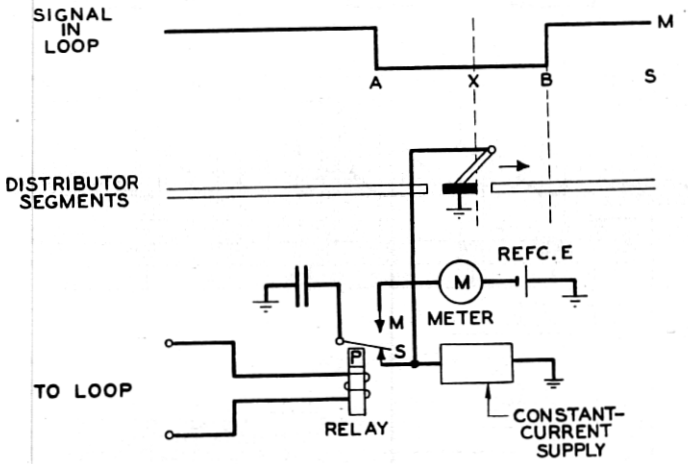


Fig. 4—Explanatory sketch of start-stop telegraph transmission measuring set.

The general features of this set will be described in the following. In Fig. 4 a condenser-charging circuit is shown with a distributor for the purpose of timing the charging intervals in the measurement of distortion occurring at transition *B*. Assume the distributor brush to be traveling in the direction of the arrow after being released by the mark-to-space transition at *A* by means of arrangements not shown. This same transition causes the relay armature to move to the spacing contact (*S*) and the condenser to begin to charge from the constant current supply, but as soon as the brush touches the grounded segment the condenser is discharged completely. After leaving the grounded segment the brush travels over an open segment and during this time the condenser accumulates a charge. At transition *B*, the armature of the relay moves to its marking contact (*M*) and the voltage of the condenser is compared with the reference voltage (REFC. *E*) which has been previously adjusted to such a value that if there is no distortion the condenser voltage and the reference voltage will be equal. However, if transition *B* does not occur at the proper time, because of distortion, the condenser voltage will differ from the reference voltage and a momentary current will flow through the indicating meter (*M*) in proportion to the amount of distortion.

Two condenser-charging circuits are provided, one for space-to-mark transitions and the other for mark-to-space transitions as is indicated in Fig. 5. Graph *A* of this figure shows an undistorted teletypewriter

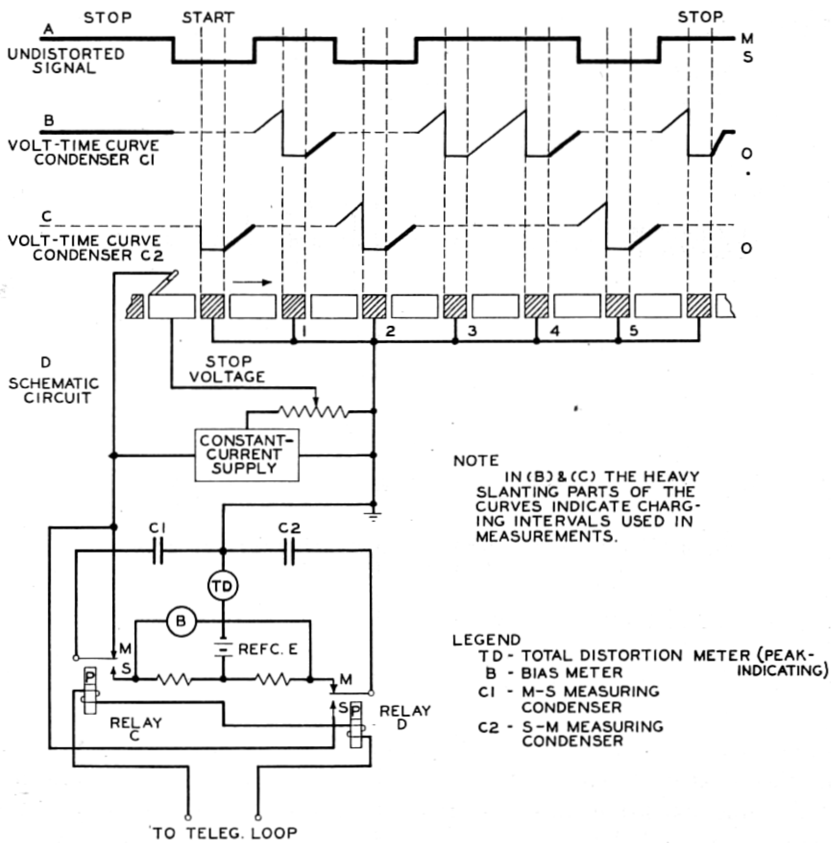


Fig. 5—Simplified diagram of start-stop telegraph transmission-measuring circuit.

character having a stop pulse, start pulse, and five selecting pulses. The segments of the distributor, laid out to show their relation to the received signal, are indicated at the top of the schematic circuit (*D*). It will be noted that there are seven short grounded segments, one for each of the pulses of the character, for initiating the condenser-charging intervals referred to above.

Assume the distributor brush to be at rest during the stop interval as shown. The measuring condenser *C*1 is now charged to the reference voltage. As the brush leaves the stop position due to the mechanism controlled by the start pulse (not shown), it travels in the direction of the arrow and the condenser charges vary as indicated by graphs B and C. It will be seen on graph B that condenser $C1$ is charged during intervals between grounded segments and mark-to-space transitions. Graph C shows that condenser $C2$ is charged between the grounded segments and space-to-mark transitions. If there is no transition while the brush is traveling between two adjacent grounded segments the condenser continues to be charged until the brush touches the second grounded segment at which time it is completely discharged. Therefore, the useful charging interval is that between a grounded segment and a transition occurring before the next grounded segment is traversed by the brush. These intervals are indicated by the heavy-lined portions of the graphs. They amount to 37.5 per cent of a unit pulse as a maximum, i.e., the maximum distortion which can be measured is about 37.5 per cent. The currents flowing as a result of the comparison of the condenser voltages with the reference voltage are indicated on a "Total-Distortion Meter" *TD* which is, in reality, a peak-indicating voltmeter, and on a "Bias Meter," *B* which is sufficiently sluggish to give an indication corresponding to the average distortion. These meters are calibrated to indicate directly the percentage distortion with miscellaneous teletypewriter characters.

Good accuracy is obtained with these sets; when measuring distortions of small or moderate amounts with a well-adjusted set, the indication is accurate to within about 2 per cent distortion at 60 words per minute. For occasional large distortions or for higher speeds, the accuracy is not quite as good, and there are certain possible mutilations of signals, such as the dropping out of pulses, which would not be readily detected.

In addition to measuring miscellaneous teletypewriter characters these sets may be used with recurring test signals in which the spacings of the transitions are such that the maximum characteristic effects will be obtained, and with signals which experience mostly bias and fortuitous effects. In this way a measure of the components of distortion may be obtained. Such tests are commonly made in adjusting variable networks to minimize characteristic distortion, i.e., making the equalization tests, referred to above, with selected teletypewriter signals.

In special testing where it is desired to separate the total distortion into its components, this may be done by measuring the systematic distortion with the first 6 signals of Fig. 1 and then measuring the bias and total distortion using the *I* character of Fig. 1 (which is substantially the same as unbiased reversals at about 11 d.p.s.). The bias component is simply the bias measured with *I* signals, the fortuitous component is taken as the difference between the total distortion and the bias of *I* signals, and the characteristic component is obtained by averaging the results for the 6 selected characters and then selecting the result which shows the maximum departure from the average.

These sets also furnish a convenient means for the measurement of mean-square values of distortion. The current impulses flowing through the total distortion meter are proportional to the distortion and it is practicable to insert in series a specially arranged meter which is calibrated to indicate the mean-square values of the distortion. The circuit used is shown by Fig. 6, the heavy lines showing

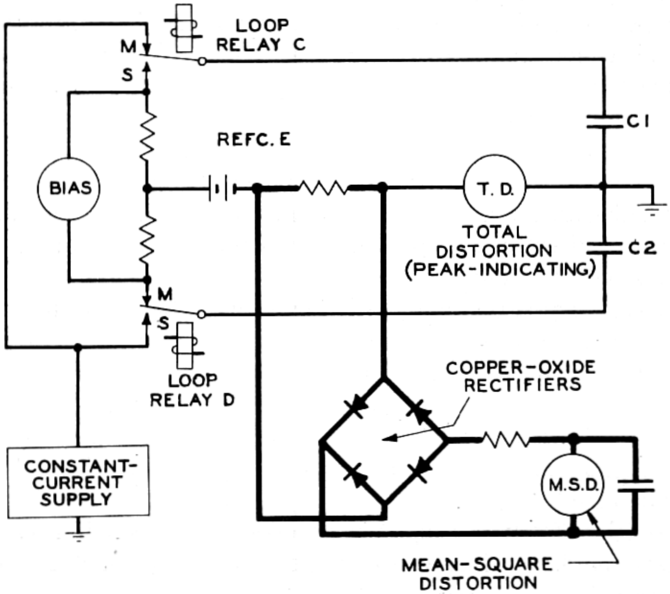


Fig. 6—Circuit of start-stop set for measurement of mean-square distortion.

the meter circuit which is inserted in series. It contains an integrating meter whose characteristic is modified by a full-wave copper-oxide rectifier, a large condenser for increasing the damping and resistances for adjusting the amplitude and response characteristics. Measurements of mean-square distortion have been found of value in connection with producing transmission ratings of telegraph circuits, these ratings being based on the assumption that the mean-square values of distortion of component parts of a circuit may be added directly to predict the total mean-square distortion.[5]

In certain other special tests, where it is desired to obtain a record of the variation in distortion, recording meters have been connected in series with the meters of the set and a continuous record made using either a recurring test message or the signals from the subscriber.

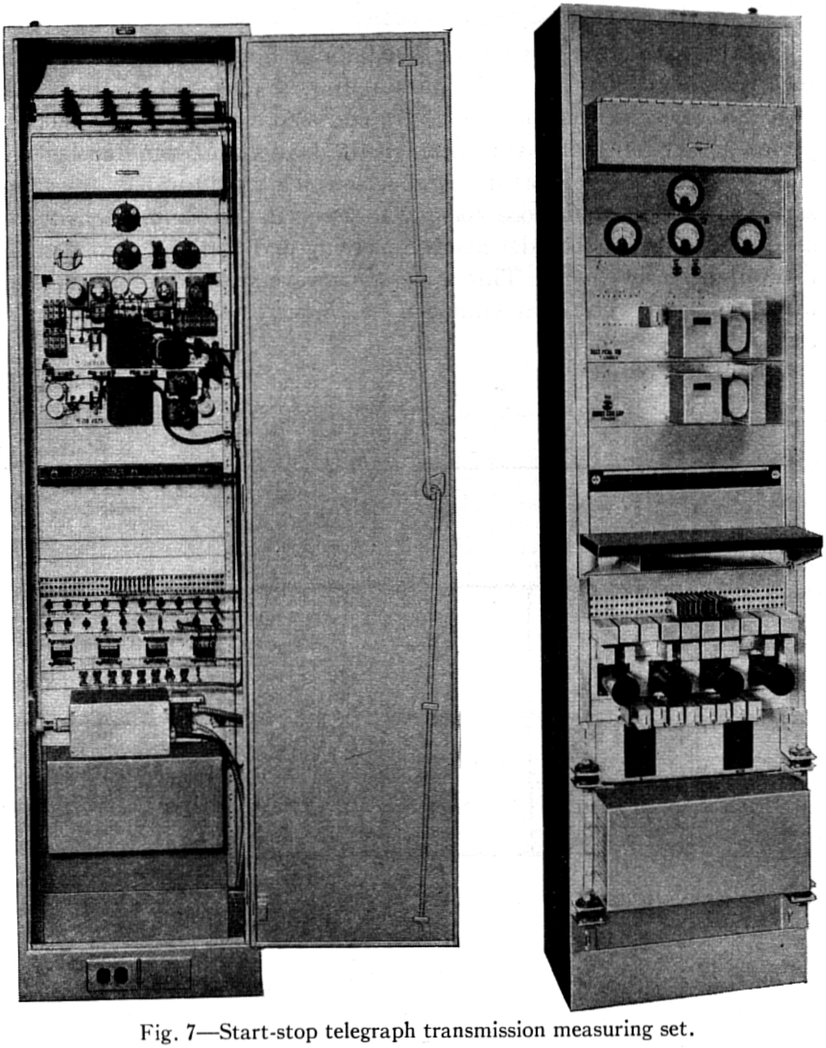


Fig. 7—Start-stop telegraph transmission measuring set.

