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PHASE SHIFTING APPARATUS

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Fig. 1.

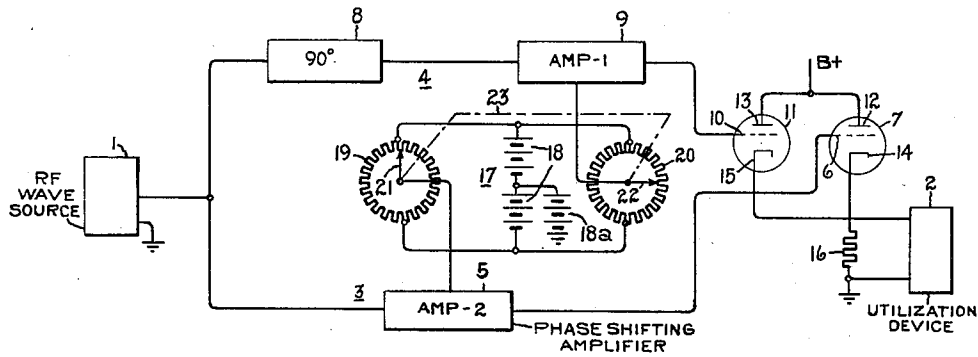
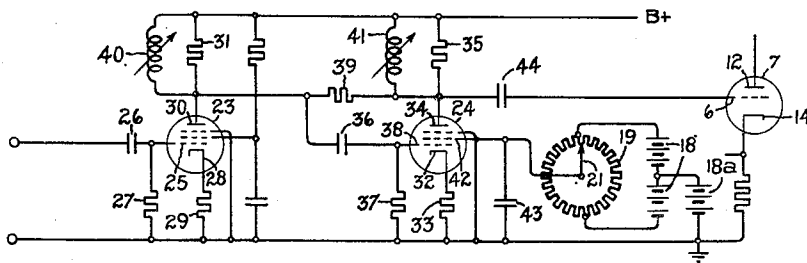


Fig. 2.



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PHASE SHIFTING APPARATUS

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9 Claims. (Cl. 323-119)

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My invention relates to phase shifting apparatus and particularly to such apparatus for use at radio frequencies.

In many types of high frequency apparatus it is necessary to provide some device for shifting the phase of signals over a wide range. This is the case, for example, in phase modulation systems. For many applications it would be desirable that such phase shifting devices be capable of operating over a range of three hundred and sixty degrees and be calibrated over that range. Furthermore, the adjustment of these phase shifting devices should not vary their input loading with variations of phase at the output. Accordingly, it is an object of my invention to provide an improved phase shifting apparatus which is suitable for operation at radio frequencies.

It is another object of my invention to provide a phase shifting apparatus including an improved arrangement for adjusting the amount of phase shift without changing the input loading of the apparatus.

It is another object of my invention to provide an improved phase shifting apparatus for securing a continuous range of phase shift of the output voltage from zero to three hundred and sixty degrees with respect to the input voltage.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 represents an embodiment of my invention and Fig. 2 is a circuit diagram of one of the phase shifting amplifiers employed in Fig. 1.

The phase shifting apparatus illustrated in Fig. 1 is arranged to provide any desired phase difference from zero to three hundred and sixty degrees between high frequency signals supplied from a source 1 and the output voltage of the apparatus impressed on a utilization device 2. The phase shifting apparatus includes two parallel branch paths 3 and 4. The path 3 includes a phase shifting amplifier 5 the output of which is impressed on a control electrode 6 of an electron discharge device 7. The path 4 includes a ninety degree phase shifting apparatus 8 and a phase shifting amplifier 9 connected to the output of the device 8 and having its output connected to a control electrode 10 of an electron discharge device 11. The electron discharge de-

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vices 7 and 11 include anodes 12 and 13, respectively, connected to a common source of direct current. The cathodes of the devices 7 and 11 indicated at 14 and 15, respectively, are connected to ground through a common output resistor 16 across which the utilization device 2 is connected.

