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PHASE SHIFTING ARRANGEMENT

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2 Sheets-Sheet 1

Fig. 1.

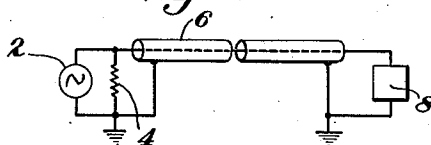


Fig. 2.

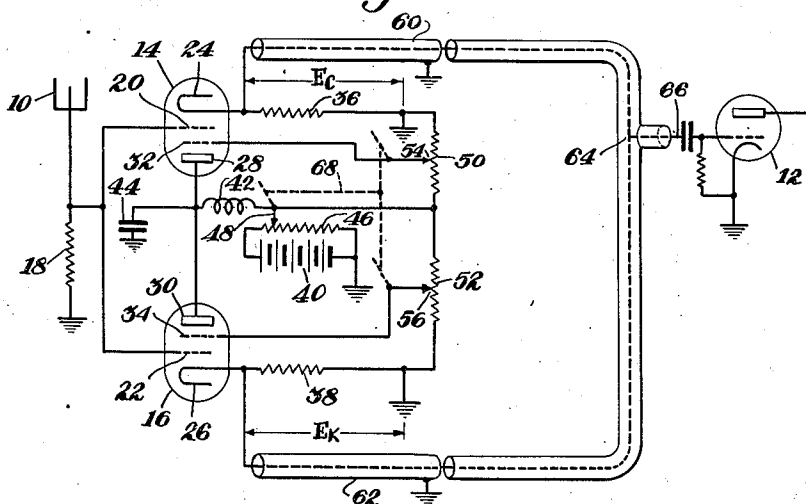
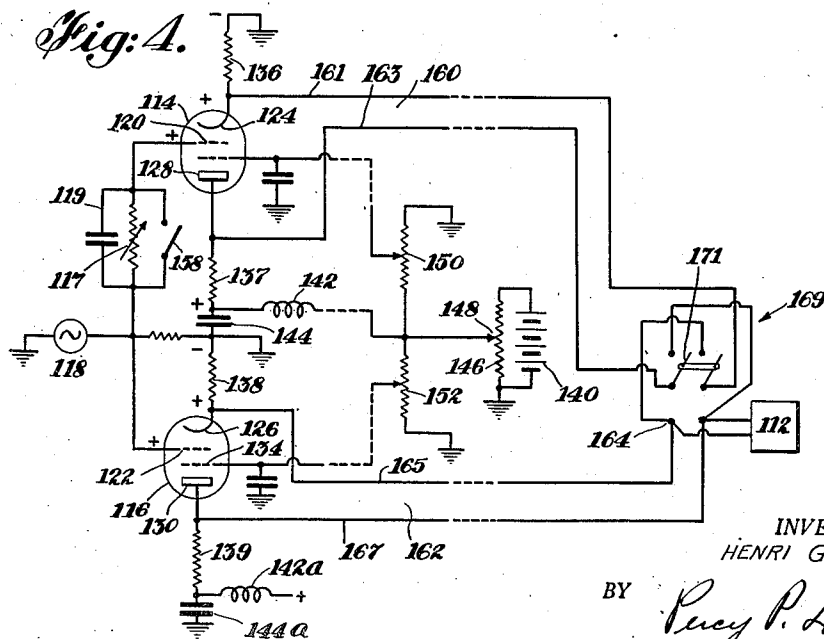


Fig. 4.



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PHASE SHIFTING ARRANGEMENT

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5 Claims. (Cl. 178-44)

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This invention relates to phase changers, and in particular to phase changers of the type employing transmission lines.

An object of my invention is to provide a phase changer by which the phase of a voltage at a given point can be controlled from a point remote thereto.

Another object of my invention is to provide a phase changer in which the voltage whose phase is to be controlled comprises the sum of two voltages which may be varied from a remote point.

A further object of my invention is to provide a phase changer employing transmission lines between the voltage which is to be changed and the control voltages which produce the change.

