

Dec. 28, 1943.

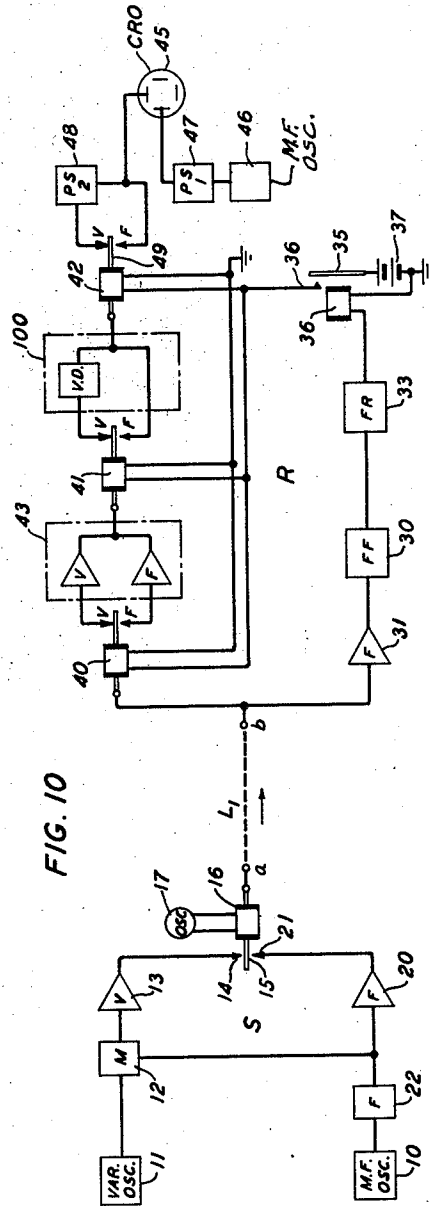
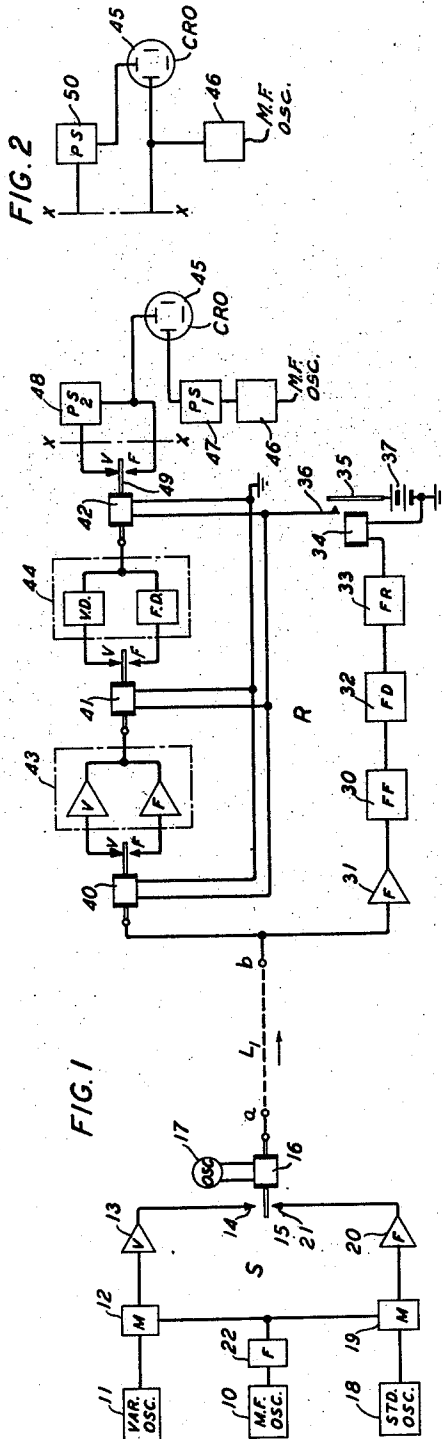
M. S. BURGESS

2,337,541

ELECTRIC CIRCUIT

Filed June 28, 1941

4 Sheets-Sheet 1



INVENTOR
M. S. BURGESS
BY *C. Sprague*
ATTORNEY

Dec. 28, 1943.

