April 23, 1957 A. C. ARMSTRONG ET AL 2,790,147

REACTANCE TUBE CIRCUITRY

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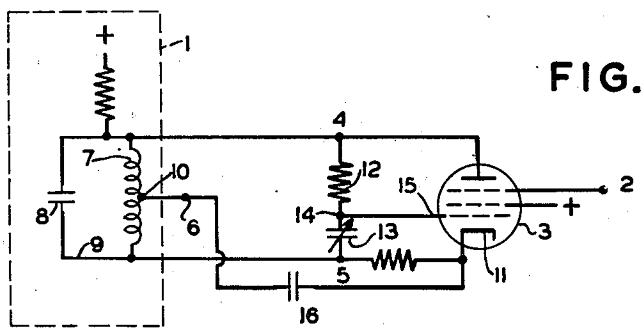

FIG. 1

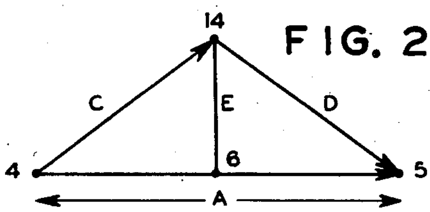

FIG. 2A

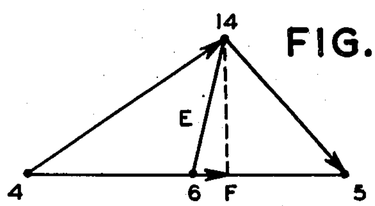

FIG. 2B

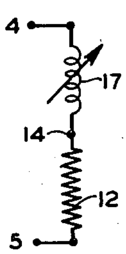

FIG. 3A

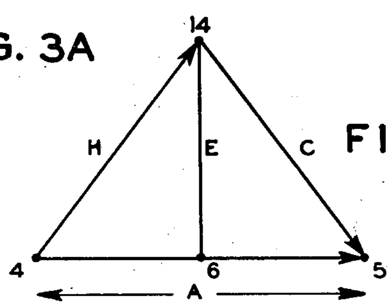

FIG. 3B

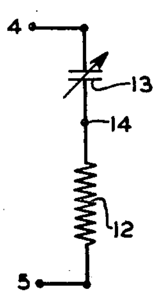

FIG 4A

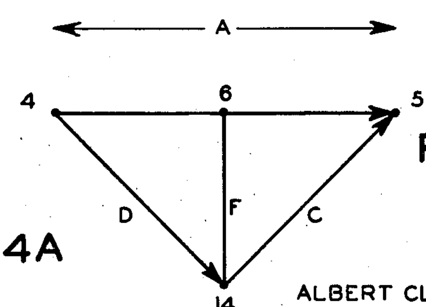

FIG. 4B

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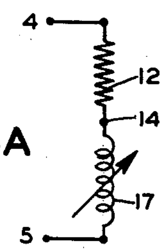

