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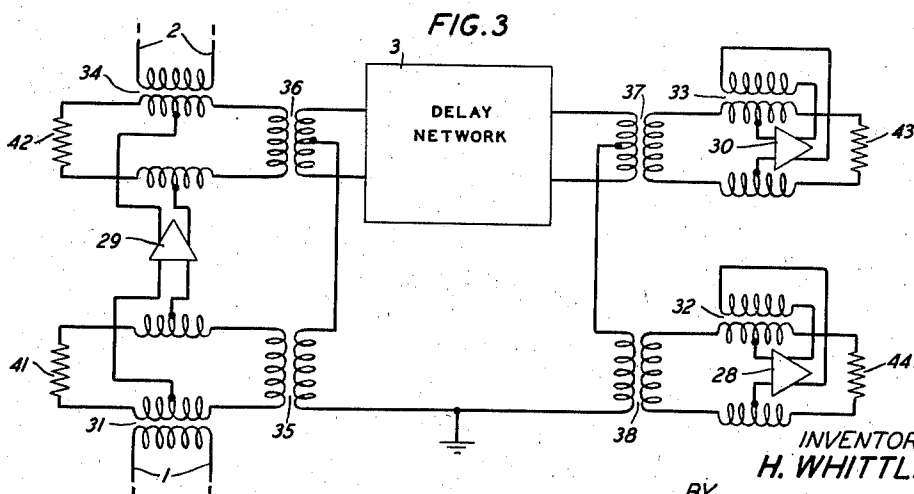
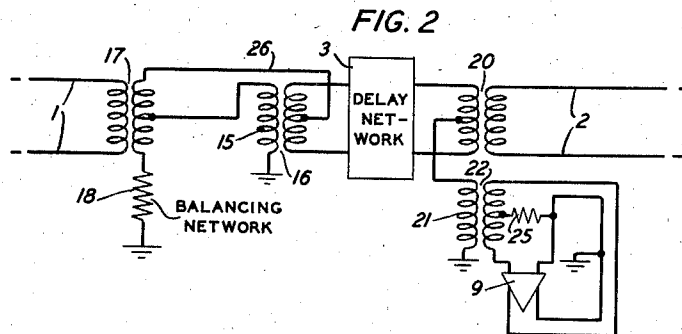
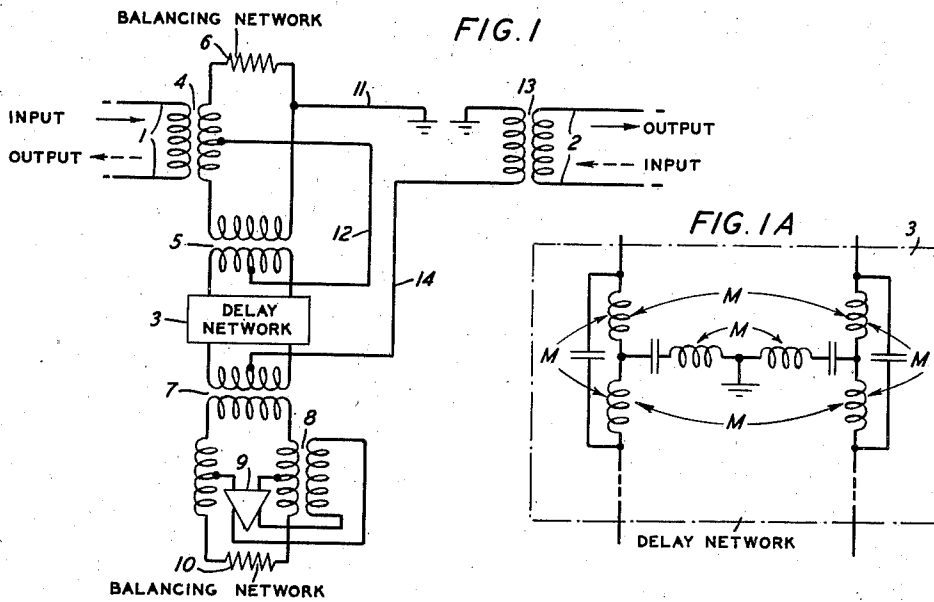
H. WHITTLE