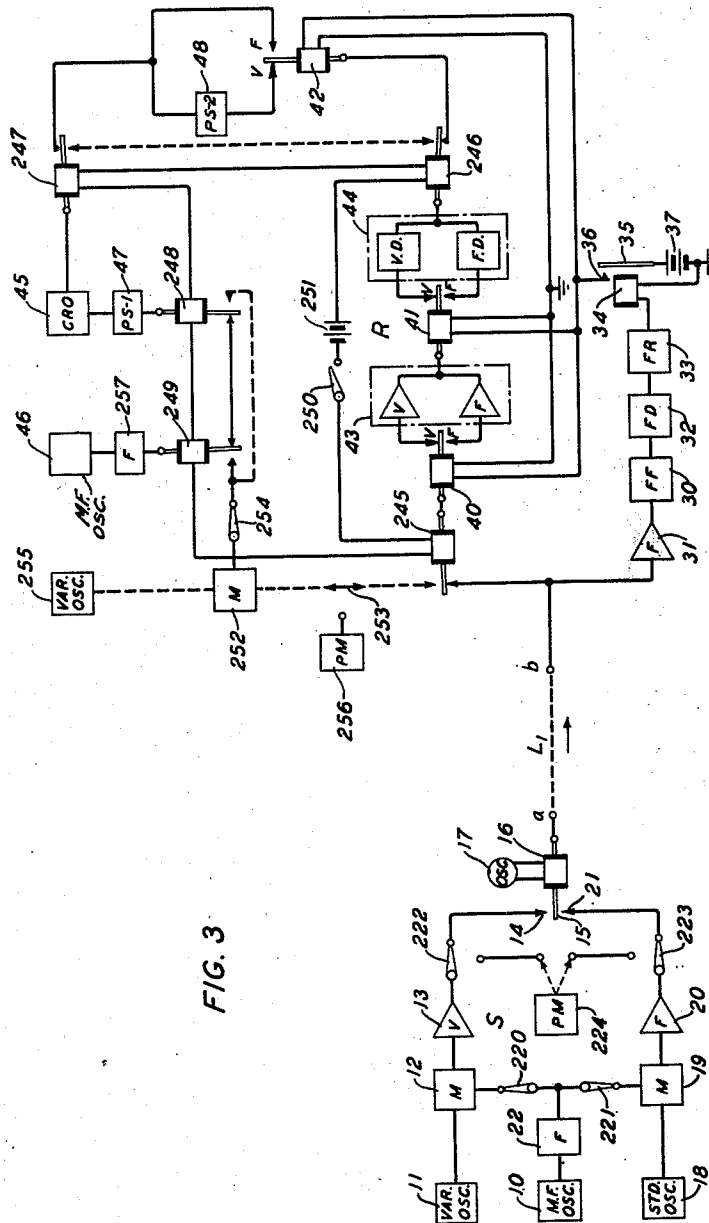
M. S. BURGESS

2,337,541

ELECTRIC CIRCUIT

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4 Sheets-Sheet 2



INVENTOR
M.S. BURGESS
BY *Ch. Sprague*
ATTORNEY

Dec. 28, 1943.

M. S. BURGESS

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ELECTRIC CIRCUIT

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FIG. 4

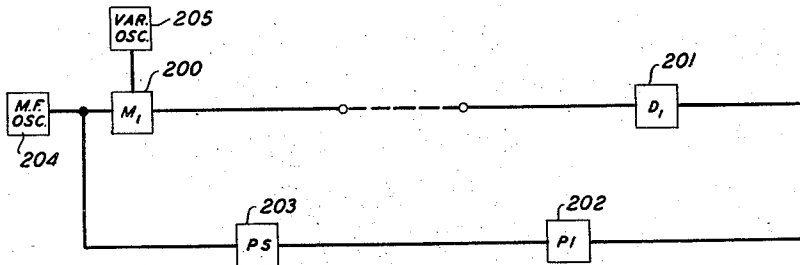


FIG. 5

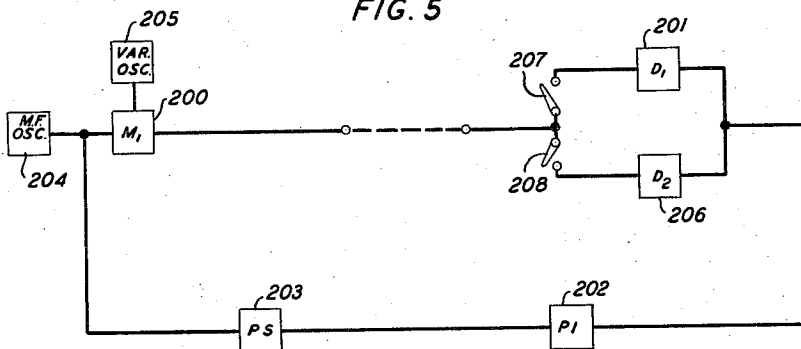
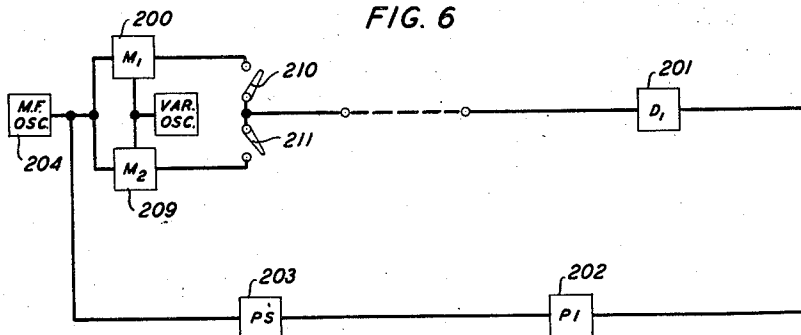


FIG. 6



INVENTOR
M. S. BURGESS
BY *Calhoun*
ATTORNEY

Dec. 28, 1943.

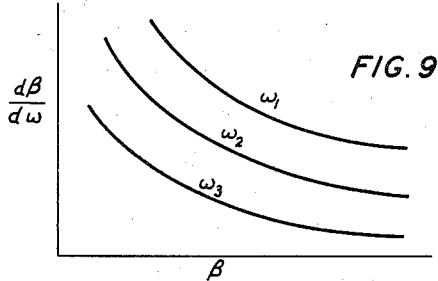
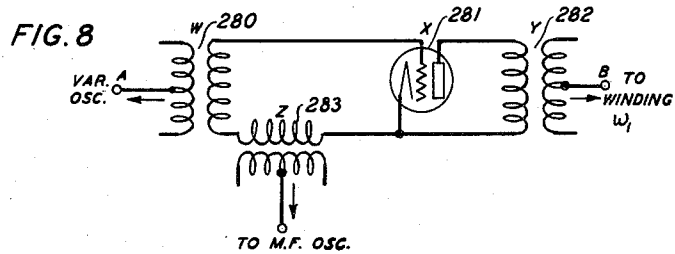
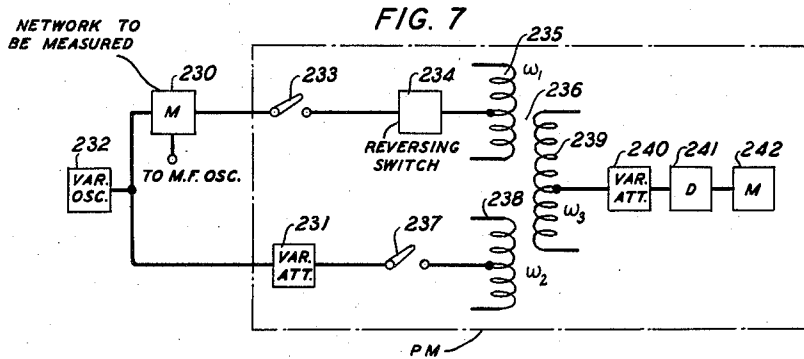
M. S. BURGESS