FIG. 5A

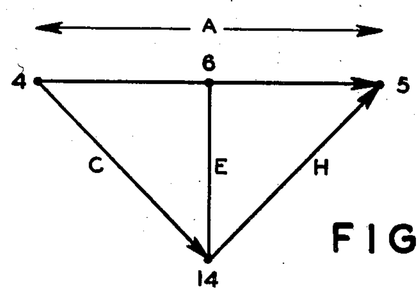

FIG. 5B

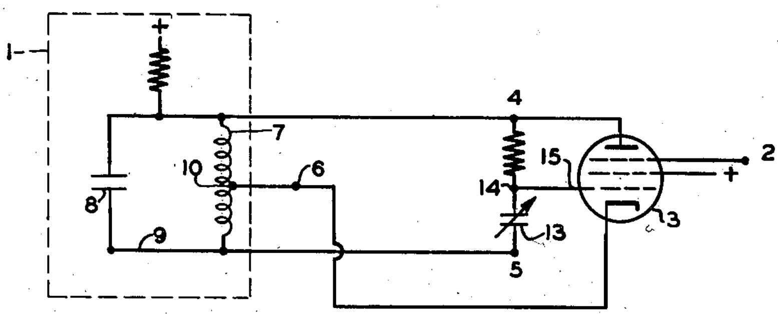

FIG. 6

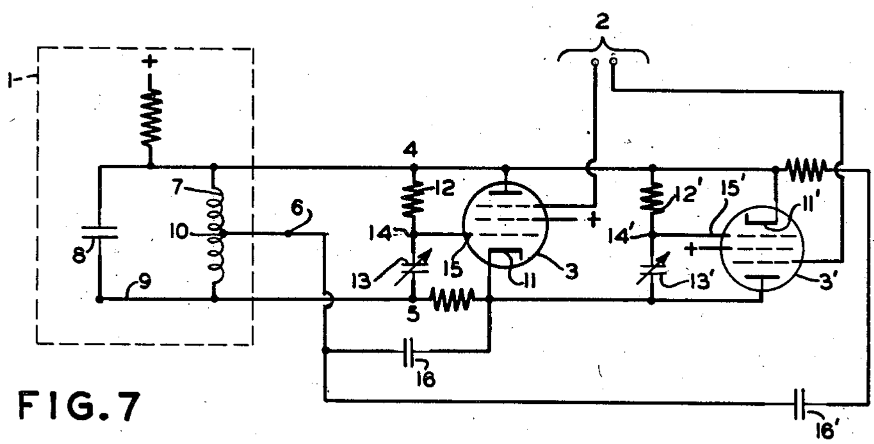

FIG. 7

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FIG. 8

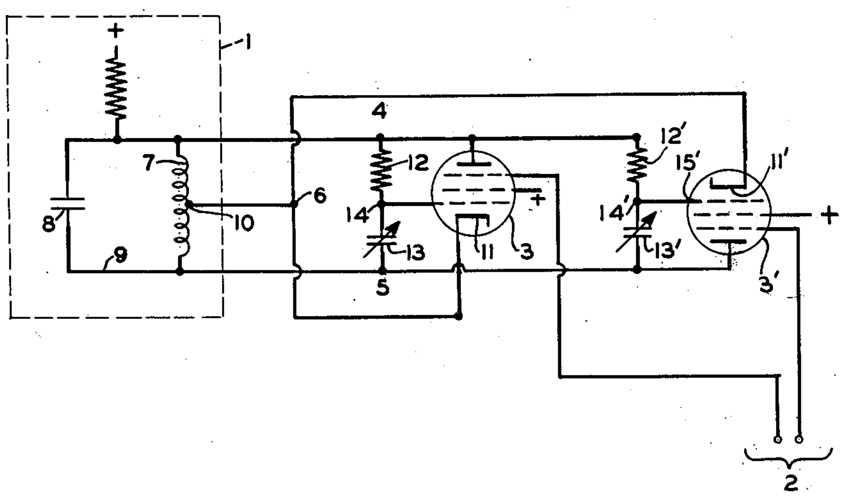
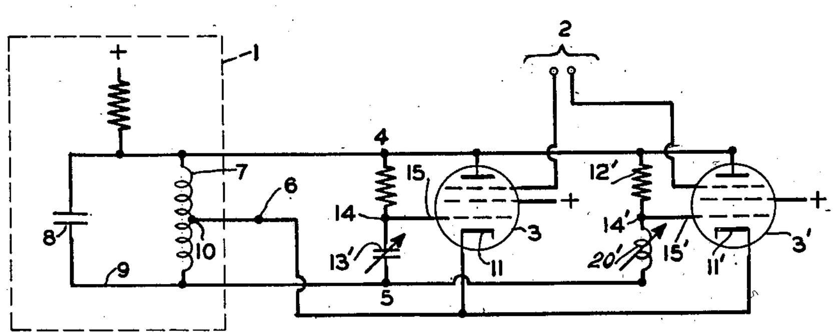


FIG. 9



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REACTANCE TUBE CIRCUITRY

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Application October 23, 1953, Serial No. 387,868

16 Claims. (Cl. 332—28)

Our invention relates to oscillator frequency modulation apparatus and more particularly relates to reactance tube circuitry for use with such apparatus.