The phase shifting amplifiers 5 and 9 have characteristics such that their output voltage may be changed from a predetermined maximum value in phase with their input through zero to a predetermined maximum value one hundred and eighty degrees out of phase with the input. By arranging two such amplifiers to supply a common output as shown in the diagram, one amplifier having its input ninety degrees out of phase with respect to the input of the other, it is possible to provide any desired phase relationship between the input signal supplied from the source 1 and the resultant output voltage across the resistance 16. The shifting of the amplitude, and thereby of the phase of the resultant output across the resistor 16 of the outputs of the two amplifiers, is effected by a biasing circuit 17 comprising a battery or other suitable direct current source 18 and two circular resistors 19 and 20 connected across the source in parallel for biasing the amplifiers 5 and 9 respectively. The normal bias of the amplifiers is provided by a battery or other source 18a connected between the midpoint of the battery 18 and ground. The resistor 19 is provided with a rotatable contactor 21 and the resistor 20 with a similar contactor 22. These contactors are movable over the circumferences of the resistors 19 and 20 and are ganged together by a suitable mechanical coupling 23 so that the phases of the outputs of the amplifiers 5 and 9 are simultaneously adjusted in such a manner as to provide a continuous phase shift from zero to three hundred and sixty degrees as the device 23 is adjusted over its range. It will be observed that the amplifier control voltage is increased as contactor 21 or 22 moves upward from either horizontal position, and that it is decreased as the contactor moves downward from such position.

It will be understood that the adjustment of the two resistors 19 and 20 is determined by the amplitudes of the outputs of the two amplifiers 5 and 9 which are necessary to provide the required resultant for any desired output of the apparatus across the resistance 16. It will be evident, for example, that the output of one of the amplifiers 5 and 9 must be at a maximum value whenever the output of the other is at zero.

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Thus, as shown in Fig. 1, the contactors 21 and 22 are mechanically maintained at positions 90 degrees from each other on the circular resistors 19 and 20, respectively. In the particular contactor positions illustrated, contactor 21 has maximum control voltage applied thereto with respect to ground, while contactor 22 has only the normal voltage of battery 18a applied thereto. If contactors 21 and 22 are now rotated 90 degrees clockwise, contactor 21 will have only the normal voltage and contactor 22 will have maximum control voltage; and so on. The mechanical ganging device necessary to secure this operation forms no part of the present invention and in order to avoid complication of the drawing the details of such device have not been illustrated.

It will readily be understood by those skilled in the art that a gain control device may be desirable to secure amplitude correction and that such correction may be applied to the first electron discharge device in each of the amplifiers 5 and 9.

The manner in which the amplifiers 5 and 9 operate to provide the characteristic described above will be understood in the following description of the circuit of the amplifier 5 as illustrated in Fig. 2, it being understood that the amplifier 9 is of the same construction. The amplifier 5 includes first and second stage electron discharge devices 23 and 24, respectively. The input signal from the source 1 is impressed on a control electrode 25 of the device 23 through a coupling capacitor 26 and across a grid resistance 27. Electron discharge device 23 includes a cathode 28 connected to ground through a biasing resistor 29 and an anode 30 connected to a suitable source of direct current through a resistance 31. The device 24 similarly includes a cathode 32, a biasing resistor 33 and an anode 34 connected to the source through a resistance 35. The output of the device 23 is coupled through a capacitor 36 and across a resistance 37 to a control electrode 38 of the device 24. In order to secure the required characteristic, a feedback path is provided between the anode 34 of the device 24 and the control electrode 38, this path comprising a resistance 39 connected between the anode 34 and the anode 30.

It will be recognized that this circuit provides negative or degenerative feedback and it can be shown that, if the feedback and plate resistors are designed so that they constitute a pure resistance and are not frequency responsive, the overall gain of the amplifier is proportional to the quantity

$$\left(1 - \frac{1}{g_{m2}R_F}\right)$$

where g_{m2} is the mutual conductance of the second stage electron discharge device and R_F is the value feedback resistor. At the higher frequencies it may be found necessary to employ tuned reactors 40 and 41 across the resistances 31 and 35 to neutralize distributed capacity in order to secure a pure resistance characteristic.