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4 Sheets-Sheet 4



INVENTOR
M. S. BURGESS.
BY
C. Sprague
ATTORNEY

UNITED STATES PATENT OFFICE

2,337,541

ELECTRIC CIRCUIT

Montague S. Burgess, Queens Village, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 28, 1941, Serial No. 400,289

11 Claims. (Cl. 179—175.3)

This invention relates to electric circuits and more specifically to methods of measuring envelope delay of transmission lines.

It is an object of this invention to provide novel methods of measuring the envelope delay of electric circuits and more particularly of transmission lines.

Envelope delay is by definition the slope of a phase versus frequency curve

$$\frac{d\beta}{d\omega}$$

The quantity

$$\frac{d\beta}{d\omega}$$

can be expressed by the following equation:

$$\frac{d\beta}{d\omega} = T + \omega \frac{dT}{d\omega} \quad (1)$$

where T is the phase delay

$$\left(\frac{\beta}{\omega} \right)$$

From the standpoint of telephotography and television the transient nature of the phenomena involved is such that all of this equation must be considered. Only when certain parts of the frequency range are required and it is known that T differs by some small quantity from the envelope delay which is within the accuracy desired should phase delay be used to replace envelope delay. In actual measurement

$$\frac{d\beta}{d\omega}$$

is not actually accomplished, the quantity measured being

$$\frac{\Delta\beta}{\Delta\omega}$$

which is sufficiently accurate for practical purposes. This measured quantity may be thought of as the true value of

$$\frac{d\beta}{d\omega}$$

at a frequency differing from the carrier by an amount equal to the modulating frequency.

$$\frac{\Delta\beta}{\Delta\omega}$$

is obtained in the various embodiments of the present invention by fixing the frequency difference and measuring the corresponding phase change. Reference is made to a paper entitled "Measurement of Phase Distortion" by Messrs.

Nyquist and Brand published in the Bell System Technical Journal, July 1930, Vol. IX, commencing on page 522, which deals with the measurement of phase distortion or delay distortion and is particularly concerned with measurements in telephone circuits. For this purpose use is made of the above-mentioned quantity "envelope delay" which is defined therein as the first derivative of the phase shift with respect to frequency.

The present invention relates in one of its aspects to methods of measuring envelope delay of straightaway television circuits each employing a single non-reversible line, that is, a line which is capable of transmitting waves in one direction only, differing in this respect from the invention described in the copending application of the same inventor, Serial No. 376,976, filed February 1, 1941 wherein the circuit measured necessarily includes a reversible line, that is, a line which is capable of transmitting waves in either direction.

In accordance with a specific embodiment of the present invention, the envelope delay of a single non-reversible line or system is obtained by the direct comparison at the receiving end of the line of two waves which are applied to the line at the sending end as modulated waves, transmitted over the line and demodulated at the receiving end. More particularly, in accordance with this embodiment of the invention, a modulated wave formed by modulating a wave from a variable oscillator (the frequency of which for convenience in description will be hereinafter designated the "measuring frequency" and which frequency is constant during a given set of readings taken to provide data for determining the envelope delay at that particular value of frequency but which is adapted to be varied to obtain the envelope delay at other frequencies) with a wave of a low fixed frequency (hereinafter designated the modulating frequency) and a modulated wave formed by modulating a wave of a standard frequency with a wave of the modulating frequency are intermittently and alternately applied to the circuit to be measured and similarly received at the receiving station where they are both detected and the resulting waves of the modulating frequency are compared with a wave of the modulating frequency from an oscillator of waves of this frequency at the receiving end of the circuit. During the intermittent application of the modulated wave of the standard carrier frequency, a phase shifter at the receiving end of the circuit is used to adjust to zero the phase difference between the modulating fre-

quency wave from the receiving end oscillator and the detected wave by observing when the elliptical pattern obtained on a cathode ray oscillograph becomes a straight line (the two waves under comparison being applied to the respective pairs of deflecting plates in the oscillograph). Similarly, when a relay in the main transmission path of the sending end of the line reverses direction to give an intermittent application of the modulated wave of the measuring frequency, a second phase shifter, also at the receiving end of the circuit, is used to adjust to zero the phase difference between the modulating frequency wave receiving end oscillator and the detected wave obtained from the modulated wave of the measuring frequency. The readings of the two phase shifters are utilized, together with various calibration readings, in obtaining the envelope delay for the particular value of measuring frequency used for the set of readings. It will be noted that the principle is used that when the resulting phase relation of each of the two demodulated waves is made equal to that of a third wave of the same frequency, then the first two waves are in phase with each other.

In calibrating the apparatus, the modulating equipment at the sending end is measured for phase change at the desired carrier frequency and from calculations with respect to certain of its component parts the phase change in the modulated wave caused by the modulating process is obtained. The delay of each of the receiving amplifiers and detectors is obtained as follows: first, the delay of a loop arrangement of modulator and detector is obtained; and, second, the delay caused by the modulator is obtained and by subtraction of one of these quantities from the other the delay of the modulating frequency wave by the demodulating process is obtained. The subtraction from the overall delay measurement of the delays in the modulating and demodulating processes gives the delay over the line to be measured.