2,191,065

WAVE TRANSMISSION SYSTEM

Filed April 23, 1938

3 Sheets-Sheet 1



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H. WHITTLE

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WAVE TRANSMISSION SYSTEM

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FIG. 4

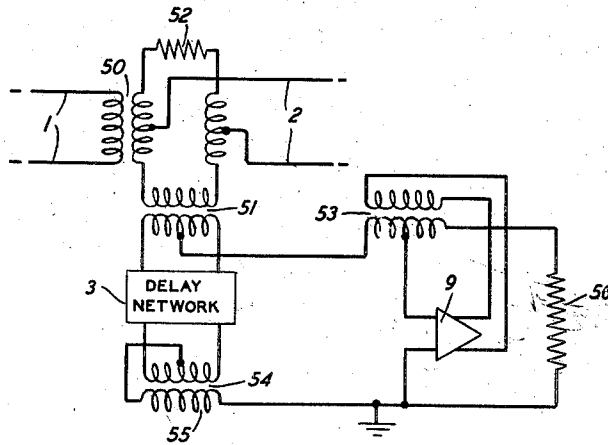
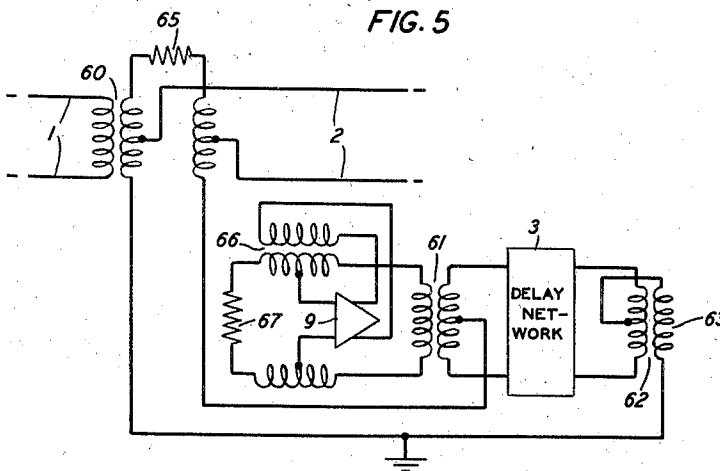


FIG. 5



INVENTOR
H. WHITTLE
BY
B. C. Feger
ATTORNEY

Feb. 20, 1940.

