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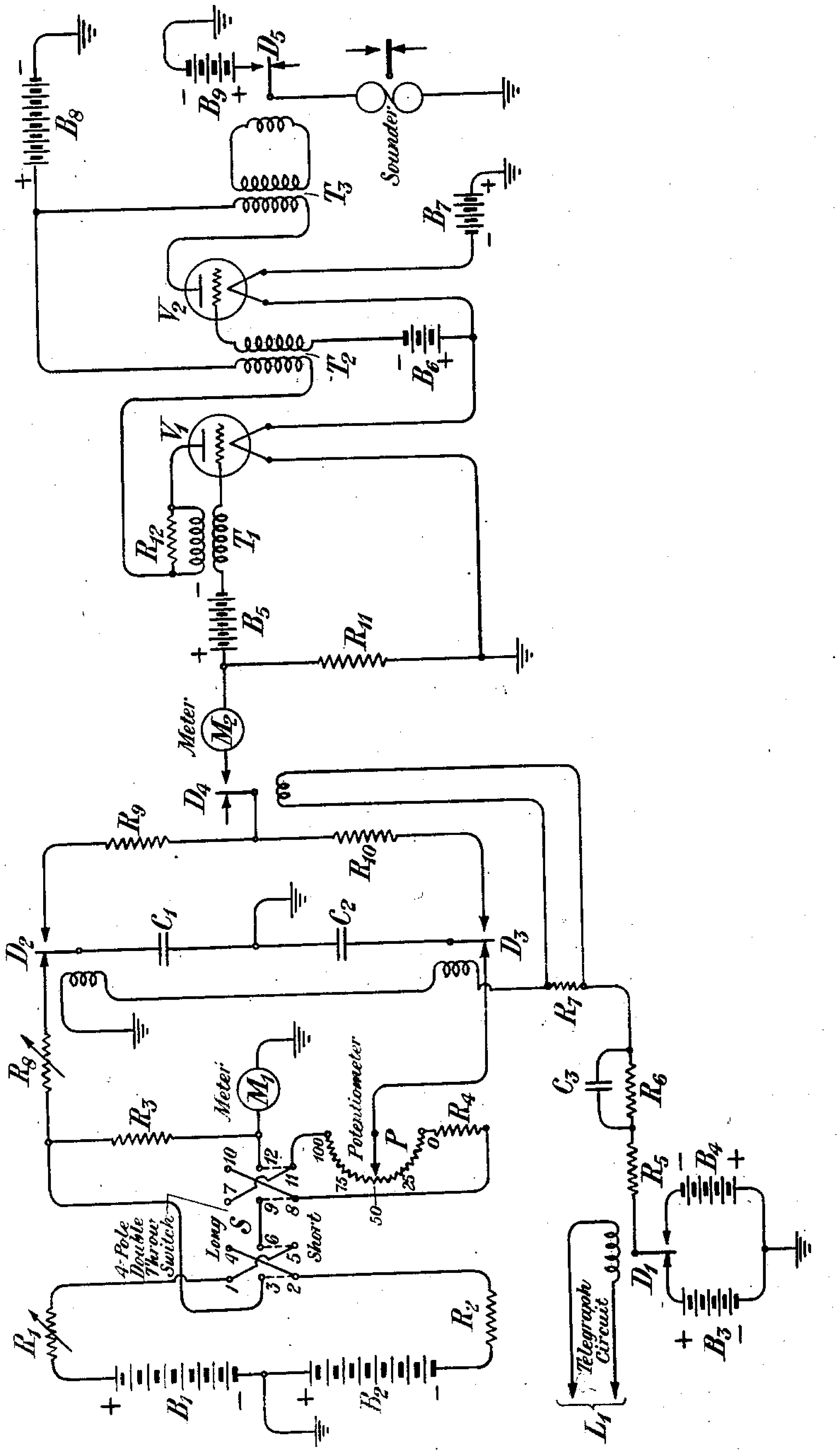

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TELEGRAPH-DISTORTION MEASURING SYSTEM.

