

July 3, 1945.

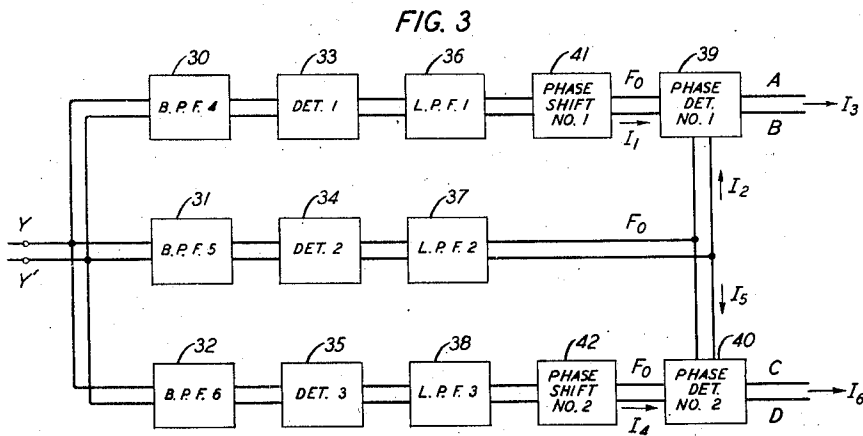
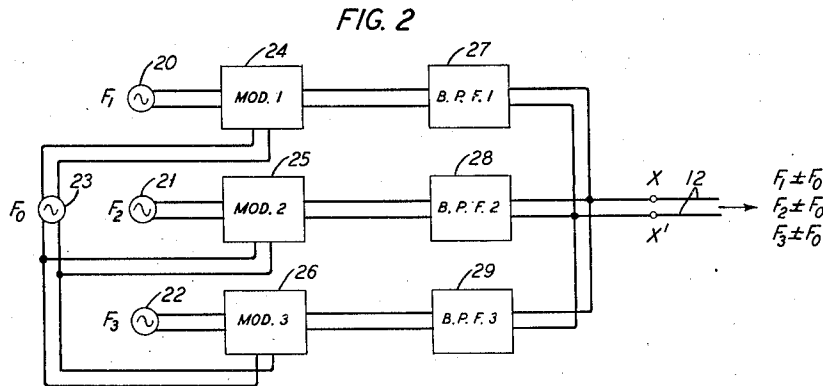
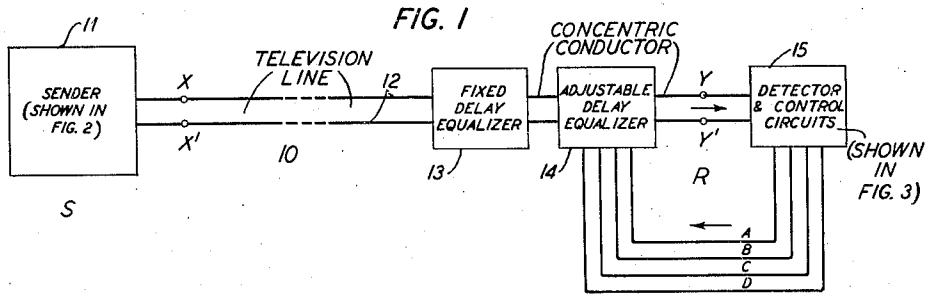
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2,379,744