In a modification, the receiver arrangement may be simplified by using a circuit which makes use of the principle that two oscillating waves of the same frequency, when applied to the same terminals, will tend to remain in phase with each other. Thus, if the wave of the modulating frequency obtained by demodulating the modulated wave of the standard carrier frequency and the output wave from the modulated frequency oscillator at the receiving end are applied to the respective pairs of plates of a cathode ray oscillograph, the two waves remain in phase with each other and the resulting pattern on the oscillograph screen is a straight line. Comparison of the demodulated wave of modulating frequency, obtained by detection from the modulated wave of the measuring carrier frequency, with the wave of modulating frequency generated at the receiving station is made through the phase shifter as before; when the pattern is a straight line a reading on the phase shifter gives the delay change. This method is otherwise similar to the method briefly described above.

In a further modification, only one wave is transmitted modulated which wave is demodulated after transmission and compared in phase with a sinusoidal wave which is also transmitted over the line intermittently with the modulated wave.

The invention will be more readily understood by referring to the following description taken in

connection with the accompanying drawings forming a part thereof in which:

Fig. 1 shows a system for measuring the envelope delay of a straightaway television circuit employing a single non-reversible line;

Fig. 2 is a circuit diagram of a modification of a portion of the receiving equipment of the system shown in Fig. 1;

Fig. 3 shows a system of the type shown in Fig. 1 with auxiliary apparatus for calibration;

Figs. 4 to 8, inclusive, are circuits used in explaining the method of calibration of the arrangement shown in Fig. 1;

Fig. 9 is a diagrammatic representation used in explaining the operation of the system shown in Fig. 3; and

Fig. 10 shows another system for measuring envelope delay.

Referring more specifically to the drawings, Fig. 1 shows, by way of example to illustrate the principles of this invention, an arrangement for measuring the envelope delay of a single non-reversible circuit L_1 . Two different modulated waves are intermittently applied to the circuit and from various readings taken the envelope delay of the line or circuit L_1 is determined. Referring now to the sending end apparatus generally designated in Fig. 1 by the reference character S, there is provided an oscillator 10, designated the modulating fixed frequency oscillator, which generates a sine wave of a fixed frequency of, for example, 5,000 or 10,000 cycles per second. This frequency is designated the modulating frequency. There is also provided an oscillator 11 which is designated the variable oscillator or measuring frequency oscillator and which generates sine waves for testing purposes of a frequency of, for example, 50 kilocycles to 1 to 2 megacycles. Any well-known oscillators may be used as the members 10 and 11. The output waves of these oscillators 10 and 11 are fed into a modulator 12 and a modulated wave is obtained which contains the measuring frequency from the oscillator 11 modulated by the low fixed frequency (the modulating frequency) from the oscillator 10. This modulated wave is amplified by the variable amplifier 13 (that is, an amplifier which can amplify a wide band of frequencies) and then transmitted over the line or circuit L_1 to the receiving station R through the upper contact 14 and the armature 15 of the relay 16. Any suitable oscillator 17 is connected to the windings of the relay 16 to cause it to oscillate the armature 15 between the upper contact 14 and the lower contact 21. The oscillator 17 may be of any suitable form to generate sine wave oscillations of any suitable frequency, such as, for example, 50 cycles per second. In general, this frequency may vary from about 10 to about 100 cycles per second.

There is also provided at the sending station a standard oscillator 18 which generates waves of a frequency of, for example, 25,000 cycles per second. The output waves of the oscillators 18 and 10 are applied to the modulator 19 and a modulated wave is obtained which contains the standard frequency from the oscillator 18 modulated by the low fixed frequency (the modulating frequency) of the oscillator 10. This modulated wave is amplified by the fixed amplifier 20 and then transmitted over the line or circuit L_1 to the receiving station R over the lower contact 21 and armature 15 of the relay 16. A filter 22 is connected between the oscillator 10 and the modulators 12 and 19 for the purpose of suppress-

ing any harmonics of the modulating frequency output.

The modulated waves produced by the modulators 12 and 19 are intermittently applied to the circuit L_1 and similarly received at the receiving station R. The sending end relay 16 is operated by a suitable low frequency from the oscillator 17 and permits the intermittent application of the modulated waves from the modulators 12 and 19, to the circuit L_1 .

During transmission, the receiving apparatus at the station R offers two paths of transmission for the waves from the modulator 19 but only one for the waves from the modulator 12 as one of these paths is so filtered by the filter 30 as to permit only the modulated wave having the lower fixed carrier frequency (that is the one from the modulator 19) to enter. A fixed amplifier 31 precedes the filter 30 in order to amplify the waves before filtering, while the filter 30 is followed by a fixed detector 32 and a rectifier 33 for detecting and rectifying the envelope which passes the filter 30. A portion of the wave which passes the filter 30 and which is detected and rectified by the detector 32 and the rectifier 33 is applied to and operates relay 34, thus closing the contact between the armature 35 and the contact 36, the positive pole of the direct current source 37 being applied to the armature 35 and the negative pole of this source 37 being connected to ground and to the coil of the relay 34. The contact 36 is connected to the windings of the relays 40, 41 and 42, these latter relays being so arranged that when the relay 34 is operated, thus closing the connection between the armature 35 and the contact member 36, the relays 40, 41 and 42 are operated to the fixed position, designated F in the drawings.

The other path for the received waves from the modulator 19 and the only path for the waves from the modulator 12 is shown at the top portion of the receiving end apparatus R. The waves travel through the variable and fixed amplifier 43, and also the variable detector 44. The final detected wave of the modulating frequency passes through the armature 49 and contact F of the relay 42 to one set of deflecting plates of the cathode ray oscillograph 45. A wave from a fixed frequency oscillator 46 at the receiving end having the same frequency as the frequency of the detected wave, that is of the modulating frequency, is applied to the other set of plates of the cathode ray oscillograph 45 through a phase shifter 47. If these two waves are out of phase the resulting pattern on the oscillograph screen will be an ellipse. By adjustment of the phase shifter 47 until the ellipse closes and becomes a straight line, the two waves are synchronized.