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This invention relates to the measurement of the magnitude of distortion of telegraph signals resulting from their transmission over line circuits, and particularly to a method and means for a rapid measurement of the various components of such distortion. This invention is specially directed to the quantitative determination of that form of distortion manifesting itself in the lengthening or shortening of the period of duration of the transmitted signal.

Heretofore the amount of distortion has sometimes been determined by ear, a good operator being able to detect the difference between good signals and those designated as unsteady or biased. Another means for determining the magnitude of distortion is the Wheatstone receiver. By means of this device which has been employed to a great extent and is satisfactory when moderate accuracy only is desired, the length of a dot made on a tape moving with uniform velocity is measured and compared with the length of an undistorted dot. This arrangement has limitations which render it undesirable, particularly in making routine tests.

The principal object of this invention is to measure rapidly the various components of telegraph distortion. For a clear understanding of this invention, distortion may be considered as being made up of three components, (1) symmetric distortion, (2) asymmetric distortion or bias, and (3) fortuitous distortion. For most measuring purposes, the first two components may be grouped together and designated systematic distortion which is the distortion of the average of a large number of successive signals. This distortion is a function of the constants of the telegraph system. The third component, namely, fortuitous distortion, varies from signal to signal and is equal to the actual distortion for any individual signal minus the average distortion of a large number of signals. This component is due to interference and accidental variations in the telegraph apparatus. My invention combines various features of distortion bridges for measuring systematic distortion with an accurate means for measuring fortuitous distortion.

Another object of this invention is to determine the frequency of occurrence of distortions which are greater than a certain given value.

This invention will be clearly understood from the following description read in connection with the attached drawing showing schematically a form of embodiment of the invention.

Batteries B_1 and B_2, which are of substantially equal voltage, are connected to ground in the manner shown in the drawing so as to apply voltages of opposite polarity to the grounded condensers C_1 and C_2, the purpose of doing which will be clear from a later description. The positive pole of battery B_1 and the negative pole of B_2 are connected through the resistances R_1 and R_2, respectively, with contacts 1 and 2, respectively, of the four-pole double-throw switch S. The contacts of the switch are so connected that when the blades are thrown from one set of contacts to the opposite set the circuit connections are reversed. The contact 3 of this switch is connected to ground through the resistance R_3 and the meter M_1 and is also connected to ground through the resistance R_8 and the condenser C_1 whenever the armature of the relay D_2 is upon its left-hand contact. Contact 8 of the switch S is connected to ground through the resistance R_4, the winding of the potentiometer P and the meter M_1 (when the switch blades are in their lower position), and it is also connected to ground through the resistance R_4, a part of the potentiometer P and the condenser C_2 when the armature of the relay D_3 is upon its left-hand contact. With the blades thrown downward as represented by the dotted lines connecting the contacts of the switch S, battery B_1 will cause current to flow through resistance R_1, contacts 1, 5, 6, 9 and 8 of switch S, the resistance R_4 and the potentiometer P, contacts 11 and 12 of switch S and meter M_1 to ground. If the armature of relay D_3 is upon its left-hand contact, current will also flow from the contact point of the potentiometer P, through the contact of relay D_3 and condenser C_2 to ground, thus charging the condenser. In similar manner, current will flow from battery B_2, through resistance R_2, contacts 2 and 3 of switch S and resistance R_3