Generally speaking, this invention may be defined as comprising the constructions and combinations recited in the annexed claims and illustrated in certain embodiments in the drawings accompanying and forming a part of this application; wherein:

Fig. 1 is a schematic diagram of a single coaxial transmission line to illustrate a principle used in operation of my invention,

Fig. 2 is a wiring diagram illustrating one of the embodiments of my invention,

Fig. 3 is a vector diagram illustrating the operation of the phase changer of Fig. 2,

Fig. 4 is a second embodiment of my invention and

Fig. 5 is a vector diagram illustrating the operation of the phase changer shown in Fig. 4.

Before describing my phase changing device, a brief explanation of one of the principles of operation of my invention will be given.

Referring to Fig. 1, I have illustrated by reference character 2, an alternating current power source connected across a resistor 4. Connected across the resistor 4 is a transmission line which is of the concentric conductor type. The far end of the transmission line is connected to a receiver or other energy translating device 8. The transmission line is so constructed that its surge impedance is made substantially equal to the impedance of the resistor 4.

The impedance looking into the translating device 8 from the transmission line may or may not be equal to the surge impedance of the transmission line, and in general there would be a decided mismatch of impedances. If a voltage is developed across the resistor 4 due to current flowing therein from the source 2, this voltage will impress a voltage wave on the transmission line and the wave will pass along the line ultimately arriving at the far end thereof where the wave will encounter an impedance which is not equal to the surge impedance of the line, and will therefore be in part reflected back toward the input end. Part of the energy of the wave will be dissipated in the impedance of the translating device 8, and it is that energy which is not dissipated which is reflected toward the input end of the line. Standing waves will be built up on the transmission line 6 due to this reflected wave. However, when this wave arrives at the input of the line, it encounters resistor 4 in which substantially all of the reflected energy is dissipated since, as above mentioned, the impedance or resistance of the resistor 4 substantially matches the surge impedance of the transmission line. Since all of the reflected energy is dissipated, none of this energy can be retransmitted to the far end of the line. The net result of the wave motion will be that a voltage will appear across the line at its far end which bears a phase relation with respect to the input voltage dependent upon the length of the transmission line.

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Now assume another source of voltage, a resistor and a transmission line having characteristics similar to corresponding elements shown in Fig. 1. If the far end of this second transmission line is also connected to the translator 8, two voltages will be impressed across the input of the translator. In general, these voltages will be of unequal magnitude and have a phase difference. The resultant voltage impressed on the translator 8 will be the vector sum of the two voltages appearing at the far ends of the transmission lines. It is preferable that the surge impedance of the two lines be equal.

Referring now to Fig. 2, I have illustrated my phase changing device as connected between an antenna 10 and a receiver or translating device 12, the latter being located at some distance from the antenna. Such an arrangement might be employed for example between the sensing antenna of a directional antenna array and a remote receiver such as is described in my copending application Serial No. 468,668, filed December 11, 1942. The output of the antenna is connected to the input circuit of two vacuum tube amplifiers 14 and 16. The input circuit comprises the resistor 18 and the leads to the grids 20 and 22 of the amplifiers. Other amplifier electrodes are the cathodes 24 and 26, the anodes 28 and 30 and the phase control grids 32 and 34 of the tubes 14 and 16 respectively. The grids 32 and 34 may be the shielding grids of an am-

plifier of the tetrode type. Pentodes or other types of amplifiers having suitable characteristics may also be employed.

The amplifier circuits are of the cathode follower type wherein the impedances 36 and 38 are located in the common paths of the input and output circuits of the amplifiers. The amplifier output circuits are energized from a suitable power supply shown as a battery 40 connected between the amplifier anodes and ground. The capacitor 44 is for by-passing the radio frequency currents to ground so that together with the choke 42, the power supply is isolated from these currents. A potentiometer 46 with variable contact 48 enables any desired voltage to be applied to the anodes of the amplifiers. Potentiometers 50 and 52 are connected across that portion of the potentiometer 46 which determines the anode voltages. Sliding contacts 54 and 56 determine the voltages which are applied to the phase control grids 32 and 34 respectively of the amplifier tubes 14 and 16.

The input end of a transmission line 60 is connected across the cathode follower resistor 36. Likewise the transmission line 62 is connected across the cathode follower resistor 38. The remote ends of the transmission lines 60 and 62 are connected together at the point 64 from where a lead 66 connects to the input circuit of the translating device 12 shown by way of example as the first stage of an amplifier.