In many electronic applications, it is necessary to shift the frequency of an oscillator above and below its natural or central frequency in accordance with the instantaneous value of an incoming modulating signal. One method of doing this is to vary the reactance of the oscillator tank circuit, thus changing the oscillator frequency. Another method is to inject a variable current into the tank circuit which is in phase with the current in a selected reactive element within the tank while maintaining the voltage across the tank substantially constant. While the injection method does not physically change the reactance values within the tank, it produces the same effect by changing the apparent reactance values, thus changing the resonant frequency of the tank accordingly.

It is conventional to use a reactance tube as a current injection device. The reactance tube, which is generally a pentode, is connected so that its plate-cathode circuit shunts the tank circuit of the oscillator. A phase shifting network consisting of a resistor and capacitor connected in series also shunts the tank circuit, and the junction of this resistor and capacitor is connected to a first control grid of the tube. The relative values of the resistor and capacitor are chosen so that the voltage at this grid is shifted almost 90° with respect to the voltage on the plate. An incoming modulating signal is supplied to the second control grid and changes the plate current of the tube accordingly. By virtue of the phase shifting network, the plate current is maintained substantially in quadrature with the plate voltage and this quadrature current can be injected into the tank circuit in the manner outlined in the preceding paragraph.

However, this reactance tube circuit has serious disadvantages. Since the phase shifting network described above must contain some appreciable resistance and since the capacitor itself must have some resistance, the phase shift between the first grid and plate must always be less than 90°. Consequently, there is a real component of voltage appearing at the first grid which introduces a plate current component which is in phase with the plate voltage. This component when injected into the tank circuit, acts as an apparent resistance which changes the Q of the tank and causes amplitude modulation of the frequency modulated output signal from the oscillator.

Moreover, since the reactance of the phase shifting network must vary with frequency, the phase shift between the first grid and the plate is variable, and the magnitude of the voltage which is fed back from the plate to the grid is variable so that the value of the apparent resistance is continuously changing; consequently, the percentage of amplitude modulation is not fixed but is continuously variable.

Since this amplitude modulation not only modifies the

power distribution in the side bands of the oscillator output signal but also causes distortion in the modulation on the carrier, it is highly desirable to prevent such amplitude modulation from appearing.

We have invented an improved reactance tube arrangement which substantially eliminates the effects of this apparent resistance and thus prevents the undesirable amplitude modulation.

Accordingly, it is an object of the present invention to provide improved reactance tube circuitry of the character indicated.

Another object is to provide improved reactance tube circuitry in which the tube grid-plate phase shift is adjustable and can be set to exactly 90° at any frequency.

Still another object is to provide improved reactance tube circuitry which includes an adjustable phase shifting network capable of providing a tube grid-plate phase shift in excess of 90°.

Yet another object is to provide improved reactance tube circuitry which includes a phase shifting network capable of delivering a feedback voltage to the grid of the tube whose magnitude is independent of frequency.

A further object is to provide improved reactance tube circuitry which employs a single-ended reactance tube.

Still another object is to provide improved reactance tube circuitry which employs a balance push-pull reactance tube arrangement.

These and other objects of the invention will be explained or will become apparent to those skilled in the art when this specification is read in conjunction with the accompanying drawings wherein:

Figure 1 shows a single-ended reactance tube circuit which illustrates one form of the invention;

Figures 2A and 2B are vector diagrams of the voltage relationships established by the circuit shown in Figure 1;

Figures 3A and 3B show respectively a first variant of the circuit shown in Figure 1 and a vector diagram for the first variant;

Figures 4A and 4B show respectively a second variant of the circuit shown in Figure 1 and a vector diagram for the second variant;

Figures 5A and 5B show respectively a third variant of the circuit shown in Figure 1 and a vector diagram for the third variant;

Figure 6 shows a fourth variant of the circuit shown in Figure 1;

Figure 7 shows a push-pull reactance tube circuit which illustrates a second form of the invention;

Figure 8 shows a variant of the circuit shown in Figure 7; and

Figure 9 shows a push-push reactance tube circuit which illustrates a third form of the invention.