to ground. Current will also flow from the same battery through resistance R_8 and condenser C_1 to ground. Resistance R_4 is equal in magnitude to potentiometer P, and the sum of R_4 and P is equal in magnitude to R_3. Because of the latter equality, the voltages across R_3 and R_4+P will be equal and opposite, provided R_1 is equal to R_2, and B_1 and B_2 have equal voltages. In the event that these voltages are not equal, the variable resistance R_1 may be adjusted to compensate for the difference. The equality of voltages across R_3 and R_4+P is then indicated by a zero reading on the meter M_1. The right-hand contacts of relays D_2 and D_3 are connected with terminals of resistances R_9 and R_{10}, respectively, the other terminals of which are connected with the armature of the relay D_4. The right-hand contact of this relay is connected through the meter M_2 with the grid circuit of the tube V_1 which is a regenerative detector. This circuit includes the negative biasing battery B_5 and the winding of the transformer T_1 through which a certain amount of energy is fed back from the plate circuit of the tube. A resistance R_{11} is connected to ground between the junction point of the meter M_2 and the battery B_5. The plate circuit of the tube V_1 includes the battery B_8, a winding of the transformer T_2, and a winding of the transformer T_1, the latter being shunted by the resistance R_{12}. The tube V_2, which acts as an amplifier, has its input coupled with the plate circuit of the tube V_1 by the transformer T_2. The grid of this tube is biased negatively by the battery B_6. The filaments of both tubes are energized by the battery B_7. The plate circuit of the tube V_2 is connected by the transformer T_3 with the winding of the relay D_5, the armature of which is connected with a sounder or other indicating device. The telegraph circuit L_1 is connected with the winding of the relay D_1, the armature of which swings between contacts connected with the batteries B_3 and B_4 of opposite polarity which are the sources for energizing relays D_2, D_3 and D_4. The armature of relay D_1 is connected through resistances R_5, R_6 and R_7 with the windings of relays D_2 and D_3. The winding of relay D_4 is shunted across resistance R_7 so that that relay will lag slightly with respect to the relays D_2 and D_3 in its operation. The purpose of this lag is to eliminate the effect of differences in armature travel time and to allow the charges on condensers C_1 and C_2 to combine and to reach a steady condition before the combining circuit is connected to the detector and amplifier. The resistances R_5 and R_6 are to limit the current through the polar relays and the condenser C_3 which shunts R_6 is designed to render the wave front of the energizing current more abrupt.

The windings of the polar relays are so connected that the armatures of the relays rest on their left-hand contacts, as shown on the drawing, during the interval of the dots or spaces whose length is to be measured. The condensers C_1 and C_2 will thus become charged. The condenser C_1 will acquire a gradual charge owing to the fact that its charging current has to flow through the high resistance R_8. The total charge on this condenser depends upon the time interval during which charging takes place, and the amount of charge is therefore an accurate indication of the dot length which is being measured. The condenser C_2 is charged almost instantly to the voltage determined by the setting of the potentiometer P, because the resistance of P and R_4 combined is comparatively small. At the end of the dot or space signal, the armatures of relays D_2 and D_3 move to their right-hand contacts, and the charges of opposite polarity on condensers C_1 and C_2 combine by flowing through resistances R_9 and R_{10}. If the two charges are equal, the condensers will be entirely discharged. In that case, no current will flow through the meter M_2 and resistance R_{11} to ground when later the armature of relay D_4 moves to its right-hand contact. If the charges are not equal, current will flow through the meter which will indicate the fact that the length of signal is different from that represented by the setting of the potentiometer.

In order to measure systematic distortion, as defined hereinbefore, it is necessary to calibrate the apparatus so that the potentiometer P will represent in terms of per cent distortion the magnitude of the residual charge that flows through the meter M to ground after the operation of the relay D_4. This calibration may be done either experimentally or mathematically.

Experimental calibration.

Any type of signal containing only dots of unit length might be used for this purpose but for the sake of simplicity assume that the signal is the well known "E" signal which consists of a single dot followed by a much longer space. The signal should be obtained from a mechanical interrupter which is driven by a motor. The latter should be provided with an adjustable governor which is set near the middle of its range so as to be adjustable in either direction.

The recurring signal thus obtained is connected to the measuring set and operates the relays. With the potentiometer P on the point marked 0, namely, the junction point between the potentiometer and the resistance R_4, the resistance R_8 is adjusted until the charges on the condensers C_1 and C_2 are equal. This condition is indicated by a lack of deflection in meter M_2. The speed of revolution of the motor is then counted and the dot length of the signal which will be called the "true dot length" is calculated.

Other points on the potentiometer P corresponding to distorted signals may now be obtained by increasing the speed of the motor so as to decrease the dot length and adjusting the potentiometer P until the meter M_2 again reads 0. The dot length for the new speed is calculated and the difference between this dot length and the original or "true" dot length expressed as a percentage of the true dot length is marked on the scale of the potentiometer P. Other points representing dot lengths shorter than the true dot length may be obtained in a similar manner.