In accordance with the circuit arrangement shown in Fig. 2 it will be observed that the voltages applied to the grids 20 and 22 are in phase and it follows therefore that the cathode follower resistors 36 and 38 are likewise in phase. If the two transmission lines 60 and 62 were of equal length, the two voltages at the ends of these lines where they join at the point 64 would also be in phase, with a phase displacement, however, with respect to the voltages at the inputs of the lines. However, in accordance with one embodiment of my invention, the lines 60 and 62 are made of unequal length, so that the two voltages arriving at the point 64 from the input ends of the lines are displaced in phase and the voltage which is ultimately applied to the input circuit of the amplifier 12 is the resultant of these two voltages. The difference in the lengths of the transmission lines determines the phase displacement of the voltages appearing at the far ends of the lines. For example, if it was desired to produce a maximum phase variation of 90°, the two lines would differ in length by one-quarter wave length.

Further operational features of the circuits of Fig. 2 can be best explained by reference to Fig. 3 wherein the two voltages across the cathode resistors 36 and 38 are represented by the vector E_c and E_k . These voltages are superimposed one above the other since they are in phase, and assumed to be of equal magnitude.

The vector E'_c represents the voltage appearing at the end of the transmission line 60 and differs in phase from the vector E_c by the angle θ . The vector E'_k represents the voltage appearing at the far end of the transmission line 62 and lags behind the voltage at the input end of the line by the angle ϕ . In this case the difference in the phase angles between the voltages E'_c and E'_k is equal to the angle α . The sum of these two voltages, E_R , is the voltage applied to the input circuit of the amplifier 12.

Suppose now it is desired to shift the phase of the voltage E_R with respect to the voltage E_c an amount where it may be represented by the volt-

age E_s . This may be done by reducing the gain of the amplifier 16. A suitable method of reducing the gain is to move the contact 56 of the potentiometer 52 downward whereby a lower voltage is impressed on the grid 34 of the tube 16. This reduction in gain has the effect of reducing voltage E_k across the resistor 38. When the voltage E_k is reduced, the voltage appearing at the far end of the line is also reduced and is represented by the vector E''_k . Combining this voltage E''_k with the voltage E'_c (the latter having not been changed) the voltage E_s results and this voltage leads the original resultant voltage E_R by β degrees.

If one wishes to increase the angle between the voltage E_R and the input voltage, E_k or E_c , the gain of the amplifier 14 is reduced by moving the potentiometer contact 54 upwards whereby a lower voltage is impressed on the grid 32 of this amplifier. The reduction in the voltage appearing across the resistor 36 now produces a reduced voltage E''_c appearing at the output end of line 60 and this voltage E''_c combined with the voltage E'_k appearing at the output end of line 62 now results in a final voltage E_s' appearing at the input of the amplifier 12.

The vector diagram of Fig. 3 has been drawn so that the two voltages appearing at the output ends of lines 60 and 62 are 120° apart. This is illustrative only, and not to be considered as limiting. It will be seen, however, that this particular phase displacement of terminal voltages results in a rather small change in the amplitude of the resultant voltage E_R . The locus of the magnitude of the resultant voltage E_R is represented by the dotted line $E'_c-E_RK'_k$.

It is usually desirable that the magnitude of the resultant voltage be maintained substantially constant and this may be accomplished by varying the position of the contact 48 of the resistor 46. In order to increase the magnitude of the vector E_s without changing its phase relation, the gain of both amplifiers 14 and 16 may be increased simultaneously and this is done by increasing the potential which is applied to the anodes of the amplifier tubes. If desired, the voltage controls 48, 54 and 56 could be mechanically inter-connected or "gauged" so that the magnitude of the resultant voltage appearing at the point 64 at the ends of the lines 60 and 62 will remain constant regardless of phase variation. This mechanical arrangement is diagrammatically illustrated at 68.