Briefly stated, our invention contemplates an oscillator having a frequency determining tank circuit including a capacitance shunted by an inductance. A network including resistance and reactance elements connected in series is connected across the inductance. We provide a reactance tube, which preferably is a pentode but which may be any high vacuum tube having at least one control grid, whose anode-cathode circuit is connected across the inductance. The control grid-cathode circuit of the tube is connected between the junction of the elements in the network and a point on the inductance which is intermediate to the ends. By virtue of this arrangement, and by suitably choosing the values of the reactance and resistance elements, it is possible to adjust the grid-plate phase shift to exactly 90° for any one oscillator frequency.

In addition, the properties of the phase shift network are such that the magnitude of the voltage feedback for the plate to the grid remains substantially constant and is independent of frequency.

The incoming modulating signal which is to modulate the frequency of the oscillator output signal may be applied either to the control grid or another grid. This single tube arrangement greatly reduces the magnitude of the apparent resistance injected into the tank circuit.

In order to obtain substantially complete cancellation of this injected resistance as well as to obtain additional circuit stability and sensitivity, we provide a second reactance tube whose plate-cathode circuit is in push-pull or push-push connection with the corresponding circuit of the first tube and whose control grid-cathode circuit is connected to a second network shunting the tank circuit. In this situation, the modulating signal is fed in push-pull to both tubes. The effect of this arrangement is to cause one tube to inject a positive resistance component into the tank while the other tube injects an equal but negative component into the tank; these components virtually cancel each other.

Referring to Figure 1, an incoming modulating signal subject to frequency variations is applied to a grid 2 of electric discharge means which may be a pentode 3. The anode-cathode circuit of this valve is connected between terminals 4 and 5 which are in turn connected to opposite ends of an inductance 7. Inductance 7 shunts capacity 8 to form resonant circuit 9 therewith. This circuit is the tank circuit of a conventional oscillator 1.

The midpoint 10 on inductance 7 is connected through terminal 6 and capacitor 16 to the cathode 11 of valve 3. The series combination of a fixed resistor 12 and a variable capacitor 13 is connected bewteen terminals 4 and 5. The junction 14 of resistor 12 and capacitor 13 may be connected to grid 2 of valve 3 but, in this example, is connected to grid 15.

In order to understand the operation of this circuit arrangement, it will be necessary to refer to the vector diagram shown in Figure 2A. The voltage developed across inductance 7 appears between terminals 4 and 5 and is identified as voltage A. The voltage produced across the terminal 4 and 6 is in phase with voltage A and is equal in magnitude to one half this voltage; this produced voltage is identified as voltage B. The sum of the voltages developed between terminals 4 and 14 (the voltage across resistor 12 identified as voltage C) and terminals 14 and 5 (the voltage across capacitor 13 identified as voltage D) must be equal to voltage A. Therefore, voltages A, C and D form a closed triangle. The voltage developed between terminal 14 and 6 is the feedback voltage applied between the grid 15 and cathode 11 of valve 3 and is identified as voltage E.

It will be apparent that if capacitor 13 is adjusted to have a reactance equal to the resistance of resistor 12 at the central frequency of oscillator 1, voltages C and D will be equal in magnitude and voltage E will be exactly 90° out of phase with voltage A. In other words, the feedback voltage applied between grid 15 and cathode 11 is exactly 90° out of phase with the plate voltage of valve 3. By adjusting capacitor 13 it is, of course, possible to adjust this phase angle in either direction about 90°.

Therefore, when the oscillator is operating at its central frequency, the phase shift is exactly 90°, and no resistive component is injected into tank circuit 9.