For positive distortions, that is, dot lengths longer than the true dot length, the switch S is thrown to the "long" position. This reverses the batterits B_1 and B_2 and also interchanges the relative positions of P and R_4. The reversing of the batterits is not important in this connection but the reversing of P with R_4 is necessary. The latter operation causes the voltage applied to condenser C_2 to be increased with a movement of the potentiometer contact from its zero position while in the previous case the voltage was decreased. The reason for this change is obvious when it is remembered that the charge on condenser C_1 will be greater as the signals are lengthened and consequently the voltage applied to condenser C_2 must be greater to neutralize the charge.

With switch S thrown as indicated above, the potentiometer may be calibrated for various positive distortions in a manner similar to that for negative distortions. It will, of course, be necessary to have two scales on the potentiometer, one which reads negative distortions and the other which reads positive distortions. The position of switch S will determine which scale is to be read.

It should be noted that the timing resistance R_8 is not readjusted during calibration, after having once been set for the true dot length. When making measurements at speeds other than that used in calibrating the potentiometer, the resistance R_8 must be readjusted. It is, therefore, necessary to have a curve or table which gives the value of R_8 to be used with a particular speed of signaling or true dot length. Such a curve may be obtained experimentally by setting the potentiometer P on 0 and determining the value of timing resistance R_8 required to make the condenser charges neutralize each other for various speeds of signaling.

It should also be noted that the distortion calibrations on the potentiometer P hold for all speeds of signaling provided the timing resistance R_8 is adjusted to the proper value for that particular speed. This will be evident by an inspection of the equation representing the charging curve of a condenser in series with a resistance.

The equation is as follows:

$$q=Q(1-\epsilon^{-\frac{t}{CR}}) \quad (1)$$

where

q=charge at time t.
Q=final or maximum charge of the condenser.
t=time elapsed since the charging began.
C=capacity of condenser.
R=resistance in series with condenser.
ϵ=base of Naperian logarithms.

As applied to the measuring set, C and Q are constant, while q, t and R are variable. Let the true dot length during calibration be represented by T' and the true dot length for any other speed after calibration by T''. Let the charges and timing resistances for the true dot lengths for these conditions be represented by q' q'' and R' R'', respectively. As pointed out above the potentiometer P is set on zero when determining the timing resistances R' and R'' for the true dot lengths in the two cases, therefore

$$q'=q'' \quad (2)$$

or

$$Q(1-\epsilon^{-\frac{T'}{CR'}})=Q(1-\epsilon^{-\frac{T''}{CR''}}) \quad (3)$$

or

$$\frac{T'}{R'}=\frac{T''}{R''} \quad (4)$$

If a point on the potentiometer has been calibrated for any distortion such as d, it means that the dot length for that particular distortion was $(1\pm d)$ T', in terms of the true dot length T'. The sign of d depends upon whether the distortion was positive or negative. Similarly for any other speed in which the true dot length is T'', this same value of distortion would give a dot length of $(1\pm d)$ T''. It is evident from equation (4) that multiplying T' and T'' by $(1\pm d)$ does not destroy the equation. Therefore, the calibration of the potentiometer in per cent. distortion at one speed, using a timing resistance R', holds true for any other speed provided the proper timing resistance R'' is chosen for that speed.

Mathematical calibration.

In some cases where the experimental method of calibrating the measuring set is not found practicable, a mathematical method may be used. Such a method will now be derived and described. The notation on the drawing forming part of this application will be used for the various values of resistance and capacity and substitutions will be made in the fundamental equation (1). The charges q and Q may be replaced by:

$$q=C_2e=C_2r_pI' \text{ and } Q=C_1E=C_1R_3I''. \quad (5)$$

Where

r_p=potentiometer resistance between contact of potentiometer P and ground.
I' =current in potentiometer circuit.
I''=current in resistance R_3.