H. WHITTLE

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FIG. 6

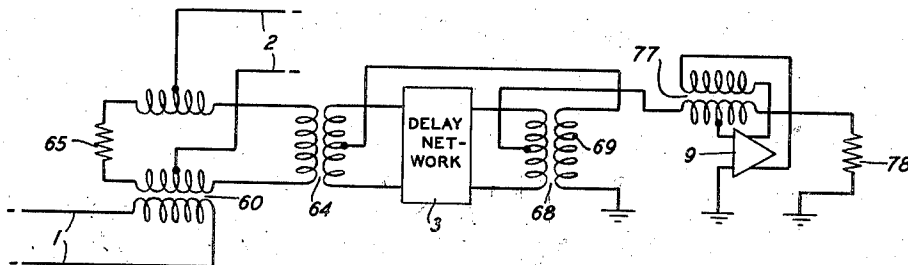


FIG. 7

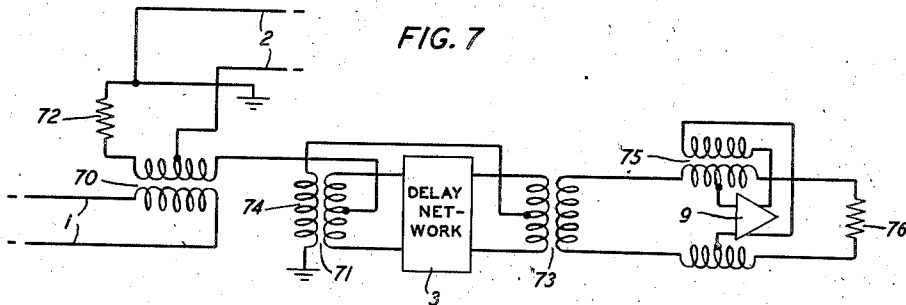
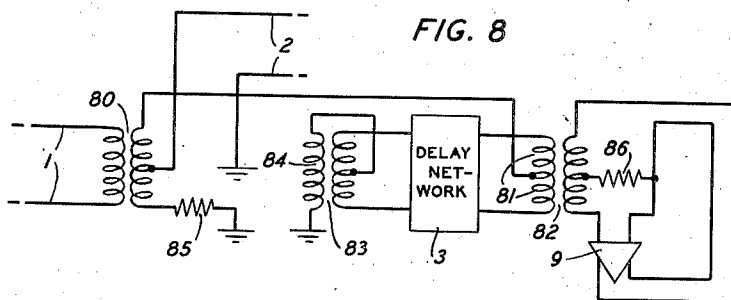


FIG. 8



INVENTOR
H. WHITTLE
BY
B. C. Leger
ATTORNEY

UNITED STATES PATENT OFFICE

2,191,065

WAVE TRANSMISSION SYSTEM

Horace Whittle, Maplewood, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 23, 1938, Serial No. 203,722

4 Claims. (Cl. 178—44)

This invention relates to controlling wave propagation, as for example delaying wave transmission.

5 An object of the invention is to reduce the amount of apparatus required to effect the desired delay or control.

10 In one specific aspect the invention is a system in which the delay obtainable with a given delay network is increased by propagating the waves through the network one or more times in one mode, for example as longitudinal currents, and also one or more times in different mode, for example as circulating currents, the delays for all of the propagations being cumulative.

15 One or more propagations in one mode may be followed by one or more in other mode, examples being indicated hereinafter.

20 In the utilized frequency band the delay-frequency characteristics for the different modes may be flat or may be complementary; or, if the delay network is used as a delay equalizer, they may be such as to combine to the desired characteristic for equalizing (i. e., compensating or correcting for) the delay-frequency characteristic of other parts of the system in which the network is used.

25 Other objects and aspects of the invention will be apparent from the following description and claims.

30 Figs. 1 to 8 show eight systems embodying the invention; and Fig. 1A shows a delay network suitable for use in any of those systems.

35 In the system of Fig. 1, waves to be transmitted from the input circuit 1 to the output circuit 2 pass three times through delay network 3. The delay network may be of any type suitable for delaying both longitudinal and circulating currents, as for example, the type indicated in Fig. 1A wherein one section of delay network is shown and the dotted lines indicate that as many sections as required may be connected in tandem relation. In each section the coils may have mutual inductance therebetween as indicated by the symbol M and the arrows in Fig. 1A.

40 The waves to be transmitted from circuit 1 to circuit 2 in Fig. 1 may be of any desired character, as for example, speech currents. They pass from circuit 1 through bridge transformer (hybrid coil) 4 to transformer 5 and balancing network 6. From transformer 5 the waves pass through the delay network 3, transformer 7 and bridge transformer 8, into the input and output circuits of amplifier 9. The waves thus applied to the input of amplifier 9 are amplified and pass back through bridge transformer 8 into