An idea of the arrangement of the measuring set for central office use may be obtained from the front and rear views which are shown in Fig. 7. It is the practice to provide multiple appearances at telegraph boards in order that one set may be used at any one of a number of positions. The unit containing the indicating meters and associated controls for mounting at the telegraph board is illustrated in Fig. 3. The set is also provided in portable form for temporary use in cases where a permanent installation is not justified.

B. Telegraph Stability Test Set

Recording meters have been used for a number of years in the measurement of the transmission stability of telegraph circuits.[1] In such a measurement a continuous graphic record is made over as long a period as desired of the variations in the bias and of the number and time of occurrence of fortuitous effects which would impair telegraph service. For this purpose telegraph reversals are impressed at the sending end and a recorder at the receiving end makes a record of the bias of these reversals. This type of test was found to be of such utility in field work that standard stability test sets were produced for this purpose.

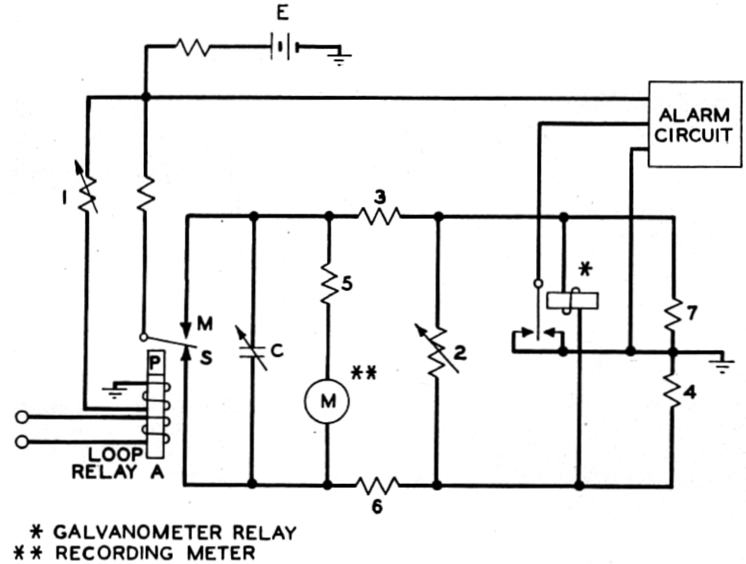


Fig. 8—Schematic circuit of telegraph stability test set.

The circuit of the telegraph stability test set is indicated in Fig. 8. This is essentially a simple bias-measuring circuit combined with an alarm circuit to indicate when given values of bias are exceeded. Movement of the armature of loop relay *A* from *M* to *S* contact or vice versa in response to the received signals causes a battery *E* to be connected first to one arm (resistances 6 and 4) and then to the other arm (resistances 3 and 7) of a bridge type of circuit containing recording meter *M*. The two arms of the bridge are balanced and the meter, being bridged across them, receives positive and negative current pulses of equal magnitude in response to the armature movements. If these pulses are of equal duration, as for telegraph dots or reversals having zero bias, the average meter current will be zero. Biased reversals will cause the meter current to average at other than zero by an amount directly proportional to the percentage bias. A center-zero recording meter is used and this provides a running record of the variation in bias. A damping condenser *C* is used to reduce the width of the trace and the amount of unsteadiness of the indication due to fortuitous effects.

The alarm circuit contains a galvanometer-relay bridged across equal resistances 4 and 7. The needle of the galvanometer-relay moves to one contact or the other when excessive values of bias are experienced, the sensitivity being adjusted for response to different values of bias by means of adjustable resistance 2. The response is made somewhat sluggish to avoid alarms being given for interruptions of short duration which are not of interest in connection with an investigation of bias stability.

A sample chart obtained by means of one of these sets is shown in Fig. 9. This chart shows slow variations in bias in the upper part and in the lower part the change in the indication due to dropping out or adding a single dot and momentary failures. Such charts do not, of course, show the characteristic distortion, since this is not present in the case of unbiased reversals.

These sets are now generally used in the field in routine checks on telegraph circuits and in special checks on circuits which have developed faults in service. Usually these checks are made with the idea of locating the cause of hits or swings which it is difficult to locate otherwise; in some cases sets are used simultaneously at several repeater points to sectionalize trouble. Charts are run for long periods, sometimes for several weeks in such tests. The stability test sets are also used to obtain data for transmission ratings of circuits, in which case it is desired to know the extent of the bias variations over long periods and the number and frequency of occurrence of hits.

Figure 10 shows a view of the portable arrangement of the set including the recording meter. The alarm buzzer and the receiving relay are located on the panel along with a row of keys for adjusting the alarm for operation on given values of bias. Jacks are provided on the side of the box for connection to circuits, batteries and the

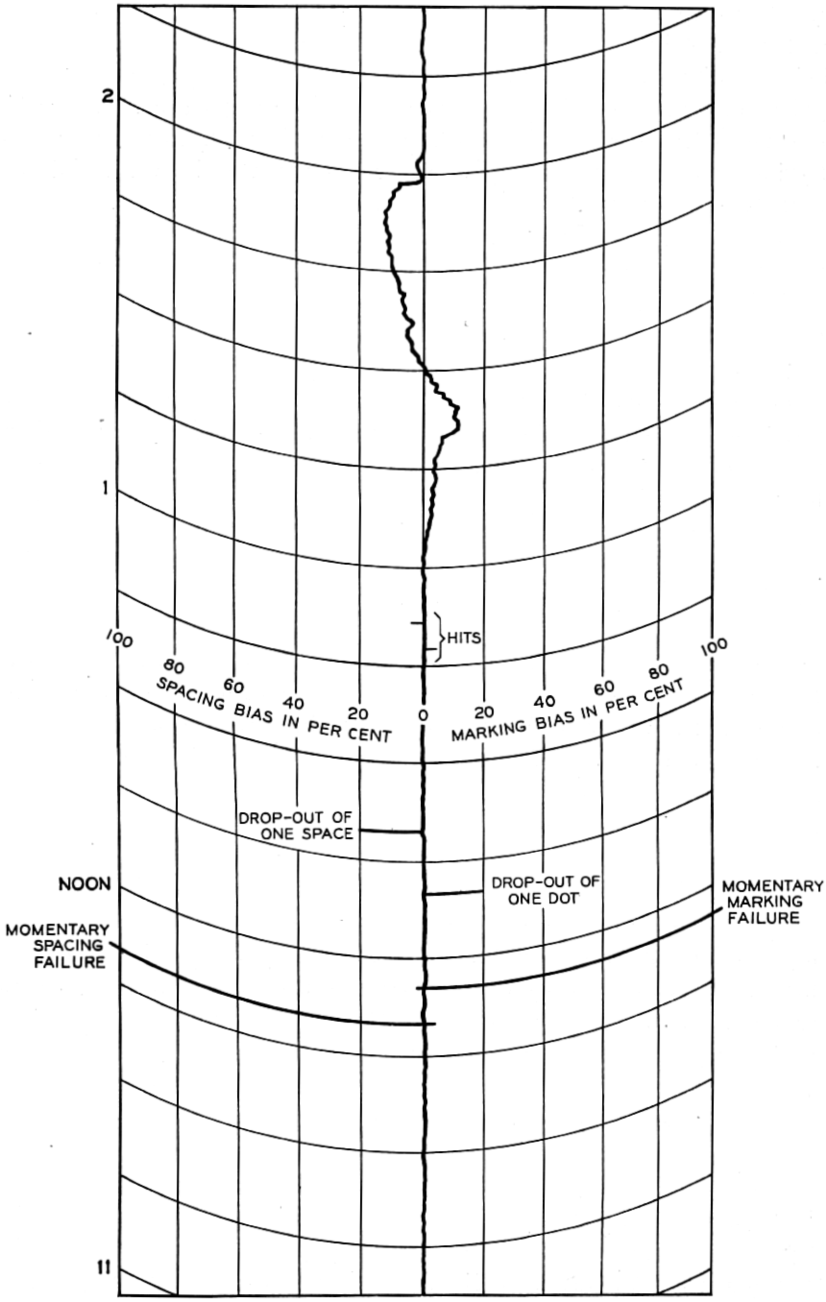


Fig. 9—Telegraph stability test—sample chart.

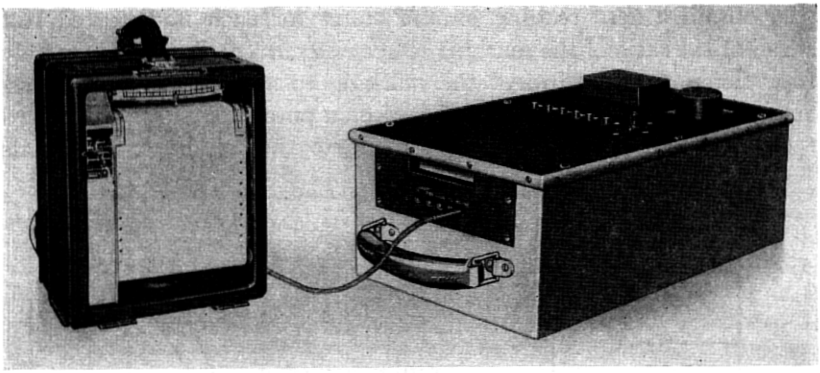


Fig. 10—Stability test set with recording meter.

recording meter. This set is also arranged for permanent mounting on a relay rack in a central office.

C. Portable Measuring Set for Use at Outlying Stations

A new measuring set has been made available for commercial use especially at outlying stations in either routine or special testing. This set is arranged for the accurate measurement of the systematic components (bias and characteristic) of distortion of recurring test signals. In addition measurements may be made of peak values of interference and of the effect of bias and variations in operating currents on the distortion. Such measurements are desirable in analyzing the causes of transmission troubles and in equalization work. By properly interpreting the results of these measurements a fair idea may be obtained of the maximum total distortion. In addition the set is arranged for the convenient measurement of the operating currents and voltages in various parts of the subscriber's circuit and in external circuits. This set may be used on either 110-volt a-c. or d-c. commercial power supply. It is mounted in an aluminum case, and weighs only about 28 lbs. (13 kg.).

The circuit employed for the measurement of systematic distortion is indicated schematically by Fig. 11. This is a simple bridge type of circuit similar to that generally used in a measurement of bias with reversals but especially arranged to indicate directly the percentage systematic distortion of the signals of Fig. 1 excepting "I" signal. The meter circuit is highly damped to prevent undesirable vibration of the meter needle in response to the 6-cycle fundamental frequency of the 60-speed teletypewriter characters. This entails the use of high resistances R, and large capacitance C. Since the voltage in the power supply is limited, a very sensitive meter M is required.

