

Dec. 9, 1930.

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1,784,194

TRANSMISSION FREQUENCY DELAY MEASURING CIRCUIT

Filed Oct. 12, 1928

Fig. 1

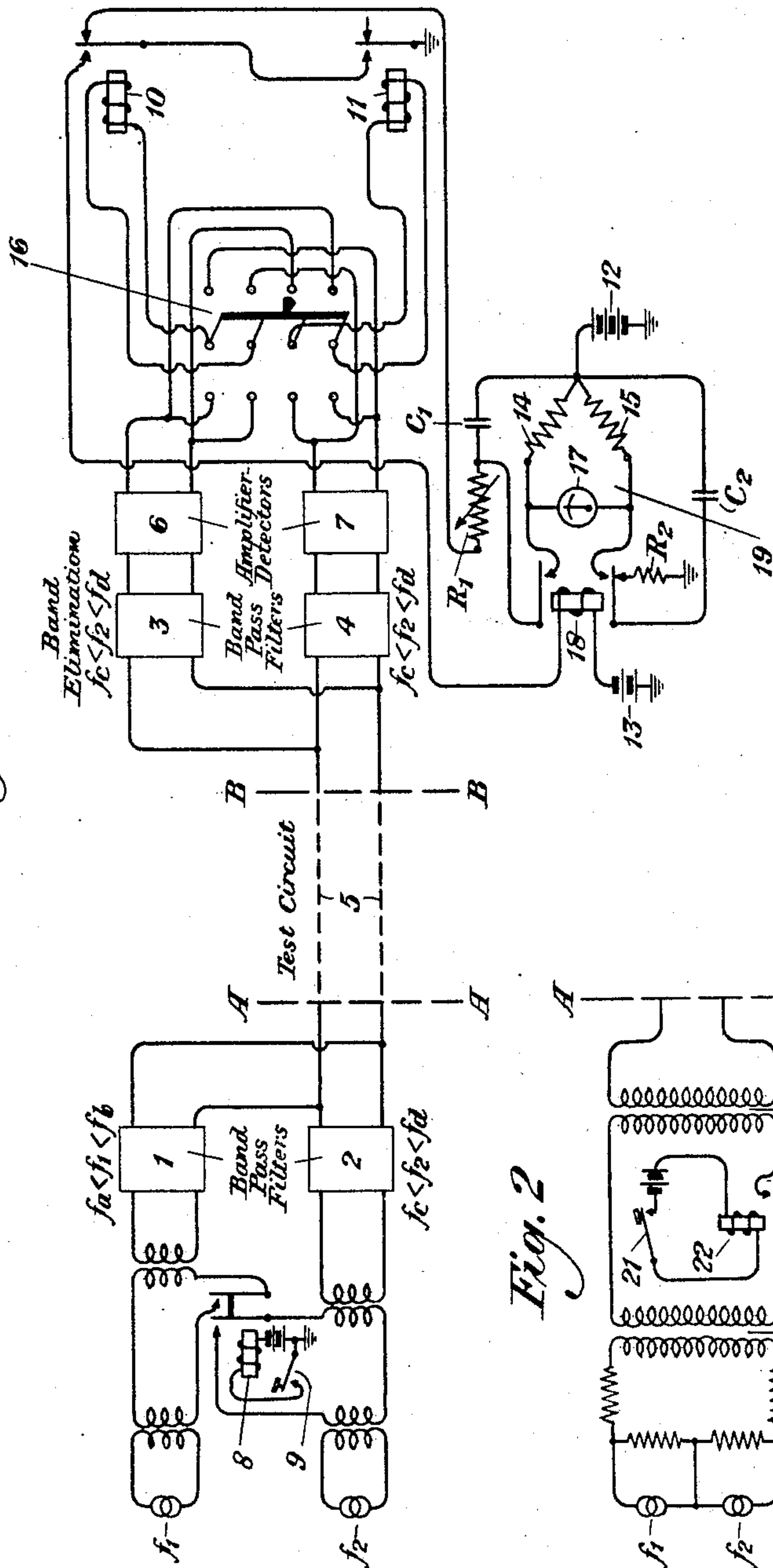
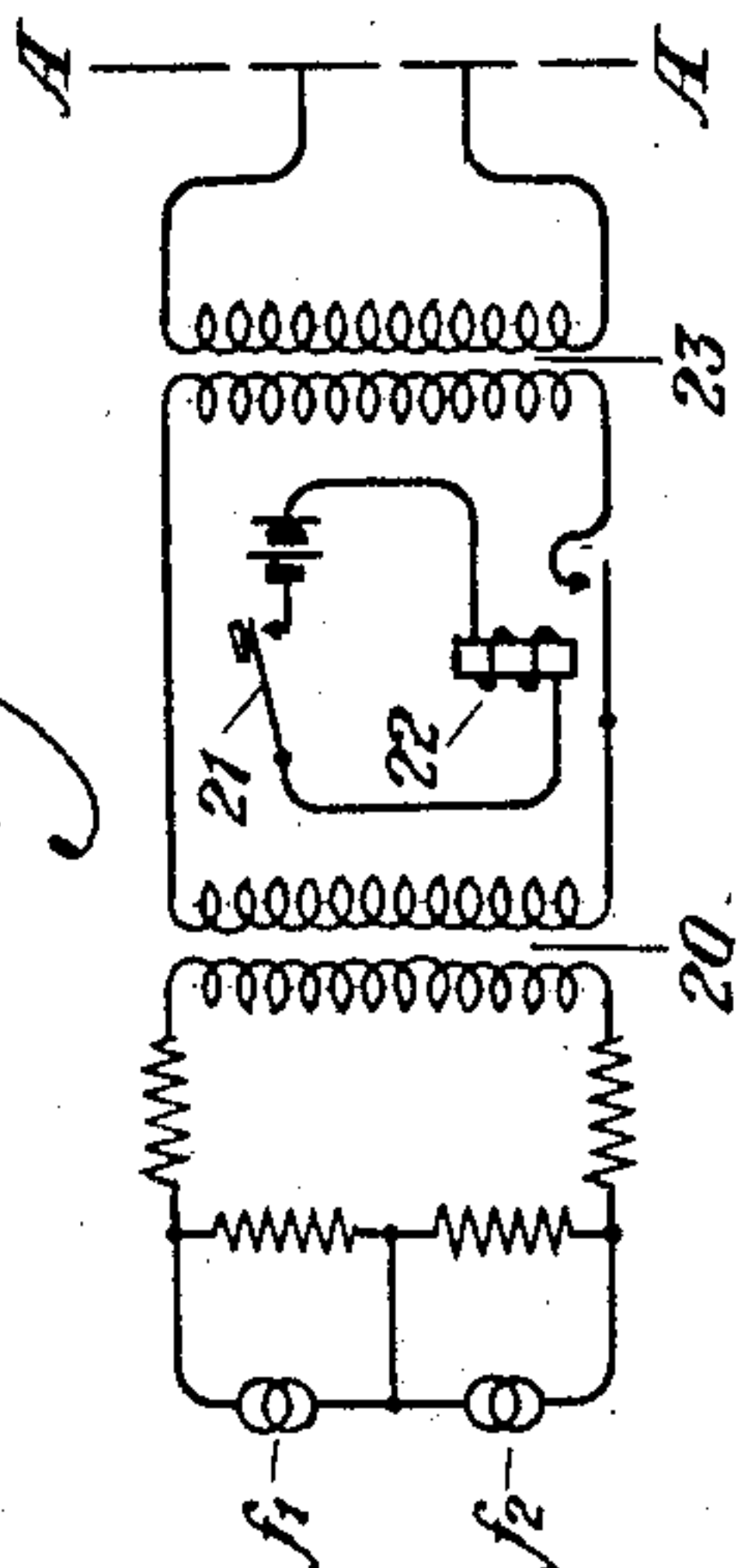