ELECTRIC CIRCUIT ARRANGEMENT EMPLOYING DELAY NETWORKS

Filed March 31, 1942

3 Sheets-Sheet 1



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ELECTRIC CIRCUIT ARRANGEMENT EMPLOYING DELAY NETWORKS

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3 Sheets-Sheet 2

FIG. 5

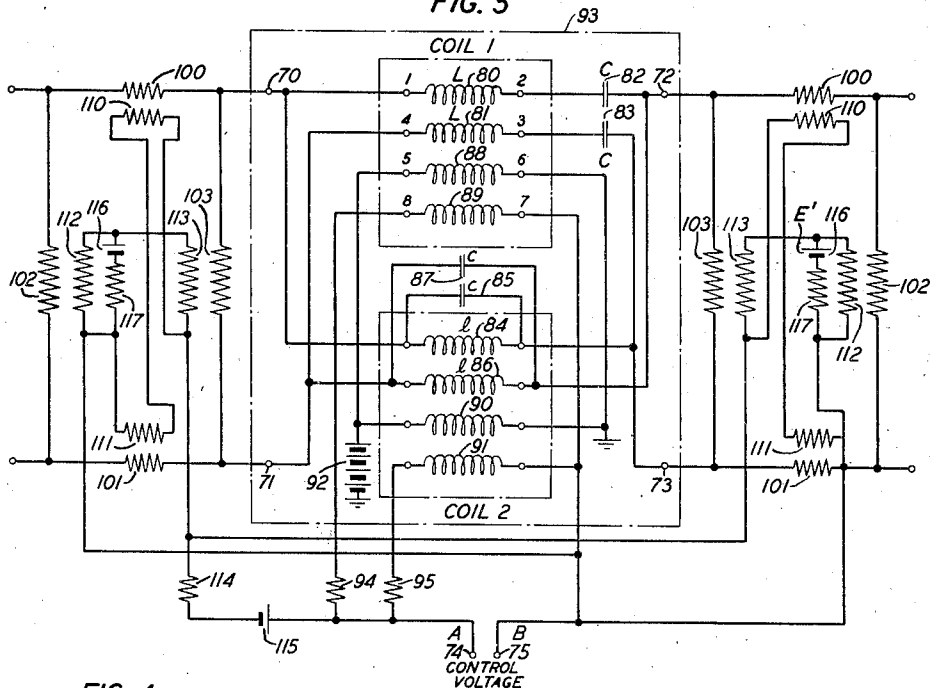


FIG. 4

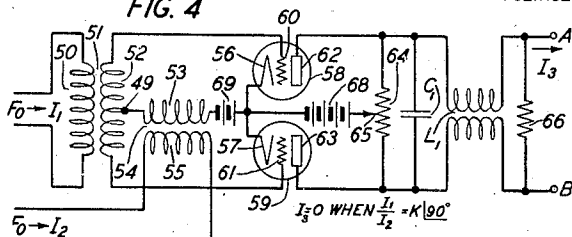


FIG. 6

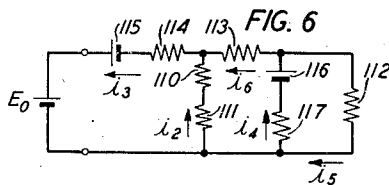


FIG. 7

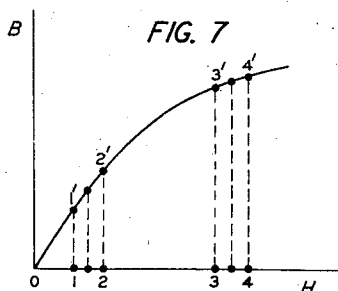


FIG. 12

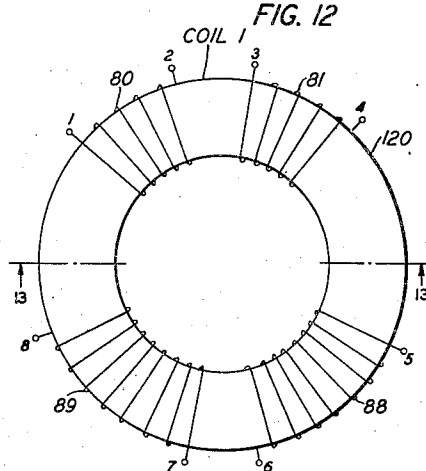
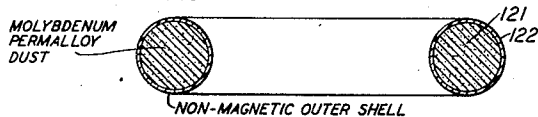


FIG. 13



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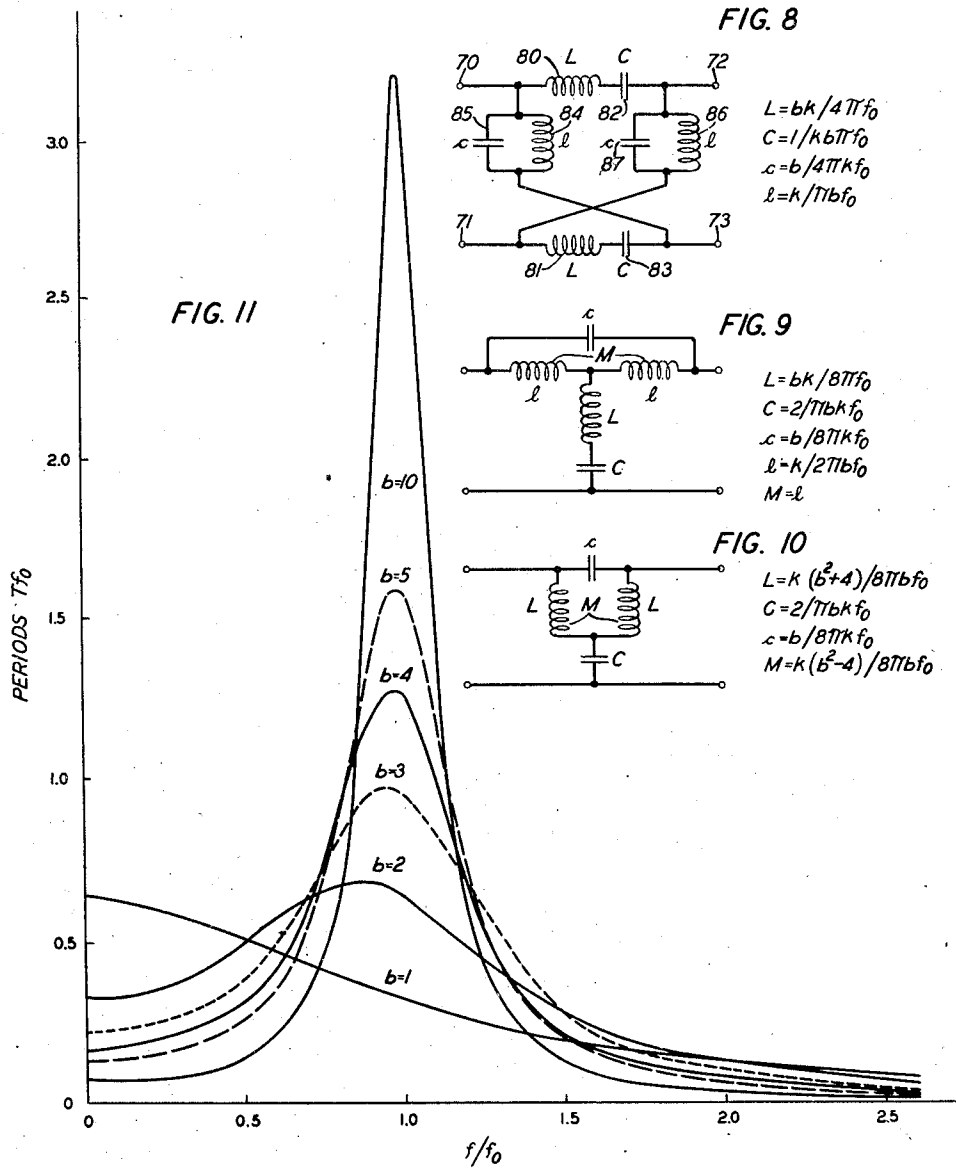
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ELECTRIC CIRCUIT ARRANGEMENT EMPLOYING DELAY NETWORKS

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,379,744

ELECTRIC CIRCUIT ARRANGEMENT
EMPLOYING DELAY NETWORKSKenneth W. Pfeiffer, Arlington, N. J., assignor to
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Application March 31, 1942, Serial No. 436,978

11 Claims. (Cl. 178-44)

This invention relates to electric circuit arrangements and more particularly, though not necessarily, to the delay equalization of waves transmitted over transmission lines.