When a modulating signal is supplied to grid 2, an apparent reactance is introduced into tank circuit 9 and its resonant frequency is changed. Consequently, the reactance of capacitor 13 also changes, and voltage C and D are no longer equal. However, as will be seen from Figures 2A and 2B, the magnitude of voltage E does not change with frequency, since voltage E is a vector which represents the radius of a circle centered at teminal 6 and having a circumference extending through terminal 4, 5 and 14.

As the capacitor reactance changes with frequency, however, the phase angle between voltages E and A is no longer 90° but is shifted to a somewhat larger or smaller angle depending on the direction in which the oscillator frequency is shifted. As this angle varies from 90°, a small component of voltage E is developed which is either in phase or opposed in phase with voltage A and is capable of introducing a resistive component into circuit 9.

Figure 2B shows the relationships between voltages when the frequency of oscillator 1 is increased beyond its central frequency. The reactance of capacitor 13 decreases, so that the magnitude of voltage D decreases. When voltage A is constant, as in this case, the sum of voltage C and D remains constant, so that voltage C increases. Consequently, the phase angle between voltage E and voltage A is decreased; and voltage F, which is a component of voltage E, is developed which is in phase with voltage A. The resistance component thus introduced is negative.

If the oscillator frequency were decreased below the central frequency, the phase angle would be larger than 90°, voltage component F would be in phase opposition with voltage A, and the resistive component is positive.

In either situation, however, the resistance component is much reduced as compared to prior systems of this kind. For example, the magnitude of the voltage fed back from the plate to the grid is maintained substantially constant so that this voltage does not introduce a variable resistance component into the tank circuit. Moreover, the range of variation of the resistive component with oscillator frequency is much less than prior systems due to the elimination of this component at the oscillator central frequency.

If the phase shifting network connected across terminals 4 and 5 of Figure 1 is replaced by the network shown in Figure 3A which includes variable inductance 17 and resistance 12 in series connection, the operation of the arrangement of Figure 1 will be exactly the same as will be seen from the vector diagram shown in Figure 3B.

In Figure 3B, H represents the voltage across the inductance 17 and all other voltages are identified in the same manner as before. Since the reactance of an inductance increases with increasing frequency, the vector diagrams shown in Figure 2B and Figure 3B are equivalent and result in the same type of circuit operation.

If the phase shifting network connected across terminals 4 and 5 of Figure 1 is rearranged as shown in Figure 4A, the circuit will operate as before except that the resistance component is positive when the oscillator frequency exceeds the central frequency and is negative when the oscillator frequency falls below the central frequency. Figure 4B shows the vector relationships established by this rearrangement.

Another form of the phase shifting network is shown in Figure 5A and includes resistance 12 and variable inductance 17 in serial connection. The resulting vector diagram is shown in Figure 5B. Comparison of Figures 4B and 5B will show that these two diagrams are equivalent and result in the same type of circuit operation.

Figure 6 shows a slightly different arrangement of Figure 1 wherein the tube 3 does not shunt the entire tank, but rather only shunts the section of inductance 7 included between terminals 4 and 6. The coefficient of coupling between the shunted and unshunted sections of inductance 7 is chosen to be substantially unity. Consequently, the effect of tube 3 is reflected from the shunted section into the unshunted section, and the circuit operation is identical with that shown in Figure 1.

As will be apparent from the foregoing discussion, our single reactance tube arrangement greatly reduces the magnitude of the resistive component and therefore reduces the undesirable amplitude modulation in like manner.

In order to substantially eliminate this component, it is necessary to use two tubes so connected that the resistive components introduced by these tubes cancel each other.