Fig. 2



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TRANSMISSION FREQUENCY-DELAY-MEASURING CIRCUIT

Application filed October 12, 1928. Serial No. 312,183.

This invention relates to means for measuring the transmission characteristics of telephone or telegraph systems and the like, and more specifically discloses means for measuring the difference in time required for transmitting any two distinct frequencies over such a transmission system.

The difference in time required for transmitting different frequencies over a transmission line has been termed the "relative delay." The relative delay of the various essential frequencies in signal transmission compared to some reference frequency furnishes one of the criteria as to the amount of distortion introduced by the circuit during such signal transmission. It will be seen therefore that a method for accurately measuring the relative delay versus frequency of a transmission system has important applications in connection with the design of equalizing networks adapted to reduce the amount of distortion in a given transmission system.

A brief discussion will be given here to bring out the relationship between the delay frequency characteristic of a transmission system and the amount of signal distortion introduced by such system. It is a well-known fact that for a perfectly distortionless line, all frequencies are attenuated by a like amount and are transmitted with the same velocity of propagation. If upon such a line, properly terminated in its characteristic impedance, a current of given frequency is suddenly impressed at the sending end, a definite period of time will elapse before any effect is noted at the receiving end and then the received current will suddenly start right off at its final steady state value. Stated somewhat differently, a perfectly distortionless line has the important steady state characteristics that all frequencies are attenuated equally during transmission over such line and the total phase change varies linearly with frequency.

A line containing distortion, on the other hand, differs significantly from a distortionless line in that if, upon a line producing distortion, a current of given frequency is suddenly impressed at the sending end, a certain period of time elapses before any effect is

noted at the receiving end and then the received current builds up gradually to its final steady state value. This gradual building up of the received current is the direct result of the distortion introduced by the circuit and is determinable from the steady state characteristic of the line, i. e., the steady state frequency-attenuation curve and the manner in which the total phase shift varies with frequency. If the line be equalized as regards steady state attenuation, that is, if suitable networks are inserted to make the overall attenuation approximately constant with frequency, then the building up time of the received current is determined solely by the relationship between total phase change and frequency. In such case, the departure of the total phase change-frequency curve from linearity gives a measure of the amount of phase distortion introduced by the line. A line equalized as regards steady state attenuation has the peculiar characteristic that current of any frequency in the equalized range applied to the sending end will build up to 50% of its final state value at the receiving end in an interval of time which is equal to the first derivative of the total phase change frequency-curve at such frequency for the circuit under consideration. It will thus be seen from this relationship that there is a direct connection between the building up time of the received current and the amount of phase distortion introduced by the circuit. And as a result of this relationship, it will be seen further that a measurement of the frequency delay curve of the circuit furnishes an experimental method of determining the amount of phase distortion.

The theoretically distortionless line is never encountered in actual practice. The best that can be done is to make the line distortionless over the essential range of signal frequencies. For example, in speech transmission, a line would be practically distortionless in which the attenuation was constant from a frequency of zero to about 10,000 cycles and for which the total phase change varied linearly with frequency over such range. A line of this type equalized over a certain frequency range might be de-

defined as a "commercially" distortionless line. The "commercially" distortionless line defined as above has the peculiar characteristic that all frequencies within the equalized range will build up to their "proximate" steady state values in the same interval of time. The time required for the received current to build up to 50% of its final steady state value will be defined herein as the "proximate" steady state current. In other words, the delay frequency curve for such a circuit over the equalized range measured to the time currents reach their proximate steady state values would be a straight line coinciding with the frequency axis. Consequently, if a delay frequency curve were obtained for a line producing appreciable distortion in the essential frequency range in such a manner that the delay in each case represented the relative time required for each frequency to reach its proximate steady state value as compared to the time for some reference frequency, the resultant curve would measure directly the amount of phase distortion introduced by the circuit, assuming, of course, such a line to be equalized to have approximately constant attenuation over the essential frequency range.

The above statements regarding the transient characteristics of telephone lines are merely stated as facts without proof. The mathematical derivations of such statements are disclosed in the following papers: (1) "Phase distortion and phase distortion correction," by S. P. Mead in the Bell System Technical Journal, vol. 7, No. 2 for April, 1928, at page 195, and (2) "Building of sinusoidal currents in long periodically loaded lines," by J. R. Carson in the Bell System Technical Journal, vol. 3, No. 4, at page 558.

Having described above the value, in the art of electrical communication of a knowledge of the frequency-delay characteristics of a transmission system, the means by which it is proposed to measure such delay characteristics will now be disclosed. Before taking up such discussion, however, the advantages of the present disclosure over the prior art will be pointed out. The present invention discloses a method of determining directly the difference in time required for transmitting any two frequencies over a transmission line; whereas in the majority of methods now known, the apparatus measures separately the total time of transmitting each frequency, the difference in time being obtained by subtraction. The latter method has the serious disadvantage that a small error in determining the total time of transmission will become a relatively large error in determining the relative delay, i. e., the difference in time of transmitting two frequencies.