To obtain a zero reading on the meter for each undistorted test character the ratio of the marking to spacing currents is made inversely proportional to the ratio of the marking to spacing time intervals. This is accomplished by means of taps on a potentiometer as indicated in Fig. 11. With the connection made to the middle or Reversals

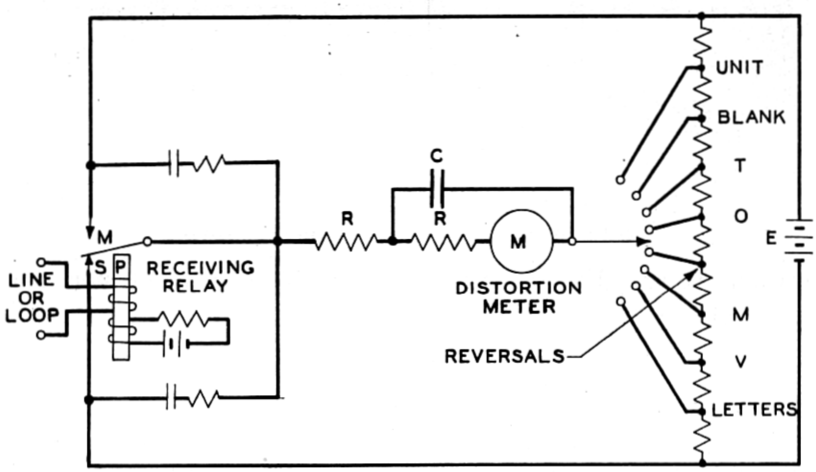


Fig. 11—Outlying-station test set. Schematic circuit for measurement of systematic distortion.

tap, equal and opposite currents flow through the meter when the relay armature rests first on its marking and then on its spacing contact. If the relay is repeating undistorted reversals, the time bias in the signals is zero and the average meter indication will be at zero. With a given undistorted recurring character such as Blank, and with the potentiometer set at the Blank tap, the meter indication will again average at zero. The meter circuit is arranged so that the systematic distortion is indicated directly in percentage based on the duration of a unit signal element of a teletypewriter character.

The circuit used in the measurement of interference is indicated by Fig. 12. The interfering effect is measured by noting on the meter *M* the biasing current which will just prevent the armature of the receiving relay from responding to the interfering currents. Movement of the armature from its contact is indicated by a response in a telephone receiver connected in the armature circuit when the switch is operated as indicated. The biasing current variation is effected by means of potentiometer *P* and the biasing current may be reversed by means of a switch (not shown).

The circuit of Fig. 12 may also be used to give an indication as to the amount of transmission degradation to be expected due to the interference measured and to given changes in operating currents. In this case the switch is operated to connect meter $M1$ in circuit for the purpose of measuring bias. The effect on the bias of changes in the biasing current for a given operating condition may then be

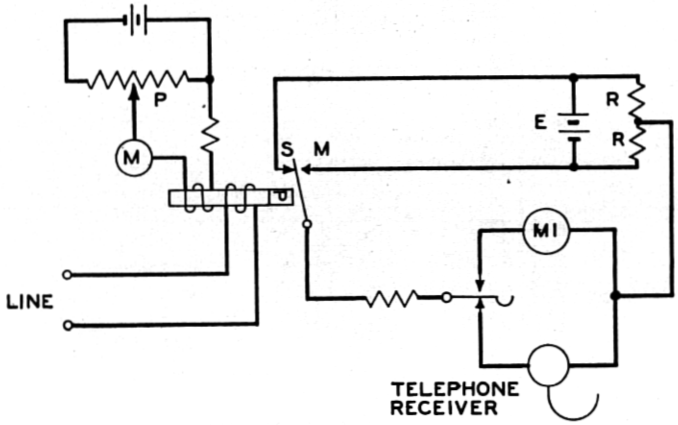


Fig. 12—Outlying-station test set. Schematic circuit for interference measurement.

noted on this meter when receiving reversals or any of the selected teletypewriter characters. The biasing current is varied by means of potentiometer P as before.

This set has several interesting operating features. By inspection of Fig. 13, which shows a view of the set, it will be seen that it contains its own receiving relay located in the lower left corner. This relay may be connected in series in a line circuit or in the local circuit of the subscriber set using the line jacks 1 and 2 (located in the upper right-hand corner of the set) or if desired convenient connection may be made by means of the splecial plug and adapter shown in the lower part of the figure. In the latter case the subscriber set relay is transferred to the measuring set and the special plug, and adapter if required, is inserted into the relay connecting block of the subscriber set in place of the relay. By operating the proper keys on the test set the currents in different circuits of the subscriber set may then be measured conveniently. Distortion may also be measured with this connection but in most cases it is desirable to measure with the receiving relay in its normal position in the subscriber set to obtain representative conditions.

Because of the advantages of the set, namely, the accuracy possible in the measurement of distortion, the convenience afforded in the

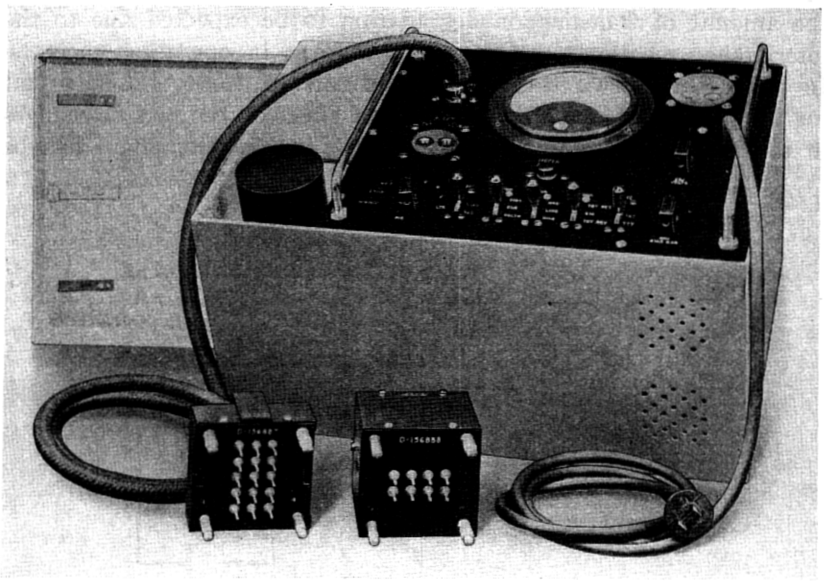


Fig. 13—Outlying-station test set.

measurement of operating and interfering currents, and the portability of the set, it is expected to be of considerable benefit in telegraph transmission maintenance work at outlying subscriber stations.

D. Distortion-Distribution Recorder

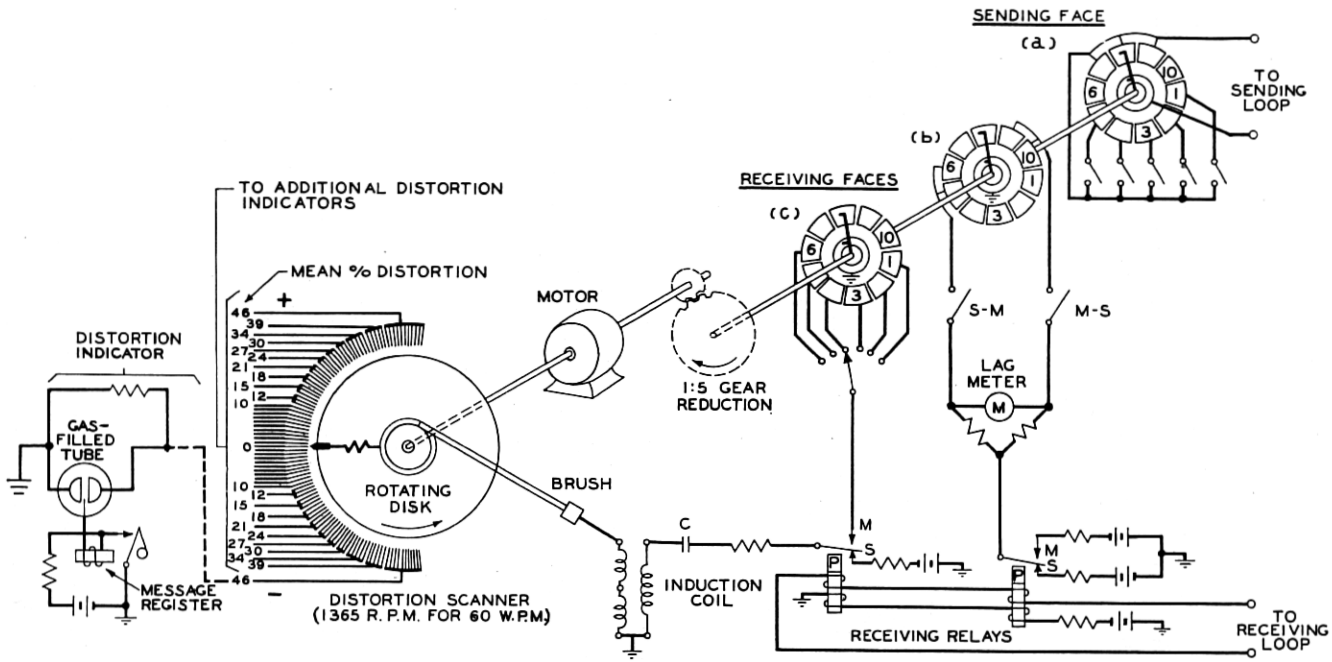
A short test to determine the peak value of the distortion existing on a circuit at any particular time is of great value but in development work it is sometimes desired to know the frequency of occurrence of different values of distortion; in other words, to obtain data from which a distribution curve of distortion may be plotted. Such distribution curves were referred to in the earlier paper and it was stated there that, in general, the distribution of distortion is in accordance with the normal law. To check this on different types of circuits in connection with work on transmission ratings of telegraph circuits and for other laboratory uses a "distortion-distribution recorder" has been devised.

The distortion-distribution recorder operates on a synchronous basis and is suitable only for testing over looped-back circuits. It may be used at any speed up to about 75 words per minute (28.5 dots per second, 57 bauds). It indicates the distortion of the transition at either end of a signal pulse, the indication being in terms of the displacement of the transition from its correct time of occurrence in the signal combination. Records of the distortion are made on message registers in ranges of one per cent for small distortions and greater ranges for larger distortions.

As shown in Fig. 14, this device contains a sending distributor face (*a*) to provide test signals and two receiving distributor faces (*b*) and (*c*). Coupled to these and running five times as fast is a large disc carrying a fine point from which a spark may be made to jump to any one of a series of stationary segments. This is referred to as "distortion-scanner" in the figure. Since the disc makes one-half revolution while the sending distributor brush is traversing one segment, one-half revolution of the disc requires the same time as one dot and is, therefore, equal to 100 per cent distortion. One hundred segments are provided as indicated, each being equivalent to 1 per cent distortion, so that this ring of segments forms a distortion scale covering the range of $\pm$ 50 per cent distortion. Distortion indicators are associated with these segments, each containing a gas-filled tube and a message register. Only the first ten segments on either side of zero are provided with individual indicating arrangements, the succeeding segments being combined in successively larger groups as shown in the figure; this affords adequate information for the usual case.

Assume the switches associated with the sending distributor face (*a*) to be operated to send the signal shown in note 2*a*. After traversing the circuit to be tested this signal operates the receiving relays, one of which is associated with a "lag-meter" and the other with a spark-producing circuit. If the time of occurrence of transition X (note 2-*a*) is to be used as a reference, the M–S switch of the lag circuit is closed and the sending segments oriented until transition X occurs while the brush of receiving distributor (*b*) is midway between segments 9 and 10, as is indicated by a lag-meter reading of zero. The positions of the segments of the receiving faces (*b*) and (*c*) with respect to the signal will now be as indicated in notes 2-*b* and 2-*c*, and the set is ready to measure the occurrence of a transition between any two segments of the sending face, for instance, transition Y or Z.