During the time interval when there is transmitted over the line or circuit L_1 a series of modulated waves (from the modulator 12) containing the frequency to be measured, there is only one path available as the filter 30 prevents these waves from reaching and operating the relay 34. Thus the relays 40, 41 and 42, which may be polarized if desired, remain in the V or variable position. This train of modulated waves then passes through the variable portion of the amplifier 43 and the variable detector 44. A variable and fixed amplifier may be thought of as two parts and the relays operate to use one of these at a time. Certain savings result in such a construction where parts of the combination of fixed and variable amplifier are interchangeable. The demodulated wave enters the relay 42 in the

upper or V position and is applied to the same plates of the cathode ray oscillograph 45 as the first demodulated wave but through the phase shifter 48.

The manner in which the arrangement shown in Fig. 1 may be used to measure the envelope delay of the single non-reversible transmission line or circuit L_1 will now be explained. A modulated wave formed, as described above, of the variable or measuring frequency from the oscillator 11 modulated with oscillations from the modulating frequency oscillator 10, is intermittently applied to the line L_1 , a modulated wave of standard oscillations from the oscillator 18 modulated by waves of fixed frequency from the oscillator 10 being also intermittently applied to the circuit L_1 . The sending end relay 16 is operated by the low frequency oscillator 17 and permits the intermittent and alternate application of these two envelopes to the circuit L_1 . The receiving end apparatus R offers two paths of transmission for the modulated wave from the modulator 19 but the lower path, as explained above, is so filtered as to permit only the modulated wave of the lower fixed carrier frequency (the standard frequency) to pass. Let it be assumed that the first pulse of received current is one containing any number of cycles of the standard carrier or reference wave, that is, the wave form produced by modulating oscillations from the oscillator 18 with those from the oscillator 10, the number of envelope cycles depending upon the modulating frequency and the frequency of operation of the sending end relay 16. This standard carrier modulated wave divides into two paths. In the lower path it is detected by the detector 32 and rectified by the rectifier 33 so that the rectified portion of the current operates the relay 34. The detected wave is sinusoidal and this must be rectified to have current in one direction to hold the relay 34 in one position over a number of cycles. This in turn puts battery on the relay windings of relays 40, 41 and 42 and causes them all to operate to the F or fixed (standard) position, so denoted by the fixed carrier wave. The other portion of this same wave then travels through the variable amplifier 43 and also the variable detector 44, both in their fixed positions, i. e., armatures of relays are held in the F position momentarily. The final detected wave of the modulating frequency passes through the armature 49 and the lower contact F of the relay 42 to one set of plates of the cathode ray oscillograph 45. A wave from the modulating frequency oscillator 46 at the receiving end is applied to the other set of plates of the cathode ray oscillograph through the phase shifter 47. If these two waves are out of phase the resulting pattern on the oscillograph screen will be an ellipse but by adjustment of the phase shifter 47 until the ellipse closes and becomes a straight line, the two waves are synchronized.

Immediately succeeding this train of standard carrier modulated waves, another series of modulated waves (that is, those formed by modulating the waves from the measuring frequency oscillator 11 and the modulating fixed frequency oscillator 10) is transmitted over the line L_1 , which waves are of the carrier frequency at which the particular set of readings is being taken. In this case there is only one path available, that is the upper one, so that with relay 34 non-operated, the other relays 40, 41 and 42 remain in the V or variable position. This train of waves then passes through the variable portion of the ampli-

fier 43 and the variable portion of the detector 44. The demodulated wave enters the relay 42 in the V position and is applied to the same plates of the cathode ray oscillograph 45 as the first demodulated wave but through a phase shifter 48. Assuming that the modulating frequency oscillator 46 remains stable for a brief measuring time interval, its phase relation will remain constant during one complete intermittent operation of relay 16. By adjusting the phase shifter 48 these two waves (that is, the demodulated wave and the wave from the oscillator 46) are synchronized. The pattern is again a straight line but may easily be made to appear as one of two intersecting straight lines by shifting the phase relation between the waves from the modulators 12 and 19 180 degrees at the sending end before they are transmitted. This reversal may be made in a number of well-known ways.

The intermittent and alternate application of these two modulated waves, forming a train or succession of one of the waves succeeded by a corresponding train of the other waves, causes the final pattern on the oscillograph screen to appear (due to the persistence of vision) as two intersecting straight lines. Should these lines open slightly during the measurement such that each tends to form an ellipse, the straight line effect or in-phase relations of the waves may be replaced by further slight adjustments of the two phase shifters 47 and 48. This method is effectively a measurement of the difference in delay between waves of a standard frequency carrier and of a measuring frequency carrier over the same line at very nearly the same instant. For practical purposes they may be considered as transmitted at the same time. The time interval difference will be so small and negligible that noises, level changes and transient effects will cancel. Noise effects may, in some cases, cause slight instability of the observed pattern of the oscillograph screen but this effect may be reduced if necessary.

Reference will now be made to Fig. 2 which shows a modification of the system shown in Fig. 1. In Fig. 2, the portion to the left of line X—X is similar to the portion to the left of the line X—X in Fig. 1. In the arrangement of Fig. 2, the comparison of the phase relations makes use of the known principle that if two oscillating waves of the same frequency are applied to the same terminals they will tend to remain in phase with each other. Under some conditions where the requirement for accuracy of measurement is not too great, the arrangement shown in Fig. 2 (which is simpler than that shown in Fig. 1) may be used. The connections shown for the cathode ray oscillograph 45 imply that the modulating frequency wave from the standard carrier modulated wave and the output wave from the modulating frequency oscillator 46 at the receiving end, remain in phase with each other; thus the regulating pattern on the oscillograph screen 45 is a straight line. Comparison of the wave obtained by detection from the measuring frequency carrier modulated wave with the modulating frequency wave is made through the phase shifter 50 as before. When the arms of the pattern are straight lines the reading of the phase shifter 50 gives the delay change. Otherwise, the method using the apparatus of Fig. 2 is the same as for that shown in Fig. 1.