In the drawings, Figure 1 discloses a cir-

cuit arrangement for measuring the relative delay of a given transmission line by the method of the present invention. Fig. 2 discloses an alternative means for applying at the sending end the frequencies to be compared.

Referring to Fig. 1, sources of frequency f_1 and f_2 are associated with transmission line 5 for which the delay is to be determined. The closure of key 9 completes a circuit to operate relay 8, the operation of which simultaneously applies frequencies f_1 and f_2 to the test circuit 5 through filters 1 and 2. These filters are band-pass filters, filter 1 being designed to pass a small range of frequencies including f_1 and filter 2 similarly designed to transmit a small range including f_2 . These filters are inserted to eliminate some of the transient frequencies which are introduced by the sudden building up of currents f_1 and f_2 in the circuit.

The frequencies f_1 and f_2 thus simultaneously applied are transmitted over the test circuit 5 from the sending end AA to the distant end BB, at which point the frequencies are separated by means of filters 3 and 4. Filter 4 is a band-pass filter which passes a small range of frequencies including f_2 . Filter 3 is a band elimination filter which eliminates a small range of frequencies including f_2 but passes all others. Thus, upon arrival of the current at the receiving end, frequency f_1 flows through filter 3 and is amplified and rectified in device 6. Frequency f_2 flows through filter 4 and is amplified and rectified in device 7. With switch 16 suitably operated, as will be explained below, the rectified currents of the two frequencies operate relays 10 and 11, respectively, thus suitably operating the delay measuring circuit.

At this point, it seems advisable to explain the manner in which the timing circuit measures the delay. The timing circuit comprises apparatus 19 together with relays 10 and 11. This timing circuit for measuring short intervals of time is described in a paper by J. Herman, entitled "Bridge for measuring small time intervals", in the Bell System Technical Journal for April, 1928, vol. 7, No. 2, at page 343. The following explanation is given there of the manner in which the device functions. Two condensers C_1 and C_2 are charged from the common battery 12. The condenser C_1 is charged through an adjustable high resistance R_1 during the time elapsing between the operation of relay 11 and the subsequent operation of relay 10. This elapsed time is the interval of time to be measured and the charge accumulated on the condenser C_1 during such time is an accurate means of measuring the time. The second condenser C_2 is used merely for comparison purposes. It is charged through a fairly low resistance R_2 and acquires its full

charge in a relatively small interval of time.

After the completion of the charging interval, relay 18 is operated and the two condensers are discharged simultaneously through the differential meter circuit comprising meter 17 and similar resistances 14 and 15 connected as shown. If the charges on the two condensers are equal, the meter 17 will show no deflection but if they are unequal the meter will show a momentary deflection, the direction of which will indicate whether the charge on C_1 is too high or too low. By repeating the charge and discharge process a few times, meantime adjusting the valve of resistance R_1 in series with condenser C_1 , the charge on the two condensers can be made equal and the meter will thus show no deflection. When this condition is obtained, the interval of time during which the charging took place may be determined from the value of the high resistance R_1 .

The relationship between the interval of time of charging and the value of the resistance R_1 required to make the charges on the two condensers equal is a direct proportion. This will be obvious from the inspection of the equation for the charge at any instant on a condenser which is being charged through a high resistance. This equation is:

$$q = Q \left[1 - e^{-\frac{t}{C_1 R_1}} \right] \quad (1)$$

where q equals the charge at time t , t equals the lapsed time in seconds since the charging began, Q equals final or maximum charge on the condenser, C_1 equals capacity of the condenser and R_1 equals the series resistance.

Since q , by adjustment of resistance R_1 is always made equal to the charge on the comparison condenser and since the charging battery is common to the two condensers, therefore using the symbols shown on the drawing for circuit 19 $C_2 E$ may be substituted for q and $C_1 E$ for a Q , the equation then becomes:

$$C_2 = C_1 \left[1 - e^{-\frac{t}{C_1 R_1}} \right] \quad (2)$$

As mentioned, the two condenser capacities are kept constant. Therefore, any change in t requires a proportional change in R_1 in order to satisfy the equation.