Referring now to Fig. 4 in which a second embodiment of my invention is illustrated, I have shown a pair of amplifier tubes 114 and 116 connected in a phase inverter circuit. The grids 120 and 122 respectively of these tubes are connected in parallel and to a source of voltage 118. It is assumed for the moment that the switch 158 is closed whereby the variable resistor 117 and the capacitor 119 are short-circuited. In the output circuit of tube 114 is a resistor 136 connected between the cathode and ground and a resistor 137 connected between the anode and ground. Likewise in the output circuit of tube 116 the resistor 138 is connected between the cathode and ground and a resistor 139 is connected between the anode and ground. Capacitors 144 and 144a are blocking capacitors and of substantially zero reactance at the operating frequency. The tubes 114 and 116 may be of the same type as tubes 14 and 16 described in connection with Fig. 2. The power supply voltage 140, the potentiometers 146, 150 and 152

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and their connection to the tube electrodes may be similar to corresponding circuit elements of Fig. 2 and require no further explanation.

Taking the circuits of tube 114 for example, it will be seen that for a given voltage variation on the input circuit, two voltages will appear in the output circuit, the voltages being developed across the resistors 136 and 137. These voltages have a 180° phase relation with respect to ground and may be made equal in amplitude by making the resistances 136 and 137 of substantially equal magnitude. Similarly the voltages developed across the resistors 138 and 139 in the output circuit of the tube 116 have a phase relation of 180° with respect to ground and may also be made of substantial equal magnitude.

Transmission line 160 is composed of two conductors 161 and 163. The conductor 161 is connected to the cathode 124, and the conductor 163 to the anode 128, of the tube 114. Because of the phase relation of the voltages developed across the resistors 136 and 137, the voltage appearing on the input end of conductor 161 is as much above ground potential as the voltage appearing on the input end of conductor 163 is below ground. In other words, with a given input voltage, there is a corresponding output voltage appearing across resistor 136 having the same phase relation as the input voltage and another voltage appearing across the resistor 137 which has a phase relation of 180° with respect to the input voltage; hence the term phase inverter which I have applied to the circuit shown in Fig. 4.

Similarly, transmission line 162 is composed of two conductors 165 and 167. One end of the conductor 165 is connected to the cathode 126, and one end of conductor 167 is connected to anode 130, of tube 116. It will be obvious from this circuit arrangement with the voltages between 165 and ground and that between 167 and ground bear the same phase relations as the voltages appearing between the conductor 161 and ground and conductor 163 and ground respectively. The magnitudes of all these voltages are preferably made substantially equal.

The far ends of the transmission lines 160 and 162 are connected together at a point 164 and to the input of a translating device 112.

I have illustrated a double-pole double-throw switch 169 near the far end of transmission line 160. With the switch blades 171 in the downward position, I will now proceed to discuss the operation of the circuit arrangement of Fig. 4 by referring to the vector diagram of Fig. 5. The voltage appearing across the input end of the line 160 is the sum of the voltages appearing across the resistors 136 and 137 and is represented by the vector V_c . The voltage appearing across the input end of the transmission line 162 is the sum of the voltages appearing across the resistors 138 and 139 and is represented by the vector V_k . These voltages have a 180° phase displacement.

The line 160 is assumed to be of such a length that the voltage appearing across it at the point 164 is retarded in phase with respect to the voltage V_c by the angles θ' . This output voltage is represented by the vector $V'c$. Similarly the voltage appearing on the output end of the line 162 is represented by the vector V_k' and the resultant voltage appearing at the point 164 is represented by the vector V_k' and the resultant voltage appearing at the point 164 is represented by the vector V_R .

Now if it is desired to change the phase of V_R

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so that it will be represented in phase by the vector V_s , this can be accomplished by reducing the gain of amplifier 116 such as by decreasing the voltage applied to the grid 134. Let us assume that this voltage is reduced by approximately one-half which also reduces the voltage V_k' to one-half or to the vector represented by V_k'' . The vector addition of V_k'' and $V'c$ is the vector V_s which represents the desired voltage.

Without changing the original voltage V_k , let the switch blades 171 in Fig. 4 be thrown to their upper position. This will change the voltage arriving at point 164 from the line 160 by 180° and the vector V_k will now be reversed or as shown by the vector V_R . Adding the vector V_R to the vector $V'c$ results in the vector V_s which has a phase relation of 90° with respect to the vector V_R . In other words, the reversing of the phase of one of the transmission lines has the effect of causing a phase shifting of 90° at the output end of the line. The addition of a reversing switch thus permits a wider phase variation in voltage without changing the lengths of the transmission lines.