It is an object of this invention to provide novel equalizing means comprising an adjustable delay network including means for correcting attenuation variations introduced by the network.

The transmission of television signals involves many problems due to the relatively wide band of frequencies comprising the signals. Not the least of these problems is that of equalizing or compensating for phase variations caused, for example, by temperature variations, on transmission line circuits carrying these wide band signals. It has already been proposed to provide basic compensation for such phase variations by the use of equalizing networks which introduce fixed delay in the system and to further compensate for these variations by providing adjustable delay equalizers in conjunction with the fixed delay equalizer. The present invention in one of its aspects relates to a transmission system containing a novel adjustable delay equalizer in which impedance elements are automatically varied in accordance with pilot signals transmitted over the line to equalize phase variations and also to correct for attenuation variations produced in the equalizer.

It is, accordingly, another object of this invention to provide apparatus for equalizing, by means of equalizing networks, phase variations in wide band signals transmitted over a line and for correcting for attenuation variations produced by the network, in which the impedances of elements in the networks are varied in accordance with auxiliary electric waves or signals.

It is a further object of this invention to provide an adjustable delay equalizer containing adjustable elements whose impedances are adapted to be varied in accordance with signals to equalize phase variations in the system containing the delay equalizer and also to correct for attenuation variations produced in the equalizer.

In accordance with the invention, in one embodiment thereof chosen by way of example for purposes of illustration, auxiliary signals or waves transmitted over pilot channels are utilized to operate continuously adjustable networks to compensate for phase variations and at the same time to compensate for attenuation variations produced by the phase adjusting means, said network consisting of impedance members having no moving parts. It has previously been pro-

posed to utilize such pilot or auxiliary signals to cause the rotation of one part of a condenser with respect to another to correct for phase variations.

It is still another object of this invention to provide a novel system for automatically compensating for the delay distortion of a transducer over a certain range of frequencies and which utilizes three pilot frequencies, two of which are the boundary frequencies of the range and the third is intermediate these two.

The equalizing network of the present invention in its preferred embodiment comprises a plurality of stationary inductance members (that is, each member is free of moving parts). The impedance of each of these members is varied by means of a current of varying intensity flowing through a winding on a core made of, for example, molybdenum permalloy dust. This current is caused to be varied in accordance with the phase difference of two waves of the same frequency (F_0) obtained respectively by demodulating two modulated waves transmitted over the television line, each comprising a pilot frequency (a different one for each of the waves) modulated by the fixed frequency F_0 which is lower than either of the pilot frequencies. The two demodulated waves of the frequency F_0 are applied to a push-pull phase detector after having been initially adjusted by phase shifters to be in quadrature. As long as this phase relation is maintained the output of the phase detector is zero, regardless of level changes on the television line. When the phase relation between the two demodulated waves changes due to variations in delay over the line, the balance is destroyed and the output current of the phase detector assumes an appreciable magnitude in one direction. When the phase relation between the input currents to the phase detector changes in the opposite direction, the output current is reversed. These output currents are, as pointed out above, utilized to control the inductances in the adjustable equalizer.

If desired, one pilot frequency may be located in the frequency spectrum just below the television band and the second just above this band. However, inasmuch as the high definition television band is of the order of several megacycles wide, superior results are obtained by providing two phase detectors, each used for correcting one half of the band for phase variations. In this latter arrangement, which is that shown in the drawings, a first pilot frequency F_1 is located at or slightly below the lower edge of the television

band, a second pilot frequency F_2 is located about in the center of the band (preferably in a "dead" portion of the television band which contains inappreciable television current), and a third pilot frequency F_3 is located at or slightly above the upper edge of the television band. The delay distortion over the frequency range F_1 to F_2 is corrected with the aid of one of the phase detectors while the distortion over the frequency range F_2 to F_3 is corrected with the aid of the second detector.

In order to give the delay equalizer a constant over-all impedance, adjustable impedance matching pads are inserted at either or both of its ends. Each of these pads comprises four thermistors, two of which are respectively connected in series with the input terminals of the delay network, a third is connected across these terminals, and the fourth is connected in a circuit parallel to that containing the third resistor, the terminals of this fourth thermistor being separated from the terminals of the third thermistor by the first and second thermistors, respectively. An auxiliary heater is provided for each of the thermistors. Two voltage sources supply direct current to all of the auxiliary heaters, these sources being so connected that an increase in the voltage of one of the sources causes a current magnitude change in one direction through three of the heaters and a current magnitude change in the opposite direction through the fourth heater. One of these sources of direct voltage can be the signal voltage used to adjust the delay network and it causes the impedance of the pad to be adjusted so that it tends to compensate for the change in impedance produced by the change of delay in the delay network.

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 is a block diagram of a portion of a television system in which delay compensators or equalizers in accordance with this invention are utilized;

Fig. 2 is a block diagram of a portion of the sending end equipment of the system;

Fig. 3 is a block diagram of that portion of the receiving end equipment of the system represented by the block in the circuit of Fig. 1 identified as detector and control circuits;

Fig. 4 is a diagram of one of the phase detectors indicated schematically in the circuit of Fig. 3;

Fig. 5 is a circuit diagram of a delay equalizer with variable elements in accordance with this invention;

Figs. 6 to 11, inclusive, are diagrammatic and graphical representations to aid in explaining the invention;

Fig. 12 is a diagram of the magnetic circuit of one of the coils of Fig. 5; and

Fig. 13 is a cross-sectional view of the core shown in Fig. 12.

Referring more specifically to the drawings, Fig. 1 shows, in block diagram form, a television system 10 including a fixed delay equalizer and also an adjustable delay equalizer in accordance with the invention. The system 10 comprises a sending station S containing sender equipment represented by the block 11, a television line 12 and a receiving station R containing (in addition to the usual television receiving apparatus which has not been shown for the purpose of simplifying the drawings and description) a fixed delay equalizer 13, an adjustable delay equalizer 14, and

detector and control circuits 15 for the adjustable delay equalizer 14. The box 11 represents suitable apparatus for sending control signals over a television line 12 to the receiving station R. It is, of course, to be understood that the sending end station also is provided with apparatus for sending video signals and various control signals, such as synchronizing signals, while the receiving station consists of, in addition to the apparatus shown in Fig. 1, the usual video and sound detectors and amplifiers, sweep circuits, and the image reproduction device, such as a cathode ray tube. The present invention in one of its aspects is concerned with equalizing the delay over a long transmission line, such as, for example, a coaxial cable used between two television stations, say of the order of one hundred miles apart, and only the equipment for equalizing the delay is being shown and described, the other equipment being well known.