If the batteries B_1 and B_2 are balanced so that meter M_1 reads zero then $I'=I''$ and equations (5) become:

$$q=C_2r_pI' \text{ and } Q=C_1R_3I' \quad (6)$$

Let T be the undistorted or true dot length corresponding to the zero setting of the potentiometer P and let $\pm d$ be the distortion reading for any point on the potentiometer. Then the length of the distorted dot will be:

$$t=(1\pm d)T. \quad (7)$$

Substituting equations (6) and (7) in equation (1) and replacing R by R_8 gives:

$$\frac{C_2r_p}{C_1R_3}=1-\epsilon^{\frac{-(1\pm d)T}{C_1R_8}} \quad (8)$$

Since the values of T, C_1 and R_8 are constant for all values of d during calibration.

$$\frac{T}{C_1R_8}=K \quad (9)$$

Equation (8) then becomes:

$$\frac{C_2r_p}{C_1R_3}=1-\epsilon^{-(1\pm d)K} \quad (10)$$

It will probably be desirable to make condensers C_2 and C_1 equal. If this is done equation (10) reduces to

$$\frac{r_p}{R_3}=1-\epsilon^{-(1\pm d)K} \quad (11)$$

The constant K may be obtained from the constants of the measuring set for the condition of zero distortion. In this case d=zero, and r_p=P, the resistance of the potentiometer.

Having found the value of K, the setting of the potentiometer P, so as to include a potentiometer resistance r_p between the potentiometer contact and ground, may be found by giving various positive and negative values of distortion to d and solving equation (10) or (11). In this way as many points as desired may be found and the potentiometer may be accurately calibrated. A good Wheatstone bridge should be used in finding the different values of r_p on the potentiometer.

The values of the timing resistance R_8 for different speeds of signaling may be found from equation (9) after the constant K has been found. This equation may be rearranged as follows:

$$R_8=\frac{T}{C_1K} \quad (12)$$

Since the values of C_1 and K are known, various values of R_8 corresponding to different speeds of signaling or true dot lengths T, may readily be obtained. Having once calibrated the set, it requires no further calibration unless the values of capacity and resistance in the measuring circuit should change. Since such changes can readily be avoided by using properly constructed condensers and resistances, it is evident that the arrangement will give accurate and reliable results over a long period of time. Frequent checking of the balance of batteries B_1 and B_2 is necessary in this connection and means should be provided for doing this accurately.

The foregoing description shows the method for obtaining the systematic distortion which, as stated, includes not only the symmetric distortion, but also the asymmetric distortion of bias.

In order to separately determine the magnitudes of these components, the following method should be used. A normal signal is sent over the telegraph circuit L_1 in the usual manner and received on the measuring set at the receiving station. The potentiometer P is adjusted until the meter M_2 reads zero. The position of the pointer on the potentiometer scale shows the average systematic distortion, that is, the symmetric distortion plus the bias. A reverse signal is then sent from the sending station, and the batteries B_3 and B_4 on the contacts of the master relay D_1 are reversed so that the polar relays will again operate properly. The distortion is again measured by the setting of the potentiometer P. This reading represents the symmetric distortion minus bias. It will, of course, be apparent that from these two readings the magnitudes of the symmetric distortion and bias can readily be calculated. In order to obtain accurate results, it is necessary that the voltages of batteries B_1 and B_2 shall be balanced, that the proper value of the timing resistance R_8 shall be used, and that a constant speed interrupter shall be used to insure uniform dot lengths.

Measurement of maximum distortion.

In the measurement of systematic distortion and its components, the description of which has just been given, it is not necessary to use the vacuum tube detector-amplifier shown upon the drawing. The value of this apparatus is found in the measurement of maximum distortion. The manner in which this apparatus functions is as follows;

The first tube, V_1, acts somewhat like a regenerative detector. The unneutralized discharge currents from condensers C_1 and C_2 flow through resistance R_{11}, and the voltage drop across this resistance is impressed on the grid of the tube. The negative grid battery B_5 has a large enough voltage so that negative discharges of the condensers have no effect in the plate circuit of the tube, only positive discharges produce any effect.

Transformer T_1 acts as a feed-back transformer to amplify the increase in plate current due to positive discharges of the condensers. A resistance R_{12} is shunted across the primary winding of this transformer to limit the feed-back effect and to prevent continuous oscillations. The feed-back arrangement may be dispensed with and replaced with additional stages of amplification where such a change is found desirable.