transformer 7 and balancing network 10. The waves thus transmitted back to transformer 7 return through delay network 3 and transformer 5 to bridge transformer 4. A part of their energy is transmitted from the bridge points of the bridge transformer, to conductors 11 and 12, the remainder going to circuit 1. So far, the transmission has been similar to that for the case of the system disclosed in A. B. Clark Patent 1,672,057, June 5, 1928, the signal having traversed the delay network twice, each time as a metallic circulating current. Now before proceeding from conductors 11 and 12 through transformer 13 to the output circuit 2, the signal passes a third time through the delay network 3, this time as a longitudinal current, the current flow being through conductor 11, ground, primary winding of transformer 13, conductor 14, and longitudinally through the halves (or portions) of a winding of transformer 7, the delay network 3 and the halves of a winding of transformer 5, to conductor 12. This current flow through the primary winding of transformer 13 induces a signal voltage in the secondary winding, which transmits the signal to the output circuit 2. Thus, the delay network 3 has delayed the signal three times in its passage from the input circuit 1 to the output circuit 2. The system is reversible, (as indicated by the arrows and legends on the drawings), the amplification then occurring between the second and third passages of the signal through the delay network.

35 In all of the figures of the circuits can, of course, be metallically connected if desired.

Although use of the amplifier 9 is desirable, it is not in all cases necessary. For example, instead of using the amplifier, the undivided winding of transformer 7 can work into an open circuit or infinite impedance, so reflection will be obtained in the general fashion disclosed in Nyquist Patent 1,607,687, November 23, 1926.

45 The system of Fig. 2 also passes the signal or other transmission through a delay network 3 three times in transmitting it in either direction between circuits 1 and 2. For example, a signal to be transmitted from circuit 1 to circuit 2 passes through the delay network forwardly as a longitudinal current, then, after amplification in amplifier 9, backwardly as a longitudinal current, and then forwardly as a metallic circulating current. A winding 15 of a transformer 16 is connected between the bridge points of a bridge transformer 17 which has a divided winding. At one end of the divided winding is a bal-

ancing network 18 for balancing (with respect to the two halves or portions of the divided winding) the impedance (to ground) connected to the other end of the winding. The latter impedance is that of the circuit extending longitudinally through the two halves or portions of the divided winding of transformer 16, the delay network 3 (including its shunt arms with grounded mid-points), and the two portions of the divided winding of transformer 20, and thence extending through winding 21 of bridge transformer 22. A network 25 connected between the bridge points of bridge transformer 22 balances the impedance faced by winding 21, thus rendering the output and input of amplifier 9 conjugate to each other. The energy of waves applied to winding 21 divides between the input and the output of amplifier 9; and the portion of the energy applied to the input of amplifier 9 is amplified, part of the amplified energy passing to network 25 and the remainder being transmitted to winding 21. Winding 21 and circuit 2 are conjugate to each other as regards transmission directly through transformer 20; and winding 15 and circuit 1 are conjugate to each other as regards transmission directly through transformer 17.

A signal to be transmitted from circuit 1 to circuit 2 first passes from transformer 17 over a circuit extending from the divided winding of that transformer through conductor 26, thence extending longitudinally through the divided winding of transformer 16, the delay network 3 and the divided winding of transformer 20, and thence extending through winding 21 and network 18 to transformer 17. This signal in winding 21 is amplified in amplifier 9 and then passes back to winding 21, and thence longitudinally back over the circuit extending through the divided winding of transformer 20, the delay network 3 and the divided winding of transformer 16, to conductor 26 and bridge transformer 17, the energy dividing so that a portion goes to winding 15 of the transformer 16 (the remainder going to circuit 1). The signal in winding 15 then passes forwardly, as a circulating metallic current, through transformer 16, delay network 3 and transformer 20, to circuit 2. The system is reversible, as in the case of Fig. 1.

In the system of Fig. 3, waves to be transmitted from the input circuit 1 to the output circuit 2 pass through the delay circuit 3 four times, twice as a metallic circulating current and twice as a longitudinal current. An amplifier or other suitable unilateral device 28, and amplifiers 29 and 30, are connected in the system by bridge transformers 31, 32, 33 and 34 and transformers 35, 36, 37 and 38. The bridge transformer 31 is connected to transformer 35 and a balancing network 41, rendering the circuit 1 and the input of amplifier 29 conjugate to each other. The bridge transformer 32 is connected to transformer 38 and a balancing network 44, rendering the output and input of amplifier 28 conjugate to each other. The bridge transformer 33 is connected to transformer 37 and a balancing network 43, rendering the output and input of amplifier 30 conjugate to each other. The bridge transformer 34 is connected to transformer 36 and a balancing network 42, rendering the output of amplifier 29 and the output circuit 2 conjugate to each other.