Basic delay equalization of the line may be attained by means of fixed delay equalizers such as those indicated by the box 13 in Fig. 1 but in order to obtain accurate results the addition of adjustable delay equalizers is necessary. Such an equalizer and the control circuits therefor are indicated in Fig. 1 and shown in greater detail in Figs. 3, 4 and 5.

Before describing the adjustable delay equalizer in detail, reference will first be made to Fig. 2 which shows, in block diagram form, sending end equipment for transmitting signals to control the adjustable delay equalizer.

The circuit arrangement shown in Fig. 2 in diagrammatic form is adapted to send modulated testing current over each pilot channel and may be connected to the line 12 at all times if the current has frequency components in the dead bands or outside the television range. If the frequencies are within the television range, the testing system may be connected to the line when no video signal is being transmitted or during such brief intervals during image transmission that the eye cannot detect any disturbance due to turning off the light of the receiving screen during testing intervals. In the specific arrangement shown in Fig. 2 three pilot frequencies F_1 , F_2 and F_3 are utilized and these frequencies are so chosen with respect to the television band of frequencies that the terminals X, X' may be connected to the television line 12 at all times. Thus in Fig. 2, F_1 , F_2 and F_3 denote pilot frequencies at the lower edge, center, and upper edge of the television range, respectively. Preferably, pilot frequency F_2 is of a frequency which corresponds to a "dead" portion of the television band, that is, a portion wherein the image signal is inappreciable. As will be pointed out more fully below, one of the phase detectors will be utilized in connection with correction for distortion in that portion of the band between the frequencies F_1 and F_2 while the second detecting arrangement will be used to correct distortion in that portion of the television band between the frequencies F_2 and F_3 . It will be appreciated that two pilot frequencies may be used instead of three, or a larger number than three may be used.

In the arrangement shown in Fig. 2, waves of the frequency F_1 are generated by any suitable oscillator 20. Similarly, waves of a frequency F_2 are generated by oscillator 21 and waves of a frequency F_3 are generated by means of an oscillator 22. An oscillator 23 is provided to generate oscillations of a frequency F_0 which is a lower frequency than any one of the pilot frequencies

F_1 , F_2 or F_3 . Oscillations from the oscillators 20, 21 and 22 are modulated by waves from the oscillator 23 by means of modulators 24, 25 and 26, respectively. The output waves from the modulators 24, 25 and 26 are applied to narrow band-pass filters 27, 28 and 29, respectively, so that only nine frequencies are transmitted simultaneously to the terminals X and X'. These nine frequencies are the three pilot frequencies and the upper and lower side-bands thereof, or, in other words, $F_1 - F_0$, F_1 , $F_1 + F_0$, $F_2 - F_0$, F_2 , $F_2 + F_0$, $F_3 - F_0$, F_3 , and $F_3 + F_0$, this order corresponding to their location in the frequency spectrum. The components F_1 , F_2 and F_3 are not essential and may be omitted by using in each case a modulating arrangement including means for suppressing the carrier.

These frequencies are then applied to the line 12 and reach the receiving station R. The waves are passed through the fixed delay equalizer 13 and the adjustable delay equalizer 14 to the detector and control circuits 15 which are shown in greater detail in Figs. 3, 4 and 5. At the terminals Y, Y', shown in Fig. 3, the first three frequencies, that is, $F_1 - F_0$, F_1 , and $F_1 + F_0$, are selected by the band-pass filter 30, the next three frequencies $F_2 - F_0$, F_2 , and $F_2 + F_0$, are selected by band-pass filters 31 while the last three frequencies, that is, $F_3 - F_0$, F_3 , and $F_3 + F_0$ are selected by the band-pass filter 32. Detectors 33, 34 and 35 and low-pass filters 36, 37 and 38 remove unwanted frequencies, leaving only the envelopes or demodulated waves of frequency F_0 entering the phase detectors 39 and 40. Phase shifters 41 and 42 are provided in order to give suitable phase relations to these envelope waves, by adjustment as described hereinafter.

One of the phase detectors, as for example, the phase detector 39, is shown in greater detail in Fig. 4. When the delay of the television line (including all of the delay equalizers) is correct, the two input waves of each phase detector (I_1 and I_2 for the phase detector 39 and I_4 and I_5 for the phase detector 40) are preferably adjusted to be in quadrature by means of the phase shifters 41 and 42. Thus current I_1 is ± 90 degrees out of phase with respect to I_2 . Current I_1 flows through the primary winding 50 of the transformer 51 having a split secondary winding 52. The middle terminal 49 of the transformer winding 52 is connected through the secondary winding 53 of the transformer 54 to the cathodes 56 and 57 of two tubes 58 and 59 which are connected in push-pull. The current I_2 from the middle path of the circuit arrangement of Fig. 3 flows through the primary winding 55 of the transformer 54. The outer terminals of the secondary winding 52 of transformer 51 are connected to the grids 60 and 61 of the tubes 58 and 59, respectively. Any suitable tubes may be used. If desired, a source of biasing potential such as the source 69 may be provided in the circuit between the common terminal of the cathodes 56 and 57 and the mid-terminal 49 of the winding 52. The anodes 62 and 63 are connected to opposite ends of a resistor 64 having a variable inner terminal 65. The inner terminal 65 of the resistor 64 is connected through a source of anode potential 68 to the common terminal of the cathodes 56 and 57. A condenser C_1 is connected across the terminals of the resistor 64 as is also the circuit including the serially connected upper and lower coils of the inductance member L_1 and the resistor 66. The elements L_1 and C_1 form a low-pass filter so that I_3 is essentially a direct