It will be seen from the above relationship that for a given feedback resistance, the output of the amplifier will be zero when

$$g_{m2} = \frac{1}{R_F}$$

Considered another way, the output signal voltage at the connection joint between anode 34 and load resistor 35 will be zero when the forward

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voltage gain through stage 23 and resistor 39 to this point is exactly balanced by the backward, or negative, voltage gain through stage 24 to this point. Thus, the over-all amplifier gain may be made zero at a finite value of mutual conductance g_{m2} of the second stage 24; and the over-all gain may be increased either in-phase or out-of-phase with the input voltage by varying g_{m2} from this value. By increasing g_{m2} the output voltage increases in amplitude in phase with the input, and by decreasing g_{m2} the output voltage is made to increase in amplitude one hundred and eighty degrees out of phase with the input voltage. The adjustment of the mutual conductance of the second stage electron discharge device 24 to effect this variation in amplitude and phase may be accomplished, for example, by adjusting the bias of a screen electrode or grid 42. The resistance 19 has been shown connected across a by-pass capacitor 43. As the contactor 21 is shifted over the resistor 19, the direct current bias on the electron discharge device 24 is changed to vary the mutual conductance of the device and thereby selectively adjust the phase and amplitude of the output voltage. The output of the amplifier shown in Fig. 2 is coupled to the control electrode 6 of the output device 7 through a capacitor 44.

When the circuits of the amplifiers 5 and 9 are arranged as shown in Fig. 2 to provide the characteristic just described, the phase of the output voltage may be varied by adjusting the biasing resistors 19 and 20 without change in the loading of the input circuits of the amplifier, and the phase of the output voltage across the resistance 16 of the phase shifting apparatus may be adjusted through its entire range without variation of the loading of the input circuit of the apparatus.

From the foregoing, it is readily apparent that I have provided a simple and easily adjusted phase shifting apparatus for securing differences in phase between the output and input voltages over a range of three hundred and sixty degrees. Furthermore, since the characteristics of the phase shifting amplifiers are secured by providing circuits which are substantially purely resistive, the phase shifting apparatus may be operated over a wide range of frequencies.

While I have described a specific embodiment of my invention, other arrangements will occur to those skilled in the art. I do not, therefore, desire my invention to be limited to the particular construction illustrated and described and I intend by the appended claims to cover all embodiments within the spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said apparatus, means for impressing the wave energy on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, the second stage of each of said amplifiers comprising an electron discharge device having an anode and a cathode and a control electrode, a feedback network between said anode and said control electrode, individual gain control means for varying the mutual conductance of each of said devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with the input voltage through zero to a maximum value one hundred and eighty degrees out

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of phase with the input voltage, a common uni-control means for simultaneously varying the adjustments of both said gain control means in a predetermined manner, the output voltage of either amplifier being zero when the output of other amplifier is a maximum, and means for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus.

2. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said apparatus, means for impressing the wave energy on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, each of said amplifiers comprising first and second stage electron discharge devices, each of said devices having an anode and a cathode and a control electrode, a feedback resistance connected between the anodes of the first and second stage devices of each amplifier, means comprising an adjustable source of unidirectional control potential for individually varying the mutual conductance of each of said second stage devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with its input voltage through zero to a maximum value one hundred and eighty degrees out of phase with its input voltage, a common uni-control means for said sources for simultaneously varying said control potentials in a predetermined manner, the output voltage of either of said amplifiers being zero when the other is a maximum, and means for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus.

3. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said apparatus, means for impressing the wave energy on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, each of said amplifiers comprising first and second stage electron discharge devices, each of said devices having an anode and a cathode and a control electrode, a feedback resistance connected between the anodes of the first and second stage devices of each amplifier, each of said second stage devices having a second control electrode, means including a source of direct current for biasing each of said second control electrodes, individual gain control means for changing the bias on each of said second control electrodes for varying the mutual conductance of each of said second stage devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with its input voltage through zero to a maximum value one hundred and eighty degrees out of phase with its input voltage, a common uni-control means for simultaneously varying the adjustments of both said gain control means in a predetermined manner, the output voltage of either amplifier being zero when the output of the other amplifier is a maximum, and means for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus.

4. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said appa-

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ratus, means for impressing the wave energy on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, the second stage of each of said amplifiers comprising an electron discharge device having an anode and a cathode and a control electrode, a feedback network between said anode and said control electrode, individual gain control means for varying the mutual conductance of each of said devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with the input voltage through zero to a maximum value one hundred and eighty degrees out of phase with the input voltage, a common uni-control means for simultaneously varying the adjustments of both said gain control means in a predetermined manner, the output voltage of either amplifier being zero when the output of the other amplifier is a maximum, means including two additional electron discharge devices for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus, each of said additional devices having an anode and a cathode and a control electrode, one of said additional devices having its control electrode connected to the output of said one amplifier and the other of said additional devices having its control electrode connected to the output of said other amplifier, and an output load impedance element common to the anode-to-cathode circuits of said additional devices.

5. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said apparatus, means for impressing the wave energy on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, each of said amplifiers comprising first and second stage electron discharge devices, each of said devices having an anode and a cathode and a control electrode, a feedback resistance connected between the anodes of said first and second stage devices of each amplifier, the over-all characteristic of each of said amplifiers being such that the gain thereof is proportional to

$$1 - \frac{1}{g_{m2}R}$$

where g_{m2} is the mutual conductance of the second stage device and R is the feedback resistance, means comprising a gain control potentiometer for individually varying the mutual conductance of each of said second stage devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with the input voltage through zero to a maximum value one hundred and eighty degrees out of phase with the input voltage, a common uni-control means for simultaneously varying both of said potentiometers so as to vary said mutual conductances in a predetermined manner, the output voltage of either of said amplifiers being zero when the other is a maximum, and means for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus.

6. A phase shifting apparatus comprising a pair of two-stage electronic amplifiers, means for applying wave energy to the input of said apparatus, means for impressing the wave energy

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on the input of one of said amplifiers in phase and on the input of the other of said amplifiers ninety degrees out of phase, each of said amplifiers comprising first and second stage electron discharge devices, each of said devices having an anode and a cathode and a control electrode, a feedback resistance connected between the anodes of said first and second stage devices of each amplifier, the overall characteristic of each of said amplifiers being such that the gain thereof is proportional to

$$1 - \frac{1}{g_{m2}R}$$

where g_{m2} is the mutual conductance of the second stage device and R is the feedback resistance, means including second control electrodes for said second stage devices and adjustable biasing means therefor for individually varying the mutual conductance of each of said second stage devices, whereby the output voltage of each amplifier may be varied in amplitude from a maximum value in phase with its input voltage through zero to a maximum value one hundred and eighty degrees out of phase with its input voltage, a common uni-control means for simultaneously adjusting both of said biasing means, in a predetermined manner, the output of either amplifier being zero when the other is a maximum, and means for combining the outputs of said amplifiers to secure a resultant output voltage of any desired phase difference with respect to the input voltage of said apparatus.

7. A phase shifting apparatus comprising a source of waves to be shifted over a given phase range, a pair of electron discharge devices each having an input and an output circuit, means for applying said waves to the input and output circuits of one of said devices with a reference phase and to the input and output circuits of the other of said devices with a different phase, separate non-frequency selective feedback circuits coupled between the input and output circuits of each of said devices, separate means for varying the

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mutual conductance of each device, and a common non-frequency selective load circuit for combining the resultant of the waves developed in the output circuits of said devices.

8. An arrangement according to claim 7 wherein said phase difference is substantially 90 electrical degrees and means for adjusting said varying means simultaneously to effect a predetermined phase change pattern.

9. Apparatus for phase shifting waves from a given source over a given phase range, comprising a pair of electron discharge devices each having an input and an output circuit, means for applying said waves to the input and output circuits of one of said devices with a reference phase, means for applying said waves to the input and output circuits of the other of said devices with a different phase other than integral multiples of 90°, individual feedback circuits coupled between the input and output circuits of each of said devices, separate means for varying the mutual conductance of each of said devices, and means for combining the resultant of the waves developed in the output circuits of said devices.

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