Figure 7 shows one such arrangement. Valve 3 and its associated phase shifting network are connected across the tank circuit 9 in like manner to the connection shown in Figure 1. Valve 3 has its anode-cathode circuit connected across the tank in reverse sense with respect to valve 3'. A second network consisting of resistance 12' and variable capacitor 13' is connected between terminals 4 and 5, and the junction 14' of this resistance and capacitor is connected to the control grid 15' of valve 3'. The incoming modulating signal is applied in push-pull across terminals 2 to drive valves 3 and 3' accordingly,

Capacitors 13 and 13' are adjusted so that the grid-plate phase shift for each valve is set for 90° at the oscillator central frequency. Consequently, the control grids of these two valves are effectively in parallel. (The two networks which include respective resistances 12 and 12' and respective capacitors 13 and 13' are required because of the variation in valve characteristics. In the event that both valves had identical characteristics, only one network would be required.)

The vectorial relationships of the voltages applied to valve 3 are shown in Figure 2A. The relationships of the voltages applied to valve 3' are the same except that the voltage A is reversed in direction due to the 180° phase shift between the plate voltages of these valves.

It will be apparent that as the oscillator frequency is shifted to either side of the central frequency, one valve injects a positive apparent resistance into the tank circuit while the other valve injects a negative apparent resistance into this circuit. Since the magnitudes of these apparent resistances are approximately equal, the desired cancellation takes place.

Moreover, by virtue of the push-pull operation, the direct current drifts of the two valves substantially cancel each other, reducing central frequency drift; the effects of changes in operating voltages are substantially reduced; and the oscillator frequency shift for a given change in the modulating signal is sharply increased.

Figure 8 shows a slightly different arrangement of Figure 7. Valve 3 is connected across one half of inductance 7 while valve 3' is connected in reverse sense across the other half of this inductance. Due to the very high coefficient of coupling between both halves of the inductance, the apparent resistance injected into one half section is reflected into the other half section and again cancellation takes place.

From consideration of Figures 2, 3 and 4, it will be seen that it is possible to drive the control grids of valves 3 and 3' in push-pull and connect the anode-cathode circuits of these valves in push-push; cancellation will then take place as before.

Figure 9 shows one such arrangement. The plate-cathode circuits of both valves are connected in parallel. The control grid of valve is connected to the junction 14 of resistance 12 and variable capacitor 13'. The control grid of valve 11' is connected to the junction 14' of resistance 12' and variable inductance 20'.

The vectorial relationships for valves 3 and 3' are shown in Figure 2A and Figure 5B respectively. It will be seen from these figures that the desired cancellation must occur.

While we have shown and pointed out and described the fundamental novel features of the invention as applied to preferred embodiments, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. It is our intention therefore, to be limited only as indicated by the scope of the following claims.

We claim:

1. In combination, an inductance; a network connected across said inductance and including in serial connection a resistance element and a reactance element; and an electric discharge valve provided with anode, cathode and control grid electrodes, one of said cathode and grid electrodes being coupled to the junction of said elements, the other of said cathode and grid electrodes being coupled to said inductance at a point intermediate the ends thereof, the anode-cathode discharge path of said valve shunting said inductance.

2. In combination, an inductance; a network shunting said inductance and including in series connection a resistance element and a reactance element; an electric discharge valve provided with anode, cathode and control grid electrodes and circuits therefor; means connecting the anode-cathode circuit of said valve across said inductance; and means coupling the grid-cathode electrode circuit of said valve between the junction of said elements and a point on said inductance intermediate its ends.

3. The combination as set forth in claim 2 wherein said reactance element is a capacitance.

4. The combination as set forth in claim 2 wherein said junction is coupled to said control grid and said inductance point is coupled to said cathode.

5. The combination as set forth in claim 2 wherein said inductance point is the inductance midpoint.

6. The combination as set forth in claim 2 wherein said reactance element is an inductance.

7. In combination with an oscillator provided with a tank circuit including in parallel connection an inductance and a capacitance, a reactance tube device responsive to an incoming control signal and comprising an electric discharge valve provided with an anode, a cathode and first and second control grids; means connecting the valve discharge path across said inductance; a network including a resistive and a capacitive element in series connection; means connecting said network across said inductance; means coupling said first grid to the junction of said elements; means coupling said cathode to said inductance at its midpoint; and means to supply said control signal to said second control grid.