current. Sliding contact 65 may be used to make a permanent compensating adjustment when tubes 58 and 59 are slightly unbalanced, so that for equal grid voltages the current I_3 is zero. Resistance 66 may be adjusted to obtain a suitable output impedance as seen looking back from terminals A—B. When the element 66 has a low resistance, the filtering action of the inductance L_1 is more effective. When the resistance of the element 66 is made very low, then additional stages of amplification are required in order to maintain I_3 at a suitable value. In operation, the circuit of Fig. 4 is carefully balanced and the transformers 51 and 54 are preferably made to have equal phase shifts. (Any inequality in their phase shifts may be compensated for by the adjustment of phase shifter 41 in the case of detector 39 or by the adjustment of phase shifter 42 in the case of detector 40.) Then the amplitude of the resultant wave applied to the grid 60 of tube 58 will equal the amplitude of the resultant wave applied to the grid 61 of the tube 59. This equality will hold regardless of variations in amplitude of either I_1 or I_2 so long as these two currents are in quadrature. Tubes 58 and 59 are rectifiers connected in opposition so that the resultant output current I_3 is zero when I_1 and I_2 are in quadrature, regardless of level changes on the television line. When the phase relation between I_1 and I_2 changes due to variation in delay distortion of the line, the input waves to the tubes 58 and 59 are unequal in magnitude. Therefore, I_3 assumes a magnitude in one direction or the other. When the phase relation between I_1 and I_2 changes in the opposite direction, the direction of I_3 is reversed. It is obvious that noise current from the line is mostly wiped out by the filters in the arrangement shown in Fig. 3 and that in case either I_1 or I_2 has superimposed noise current, these would not contribute to the value of I_3 because noise current added to either I_1 or I_2 separately produces equal increments in the magnitude of the two grid voltages, and the rectified output waves are affected equally in amount, so that I_3 , which is proportional to their difference, is unchanged. The possibility of the same noise current being present in both I_1 and I_2 is unlikely. The output waves produced across the terminals A, B and C, D from the phase detectors 39 and 40 may be utilized to control parts of the adjustable delay equalizer (one part of which is shown in greater detail in Fig. 5) to compensate for delay distortion variations in the range between the pilot frequencies whose envelopes enter the respective phase detectors. Fig. 5 shows one section of the coil arrangement for the adjustable delay network or equalizer which, for example, is adapted to be connected to the terminals A and B of the phase detector 39. A similar section (not shown) is adapted to be connected to the terminals C and D and to be connected in tandem with the coil section of Fig. 5. The section of the adjustable delay equalizer shown within the area enclosed within dotted lines in Fig. 5 is of the lattice type having input terminals 70 and 71 and output terminals 72 and 73 and terminals 74 and 75 which are connected to the terminals A and B of the phase detector 39. Several forms of non-dissipative networks for producing delay correction are shown in Figs. 8, 9 and 10 and this invention is applicable to any one of them or, for that matter, to any type of equalizer wherein it is desired to vary the impedance of a member thereof. The arrangement included within the large dotted box 93 in Fig. 5

corresponds to the equalizer shown in Fig. 8 to the coils of which have been added additional windings as will appear more fully in the description below. In the circuit arrangement of Fig. 8 there are arranged between the input terminal 70 and the output terminal 72 a series inductance member 80 and a series condenser 82, while between input terminal 71 and the output terminal 73 are a series inductor 81 and a series condenser 83. Connected between the input side of the inductor 80 and the output side of the condenser 83 are the parallel connected inductor 84 and capacitor 85, and connected between the input side of the inductor 81 and the output side of the capacitor 82 are the parallel connected inductor 86 and capacitor 87. Corresponding elements in Fig. 5 have been given the same reference characters. Coils 80 and 81 are mounted, by way of example, on the same core together with two additional windings 88 and 89. Similarly inductors 84 and 86 are wound on the same core together with two additional windings 90 and 91. The windings 88 and 90 are supplied with current from a source 92, the two windings being connected in parallel. The winding 89 is connected to the terminals 74 and 75 across which is applied the control voltage, a resistor 94 being connected in series with the winding. Similarly, the coil winding 91 is connected to the terminals 74 and 75, the resistor 95 being connected in series with the winding 91. The windings 80, 81, 88 and 89 will be hereinafter designated coil 1 while the windings 84, 86, 90 and 91 will be hereinafter designated coil 2. A suitable coil (coil No. 1 or coil No. 2) preferably comprises four windings on a toroidal core. A suitable core structure is shown in Figs. 12 and 13 (Fig. 13 being a sectional view taken along the line 13—13 in Fig. 12). The core 120 may comprise very minute particles 121 (to reduce iron losses) of magnetic material pressed firmly together. Suitable material is molybdenum permalloy dust (particles are of the order of a few microns in diameter). If necessary, to keep particles from flaking off, an outer shell 122 of non-magnetic material may be provided. On the core 120 four separate windings, for example, windings 80, 81, 88 and 89, are placed. Each winding is preferably insulated from the others. Windings 80 and 81 are carefully balanced to have equal inductances, and resistances as low as possible. If the circuit diagram desired is such as to require a series (aiding) connection of windings 80 and 81, terminal 2 of winding 80 is connected to terminal 3 of winding 81. Windings 88 and 89, through which direct current is caused to pass, are not necessarily equal. They should either carry more than the windings 80 and 81 or else should have more turns, or both, so that the ampere-turns due to windings 88 and 89 are large compared to the ampere-turns of windings 80 and 81. If it is desired to connect windings 88 and 89 in a series (aiding) circuit, terminal 6 of winding 88 is connected to terminal 7 of winding 89. The connections shown in Fig. 5 are for the network of Fig. 8 with, as pointed out above, the windings 80 and 81 (coil No. 1) being wound on one core and the windings 84 and 86 (coil No. 2) being wound on a second core. Each coil has two biasing windings, that is, the windings 88 and 89 for coil No. 1 and the windings 90 and 91 for coil No. 2. The source of potential 92 produces a large constant magnetomotive force in one direction which will be called the positive direction. The variable direct current output from the phase detector 39 previously described is applied