Returning now to the original discussion, assume that switch 16 is thrown to the left and that frequency f_2 builds up to its proximate steady state value at the receiving end before frequency f_1 . The amplifier-detectors 6 and 7 are so adjusted that relays 10 and 11 will be operated by the rectified proximate steady state currents of frequencies f_1 and f_2 , respectively. Frequency f_2 under the above assumption operates relay 11 first. This starts the charging of condenser C_1 over the

circuit from battery 12 through condenser C_1 , resistance R_1 , back contact of relay 10 and front contact of relay 11 to ground. Condenser C_2 meantime has been charged to the potential of battery 12 through the low resistances R_2 . When frequency f_1 subsequently builds up to its proximate steady state current, relay 10 operates, opening the circuit containing condenser C_1 and thus preventing any further charge from accumulating thereon. At the same time, the operation of relay 10 closes a circuit to operate relay 18 from battery 13 through the winding of relay 18, front contact of relay 10 and front contact of relay 11, which is still operated, to ground. The operation of relay 18 connects the condensers C_1 and C_2 in the differential meter circuit as explained above, thus permitting the discharge thereof, and the deflection of the needle of meter 17 indicates whether resistance R_1 is adjusted to a proper value or not. By opening and closing key 9 at intervals, thus transmitting fairly long pulses of frequencies f_1 and f_2 , meantime adjusting resistance R_1 , a balance can be obtained so that the meter 17 shows no deflection. From the setting of resistance R_1 , when the balance is obtained, the delay of frequency f_1 as compared to f_2 is determined directly in seconds through proper calibration of the resistance R_1 .

If in a given instance, with switch 16 thrown to the left, frequency f_1 arrived before frequency f_2 , relay 10 would first be operated, followed by relay 11. Under this condition, no charge would ever be accumulated on condenser C_1 and hence no balance could be obtained. In such case, it would be necessary to throw switch 16 to the right, thus reversing the relays by connecting relay 10 to detector 7 and relay 11 to detector 6. With this arrangement, frequency f_1 arriving first would operate relay 11 and subsequently the arrival of frequency f_2 would operate relay 10, in which case a balance on meter 17 could be obtained and the delay thus determined.

Since there is delay in the filters and in the measuring circuit as a whole, it is necessary that the delay measuring circuit be calibrated for zero test circuit, i. e., with the circuit at AA connected directly to the circuit at BB. With this arrangement and the frequencies f_1, f_2 applied, the delay of the measuring circuit is determined once for all and a suitable correction equal to this delay is thereafter applied to all measurements made with a test circuit 5 connected.

Frequencies f_1 and f_2 may, of course, be any two frequencies with the result that filters 1 to 4, inclusive, must be adjustable or the same frequency f_2 may be used in all cases as a reference frequency and frequency f_1 only varied, in which case filters 2, 3 and 4 could be fixed and filter 1 variable.

If frequencies f_1 and f_2 are well separated,

it would be possible to omit filters 1 and 2 at the sending end in which case a circuit arrangement like that of Fig. 2 could be used. With the circuit of Fig. 2, frequencies f_1 and f_2 are applied to transformer 20 through a suitable resistance network adapted to maintain at all times a suitable load connected to the frequency generators. The operation of key 21 closes the circuit to operate relay 22 which in turn, closes the circuit to simultaneously apply frequencies f_1 and f_2 to line 5 through transformer 23. The arrangement of Fig. 2 is preferable to that of Fig. 1, due to the possibility of error being introduced in the latter case through failure of the simultaneous closure of the contacts of relays 8.

With the arrangement of Fig. 2, it would probably be necessary to use two reference frequencies, say of 1,000 and 2,000 cycles, otherwise when the comparison and reference frequencies were close together, the transients due to one frequency might operate prematurely the receiving apparatus associated with the other frequency. To avoid this, frequency f_2 might be adjusted at 1,000 cycles for measuring the delay of frequencies above 1,500 cycles, and adjusted at 2,000 cycles for measuring the delay of frequencies below 1,500 cycles.

What is claimed is:

1. The method of measuring the relative delay of a transmission circuit, which consists in simultaneously impressing upon the sending end of said circuit a pair of distinct single frequency currents, separating said frequencies at the receiving end to facilitate measurement thereon, and measuring the difference in time of arrival of said frequencies.