If for instance the displacement of transition Y with respect to transition X is to be measured, the switch associated with face (*c*) is set to connect to segment 4. When transition Y occurs the receiving relays operate to marking, condenser C is discharged through the primary of the induction coil and a spark jumps from the scanning point to a stationary segment. If transition Y is not distorted the spark will jump when the scanning point is opposite segment O. This will cause the gas tube associated with segment O to fire and



NOTES:
(1) RECEIVING FACES MAY BE ORIENTATED WITH RESPECT TO SENDING FACE BY MEANS NOT SHOWN
(2) (a) SIGNAL FROM SENDING FACE
(b) POSITION OF SEGMENTS OF REC. FACE (b)
(c) POSITION OF SEGMENTS OF REC. FACE (c)

Fig. 14—Schematic circuit of distortion-distribution recorder.

operate the message register which in turn will extinguish the tube by momentarily short-circuiting the anode potential. Other transitions in the signal will not cause the condenser C to be discharged through the coil because the brush of face (c) will not be traversing the proper segment and there will be no path to ground.

The complete circuit of the device contains a selecting switch which automatically changes the signal combination for each revolution of the brush arm of face (a) and reversing switches to invert the signals and the relay connections. These have been omitted for the sake of briefness and clarity. It is thought, however, that the above description will give a good idea of how this device operates to make a record of the frequency of occurrence of distortions. A sample of such a record is plotted in Fig. 15, this being from data obtained over a

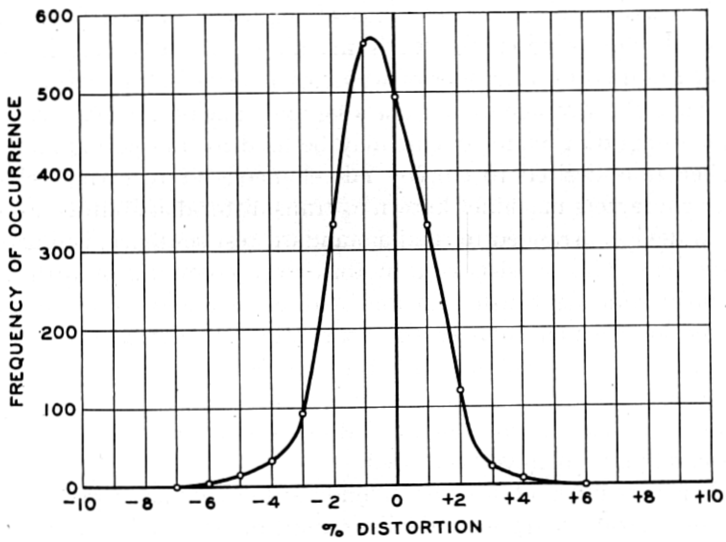


Fig. 15—Typical curve obtained with distortion-distribution recorder.

short-wave radio link. The measurements covered a 15-minute period and one transition of a repeated signal was observed continuously during this period. By inspection it is seen that this circuit has bias of − 1 per cent and the r.m.s. value of distortion is about ± 3 per cent. With miscellaneous signals and with characteristic distortion present, the curve would have several peaks and would be somewhat irregular, but would have the general shape of a normal-law distribution curve.

E. Sources of Test Signals

Bell System telegraph circuits are tested at present with both substantially perfect and distorted test signals. The quality of the test signals is, of course, of prime importance because the measurements are generally made on a straightaway basis and it is not practicable to make correction for accidental distortion in the test signals at the sending end of the circuit. On high-grade circuits where the distortion is generally less than about 5 per cent, distortion in excess of a few per cent in the test signals is very undesirable.

Undistorted Test Signals

Substantially perfect test signals are usually supplied from motor-driven commutators. One type supplies telegraph reversals. In this case an accurately governed motor drives two brush arms, each of which is associated with two rings of segments so that four sources of signals are provided by each machine. These reversals or dot signals are used in a number of ways, their principal advantage being that since the average of the marking and spacing intervals is zero, a simple integrating meter circuit may be used for measuring bias.

When it is desired to employ miscellaneous or recurring teletypewriter characters machines known as transmitter-distributors are used. Such a device, arranged to send a standard test sentence, is illustrated in Fig. 16. This consists of a motor-driven commutator with a continuously rotating brush arm and a direct-coupled cam transmitter (on the left) which changes the connections to the segments of the commutator in accordance with the code which is cut on the cams. In another form of this device a tape transmitter [4] is used; the tape is usually of parchment although metal tapes and wheels drilled with the code combinations have been used.

When a number of sources of undistorted signals is required in a repeater station a device called a "multiple-sender" is used. This employs the distributor of Fig. 16 to operate a number of relays. The transmitting contacts of these relays are connected to jacks at convenient locations in the telegraph test board. The standard test sentence supplied by this device contains desirable signal combinations for testing transmission over lines and also for testing the operation of teletypewriters.

The signals from the commutator face traverse two groups of relay windings, a marking group and a spacing group, the circuit being as indicated in Fig. 17. This circuit effectively provides polar operation of the relays, the transmitter closing the circuit through one group of windings to operate the relays to their marking contacts and through

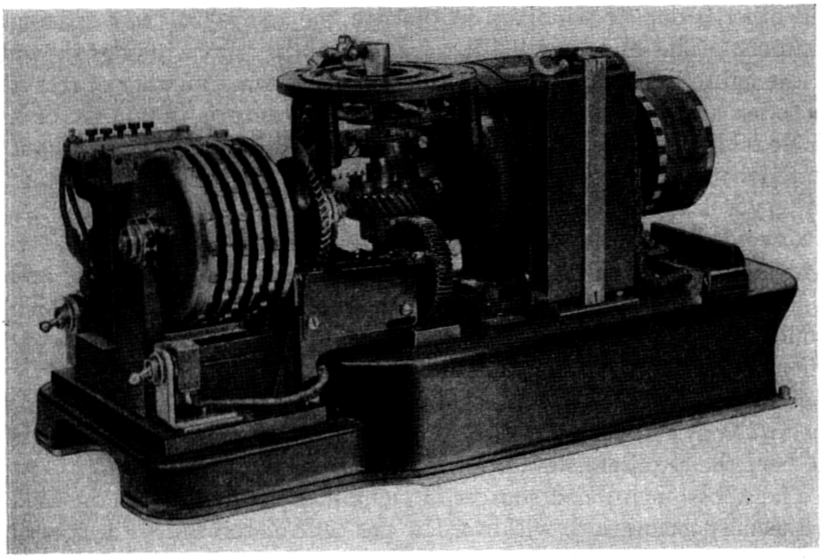


Fig. 16—Test-sentence transmitter-distributor.

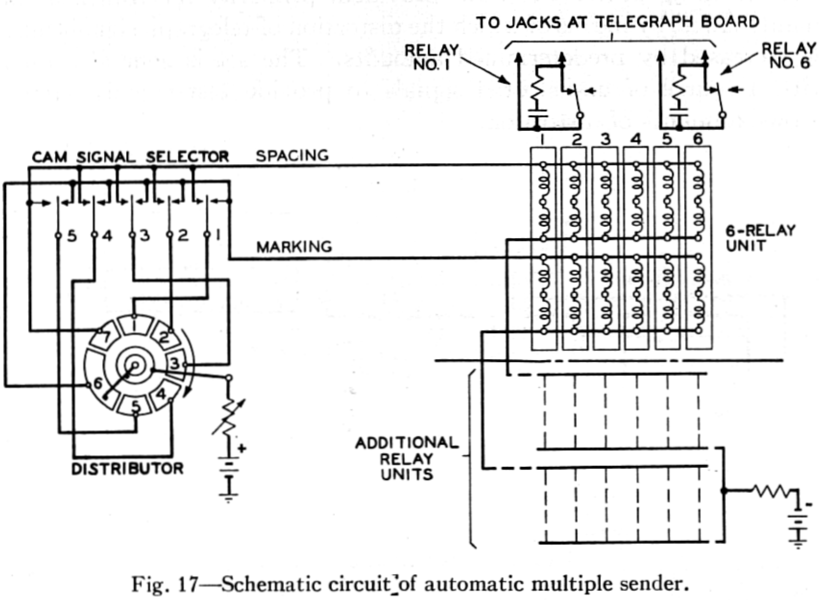


Fig. 17—Schematic circuit of automatic multiple sender.

the other group of windings to operate the relays to their spacing contacts. The series-parallel arrangement of the relay windings shown in the figure has the advantages that with the same number of relays in series and in parallel the combined inductance is only that of a single relay, and that any relay may be removed for inspection without materially affecting the operation of the others. Only one transmitting battery is used in this circuit and thus errors due to battery inequalities are avoided. As indicated in the figure, a spark-reducing circuit is associated with each output for the purpose of minimizing arcing and to neutralize the effect of travel-time of the relay armature which would otherwise cause the transmitted signals to be biased to spacing when opening and closing the circuit under test.

Each group contains 6 relays in parallel and any number of groups up to 8 may be used in series to provide a maximum of 48 outputs to meet the requirements for offices of various sizes.

The above-mentioned sources of signals as maintained in the field are usually accurate to within a few per cent distortion. For special uses it is possible to reduce this inaccuracy somewhat by additional maintenance.

Distorted Test Signals

A repeating device has been provided, primarily for transmission maintenance, by means of which the distortion of telegraph signals may be increased by predetermined amounts. The set is generally used with a source of undistorted signals to provide test signals having known amounts of distortion.

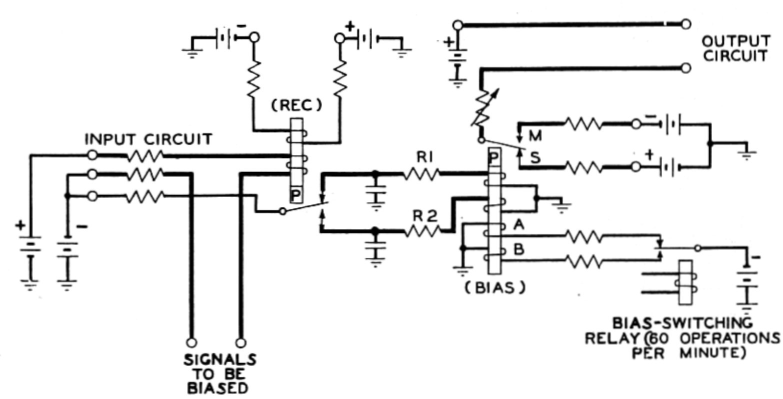


Fig. 18—Bias-producing circuit.

The schematic circuit of the signal-distorting device is shown by Fig. 18. The signals to be distorted are connected to the input and are repeated by the receiving relay (Rec) of the device into a biasing relay (Bias) through a network which modifies the wave-shape of the signals and permits them to be biased easily by changing the current through the auxiliary windings *A* and *B* of the Bias relay.