Coupling between the first and second tubes is accomplished by means of transformer T_2, which has its primary winding connected in series with that of T_1 in the plate circuit of the detector tube V_1. The output of the second tube V_2 is stepped down to a lower voltage by means of transformer T_3 and operates the polar relay D_5. The relay operating current, which is obtained in this manner, consists of a positive and a negative impulse of current for each positive condenser discharge through resistance R_{11}. This is due to the action of the transformer T_3. As a result, the armature of relay D_5 moves from its spacing contact to its marking contact and back to its spacing contact for each discharge impulse. The sounder connected to the relay armature will, therefore, give one click for each positive discharge impulse.

Assume that it is desired to measure the maximum negative distortion of signals. The circuit arrangement is then exactly as shown on the drawing. The positive battery B_1 is connected to potentiometer P and the negative battery B_2 to the timing resistance R_8. As a result, the condenser C_2 will get a positive charge and the condenser C_1 a negative charge.

If the potentiometer P is set at any particular value of distortion, the condenser C_2 will get a definite positive charge for each dot. This charge will be practically constant for all dot lengths, even for extremely short dots. The condenser C_1 will get a negative charge whose value will depend on the particular length of the dot during which the condenser is charged. It is evident that the positive charge on C_2 may be decreased sufficiently, by adjusting the potentiometer, so that condenser C_1 will always have an excess negative charge. Since only an excess positive charge operates the sounder at the output of the detector-amplifier, the maximum negative distortion is obtained by adjusting the potentiometer to the point where the sounder just fails to operate. The value of this distortion is then read directly on the negative scale of the potentiometer.

For positive distortions the switch S is thrown to the "long" position. This reverses the batteries B_1 and B_2 so that C_2 gets a negative charge and C_1 a positive charge. Adjusting the potentiometer in this case increases the negative charge on C_2 until it exceeds the positive charge on C_1, even for the longest dots. The point at which this condition occurs is observed by the failure of the sounder to operate and the value of distortion is read on the positive scale of the potentiometer.

To separate the maximum fortuitous distortion from the systematic distortion and bias, it is only necessary to subtract the average distortion obtained previously from the maximum distortions obtained above. If the maximum distortions were obtained from the normal signal, the corresponding average distortion should be used and vice versa for a reversed signal.

For certain classes of measurements, where large distortions occur at infrequent intervals, the sounder may be provided with contacts and made to operate a counting device such as a message register. In this case, the potentiometer P is set at any desired value of distortion. Whenever the distortions exceed the setting of the potentiometer, a record will be made on the message register. In this way an accurate record of the operation of a telegraph circuit during a long period of time may be obtained with very little effort.

What is claimed is:

1. The method of measuring distortion of telegraph signals, which consists in charging two condensers from a direct current source and determining the magnitude of the distortion of the signal by the difference in the charges taken by the said condensers.

2. The method of measuring distortion of telegraph signals which consists in charging two condensers during the time in which a telegraph signal keeps the circuits of the condensers closed, combining the charges and measuring the resultant charge.

3. The method of measuring distortion of telegraph signals which consists in charging a condenser and limiting the rate of charging, charging another condenser without any limitation upon its charging rate, and comparing the two charges thus produced.

4. In a telegraph distortion measuring system the combination with a source of signals to be measured, of a plurality of condensers, a source of potential individual to each condenser, a resistance in series with one of said condensers, switching means to

combine the charges upon the condensers, and means to measure the combined charge.

5. The method of measuring distortion of telegraph signals which consists in charging two condensers at different rates during the time intervals corresponding to the elements of telegraph signals, combining the charges so that they tend to neutralize each other and determining the magnitude and polarity of the resultant charge.

6. The method of measuring the duration of rapidly recurring electric current impulses which consists in charging a condenser to values of electric charge determined by the lengths of said impulses, charging a second condenser to values of electric charge under the control of the operator, combining said charges after each impulse so that said charges tend to neutralize each other, and determining the magnitude and polarity of the resultant charges.

7. The method of measuring the maximum deviation in length from a given value, of a rapid succession of electric current impulses, which consists in charging a condenser to a value determined by the length of said impulses, charging a second condenser to any desired value, combining said charges, and determining whether the charge on said first condenser is greater or less than that on said second condenser.

In testimony whereof, I have signed my name to this specification this 13th day of November, 1924.

JOSEPH HERMAN.