Waves to be transmitted from circuit 1 to circuit 2 pass from circuit 1 into hybrid coil 31. A portion of their energy is dissipated in net-

work 41. The remainder passes through transformer 35, thence longitudinally through the divided winding of transformer 36, delay network 3 and the divided winding of transformer 37, to transformer 38. The signal received by transformer 38 is amplified in amplifier 28 and transmitted back through transformer 38, thence longitudinally back through the divided winding of transformer 37, delay network 3 and the divided winding of transformer 36, to transformer 35. The energy thus received by transformer 35 is transmitted through bridge transformer 31, a portion being dissipated in circuit 1 and the remainder being amplified by amplifier 29 and transmitted into bridge transformer 34. Of the energy thus received by bridge transformer 34, a portion is dissipated in network 42 and the remainder is transmitted to transformer 36. The signal thus received by transformer 36 is passed forwardly through the delay network 3 as a metallic circulating current, and through transformer 37 to amplifier 30. It is amplified in amplifier 30 and transmitted, as a metallic circulating current, back through transformer 37, delay network 3 and transformer 36, into bridge transformer 34. A portion of the energy thus received by the bridge transformer 34 is dissipated in the output of amplifier 29 and the remainder goes to output circuit 2. The system is unilateral (not reversible), since the device 29 is a unilateral device.

The delay network section or sections may be designed to give a uniform delay over the required band both for longitudinal and metallic circulating currents. For example, when the windings on opposite sides of the line are parallel aiding to longitudinal and series opposing to metallic currents the inductance given by the windings may be made of the same order of magnitude for both connections making the delay characteristics similar for the two connections. However, in some cases the delay network may preferably be designed so that the delays of the longitudinal and the metallic circulating currents are complementary. For example, in the case of the metallic circulating current the connection of the coils on opposite sides of the line may be series aiding, and for this connection they give a high inductance; whereas to the longitudinal current the connection of the coils on the opposite sides of the line would be parallel opposing, and for this connection the impedance ordinarily will give a small inductance. The circulating currents will then receive a large delay at low frequencies while the longitudinal currents will receive a large delay at high frequencies. By proper proportioning of the elements a uniform delay for all useful frequencies can thus be obtained. If desired, with either of the above-mentioned connections, the elements of the delay network may be proportioned to give the network a delay-frequency characteristic that, instead of being flat, has a prescribed shape rendering the network suitable for equalizing, over the required frequency range, the delay of other parts of the system in which the network is used.

These considerations as to delay characteristics apply also to the circuits of Figs. 1, 2, 4, 5, 6, 7 and 8; though in the case of Figs. 1 and 2, allowance must be made for the fact that the number of times the current passes through the delay network is not the same for the circulating current as for the longitudinal current.

The system of Fig. 4 gives four passages of a signal through delay network 3 in transmission

from circuit 1 to circuit 2, and is shown as using but one amplifier, the amplifier 9. As in the case of the amplifier 9 of Figs. 1 and 2, and the amplifiers 43 and 44 of Fig. 3, the amplifier and its associated bridge transformer and balancing network can be omitted when not required for impedance matching or amplification.

In the first and last passages of the signal through the delay network the current is entirely a metallic circulating current; and in the second and third passages of the signal through the delay network the current is a longitudinal current through the delay network, flowing through the two sides of the network in parallel.

A bridge transformer 50 and a transformer 51 connect circuits 1 and 2 to the delay network 3. To render circuits 1 and 2 conjugate to each other, a network 52 balances the impedance of the delay network to circulating currents. Amplifier 9 is connected in circuit by a bridge transformer 53. The divided winding of this bridge transformer is connected at one end to a circuit extending longitudinally through the two halves or portions of the divided winding of transformer 51, the delay network 3 and the two portions of the divided winding of a reflection transformer 54, and thence extending through the other winding 55 of the latter transformer, to ground. The impedance-to-ground that this circuit (including the impedance of the delay network to longitudinal currents) attaches to this one end of the divided winding of transformer 53, is balanced by the impedance of network 56, so the output and input of amplifier 9 are conjugate.