The manner in which bias is produced will be understood more fully by reference to Fig. 19 which shows graphs of the currents in the

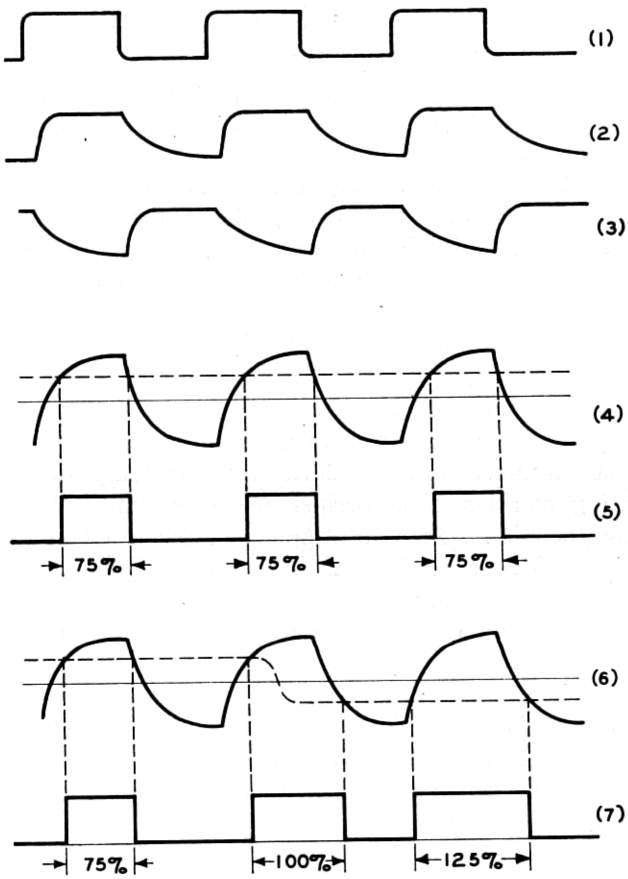


Fig. 19—Currents in bias-producing circuit.

bias-producing circuit. The current in the receiving relay input circuit is indicated by 1. These are undistorted substantially square-topped reversals. The currents flowing through the operating windings of the Bias relay in response to the marks and spaces of the reversals are shown by 2 and 3. In the case shown by 2, it is seen that at the beginnings of the marking pulses the wave fronts are steep and that the current gradually decays to zero at the beginnings of the spacing pulses. In 3 this condition is reversed so that the net operating current for the Bias relay, being the difference between the currents of 2 and 3, has a rounded wave shape for both the beginnings of marks and the beginnings of spaces as is indicated at 4. This is a symmetrical wave about the zero axis and if there is no bias effect in the Bias relay the signals will be repeated unbiased. However, if current is passed through one of the auxiliary windings of the Bias relay the operating point of this relay will be shifted as indicated by the dotted line and the repeated signals will be biased, as shown by 5. In this case the bias is 25 per cent spacing so that the repeated unit marks are 75 per cent of their original length.

One of the auxiliary windings of the Bias relay is used for introducing marking bias and the other for spacing bias, and the sign of the bias may be changed by switching from one winding to the other. Then the bias effect reverses according to the dotted line of 6, and the signal is affected as is indicated by 7. By reversing the bias periodically under the control of a commutator arrangement an effect known as "switched bias" is produced. The reversing operation occurs 60 times per minute and is not synchronized with the signals and accordingly produces a fortuitous effect on some of the signals.

The signals obtained from this device are commonly used in testing the operating margins of subscriber teletypewriters. In this case perfect teletypewriter signals are applied to the input of the device and are distorted by a predetermined amount in passing through it. These signals are then applied to the circuit extending to the subscriber station. If the receiving teletypewriter at the station responds faithfully when set at its optimum orientation point it is considered to be satisfactory for service.

Distorted signals obtained from this device are also used to determine the extent of the distorting effects in line circuits. For this purpose the set may be connected at either the sending or the receiving end of the line and a distortion-measuring set at the receiving end to give an indication of the increase in distortion caused by predistorting the signals. With the set used at the sending end, the results of the test indicate how much distortion may be applied as from preceding telegraph sections. With distortion added at the receiving end, the test may be used to show the margin in the receiving apparatus before failure.

A front view of a panel-mounted telegraph signal-biasing set of the relay type is shown in Fig. 20.

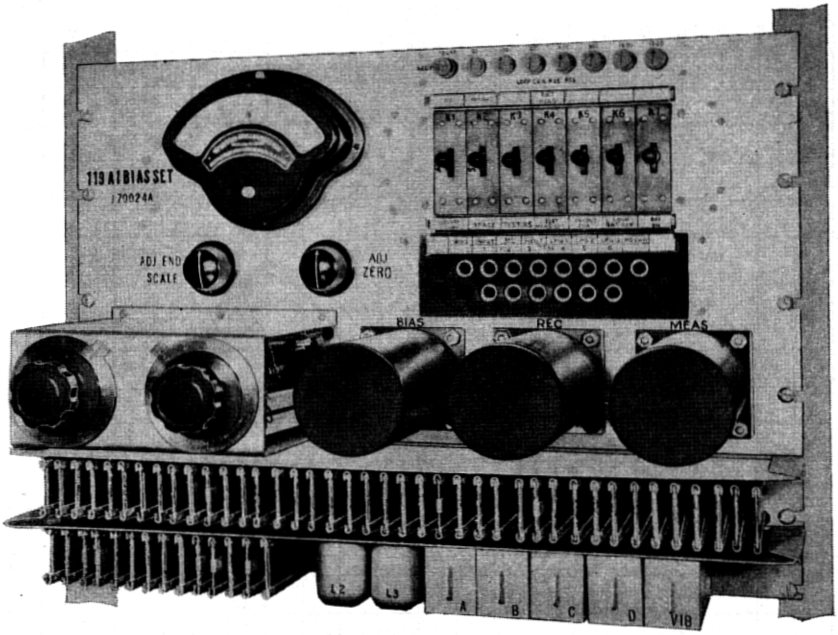


Fig. 20—Telegraph signal-biasing set.

F. Measuring with Teletypewriters

As is well known, the start-stop teletypewriter, when properly adjusted for this purpose, may be used as a transmission-measuring device. The usual procedure in field testing is to compare the range over which the orientation range finder may be shifted with substantially perfect signals to that obtained with signals from the line under test. The orientation range finder is shifted above and below the usual setting until perfect copy is no longer obtained, these limiting positions determining the margins.

At the time of the previous paper,[1] the orientation range test was the only test available to the field forces in the Bell System which utilized the start-stop principle. At that time the teletypewriter was not convenient to use and generally the results were not as accurate as desired. However, the machines have been much improved and better methods of use have been developed so that now orientation margin tests furnish a better indication of the grade of transmission. At the same time, the more convenient measuring sets described above have become available and this has, of course, reduced the field of use of the teletypewriter as a measuring device.

One of the improvements in the machines from the standpoint of

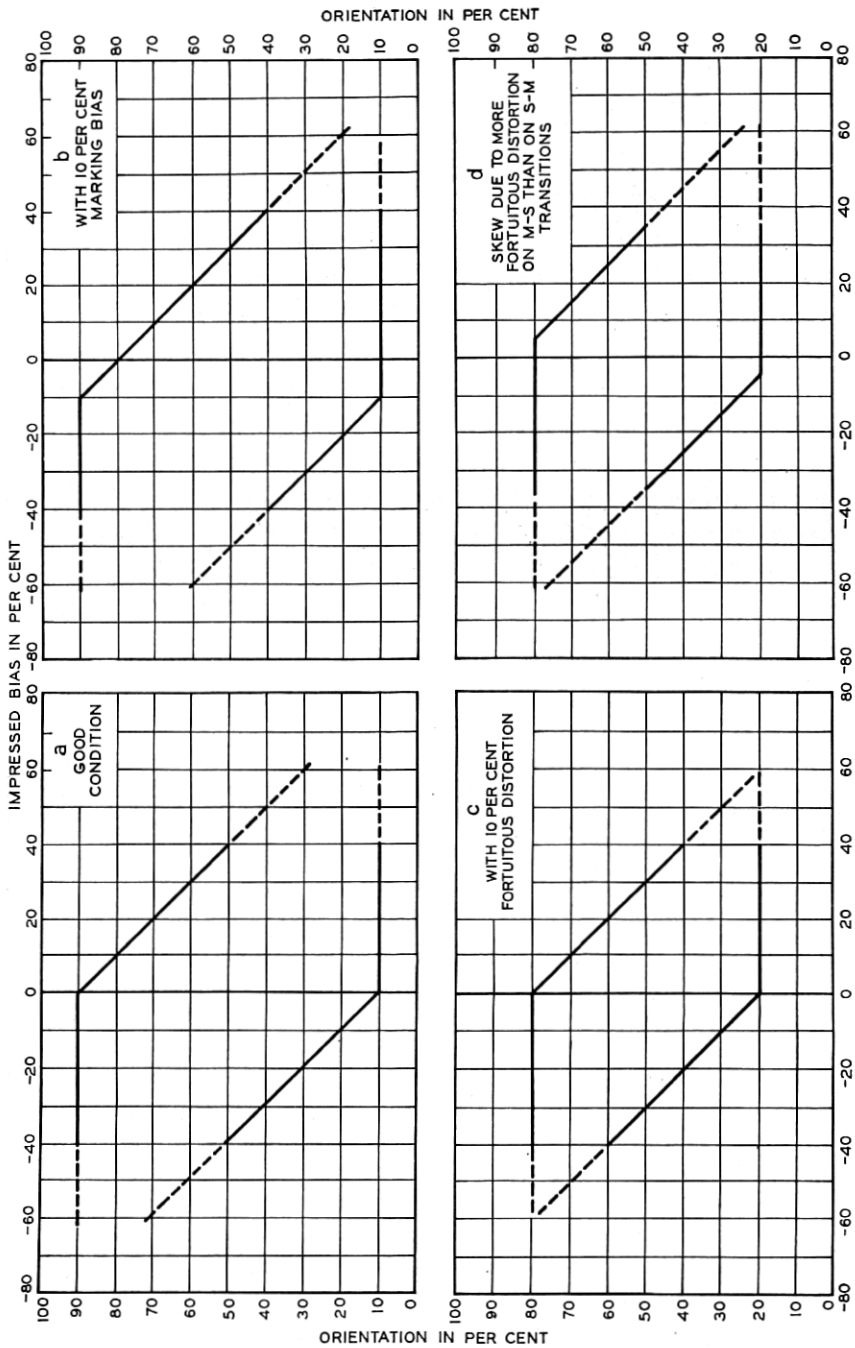


Fig. 21—Diagrams showing the effect of internal distortion on orientation limits of teletypewriters.

transmission testing consists in the addition of a small crank which extends through the cover and which is coupled to the range finder. The crank has a detent which assists in making settings to the nearest per cent, the scale being arranged to indicate directly the distortion in percentage of a unit selecting pulse. This crank and scale arrangement increases the convenience of measurement considerably.

It is of considerable importance to remove as far as practicable the internal distortion [7] of teletypewriters used for measuring purposes. These internal distortions can be identified as bias, characteristic and fortuitous effects. These effects reduce the margin from the theoretical limit of ± 50 per cent to about ± 40 per cent for the usual machines operating at 60 words per minute.

The presence of internal distortion can be readily determined by using signals biased by various amounts and noting the effect on the orientation range. With a machine satisfactory for measuring purposes, the results obtained would be as indicated on Fig. 21*a*. Here the range is from 10 to 90 per cent for reception of perfect signals. Marking bias reduces the upper range in direct proportion and spacing bias likewise reduces the lower range in direct proportion; thus the machine would be satisfactory for measuring purposes.

If the machine had internal marking bias, the orientation parallelogram would be as shown in Fig. 21*b*. Here the range with perfect signals is from 10 to 80 and marking bias reduces the range in proportion to the bias but spacing bias first increases the range until the internal bias is compensated and then decreases the range as the impressed bias is further increased. With internal spacing bias the parallelogram would be shifted to the other side of the zero line by the amount of the bias. It is obvious therefore that biased machines do not give accurate results in measuring.