to the winding 89 of coil 1 and to the winding 91 of coil 2 through current limiting resistors 94 and 95. The direct current varies so as to affect the total bias on these inductances in accordance with the desired delay correction. The manner in which this correction is obtained will now be described. Coils 1 and 2 are of the type known as non-linear coils, that is, they are wound on cores having variable permeability. An inductance which changes appreciably with current strength over the range of signal currents used is undesirable because it acts in a similar fashion to a varistor in that signal frequencies generate harmonics and modulation occurs resulting in additional frequencies and in interference from one part of the frequency spectrum to another. Therefore it is important that the inductance shall not change appreciably over the range of signal currents used, but it may safely be such as to vary appreciably when a much greater current variation occurs. In order not to produce unwanted modulation products, the alternating signal component (at terminals 70 and 71) amplitude is preferably small and a relatively large direct current (from the lines 74 and 75) is used to regulate the inductance value. For example, let a non-linear coil have the magnetization characteristic shown in Fig. 7 wherein ampere turns per unit length (H) and flux density (B) are the coordinates. Let a direct current flow in the winding 88 of the coil which produces a value of H halfway between points 1 and 2, Fig. 7. Let signal current flow in windings 80 and 81 of the coil which produces a fluctuation in total H so that it varies between points 1 and 2. The flux density accordingly varies between values denoted by the ordinates 1' and 2'. The inductance is proportional to the slope of the curve in this region which may be regarded as a straight line when the signal is very small. When the direct current is raised so that the total value of H fluctuates between points 3 and 4 and B fluctuates between points 3' and 4', it is seen that the slope, and consequently the inductance, is reduced in the order of one-third. Therefore, an appreciable change in inductance can be produced by varying a large direct component of the magnetomotive force. Yet, for a given direct current in winding 88 the fluctuations in H due to small signal currents in windings 80 and 81 do not appreciably affect the coil inductance. Thus a non-linear coil is effectively a linear coil if the signal currents are kept very small in comparison to the direct biasing current, and the exact value of the inductance is determined by variations in this biasing current. In coil No. 1 the biasing current is supplied in two parts. A steady component flows through winding 88, and its value is substantially constant. The control current $\pm I_3$ entering at terminals 74 and 75 gives rise to a second biasing component in winding 89, so that the net value of biasing ampere-turns due to both windings 88 and 89 may be either great or small depending upon the direction of I_3 .

Reference will now be made to the circuits shown in Figs. 8, 9 and 10 and to the curves shown in Fig. 11 wherein the periods T/f_0 (where T is the envelope delay $d\phi/d\omega$, expressed in seconds, and f_0 is the resonant frequency) is plotted against f/f_0 . For a more complete explanation of Fig. 11 reference is made to Patent No. 1,675,460, issued July 3, 1928, to H. Nyquist. As explained therein, lines 118—130 of page 3, these coordinates are selected in order to facilitate use of the curves for any value of f_0 . For example, if $f_0=1$ cycle, the

ordinates give delay in seconds; if $f_0=1000$ cycles, the ordinates give delay in milliseconds; if $f_0=10^6$ cycles, the ordinates give delay in microseconds, etc. Each of the circuits shown in Figs. 8, 9 and 10 has a resistance k for the characteristic impedance and in this sense they are equivalent. The delay of one section of the secondary network is given by the following formula:

$$Tf_0 = \frac{b}{2\pi} \frac{1 + \frac{f_0^2}{f^2}}{1 + \frac{b^2}{4} \left(\frac{f}{f_0} - \frac{f_0}{f} \right)^2}$$

The parameter b governs the peak value of the delay, T , and, as pointed out above, f_0 is the resonant frequency. Such networks as shown in Figs. 8, 9 and 10 are well known and have an envelope delay versus frequency characteristic with a peak somewhat below the resonant frequency f_0 , but produce substantially no attenuation, as described in the Nyquist patent referred to above. For values of the parameter b which are considerably greater than unity, the frequency at which maximum delay occurs may be shifted by changing the value of f_0 . Consequently, if the delay equalizer has variable tuning its delay hump may be shifted in the frequency spectrum. When the value of f_0 is considerably above the transmitted frequency band, as determined by band-pass filters associated with any system in which the delay equalizer is located in tandem with the line, the raising of the tuning, or resonant frequency f_0 of the delay equalizer slightly moves the peak value of its delay to a higher frequency and the delay equalizer is found to have less delay at any frequency within the transmitted band. This delay decrement is more pronounced near the upper edge of the transmitted band than at the lower edge so that the delay versus frequency characteristic of the system is thereby given a downward twist, which is more pronounced near the upper edge of the frequency spectrum than near the lower edge. That this is so may be easily verified by computing values of T from the ordinates Tf_0 of Fig. 11 for two different values of f_0 and for the same value of parameter b , considerably greater than unity, plotting the results as delay versus frequency characteristics and observing the delay decrement at lower frequencies as f_0 is raised. Conversely, it follows that lowering f_0 slightly tends to increase the delay at lower frequencies, the increment being more pronounced near the high edge of the transmitted band where the delay characteristic of the network is steep. Thus it may be demonstrated that when f_0 is considerably above the transmitted band, small variations in tuning frequency result in changing the slope of the delay versus frequency characteristic of the system within the pass-band, and the effect is greater near the upper edge of the band. When the inductances are increased, f_0 is lowered and the delay within the pass-band swings up (increases) near the upper edge, and vice versa. In a similar manner it can be demonstrated if the value of f_0 is below the lowest transmitted frequency, inductance variations will swing the delay characteristic at low frequencies up or down depending upon whether the inductances are decreased or increased respectively. If the fixed delay equalizer gives a hump of delay in the center of the transmitted band, the adjustable delay equalizers resonating above and below the band, may be used in the manner indicated above to adjust the over-all

delay to be flat or to obtain slope at either edge of the band.