2. The method of measuring the relative delay of a transmission circuit, which consists in simultaneously impressing upon circuits individual thereto, a pair of distinct single frequency currents, filtering such currents to suppress the extraneous frequencies, impressing said filtered currents upon the sending end of the transmission circuit, separating said frequencies at the receiving end to facilitate measurement thereon, and measuring the difference in time of arrival of said currents.

3. The method of measuring the relative delay of a transmission circuit, which consists in simultaneously impressing upon the sending end of said circuit, a pair of distinct single frequency currents separating said frequencies at the receiving end to facilitate measurement thereon, and measuring the difference in time required for said received frequencies to build up to a predetermined fraction of their final steady state values.

4. The method of measuring the relative delay of a transmission circuit which consists in simultaneously impressing upon the sending end of said circuit, a pair of distinct single frequency currents separating said fre-

quencies at the receiving end to facilitate measurement thereon, individually amplifying and rectifying said frequencies thereat, causing each said rectified current to operate individual relay means upon building up to a predetermined portion of its final steady state value, and operating time indicating means in accordance with such relay operations to measure the intervening time interval.

5. The method of measuring the relative delay of a transmission circuit, which consists in simultaneously impressing upon circuits individual thereto a pair of distinct single frequency currents, filtering such currents to suppress the extraneous frequencies, impressing said filtered currents upon the sending end of the transmission circuit, separating said frequencies at the receiving end to facilitate measurement thereon, individually amplifying and rectifying said frequencies thereat, causing each said rectified current to operate individual relay means upon building up to a predetermined portion of its final steady state value, and operating time indicating means in accordance with such relay operations to measure the intervening time interval.

6. Means for measuring the relative delay of a transmission circuit, comprising in combination a plurality of sources of distinct single frequency currents, means for simultaneously impressing said frequencies upon the transmission circuit, means at the receiving end for separating the frequencies to facilitate measurement thereon, and timing means for measuring the differences in times of arrival of said currents.

7. Means for measuring the relative delay of a transmission circuit, comprising a current source of reference frequency, a second current source adjustable in frequency, means for simultaneously impressing on the transmission circuit at the sending end current from both said sources, means at the receiving end for separating the transmitted frequencies, and timing means thereat for measuring the difference in time of arrival of said frequencies.

8. Means for measuring the relative delay of a transmission circuit, comprising in combination a pair of distinct single frequency current sources, means for simultaneously impressing said frequencies upon the sending end of said transmission circuit, filter means at the receiving end for passing the received frequencies into channels individual thereto, amplifying rectifying means individual to each said channel, relay means individual to each rectifier output operable upon said rectified current attaining a predetermined fraction of its final steady state value, and timing means operated in accordance with the successive operation of said relay means

for measuring the intervening time interval.

9. Means for measuring the relative delay of a transmission circuit, comprising in combination a pair of distinct single frequency current sources, means for simultaneously impressing said currents on the transmission circuit, means at the receiving end for passing each frequency into a channel individual thereto, amplifier rectifier means individual to each channel, relay means individual to each rectifier output operable upon said rectifier current attaining a predetermined fraction of its final steady state flow, timing means operated in accordance with the successive operations of said relay means for measuring the intervening time interval, said timing means comprising a source of potential for charging a first capacity to the potential thereof and for charging a second capacity through an adjustable resistance during the interval between the successive relay operations, means thereafter to simultaneously discharge said capacities through a differential meter circuit, means to adjust said variable resistance until said meter shows no deflection upon discharge of said capacities, and a calibration for said adjustable resistance to indicate the delay.

10. Means for measuring the relative delay of a transmission circuit, comprising in combination a pair of distinct single frequency current sources, filtering means individual to each current source for eliminating extraneous frequencies, a connection from the output of each filter to the sending end of the transmission circuit, means for simultaneously impressing said currents upon said filters for transmission over the circuit, filter means at the receiving end for passing the received frequencies into channels individual thereto, amplifying rectifying means individual to each said channel, relay means individual to each rectifier output operable upon said rectified current attaining a predetermined fraction of its final steady state value, timing means controlled in accordance with the successive operation of said relay means for measuring the intervening time interval, a reversing switch interposed between said rectifying means and said relay means for connecting the relays to the rectifier means in proper sequence to insure proper operation of said timing means for measuring the delay.

In testimony whereof, I have signed my name to this specification this 9th day of October, 1928.

DOREN MITCHELL.