Characteristic and fortuitous effects may also be present in teletypewriters to such an extent as to make the machines unsatisfactory for testing purposes. It will be appreciated that internal characteristic distortion changes from signal to signal and when receiving miscellaneous teletypewriter characters, it has much the same effect as fortuitous distortion and the upper and the lower margin limits would be reduced about equally as shown in Fig. 21*c*. If the machine distortions do not have the same effect on mark-to-space and space-to-mark transitions, a skewing effect is produced in the orientation parallelograms. Fig. 21*d* shows skew due to the fortuitous effect of the mark-to-space transitions, being greater than the fortuitous effect of the space-to-mark transitions. Teletypewriters showing such skew effects do not give margin reductions proportional to the impressed distortion and are, therefore, not suitable for measuring purposes.

It is apparent from the above discussion that it is necessary to adjust teletypewriters for minimum internal distortion before they can be used for measuring purposes. Where it is desired to use teletypewriters in testing, procedures have been established in the Bell System to insure that they will be in proper condition and fairly good results are obtained with them.

Although the effect of distortion on the orientation margins has been discussed previously [4, 5, 7] it may be of value to state here how distortion affects the margins at the lower and upper orientation limits in connection with the use of teletypewriters for testing purposes. In general, the maximum reduction corresponds numerically to the total distortion as indicated by the start-stop type of measuring set described above. Distortions other than bias usually affect both orientation limits equally so that the amount of bias can be estimated by subtracting the smaller reduction of the two from the larger. In addition it is possible to obtain an idea of the characteristic distortion by the indications obtained during the orientation test. If the orientation limits are fairly definite, that is, if the copy changes from good to bad when the range finder is moved only a small distance, it is likely that the distortion is due to bias. If there is a definite range over which certain characters are found to be consistently in error this is due to characteristic distortion. If the limits are not definite, that is, if there is a range over which errors occur but not consistently on certain characters this is probably due to fortuitous distortion. Although a qualitative analysis of the distortion may be made in the manner discussed above, this indirect method is somewhat laborious and may give misleading results. Moreover, it is impossible to get a measurement of isolated distortions of high value.

G. Telegraph Service Monitoring Set

An automatic telegraph service monitoring set has been designed for the purpose of giving an alarm at repeater stations whenever the distortion on circuits becomes abnormally high or whenever an excessive number of large distortions or "hits" is experienced. This set is still under development; however, a description of it will be given because it is thought to be of general interest to those concerned with telegraph transmission measuring.

In the interest of economy and simplicity this set contains a so-called shortest-pulse type of measuring circuit rather than a start-stop type. Measurement on this basis will of course result in a loss in accuracy for some signal combinations because of the fact, as mentioned earlier, the distortion of the stop pulse is not added to the distortion of other pulses. However for the purpose for which it is used, namely to detect trouble conditions on working circuits, the accuracy is believed to be adequate.

In this set two measuring circuits are provided, one for measuring marks and the other spaces. These are condenser-charging circuits in which the charge on the condenser is an indication of the duration of the pulse. These condenser voltages are compared to a reference voltage and only those less than the reference voltage are permitted to influence the distortion indicator. Therefore, only the shortest pulses are measured and this permits observation on working teletypewriter circuits without involving a start-stop arrangement. By adjustment of the time constant of the condenser-charging circuits, as for instance by means of continuously variable resistances, the percentage distortion for which an alarm is given may be varied at will.

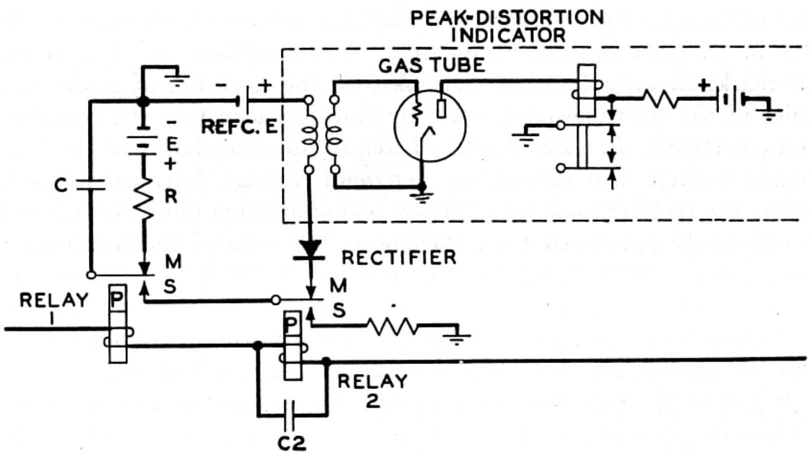


Fig. 22—Distortion-measuring circuit of telegraph service-monitoring set.

The distortion-measuring portion of the circuit used in the measurement of marks is indicated by Fig. 22. Condenser *C* is charged during marking intervals through high resistance *R* by voltage *E;* thus a voltage is produced on the condenser which depends upon the duration of the marking interval as is indicated by Fig. 23. At the time of the transition from mark to space the condenser voltage is momentarily compared to that of a reference source by way of the armature and marking contact of relay 2 of Fig. 22. Immediately afterwards the condenser charge is dissipated by the armature of relay 2 moving to its spacing contact. The small delay required in the operation of relay 2 with respect to relay 1 is obtained by connection of condenser $C2$ around the windings of relay 2.

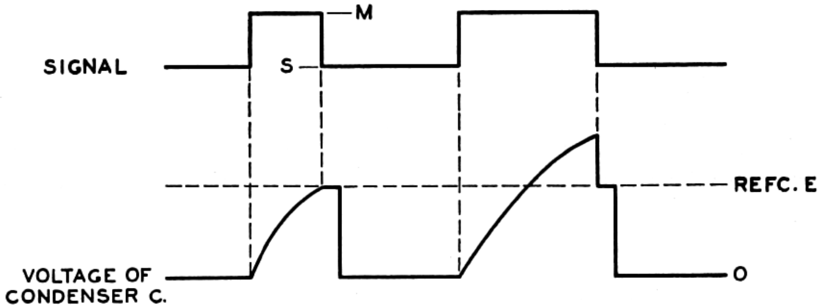


Fig. 23—Variation of charge on measuring condenser in telegraph service-monitoring set.

If at the time of the momentary comparison between the condenser and reference voltages these two voltages are equal, no current will flow in the peak distortion indicator. This condition can be obtained for marks of unit duration (for instance the duration of a selecting pulse of the teletypewriter code) by suitably adjusting the reference voltage REFC. E. For marks of longer duration however the condenser voltage will exceed the reference voltage but, by properly poling the rectifier in series with the peak-distortion indicator, current is effectively prevented from flowing at the time of the momentary comparison. With this poling of the rectifier the current flowing due to the marks being shorter than unit duration will affect the peak-distortion indicator and if suitably adjusted will cause a gas-filled tube to operate and thereby give an indication of distortion.

It will be apparent that the measurements of spaces may be accomplished by providing for that purpose another circuit of the same type as that of Fig. 22. For the measurement of both marks and spaces four relays are required, but only one peak-distortion indicator is necessary.

Associated with the measuring circuit is a counting circuit which counts the number of excessive distortions experienced in a given time. This circuit is indicated schematically by Fig. 24. In this circuit the charge of the condenser C is mixed with that of a larger condenser $C2$ at each operation of the gas-filled tube of the distortion measuring circuit. Thus the charge on the larger condenser becomes an indication of the number of excessive distortions. By arranging a timer to discharge this condenser through an indicating circuit suitably designed an alarm may be obtained whenever the number of excessive distortions exceeds any predetermined number up to about 7 within a given time. For this purpose another gas-filled tube is

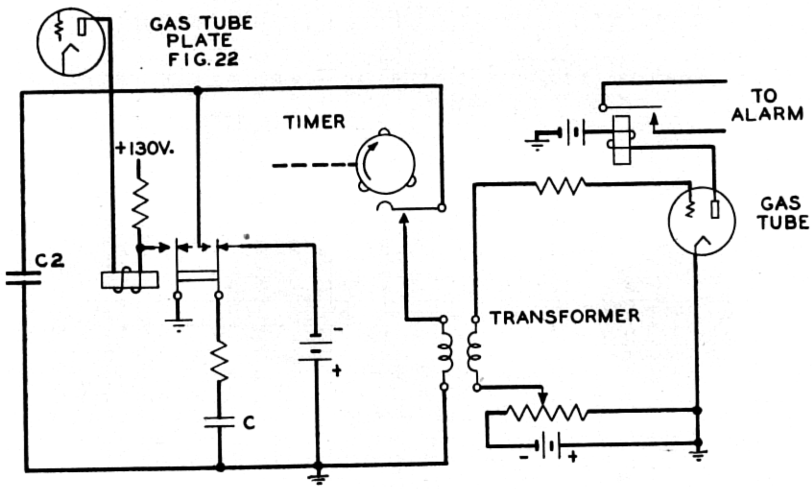


Fig. 24—Counting and alarm circuit of telegraph service-monitoring set.

employed having a potentiometer associated with it for the purpose of adjusting the grid-biasing potential so that the tube will fire only for voltages exceeding definite amounts corresponding to definite numbers of excessive distortions. It is apparent that this type of counting circuit could be replaced by a counting-relay circuit or by a selector-switch circuit such as is used in automatic telephony.

A front view of the monitoring set, arranged for mounting on a relay rack in a central office, is shown by Fig. 25.

In the present arrangement these sets have jacks at a number of places along the telegraph board in the central office, for the purpose of permitting attendants to use the set conveniently. Alarm lamps and signals are provided at the board to attract the attention of the attendant. As the use of these sets is developed, it may be found desirable to employ them in conjunction with a patrol arrangement by means of which a given set may be connected in turn to each of a number of circuits for a short interval. An arrangement of this sort was described by W. Schallerer.[8]

Other Developments

Other types of measuring apparatus have been used experimentally in the Bell System and have been found of value in laboratory work

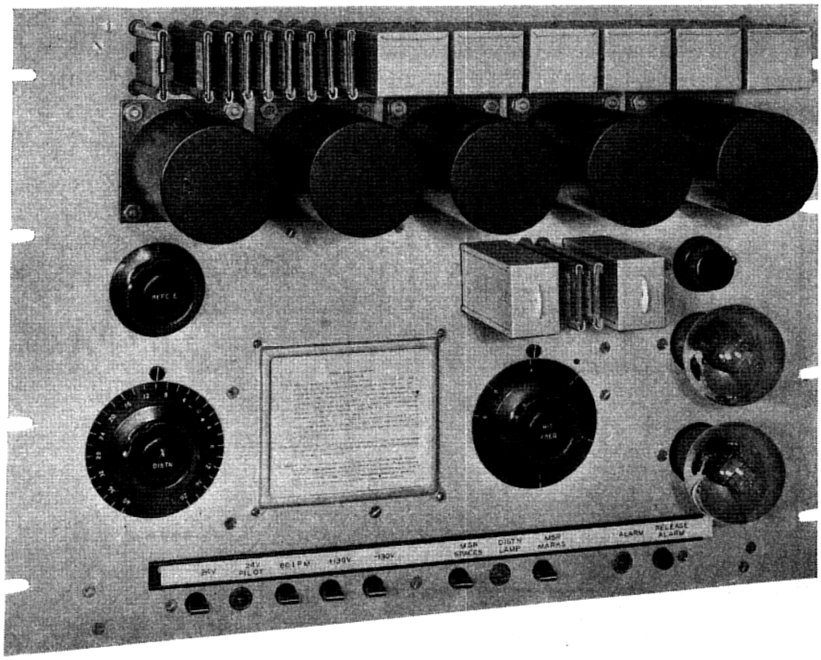


Fig. 25—Telegraph service-monitoring set, test design.

and special investigations. Among these devices are start-stop and synchronous distortion indicators employing flashes of light to indicate the position of the transitions of teletypewriter signals and a photographic recorder of teletypewriter signal transition points. A synchronous flashing indicator in combination with a distributor arranged to supply teletypewriter signals with adjustable bias is in use in shop tests of teletypewriters and in the laboratory.