In transmission from circuit 1 to circuit 2, signals pass from circuit 1 into bridge transformer 50 and are transmitted through transformer 51, delay network 3 and transformer 54 as a circulating current. The current thus passing through the two portions of the divided winding of transformer 54 in series induces a voltage in winding 55 of this reflection transformer. This voltage sends current longitudinally through these two portions of this divided winding, the delay network 3 and the two portions of the divided winding of transformer 51, this current passing into bridge transformer 53. Waves thus received by transformer 53 are amplified by amplifier 9 and transmitted longitudinally through the divided winding of transformer 51, the delay network 3 and the divided winding of transformer 54, and pass on through winding 55 of transformer 54 and network 56. The current thus received by winding 55 induces voltage in the other winding of transformer 54. This voltage causes signal current to flow, as a circulating current, through the delay network 3, transformer 51, and bridge transformer 50, to circuit 2. The system is reversible.

The system of Fig. 5 is similar to that of Fig. 4, but the first and last passages of the signal current through the delay network are passages as longitudinal current. The signal passes from circuit 1 into bridge transformer 60. A portion of the energy from this transformer is passed longitudinally through the divided winding of transformer 61, delay network 3 and the divided winding of reflection transformer 62, and on through winding 63 of transformer 62. The remainder of the energy from bridge transformer 60 is passed to balancing network 65, which renders circuits 1 and 2 conjugate. The current in winding 63 induces voltage in the divided winding of transformer 62. Due to this voltage the signal is sent back through delay network 3,

but as a circulating current. From the delay circuit, the signal passes through transformer 61 and bridge transformer 66 to the input and output of amplifier 9. The signal received by the input of amplifier 9 is amplified in the amplifier. A portion of the energy of the amplified signal is dissipated in the balancing network 67. The remainder is passed through the delay network 3, the current being a circulating metallic current. This current flows through the divided winding of transformer 62, inducing voltage in winding 63. This voltage causes current to flow longitudinally through the divided winding of transformer 62, delay circuit 3, and the divided winding of transformer 61, to the bridge transformer 60. A portion of the energy of the signal thus transmitted to the bridge transformer 60 goes to circuit 1, the remainder going to circuit 2. The system is reversible, for passing waves four times through the delay network in their transmission from circuit 2 to circuit 1.

Fig. 6 shows a four-passage delay network circuit in which longitudinal and circulating transmissions are in the same direction through the delay network 3 before passing through amplifier 9, and likewise both are in the opposite direction after passing through the amplifier. In passage from circuit 1 to circuit 2, signals from circuit 1, entering bridge transformer 60 are received by transformer 64 and balancing network 65. Those received by transformer 64 are transmitted through transformer 64, delay network 3 and transformer 68 as a circulating current, the propagation through delay network 3 being from left to right in the figure. The signals thus received by winding 69 of transformer 68 are then passed longitudinally through the divided winding of transformer 64, delay network 3 and the divided winding of transformer 68, to bridge transformer 71, which has a balancing network 78, rendering the output and input of amplifier 9 conjugate and transmits the applied signals to the input and output of amplifier 9. Those applied to the input of amplifier 9 are amplified and transmitted back into bridge transformer 71 which transmits a portion of their energy to network 78 and transmits the remainder as a current flowing longitudinally through the divided winding of transformer 68, delay network 3 and the divided winding of transformer 64, and on through winding 69 of transformer 68. The signals thus received by winding 69 are then transmitted through transformer 62, delay network 3 and transformer 64 as a circulating current, and pass into bridge transformer 60, which sends a portion of their energy to circuit 1 and the remainder to circuit 2. The system is reversible for transmitting from circuit 2 to circuit 1.