8. The combination as set forth in claim 6 wherein one element in said network is variable.

9. In combination, an inductance; a network shunting said inductance and including in series connection a resistance element and a reactance element; an electric discharge valve provided with anode, cathode and control grid electrodes and circuits therefor; means connecting the anode-cathode circuit of said valve across a section of said inductance; and means coupling said control grid to the junction of said elements.

10. In combination with an inductance, first and second electric discharge devices, each device being provided with anode, cathode and control electrodes and circuits therefor, the anode-cathode circuits of said devices being connected across said inductance in push-pull connection, a network including in series a resistance and a reactance, said network shunting said inductance, and means coupling the grid-cathode electrode circuit of each device between the junction of said resistance and a point on said inductance intermediate the ends thereof.

11. In combination with an inductance, first and second electric discharge devices, each device being provided with anode, cathode and control electrodes and circuits therefor, the anode-cathode circuits of said devices being connected across said inductance in push-pull connection; first and second networks, each network being connected across said inductance and including in series a resistance element and a reactance element; means coupling the grid-cathode electrode circuit of said first device between the junction of said elements in said first network and a first joint on said inductance intermediate the ends thereof; and means coupling the grid-cathode electrode circuit of said second device between the junction of said elements in said second network and a second intermediate point on said inductance.

12. Apparatus for varying the resonant frequency of a tank circuit in accordance with an incoming signal,

said tank circuit including an inductance shunted by a capacitance, said apparatus comprising first and second electric discharge devices, each device provided with an anode, a cathode, and first and second control grids and circuits therefor; means connecting the anode-cathode circuits of both devices in push-pull across said inductance; first and second networks connected in parallel with each other and with said inductance, each network including resistance and capacitance elements in series connection, one of said elements being variable; means coupling the cathodes of both devices to the midpoint of said inductance; means coupling the first grid of said first device to the junction of said elements in said first network and coupling the first grid of said second device to the junction of said elements in said second network; and means to apply said incoming signal in push-pull to the second control grids of both devices.

13. In combination, an electrically closed loop including in serial connection in the order named first and second inductances, a resistor and a capacitor, said loop further including first and second output terminals respectively connected to the junction of said inductances and the junction of said resistor and capacitor, and first and second input terminals respectively connected to the ends of said first and second inductances remote from the junction thereof; and an electric discharge valve provided with anode, cathode, and control grid electrodes and circuits therefor, the anode-cathode circuit being connected between said input electrodes, the grid-cathode electrode circuit being connected between said output electrodes.

14. In combination with an inductance provided with a terminal point intermediate its ends, first and second electric discharge devices, each device being provided with anode, cathode and control grid electrodes and circuits therefor, the anode-cathode circuit of said first device being coupled between one end of said inductance and said terminal point, the anode-cathode circuit of said second device being coupled between the other end of said inductance and said terminal point, the anode-cathode circuits of said devices being connected in reverse

sense, a network including in series a resistance and a reactance, said network shunting said inductance, and means coupling the control grids of both devices to the junction of said resistance and reactance.

15. In combination with an inductance, first and second electric discharge devices, each device being provided with anode, cathode and control grid electrodes and circuits therefor, the anode-cathode circuits of said devices being connected across corresponding half sections of said inductance in push-pull connection; first and second networks, each network being connected across said inductance and including in series a resistance element and a reactance element; means coupling the control grid of said first device to the junction of said elements in said first network; and means coupling the control grid of said second device to the junction of said elements in said second network.

16. In combination with an inductance, first and second electric discharge valves, each valve being provided with anode, cathode and control electrodes and circuits therefor, the anode-cathode circuits of each valve being connected in parallel across a section of said inductance; first and second networks connected in parallel across said inductance, said first network including a resistance element and a capacitance element in serial connection, said second network including a resistance element and an inductance element in series connection; means coupling the grid of said first valve to the junction of said elements in said first network; and means coupling the grid of said second valve to the junction of said elements in said second network.

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