Acknowledgment

In the development of the practical telegraph transmission measuring devices, which have been described, many members of the Bell System have contributed valuable ideas and effort. The authors wish to express their appreciation of the cooperation they have received.

APPENDIX

General

This appendix considers characteristic distortion of telegraph signals from the standpoint of the development of simple and convenient testing technique for application primarily to circuits transmitting start-stop teletypewriter signals.

A previous paper [2] developed methods of determining the correct transfer admittance for distortionless transmission under certain assumed conditions. One general and simplifying assumption was that the time interval between transitions in the telegraph signals would be an integral number of time units. If telegraph circuits were to be designed for the transmission of telegraph signals of this nature, distortionless transmission would be expected when the overall transfer admittance of the circuit was one of the many possible admittances discussed in the previous paper. Although a knowledge of the admittance requirements is a helpful guide in the design of circuits and permits the establishment of certain boundaries, the exact adjustment of transfer admittance to the proper value for satisfactory transmission on the basis of admittance measurements presents many practical difficulties and up to the present has not been generally used.

Another approach to the problem is the actual transmission of miscellaneous signals of the type required and the adjustment of the transfer admittance on a cut-and-try basis until the overall results are satisfactory. For relatively simple circuits satisfactory results can be obtained in this manner. However, for circuits which are electrically long and contain complex networks, a more orderly approach is desirable.

The problem may also be approached from the standpoint of adjusting the transfer admittance of the circuit so as to minimize the transient associated with each transition at the times at which succeeding transitions may occur. This may, of course, be done by means of oscillograph observations, but this procedure has serious practical disadvantages. An advantageous method, however, is to measure the characteristic distortion of simple signal combinations while making the adjustments. For this purpose, signals, each composed of two transitions, repeated at intervals long compared to the duration of the appreciable transient, are used. If the circuit is adjusted so as to transmit without distortion signals having respectively separations of one, two, three, etc. signal elements, between transitions, the requirements for distortionless transmission of miscellaneous signals of the nature under consideration are met, as will be shown below.

Repeated two-transition signals with varying integral time-unit intervals between transitions may be considered as telegraph reversals having a frequency determined by the period of repetition and bias determined by the interval between transitions. Therefore, telegraph reversals of varying bias may be used as a source of test signals, with a simple bias-measuring set at the receiving end and the input bias-output bias characteristic of a circuit determined for checking the characteristic distortion. The possible use and meaning of such measurements are discussed in the following:

Bias In-Bias Out

For the purpose of discussion consider the particular code indicated by Fig. 26.

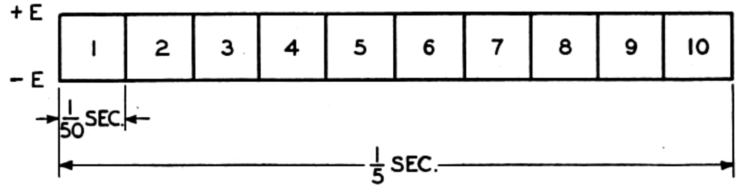


Fig. 26—Special telegraph signal. Each character consists of ten time units. Each time unit is one-fiftieth second and may be $+E$ or $-E$ depending on the character transmitted.

Each character to be transmitted is composed of ten time units, each unit being 1/50 second, so that it takes 1/5 second to transmit any of the 1024 possible characters. Although the nominal speed of signaling is 25 dots per second, the fundamental frequency of any character sent repeatedly is 5 cycles per second considered in the Fourier sense. Among the many possible signal combinations are the following which are equivalent to 5-cycle reversals with the amounts of bias indicated below.

Time Units Mark	Time Units Space	Time Bias $= 100 \frac{M-S}{M+S}$
10	0	+100%
9	1	+80%
8	2	+60%
7	3	+40%
6	4	+20%
5	5	0%
4	6	−20%
3	7	−40%
2	8	−60%
1	9	−80%
0	10	−100%

It is obvious for a symmetrical circuit that if signals with any amount of positive bias are transmitted accurately signals with the corresponding amount of negative bias will be transmitted since this corresponds to a reversal of the sending polarities.

The transfer admittance for distortionless transmission of these signals will now be derived for the case in which the band width is a minimum. It has been shown in a previous paper [2] that the minimum band width required is equal numerically to the speed of signaling.

Therefore a band width of 25 cycles will be necessary and sufficient for the signals listed above; this band will also meet the requirements for transmitting the remaining characters of the possible 1024.

The Fourier series for the biased reversal is

$$E(t) = E - \frac{bE}{2\pi} + \frac{E}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} [\sin n(\omega t - b) - \sin n\omega t],$$

where E and b are defined in Fig. 27, which shows the impressed voltage

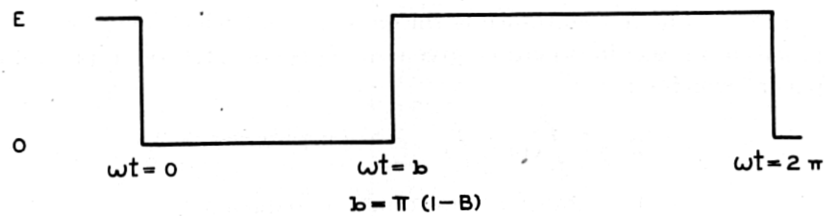


Fig. 27—Voltage wave for biased reversal.

wave at the transmitting end of the circuit, and B is percentage bias divided by 100.

Let the transfer admittance be Y_n at frequency corresponding to $n\omega$. Then, the requirement for perfect transmission of the reversal, assuming the receiving device to operate when the current passes through $EY_0/2$, is that

$$f(t) = EY_0/2 \text{ at } \omega t = 0 \text{ and at } \omega t = b,$$

where $f(t)$ denotes received current.

$$\text{At } \omega t = 0 \text{ or } b, f(t) = \left(E - \frac{bE}{2\pi} \right) Y_0 + \frac{E}{\pi} \sum_{n=1}^{\infty} \frac{Y_n}{n} \sin (-nb).$$

Hence, assuming for simplicity that $Y_0 = 1$

$$\frac{E}{2} = E - \frac{bE}{2\pi} + \frac{E}{\pi} \sum_{n=1}^{\infty} \frac{Y_n}{n} \sin (-nb).$$

Substituting the value of b and transforming

$$\frac{B\pi}{2} = \sum_{n=1}^{\infty} \frac{Y_n}{n} \sin nb.$$

In accordance with the assumption that band width is a minimum,

$Y_n = 0$ for $n \geq 5$. Therefore, the values of Y_n may be determined from the following equations wherein the values of nb are in degrees.

$$\begin{aligned}
\text{For } B&=.2 \quad .1\pi = Y_1 \sin 144 + \tfrac{1}{2} Y_2 \sin 288 + \tfrac{1}{3} Y_3 \sin 432 + \tfrac{1}{4} Y_4 \sin 576,\\
B&=.4 \quad .2\pi = Y_1 \sin 108 + \tfrac{1}{2} Y_2 \sin 216 + \tfrac{1}{3} Y_3 \sin 324 + \tfrac{1}{4} Y_4 \sin 432,\\
B&=.6 \quad .3\pi = Y_1 \sin 72 + \tfrac{1}{2} Y_2 \sin 144 + \tfrac{1}{3} Y_3 \sin 216 + \tfrac{1}{4} Y_4 \sin 288,\\
B&=.8 \quad .4\pi = Y_1 \sin 36 + \tfrac{1}{2} Y_2 \sin 72 + \tfrac{1}{3} Y_3 \sin 108 + \tfrac{1}{4} Y_4 \sin 144.
\end{aligned}$$

Solving these simultaneous equations it is found that $Y_1 = .967$, $Y_2 = .865$, $Y_3 = .685$, $Y_4 = .408$.

The computed admittance is the same as that which may be computed from the information given in Appendix III of a previous paper [2] which is:

$$Y = \frac{\pi}{2}\frac{f}{f_s}\cot\frac{\pi}{2}\frac{f}{f_s},$$

Y = transfer admittance at frequency f,

f_s = dotting speed.

Since the bias of the signals at the circuit output must equal the bias of the signals at the circuit input for the magnitudes of bias entering

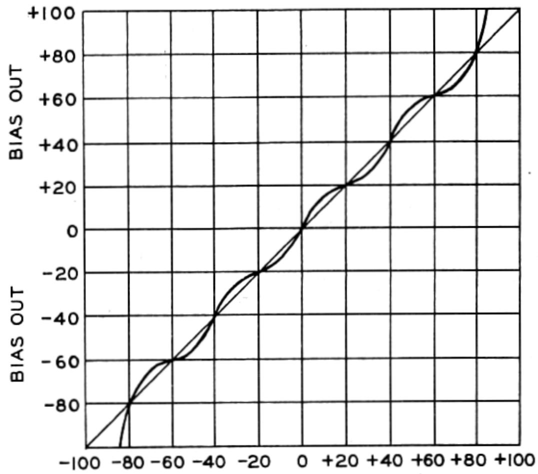


Fig. 28—Bias in-bias out characteristic for transmission of telegraph signals formed in accordance with Fig. 26 over a system having a band width equal to the dotting speed.

into the determination of the admittance, and since the transmission of additional harmonics of the fundamental frequency would be required to make the input bias equal to the output bias at additional magnitudes of bias, the Bias In-Bias Out characteristic for a circuit having an admittance as computed above would have the general characteristics indicated in Fig. 28.

Considered in terms of the transient behavior, if the circuit had the transfer admittance defined by the above equation, or any of the infinite number of other prescribed admittances using higher frequencies, the transient resulting from a single transition would be such as to have zero value at each of all possible future transition points. Also if the circuit were adjusted so that the four simple characters were transmitted with negligible distortion, the transients would fulfill the conditions for the satisfactory transmission of the other 1020 possible characters.

From Fig. 28, it is obvious that a circuit which had a perfect transfer admittance and a frequency band width large compared to the character repetition frequency, would have a Bias In-Bias Out characteristic which crossed the 45-degree line at many points and approached it as a limit. It is interesting to note the relation between the deviations of the Bias In-Bias Out characteristic from the 45-degree line and the frequency band width. In the example under discussion there are five waves in the characteristic which correspond to the frequency band width divided by the number of characters per second. The band width required is numerically equal to the product of the number of waves in the Bias In-Bias Out characteristic and the number of characters transmitted per second.

Start-Stop Teletypewriter Signal

Start-stop teletypewriter systems may employ varying speeds and signal arrangements. The 60-word-per-minute (60-speed) system is the one most generally used in the Bell System and is taken as an example in this appendix. Similar methods of analyses and tests could be applied to other systems.

The 60-speed teletypewriter signal consists of a starting unit which is always spacing, five selecting units, and a stop signal which is 1.42 units in length and is always marking. The duration of a unit signal pulse is 22 milliseconds and the total length of each character is, therefore, $1 + 5 + 1.42 = 7.42$ times units or 163 milliseconds. With no pause between succeeding characters there are 368 operations per minute or

$$\frac{368}{60} = \frac{1}{.163} = 6.13 \text{ operations per second.}$$

The problem of transmitting these signals without distortion is similar to the problem just discussed except instead of uniform spacing between possible transitions of 1/50 second, the transitions may be spaced at intervals of either.022 second, .031 second, or combinations of these intervals, and the frequency of repetition is 6.13 instead of 5 per second.

As indicated in Fig. 1, there are six teletypewriter characters (Blank, *T*, *O*, *M*, *V*, and Letters) which correspond to 6.13 cycle reversals biased by certain amounts. It will now be shown that if these six characters can be transmitted without distortion, the other 26 characters will also be transmitted without distortion. The method is the same as that used in the preceding problem.