Reference will now be made to Fig. 3 which shows a circuit arrangement which is a modification of that shown in Fig. 1 wherein detection

of the two modulated waves is made at the receiving end. In Fig. 3 all parts which are similar to those of Fig. 1 have been given the same reference characters. In the arrangement of Fig. 3 auxiliary apparatus is supplied for determining the calibration of sending and receiving parts of the apparatus to a sufficient degree of accuracy for practical purposes.

The calibration of the arrangement shown in Fig. 1 is dependent upon the direct connection of a to b. The inherent difficulty in calibrating this apparatus arises in the determination of the delay of the wave caused either by a modulator or a detector when these two pieces of apparatus become separated. When two or more detectors or modulators function at the same frequency certain delay relations between either taken alone are helpful for some circuit arrangements. A reference will now be made to Figs. 4 to 9, inclusive, which show simplified circuit arrangements and curves to aid in the understanding of the calibration of the apparatus shown in Fig. 3. Referring now to Fig. 4, a modulator 200 and detector 201 are connected in a loop circuit with a phase indicator 202 and a phase shifter 203. Oscillators 204 and 205 are connected to a modulator 200. According to the loop principle for delay measurements set forth in Patent 1,645,618, October 18, 1927 to Nyquist, the delay of the circuit shown in Fig. 4 is $M_1 + D_1 = R_1$ where R_1 is the setting of the phase shifter 203, M_1 is the delay of the modulator 200 and D_1 is the delay of the detector 201. The phase indicator 202 is included in the loop to indicate the delay. Oscillator 204 generates oscillations at the modulating frequency while oscillator 205 generates oscillations at the measuring frequency. Referring now to Fig. 5 the modulator 200 may be connected to either detector 201 or detector 206 by closing switches 207 or 208, respectively. In either case a similar loop is formed and for both loops the relations are:

$$M_1 + D_1 = R_1$$

$$M_1 + D_2 = R_2$$

where D_2 is the delay of the detector 206 and R_2 is the setting of the phase shifter 203.

The solution of these two equations is:

$$D_1 - D_2 = R_1 - R_2$$

and

$$M_1 = \frac{R_1 + R_2 - (D_1 + D_2)}{2}$$

Referring now to Fig. 6, modulators 200 and 209 may be connected in loop with detector 201 similarly as above by making use of switches 210 or 211. For both loops the relation becomes:

$$M_1 + D_1 = R_1$$

$$M_2 + D_1 = R_1$$

where M_2 is the delay of the modulator 209 and R_1 is the setting of the phase shifter 203. Solving these last two equations gives:

$$M_1 - M_2 = R_1 - R_1$$

and

$$D_1 = \frac{R_1 + R_3 - (M_1 + M_2)}{2}$$

These results show that it is possible to obtain the delay of the sum of a modulator and detector at the same frequency, and also the difference in delay of two detectors or two modulators, for example. In the equation

$$D_1 - D_2 = R_1 - R_2$$

R_1 and R_2 are direct readings obtained from the settings of the phase shifter. In the equation

$$M_1 = \frac{R_1 + R_2 - (D_1 + D_2)}{2}$$

set forth above R_1 and R_2 are easily obtained, but there is no simple way to obtain the magnitude of $(D_1 + D_2)$, consequently one cannot obtain a value for M_1 since the equation will contain the undetermined quantity $(D_1 + D_2)$. The case for modulators is similar. Difference relations between any number of detectors or modulators can easily be measured. This equation also gives the expression for the delay of a modulator in terms of the sum of the delay of two detectors or the delay of a detector in terms of the sum of the delay of two modulators. It is this sum, and also that of the delay of a modulator alone or detector alone, which is difficult to obtain and which give rise to calibration difficulties when the modulator and detector elements must become separated, such as in delay difference measurements involving a straightaway circuit.

In a method now to be described, a solution for this difficulty is shown and results are obtained which are sufficiently accurate for envelope delay measurements at television frequencies. Referring to Fig. 3, the modulators 12 and 19 and their associated amplifiers, not shown for simplicity in the drawings, at the sending end are first to be calibrated. This may be accomplished by opening switches 220 and 221 and also opening switches 222 and 223 and connecting one modulator at a time to the apparatus indicated by the box 224 bearing the reference characters PM (which indicates phase measuring equipment).

In this connection a diagram in greater detail of either of the modulators of Fig. 3 is shown in Fig. 8. The object is to measure the phase change occurring in the modulator at the desired carrier frequency and, from calculations of certain of its component parts to obtain the phase change in the wave caused by the modulating process. In Fig. 8, the parts most concerned are the transformer 280, vacuum tube 281, the output transformer 282 and the transformer 283. To obtain the reading of the phase change, the following procedure is necessary: The phase change caused by direct transmission from terminal A to terminal B through the modulator is measured. Let this be $W + X + Y$ where W , X and Y indicate the delay in the transformer 280, the vacuum tube modulator 281 and the transformer 282, respectively. The phase change in the transformer 280 is computed and subtracted, leaving $X + Y$. The phase change in the transformer 283 indicated by Z is computed, this phase change being caused by the modulating frequency. The result is added to $X + Y$ to give $X + Y + Z$. These operations may be expressed as follows:

Measure to obtain $f_1(\beta) = W + X + Y$
 Compute to obtain $f_2(\beta) = W$
 Subtract to obtain $f_3(\beta) = X + Y$
 Compute to obtain $f_4(\beta) = Z$
 Add to obtain $f_5(\beta) = X + Y + Z$

Having determined $f_5(\beta)$, the corresponding envelope delay (of the modulator) may be obtained from a set of predetermined characteristic relations of the modulator for β and

$$\frac{d\beta}{d\omega}$$

for various values of ω as shown in Fig. 9, wherein envelope delay

$$\frac{d\beta}{d\omega}$$

is plotted against phase change β to give a family of curves for different values of carrier frequency ω , that is for ω_1 , ω_2 , and ω_3 , respectively.