In the circuit shown in Fig. 8 the condensers are assumed fixed and consequently the values

$$C = \frac{1}{kb\pi f_0}$$

and

$$c = \frac{b}{4\pi k f_0}$$

are constant. Therefore,

$$\sqrt{Cc} = \frac{1}{2k\pi f_0}$$

is constant. Consequently kf_0 is also constant. Thus it is seen that if f_0 is to vary, then k , the characteristic impedance of the network must vary in the opposite direction, in order that the product may remain constant. Suppose, for example, that f_0 is to increase from 100 kilocycles to 110 kilocycles. If k is 110 ohms it must then decrease to 100 ohms in order for the product kf_0 to remain constant at 11×10^6 . Since the inductances are proportional to k/f_0 the inductances have to be decreased according to the ratio

$$\left[\frac{1}{1.1} \right]^2 = \frac{1}{1.21}$$

A similar explanation applies to the circuits shown in Figs. 9 and 10, the formulas for which are given on the drawings.

The system shown in Fig. 1 therefore operates as follows: The three modulated waves produced by modulating waves of the frequencies F_1 , F_2 and F_3 with a wave of the frequency F_0 are filtered by the three band-pass filters 27, 28 and 29 and transmitted over the line 12 where they pass through the fixed delay equalizer 13 and the adjustable delay equalizer 14 to the detector and control circuits 15 where they cause to be set up (see Figs. 3 and 4) two variable direct currents I_3 and I_6 . Each of these two currents is used to control the flow of current in the spare winding of two coils (as, for example, windings 89 and 91 in Fig. 5) to vary the inductance by suitable amounts so that the coils when used as elements in the delay equalizers give delay changes in the desired direction to produce delay distortion compensation. This is due to the fact that the coils have non-linear core material.

The magnetomotive force in the coil due to television current is small compared to the magnetomotive force due to the current I_3 (or due to the current I_6) in order not to produce non-linear effects in the television image.

While preferably the pilot channels are connected to the line at all times and are located outside of or in "dead" portions of the spectrum, in some cases it is advisable to have the pilot channels connected only periodically. If pilot channels are on only for brief instants periodically, then the currents I_1 , I_2 , I_4 and I_5 in Fig. 3 are short spurts of tone. Consequently the direct currents I_3 and I_6 will consist of short pulses. It will be necessary to select the average values of these pulses, for example, by using low cut-off, low-pass filters in tandem with the outputs of the two phase detectors, in order to obtain smooth direct currents to control the variable inductance.

A much greater amplification is then required of the tubes 58 and 59 for a given control current than if the pilot channels are permanently connected. Additional tubes may be used if necessary to obtain amplifying stages between transmitter 51 and detector tubes 58 and 59, or a direct

current amplifier may be used at the output of the push-pull detector. When there is sufficient gain, tubes 58 and 59 may be replaced by copper-oxide rectifiers.

The currents I_3 and I_5 not only control inductances, but may also be used to control varistors if resistance variations are necessary or desirable in these networks. In this case the direct current controlling the varistor is generally large compared to the alternating current signal to reduce non-linear effects on signal transmission.

Referring again to Fig. 5, it usually happens that the accompanying changes in the characteristic impedance k of the equalizer within the box 93 produce reflection effects. If they are serious, automatic adjustable impedance matching pads may be inserted at either or both ends of the delay equalizer, that is, before the input terminals 70 and 71 and following the output terminals 72 and 73 of equalizer section 93, in order to give the delay equalizer section a constant over-all impedance. The pads can also be designed to keep the loss constant. As an illustration of this, let the delay network be terminated in equal pads as shown in Fig. 5. Consider the pad consisting of the resistances 100, 101, 102 and 103. These members contain thermistors having respectively the heaters 110, 111, 112 and 113 which are to control the pad resistances in whatever manner is necessary to produce over-all constant loss and impedance for the entire circuit section shown in Fig. 5.

Suppose the impedance of the lattice type network shown in the box 93 in Fig. 5 increases. It may be desirable to increase the resistances of the members 100, 101 and 103, in order to match the network with a higher impedance, and it would then be necessary to decrease the resistance of the member 102 at the same time in order to shunt down the over-all impedance to the desired value. The desired amounts of increase or decrease of these thermistors' resistances can be evaluated by well-known formulas of the prior art.

The heaters 110, 111, 112 and 113 are not sensitive to change in direction of current. If the direct current from the phase detector is the only source of heat, the thermistors perform alike for either polarity of current. In order that the heater shall become cooler for one polarity of current a biasing battery 115 is introduced. In order that the purpose thereof be easily understood, assume as a first approximation that the source of control voltage applied to terminals 74 and 75 has a low internal resistance so that the circuit containing the elements 110 to 117 inclusive may be considered independently of the circuit containing elements 89, 91, 94, and 95. Now if the voltage of battery 115 is larger than the magnitude of the polar control voltage, the resultant value of these two voltages is a variable direct voltage which can swing from a low to a high value, thus providing a suitable unidirectional voltage of variable magnitude for operating heaters. If the direct current biasing battery 115 is located directly in series with the wire joining terminal 74 and resistor 95, instead of in the location shown on Fig. 5, then the current in windings 89 and 91 is a unidirectional current of variable magnitude, and it is unnecessary to have windings 88 and 90, or battery 92, in order to obtain the variation in ampere-turns indicated in Fig. 7. When the internal resistance of the source of control voltage applied to terminals 74 and 75 is appreciable, it is no longer possible to

compute currents and voltages for the circuits of the heaters and of the coils independently of each other. They must be designed to work together, a procedure well known to engineers who apply Kirchhoff's laws to the solution of simultaneous equations involving currents and voltages in any complicated mesh. However, the purpose of the biasing battery 115 remains the same.

Suppose it is desired that the heater element 112 heat or cool oppositely to the heater elements 110, 111 and 113. For this purpose, another biasing battery 116 in series with the resistance 117 is added in parallel with the heater element 112. A resistor 114 is connected in series with the battery 115.