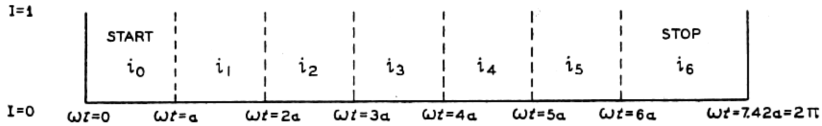


Fig. 29—7.42-Unit code start-stop teletypewriter signal.

Figure 29 indicates any teletypewriter signal where $i_0 = 0$, and $i_6 = 1$. i_1, i_2, i_3, i_4, i_5, may have values of 0 or 1 depending on the particular character. The Fourier series for the received current over a circuit with a transfer admittance Y having unit value at zero frequency, is

$$
\begin{aligned}
f(t) = \frac{i_1 + i_2 + i_3 + i_4 + i_5 + 1.42}{7.42} &+ \frac{1}{\pi}\sum_{n=1}^{n=\infty} \frac{Y_n}{n}\{i_1[\sin n(\omega t - a) - \sin n(\omega t - 2a)] \\
&+ i_2[\sin n(\omega t - 2a) - \sin n(\omega t - 3a)] \\
&+ i_3[\sin n(\omega t - 3a) - \sin n(\omega t - 4a)] \\
&+ i_4[\sin n(\omega t - 4a) - \sin n(\omega t - 5a)] \\
&+ i_5[\sin n(\omega t - 5a) - \sin n(\omega t - 6a)] \\
&+ 1\,[\sin n(\omega t - 6a) - \sin n\,\omega t]\}.
\end{aligned}
$$

Suppose that the transmitted frequency band is limited to 6 times the fundamental, i.e. $n = 1$ to 6, and Y_n adjusted so that the characters "Letters" *V*, *M*, *O*, *T* and "Blank" are transmitted perfectly.

The transfer admittance will now be determined for this case. The expression for $f(t)$ may be written for the characters just mentioned, and would have the value 1/2 at $\omega t = a$, for "letters," at $\omega t = 2a$ for *V*, at $\omega t = 3a$ for *M*, etc. Accordingly there result six equations which may be simplified as follows:

"Letters" $\sum_{1}^{6} \frac{Y_n}{n} \sin na = \frac{2.71\pi}{7.42}$,

V $\sum_{1}^{6} \frac{Y_n}{n} \sin 2na = \frac{1.71\pi}{7.42}$,

M $\sum_{1}^{6} \frac{Y_n}{n} \sin 3na = \frac{.71\pi}{7.42}$,

O $\sum_{1}^{6} \frac{Y_n}{n} \sin 4na = \frac{-.29\pi}{7.42}$,

T $\sum_{1}^{6} \frac{Y_n}{n} \sin 5na = \frac{-1.29\pi}{7.42}$,

"Blank" $\sum_{1}^{6} \frac{Y_n}{n} \sin 6na = \frac{-2.29\pi}{7.42}$.

The values of Y_n computed by solving these equations were plotted on Fig. 30 and a curve was drawn through them. It will be understood, that, on the scale of abscissae, F is the fundamental frequency of the character and the coefficients of F are values of n.

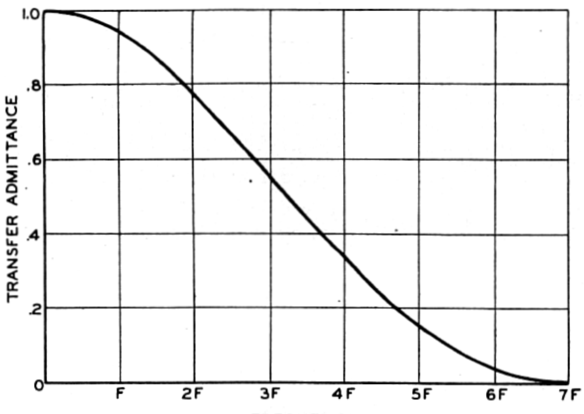


Fig. 30—Transfer admittance characteristic for undistorted transmission using frequencies up to seven times the fundamental frequency of the character.

By the methods employed in the previous paper [2] it can be shown that, for signals employing the same permissible intervals between transitions, the solutions of equations similar to the above approach the smooth curve as a limit as the period of repetition is lengthened.

These equations may be used to prove that when the six simple characters are perfectly transmitted, all other teletypewriter signals may be transmitted on a repeated basis. For distortionless transmission $f(t)$ should equal 1/2 at each transition point, assuming that the relay operates at this value of current. If the expression for $f(t)$ is written for each of the conditions which may occur, and is found to equal 1/2 at the transition points, the proof is complete. For this purpose the summation signs may be eliminated by substituting from any of the six simultaneous equations numerical values in place of summations of terms, in the equation for $f(t)$, with the following results:

CONDITIONS

$\omega t=0 \quad i_0=0 \quad i_6=1$

$$f(t)=\frac{1}{7.42}[i_1+i_2+i_3+i_4+i_5+1.42+i_1(-1)+i_2(-1)+i_3(-1)+i_4(-1)+i_5(-1)+1(2.29)]=\tfrac{1}{2},$$

$\omega t=a \quad i_0=0 \quad i_1=1$

$$f(t)=\frac{1}{7.42}[1+i_2+i_3+i_4+i_5+1.42+1(2.71)+i_2(-1)+i_3(-1)+i_4(-1)+i_5(-1)+1(1.29-2.71)]=\tfrac{1}{2},$$

$\omega t=2a \quad i_1=0 \quad i_2=1$ or $i_1=1 \quad i_2=0$

$$f(t)=\frac{1}{7.42}[0+1+i_3+i_4+i_5+1.42+0(2.71)+1(2.71)+i_3(-1)+i_4(-1)+i_5(-1)+1(.29-1.71)]=\tfrac{1}{2},$$

$\omega t=3a \quad i_2=0 \quad i_3=1$ or $i_2=1 \quad i_3=0$

$$f(t)=\frac{1}{7.42}[i_1+0+1+i_4+i_5+1.42+i_1(-1)+0(2.71)+1(2.71)+i_4(-1)+i_5(-1)+1(-.71-.71)]=\tfrac{1}{2},$$

$\omega t=4a \quad i_3=0 \quad i_4=1$ or $i_3=1 \quad i_4=0$

$$f(t)=\frac{1}{7.42}(i_1+i_2+0+1+i_5+1.42+i_1(-1)+i_2(-1)+0(2.71)+1(2.71)+i_5(-1)+1(-1.71+.29)]=\tfrac{1}{2},$$

$\omega t=5a \quad i_4=0 \quad i_5=1$ or $i_4=1 \quad i_5=0$

$$f(t)=\frac{1}{7.42}[i_1+i_2+i_3+0+1+1.42+i_1(-1)+i_2(-1)+i_3(-1)+0(2.71)+1(2.71)+1(-2.71+1.29)]=\tfrac{1}{2},$$

$\omega t=6a \quad i_5=0 \quad i_6=1$

$$f(t)=\frac{1}{7.42}[i_1+i_2+i_3+i_4+0+1.42+i_1(-1)+i_2(-1)+i_3(-1)+i_4(-1)+0(2.71)+1(2.29)]=\tfrac{1}{2}.$$

Hence it is concluded that if an admittance can be found such that "Blank" *T*, *O*, *M*, *V* and "Letters" are transmitted without distortion any other teletypewriter signal may be transmitted on a repeated basis, since the correct current value (1/2) will be obtained at any transition regardless of what other signal combination is used for the remainder of the character.

Computations have also been made for the case of a repeated signal combination consisting of any two teletypewriter characters. The results indicate that this may also be transmitted without distortion if the requirements have been met for the six simple characters sent repeatedly.

When distortion is present, there is deviation of the received current from the desired value at the time it should be 1/2 and the deviation to be expected at any transition for any character may be computed from equations similar to those given above. This, of course, differs from the amount of distortion which would be measured in per cent. It is of interest that the characteristic distortion on the more complicated characters may be materially greater than that measured on the simple two-transition characters.

The transient behavior of a circuit having the transfer admittance specified by the smooth curve of Fig. 30 may be determined by methods utilizing the Fourier integral. However, certain characteristics of this transient, namely, the points at which it must be zero, are known in advance from the conditions entering into the determination of the admittances. Although these conditions do not directly prescribe the magnitude of the transient at other points, additional information may be obtained from an inspection of Fig. 31.

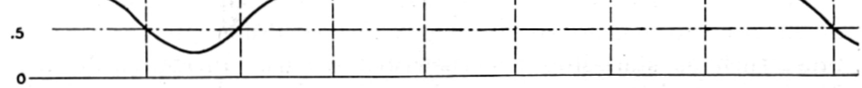


Fig. 31—Received current for "letters" character assuming the transfer admittance of Fig. 30.

This figure shows the computed received current over a telegraph circuit having the admittance shown in Fig. 30 when a repeated teletypewriter "Letters" signal is transmitted. It may be noted that the transient decays to inappreciable amplitudes at times greater than the shortest time unit of .022 second. This is significant, since it means that a particular arrangement of transitions is not of practical importance as long as transitions do not come at intervals closer than .022 second. With this admittance, therefore, no difficulty would be expected from keyboard sending, the signals from which differ from the signals previously discussed, in that the lengths of the stop signals occur on a random basis, and are never shorter than .031 second, depending on the typist.

However, if signals containing bias or other distortion such as indicated on Fig. 31 as distortion of future transition points were transmitted over the circuit, thus decreasing the minimum interval between transitions, the transient from one transition, for example, might affect following transitions. A circuit having a shorter build-up time could be made to introduce less distortion on transitions spaced at very short intervals. The rate of build-up is a function of the area under the transfer-admittance curve and from a design standpoint it is necessary to provide a suitable frequency band-width to make the slope of the received signals sufficient so that characteristic distortion will not be excessive when closely spaced transitions are transmitted, and also so that certain types of interference will not cause excessive fortuitous effects.

Where the available band width is limited the area under the admittance curve could be increased by transmitting the permissible harmonic frequencies at a greater amplitude. The transient of such a circuit would continue at appreciable magnitudes for a greater length of time and the minimum distortion would be increased but the general circuit stability might be improved.

The foregoing discussion of telegraph signal transmission has shown that when a circuit is adjusted to transmit without distortion certain selected repeated characters, the circuit can transmit on a repeated basis any of the characters possible with signals of the nature represented by the selected characters. This is true not only for the signals in which transitions are spaced at integral units of time but for signals in which transitions are spaced at predetermined non-integral units of time, such as start-stop teletypewriter signals. Incidental to the development of the proof of the later statement, the prescribed admittance for transmission without distortion was evaluated. The prescribed admittance for signals employing integral units between transitions was also similarly determined and found to be the same as that which had been determined from a somewhat different approach in a previous paper.[2]

The admittances considered have been idealized somewhat, inasmuch as no physical circuit will cut off completely at the higher frequencies and, in addition, the effective transfer admittance is not only a complex, and frequently nonlinear quantity, but is determined in part by the characteristics of transmitting and receiving relays and other terminal equipment. In the present state of the art, it is difficult to make practical use of transfer admittances in predicting the performance of a telegraph circuit.

The significant point is that the satisfactory transmission of the selected characters is an indication of the ability to transmit the desired telegraph signals satisfactorily. Also, the measurement of the distortion on the selected characters is particularly useful when it is desired to equalize individual circuits of varying length and makeup to secure a minimum of distortion.

The testing procedures suggested by the considerations of the foregoing have been incorporated into the testing instrumentalities discussed in the main paper. These methods have been used for several years in the adjustment and maintenance of telegraph circuits and found to be of considerable utility.

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