The apparatus in the box designated PM in Fig. 3 is characteristic of that shown within the portion shown by the dotted lines in Fig. 7. This is a schematic diagram of a circuit for obtaining phase measurement. The circuit briefly shown in Fig. 7 is disclosed in greater detail in Patent 1,684,403 issued September 18, 1928, to W. P. Mason. This method of obtaining phase measurement comprises the step of measuring the ratio of the vector sum and difference of the current transmitted through a network of unknown characteristics with respect to the shift produced in a network of known characteristics. In Fig. 7 the circuit or element 230 to be measured and the variable attenuator 231 are connected to a source of variable frequency current 232. The switch 233 connects the circuit 230 through a reversing switch 234 to the primary winding 235 of a transformer 236 while a switch 237 connects the variable attenuator 231 to the primary winding 238 of the transformer 236, the secondary winding 239 of which is connected through a variable attenuator 240 and an amplifier-rectifier 241 to a meter 242. The operation of the circuit shown in Fig. 7 is as follows: With the switch 233 closed and the switch 237 open, the value of the current in the output of the circuit 230 is indicated on the meter 242. By opening switch 233 and closing switch 237 the output of the variable attenuator 231 is indicated on the meter 242. The attenuation of the variable attenuator 231 can then be adjusted until the amplitude of the output current is equal to the amplitude of the current in the output of the circuit 230. This operation corresponds to the usual method of measuring loss and if the variable attenuator 231 is calibrated it may be read to give the loss in the circuit 230. By closing both switches 233 and 237 and reversing the switch 234, the vector sum of the two equal currents will be indicated on the meter 242. Placing the switch 234 in a reverse position, the vector difference of the two equal currents will be indicated on the meter 242. With the reversing switch 234 in a position giving the larger reading on the meter 242, the variable attenuator 240 may be adjusted to produce sufficient attenuation to give the same reading on the meter as was obtained with the reversing switch in the other position and the variable attenuator 240 cut out. The phase angle between the two currents can then be determined by the amount of line inserted. The phase change can then be computed from the following formula:

$$\theta = \cos^{-1} \frac{1 - \alpha^2}{1 + \alpha^2} \times \frac{K_1^2 + 1}{2K_1}$$

in which α is the attenuation constant corresponding to the line inserted in calibrating variable attenuator 240 to decrease the aiding current to the same value as the opposing, and K_1 is the ratio of the current output of the upper portion of the circuit of Fig. 7 to the current output of the lower portion of the circuit of Fig. 7. K_1 is determined by the amount of calibrating line or network 240 it is necessary to insert in series with the network 230 in order to

get the same reading on the meter 242 as when the arm containing the variable attenuator 231, set for no attenuation, is connected thereto. For a more complete description of this method of measuring phase measurement, reference should be made to the above-mentioned Mason patent.

Having made suitable calibrations at the sending end the two modulated waves may be put in phase with each other by suitable means (not shown) at their point of connection *a* in Fig. 3, to the circuit L_1 . There therefore remains the comparison of the delay of the two detected waves at the receiving end. Their difference in delay is now only that caused by the circuit L_1 and the receiving amplifier and detector apparatus. The delay of the latter is obtained according to two operations, one involving the delay measurement of a loop arrangement for modulator and detector. The other is a determination of the delay caused by the modulator in accordance with the principles just outlined. The subtraction of these two quantities gives the delay of the modulating frequency wave by the demodulating process. This can be explained briefly as follows: With the armatures of the receiving end relays 245, 246, 247, 248 and 249 in the contact positions shown in Fig. 3, it will be observed that the receiving end apparatus is the same as that shown in Fig. 1, consequently the method of delay comparison is the same. In this calibration the oscillograph 45, phase shifters 47 and 48 and the fixed frequency (modulating frequency) oscillator 46 which are part of the receiving delay measurement apparatus are shown so connected that they may be used for both calibration and measurement. The only explanation necessary here relates to closing the switch 250 shown in circuit with the battery 251 and the windings of the relays 245, 246, 247, 248 and 249. When the switch 250 is closed the armatures of the relays 245, 246, 247, 248, and 249 move to the contact positions opposite those shown in the drawing, Fig. 3. In these positions it will be observed that the circuit thus formed is a simple loop arrangement involving modulator 252, bridging element 253, upper contact and armature of relay 245, amplifier 43 and detector 44, armature and upper contact of relay 246, lower contact and armature of relay 247, cathode ray oscillograph 45, phase shifter 47, armature and right-hand contact of relay 248 and switch 254 back to the modulator 252. A source of variable oscillations 255 is connected to the modulator 252. Such a loop method of measuring delay is disclosed in the above-mentioned patent to Nyquist. An adjustment of the phase shifter 47 will give the delay of the modulator 252, the amplifier 43, and the detector 43. By opening switch 254 and connecting modulator 252 to the phase measuring apparatus, designated by the box PM and bearing the reference character 256, in place of the bridging element 253, direct transmission of the carrier frequency can be made through the modulator 252 and its delay determined by the method as already explained in connection with the modulators at the sending end. Subtracting this result from the loop measurement gives the complete calibration for the receiving end amplifier 43 and detector 44. Subtracting this calibration from the overall envelope delay measurement gives the envelope delay of the circuit L_1 at the particular value of measuring frequency. Additional sets of readings are taken at other values of

measuring frequencies to determine the frequency-envelope delay characteristic of the circuit or apparatus.