Reference will now be made to Fig. 6 which is a simplified circuit diagram of the heater elements and their connections to the sources of potential. Assume a voltage E_0 is applied to the terminals A and B from the phase detector 39 and that its internal impedance may be neglected or lumped with the resistance 114. Let $E_0=0$ and the currents are as indicated by the arrows in Fig. 6. Now let E_0 become positive. Then it follows from Kirchhoff's laws that E_0 is in such a direction that it tends to diminish i_2 and i_5 , but E_0 will augment i_3 . Thus the heaters 110, 111 and 113 will cool but the heater 112 will become warmer. The opposite happens when E_0 is reversed in direction.

The pad connected to the output terminals 72 and 73 of the delay equalizer is similar to that connected to the input terminals 70 and 71 so similar reference characters have been used for similar elements.

There are various other possible pad arrangements such as the H-type or the T-type. The latter is suitable, along with bridged T-type delay networks, for coaxial systems. There are a considerable number of other non-dissipative constant K-type networks which are the equivalent of one or more lattice-type sections, suitable for use as delay equalizers.

The advantage of the adjustable equalizer described above is that it is continuously adjustable as distinguished from an arrangement wherein various resistance pads are inserted or taken out of an equalizer or contacts are operated thus momentarily breaking the circuit, or producing sharp discontinuities in the transmission. The arrangement is also superior to a continuously moving potentiometer as contacts get worn and they spark causing distortion, and it is also superior to the type using rotating condenser plates or to other arrangements requiring moving parts which wear out in time or require adjustments.

Various modifications other than those specifically pointed out above may be made in the embodiments described without departing from the spirit of the invention, the scope of which is indicated in the appended claims. While the invention, in its preferred aspects, relates to delay systems and equalizers, it will be understood that certain features of the invention may have other applications.

What is claimed is:

1. A system for automatically compensating for the delay distortion of a transducer over a certain frequency range comprising means for modulating a wave of the lowermost frequency of said range by a modulating wave of a still lower frequency, means for modulating a wave of the uppermost frequency of said range by said modulating wave, means for transmitting certain of the modulation products, at least, of each of

said modulations over the circuit, means for detecting from each of said modulated waves a frequency component corresponding to said modulating wave, means for obtaining a variable direct current corresponding to the difference in phase between said frequency components, means including a variable delay equalizer through a portion of which said direct current passes for compensating for the delay distortion of said system represented by said variable direct current, said delay equalizer including a plurality of inductance members which have their inductance varied by said variable direct current, and means including adjustable impedance matching pads for correcting for reflection effects resulting from varying said equalizer.

2. In combination, a delay network, an attenuating network in circuit therewith, signal generating means, and means under control of said signal for both automatically varying the delay in said delay network and simultaneously automatically varying the attenuation introduced by said attenuation network to compensate for the change in attenuation in said delay network resulting from varying said delay network.

3. In combination, a delay network, an attenuating network in circuit therewith, means for automatically varying the delay in said delay network and simultaneously automatically varying the attenuation introduced by said attenuation network to compensate for the change in attenuation in said delay network resulting from varying said delay network, said means comprising means for producing a variable direct current representative of the time interval between two electric variations transmitted over said networks.

4. A system for automatically compensating for the delay distortion of a transducer over a certain range comprising means for modulating a first pilot frequency corresponding to the lower boundary frequency of said range with a modulating wave of a still lower frequency to produce a first modulated wave, means for modulating a second pilot frequency corresponding to a frequency intermediate the upper and lower boundary frequencies of said range with said modulating wave to produce a second modulated wave, means for modulating a third pilot frequency corresponding to the upper boundary frequency of said range with said modulating wave to produce a third modulated wave, means for transmitting said three modulated waves over said transducer, means for demodulating said three modulated waves to produce three resultant waves of said modulating frequency, equalizing apparatus in circuit with said transducer, means for utilizing the two resultant waves corresponding to the first and second of said modulated waves to vary a first portion of said equalizing apparatus in such a way as to compensate for the delay distortion of said transducer over that portion of said certain range between said first and second pilot frequencies, and means for utilizing the two resultant waves corresponding to the second and third of said modulated waves to vary a second portion of said equalizing apparatus in such a way as to compensate for that portion of said certain range between said second and third pilot frequencies.

5. The combination of elements as in claim 4 in further combination with means for applying a television band of frequencies to said transducer, said first pilot frequency being at least as low as the lower boundary frequency of said band and said third pilot frequency being at least as high as the upper boundary frequency of said band.

6. The combination of elements as in claim 4 in further combination with means for applying a television band of frequencies to said transducer, at least one of said pilot frequencies being equal to a frequency within said band whereat the signal intensity is low compared with the signal intensity at other frequencies in the band.

7. In combination, a delay network, an attenuating network in circuit therewith, said two networks being normally matched in impedance, signal generating means, means under control of said signal for varying the delay in said delay network, thereby causing a change in impedance thereof and tending to disturb the impedance match between the delay network and the attenuating network, and means under control of said signal for varying the impedance of said attenuating network in a direction to compensate for said change in impedance of said delay network.

8. The combination of elements as in claim 7 in which said attenuating network comprises a plurality of thermistors each of which has an associated heating coil, and means for varying the current through said coils in response to the variations in said signal.

9. The combination with transmission means the delay characteristics of which may vary, of a resistance network associated with said means comprising a first thermistor connected in a circuit across the two leads to the terminals of said transmission means, a second thermistor connected in a circuit parallel to that containing the first thermistor, third and fourth thermistors connected in said leads, respectively, each between the connections of said circuit to the lead containing that thermistor, an auxiliary heater for each of said thermistors, a source of direct voltage supplying current to all of said auxiliary heaters, a second source of direct voltage supplying current to all of said heaters, means for connecting said sources to said heaters so that an increase in the voltage of one of said sources causes a current magnitude change in one direction through three of said heaters and a current magnitude change in the opposite direction through the fourth heater, and means for varying one of said sources, whereby said variation in a given direction causes the resistance of one of said thermistors to increase and that of the others to decrease.

10. The combination of elements as in claim 9 in which said transmission means has a variable element under control of said means for varying said one of said sources.

11. The combination of elements as in claim 9 in which said transmission means has a variable inductance element under control of said means for varying said one of said sources.

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