Fig. 7 shows a system which is similar to that of Fig. 6 but in which the longitudinal delay is first in the sequence of delays. Bridge transformer 70 connects circuits 1 and 2 through the divided winding of transformer 71 to delay network 3, and balancing network 72 associated with the bridge transformer 70 renders circuits 1 and 2 conjugate. Transformer 73 connects the delay network to amplifier 9 through a bridge transformer 75, which has associated therewith a balancing network 76 for rendering the amplifier output and input conjugate. Signals from circuit 1 pass longitudinally through the delay network to winding 74 of transformer 71, this passage through the delay network being from left to right in the figure. Then the signals pass

again from left to right through the delay network, this time as a metallic circulating current. Then the signals are amplified and are transmitted back through the delay network (from right to left), as a metallic circulating current. Then they are transmitted from winding 74 longitudinally through the delay network (again from right to left), and pass through bridge transformer 70 to circuit 2. The system is reversible, for transmitting from circuit 2 to circuit 1.

Fig. 8 shows a simplified system for obtaining four passages of the signal through the delay network 3 in transmission between circuits 1 and 2. Bridge transformer 80 has connected to one end of its divided winding a circuit extending longitudinally through divided winding 81 of transformer 82, delay network 3 including the shunt arms of the delay network, with their grounded mid-points) and the divided winding of transformer 83, and extending thence through winding 84 of reflection transformer 83 to ground. A network 85 for balancing this grounded circuit or impedance is connected to the other end of the divided winding of the bridge transformer 80, so circuits 1 and 2 are conjugate to each other. The bridge transformer 82 connects the input and output of amplifier 9 to the delay network, a balancing network 85 rendering the amplifier output and input conjugate.

Signals from circuit 1, transmitted through bridge transformer 80, pass through the grounded circuits connected to the ends of its divided winding in series. One of these grounded circuits is network 85, and the other includes winding 81, delay network 3 and the windings of transformer 83, the current from bridge transformer 80 passing longitudinally through the portion of this other circuit extending through divided winding 81, delay network 3 and the divided winding of transformer 83. The signal thus received by winding 84 is transmitted again through the delay network 3, this time from left to right as a metallic circulating current. Then it is amplified by amplifier 9 and returned to the delay network. It passes a third time through the network 3, this time from right to left as a circulating current. In flowing through the divided winding of reflection transformer 83 it induces signal voltage in winding 84. This voltage sends the signal a fourth time through network 3, this time as a longitudinal current. This fourth passage

through network 3 is from left to right in the figure. The signal is then transmitted from the delay network to bridge transformer 80, a part of its energy going to circuit 1 and the remainder passing to circuit 2. The system is reversible for transmitting from circuit 2 to circuit 1.

What is claimed is:

1. The method which comprises propagating waves in one mode through a delay path and propagating the same waves twice in another mode through the same delay path and rendering the delays in the several propagations cumulative.

2. The method which comprises applying to one end of a wave transmission path including a transmission delay network of lumped impedances waves to be transmitted through the path, passing them at least twice in one direction and once in the opposite direction through the network without affecting the output of the path at its other end before completion of said passages, and transmitting the waves so passed through the network from the network to said other end of the path.

3. The method of producing a desired degree of change in electric wave currents between a pair of input terminals and a pair of output terminals which comprises sending the currents from the input terminals without immediate substantial effect on the output terminals through a transmission delay network that produces a portion of the desired change, transmitting the currents again through the said network to produce another portion of the desired change, and transmitting the currents at least once again through the said network to produce a further portion of the desired change and making them effective on the output terminals of the system substantially immediately upon completion of their last transmission through said network.

4. A transmission delay system comprising a delay path, means for applying waves to said path in such manner that they are propagated through the path in one mode, and means for twice successively applying the same waves to said path in such manner and at such times with respect to said propagation that they are twice successively propagated therethrough in another mode and the delays in the several propagations are rendered cumulative.

HORACE WHITTLE.