In the modification shown in Fig. 10 only one wave is transmitted modulated (which is demodulated after transmission over the line L_1) and compared in phase with a sinusoidal wave of the modulating frequency which is transmitted over the line L_1 intermittently with the modulated wave. The circuit of Fig. 10 differs from that of Fig. 1 in that the standard oscillator 18, the modulator 19, the fixed detector 32, and the fixed detector portion of the detector 44 are removed, together with their functions. The sinusoidal wave is rectified by the rectifier 33 and controls the relay 34 as in the system of Fig. 1. The method of measuring envelope delay is otherwise similar to the method described above in connection with Fig. 1.

Various other changes may be made in the embodiments above disclosed without departing from the spirit of the invention. While the principles given above have been applied specifically to measurements of envelope delay, it is obvious that certain of these principles may be applied in other fields.

What is claimed is:

1. A method of measuring the envelope delay of a transducer which comprises applying intermittently and alternately to one end of the transducer a first modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second modulated wave having a known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, and utilizing said modulated waves at the opposite end of said transducer in determining the envelope delay thereof.

2. A method of measuring the envelope delay of a transducer which comprises applying intermittently and alternately to the sending end of the transducer a first modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second modulated wave having a known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, detecting said modulated waves at the receiving station to obtain two waves of the second frequency, and comparing the phase of the resulting detected waves of the second frequency with a wave of said second frequency generated at the receiving station.

3. The method of measuring the envelope delay of a transducer which comprises applying intermittently and alternately to the transducer a first modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second modulated wave having a known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, detecting at the receiving end of said transducer the modulated waves to produce two detected waves of said second frequency, applying the two detected waves alternately to one of the two sets of deflecting plates in a cathode ray tube, the plates of one pair being arranged to deflect the beam in a direction substantially at right angles to the deflection produced by the

other pair, applying a wave of the second frequency available at said receiving end to the second of said two sets of deflecting plates, shifting the phases of each of the two detected waves with respect to that wave available at the receiving end until straight line patterns are obtained on the screen of said cathode ray tube, and utilizing the phase shift readings in determining the envelope delay of the transducer.

4. A method of measurement comprising intermittently and alternately applying two modulated waves having a known phase relationship with respect to each other to a transmission line, detecting said waves to obtain two waves of the same frequency but of different phase relationship, and measuring the difference in phase between said two detected waves.

5. The method of measuring the envelope delay of a single irreversible transmission path which comprises intermittently and alternately transmitting over said path two waves having a known phase relationship with respect to each other, at least one of said waves comprising a wave of a first frequency modulated by a wave of a second frequency, and utilizing said waves at the receiving end of said path in determining the envelope delay thereof.

6. The method of determining the envelope delay of a transducer between a first and a second station which comprises transmitting from the first station to the second station over the transducer intermittently and alternately a first modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second modulated wave of known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, detecting said first modulated wave at said second station to obtain a wave of the second frequency, detecting said second modulated wave at said second station to obtain a wave of the second frequency, synchronizing by means of a phase shifter the phase of said first detected wave with a wave generated at the second station of the second frequency, synchronizing by means of a second phase shifter the phase of said second detected wave with that of the wave of said second frequency generated at said second station, and utilizing the readings of said phase shifters in determining the envelope delay of said transducer.

7. The method of determining the envelope delay of a transducer between a first and a second station which comprises transmitting from the first station to the second station over the transducer intermittently and alternately a first modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second modulated wave of known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, detecting said first modulated wave at said second station to obtain a wave of the second frequency, detecting said second modulated wave at said second station to obtain a wave of the second frequency, alternately and intermittently applying said first detected wave and a wave of

said second frequency generated at said second station across different coordinate pairs of deflecting plates of a cathode ray tube, and applying to the pair of plates to which the first detected wave is applied the second detected wave between applications of said first detected wave.

8. The method of determining the envelope delay of a transducer between a first and a second station which comprises transmitting from the first station to the second station over the transducer intermittently and alternately a first modulated wave produced by modulating a wave of a first frequency with a wave of the second frequency, and a second modulated wave of known phase relationship with respect to the first modulated wave, said second modulated wave being produced by modulating a wave of a third frequency with a wave of said second frequency, detecting said first modulated wave at said second station to obtain a wave of the second frequency, detecting said second modulated wave at said second station to obtain a wave of the second frequency, alternately and intermittently applying said first detected wave and a wave of said second frequency generated at said second station across different coordinate pairs of deflecting plates of a cathode ray tube, applying said second detected wave to the same pair of deflecting plates to which the first detected wave is applied between applications of said first detected wave, and shifting the phase of each of said detected waves so that each of the patterns observed on the cathode ray tube is a straight line.

9. A method of measuring the envelope delay of a transducer which comprises applying intermittently and alternately to the transducer a modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second wave of said second frequency of known phase relationship with respect to the modulated wave, and utilizing said modulated wave and said second wave at the receiving end of said transducer in determining the envelope delay thereof.

10. A method of measuring the envelope delay of a transducer which comprises applying to the transducer a modulated wave produced by modulating a wave of a first frequency with a wave of a second frequency, and a second wave of said second frequency of known phase relationship with respect to the modulated wave, and utilizing said modulated wave and said second wave at the receiving end of said transducer in determining the envelope delay thereof.

11. The method of determining the envelope delay of an irreversible transducer between a first and a second station which comprises transmitting from the first station to the second station over the transducer a first wave produced by modulating a wave of a first frequency with a wave of a second frequency, transmitting also from the first station to the second station a second wave of the second frequency of known phase relationship with respect to said first wave, said transmission of the two waves being intermittent over said transducer, and utilizing these two waves at the second station to produce a distinct pattern on a cathode ray oscillograph.

MONTAGUE S. BURGESS.