As mentioned in connection with the description of Fig. 2, it is also possible and frequently desirable to keep the magnitude of the output voltage constant and this may be done by adjusting the potentiometer tap 148 so that the gain of both amplifiers will be increased or decreased simultaneously as the case may be. It is of course assumed that the amplifiers are linear and that a change of anode voltage will not result in any appreciable relative change of voltages across any of the resistors 136, 137, 138 and 139.

In both of the embodiments of my invention as illustrated in Figs. 2 and 4, it has been assumed that the input voltages to the grids of the two amplifier tubes are in phase. In accordance with another modification of my invention, I may change the phase of the voltage applied to one of the grids, for example, the grid 120 of tube 114 in Fig. 4, by opening switch 158 and placing in the grid circuit a parallel combination of resistance and capacitance 117 and 119. This resistance and capacitance represents a time delay circuit. The time delay may be varied by varying the resistance 117. Under these conditions the phase of the voltage appearing at the input of the line 160 is varied with respect to the phase of the voltage appearing at the input of line 162, while maintaining the magnitude of these two voltages substantially constant. Varying the phase of the voltage at the input of line 160 causes the same phase change to appear at the end of the line 160 and thereby causes a change in the resultant voltage appearing at the point 164.

In Fig. 4 I have shown portions of transmission lines 160 and 162 and the leads between certain tube electrodes and the potentiometer arrangements as dotted for the purpose of representing the fact that the controls for the amplifier tubes may be located at a distance as, for example, at the same point as is the translating device 112. With the controls so located, the phase of the voltage applied at point 164 may be controlled from the position of the translating device even though the actual controlling voltages appear in equipment remotely located as for example near a source 118. This source may be an antenna and resistance combination as illustrated, as example, in Fig. 2 by the characters 10 and 18 respectively.

While I have described above the principles of my invention, in connection with specific apparatus and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of my invention as set forth in the objects of my invention and the accompanying claims.

I claim:

1. A phase control apparatus comprising two vacuum tube amplifiers of the cathode follower type comprising an impedance element in the cathode circuit of each amplifier, each element having a given impedance value, two transmission lines of unequal lengths, one end of one transmission line being connected across one of the impedance elements, one end of the other transmission line being connected across the other of the impedance elements each transmission line having a surge impedance substantially equal to the value of the impedance element across which it is connected, a translating device, the other end of each of said transmission lines being connected to said translating device for applying a voltage thereto, and means for varying the gain of at least one of said amplifiers whereby the phase of said applied voltage is controlled.

2. A phase control apparatus comprising two vacuum tube amplifiers of the phase inverter type, impedance means in the plate-cathode circuit of each amplifier, each impedance means having an intermediate point at radio frequency ground potential, two transmission lines of unequal lengths, one end of one line being connected across one of said impedance means, one end of the other line being connected across the other of said impedance means, each line having a surge impedance substantially equal to the value of the impedance means across which it is connected, a translating device, the other end of each of said transmission lines being connected to said translating device for applying a voltage thereto, and means for varying the gain of at least one of said amplifiers whereby the phase of said applied voltage is controlled.

3. A phase control apparatus in accordance with claim 2 wherein each of said impedance means is substantially a pure resistance.

4. A phase control apparatus in accordance with claim 2 further comprising a switching means connected to one of said transmission lines whereby the phase of the voltage applied to said translator may be reversed.

5. A phase control apparatus comprising two voltage sources having a given phase relation, said sources comprising two thermionic vacuum tubes, each of said tubes having a cathode, a grid and an anode and each tube having an input circuit connected between the grid and cathode thereof and an output circuit connected between the cathode and anode thereof, two impedance elements, one of said elements being common to the input and output circuits of one of said tubes and the other element being common to the input and output circuits of the other of said tubes, power supply means connected between the anode and cathode of each of said tubes and means for exciting said input circuits whereby voltages are developed across said impedance elements having said given phase relation, two transmission lines of unequal lengths, one end of one of said lines being connected to one of said impedance elements and one end of the other line being connected to the other impedance element, each line having a surge impedance substantially equal to the impedance value of the impedance element to which it is connected, an energy translating device having an input circuit, the other end of each of said transmission lines being connected to said last mentioned input circuit for applying a voltage thereto, and means for varying the phase of said applied voltage comprising means for varying the amplitude of the voltage developed across at least one of said impedance elements.

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