April 21, 1942.　　W. VAN B. ROBERTS　　2,280,606

ELECTRONIC REACTANCE CIRCUITS

Filed Jan. 26, 1940

Fig. 1

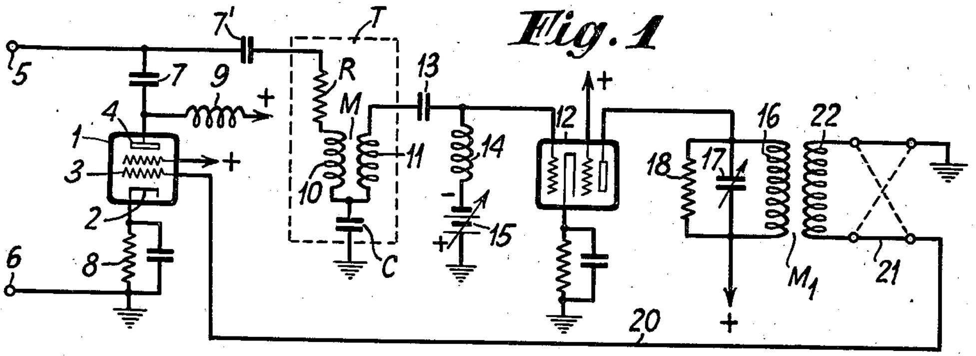


Fig. 2

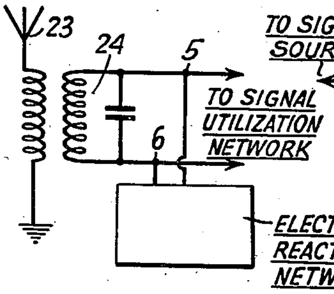


Fig. 3

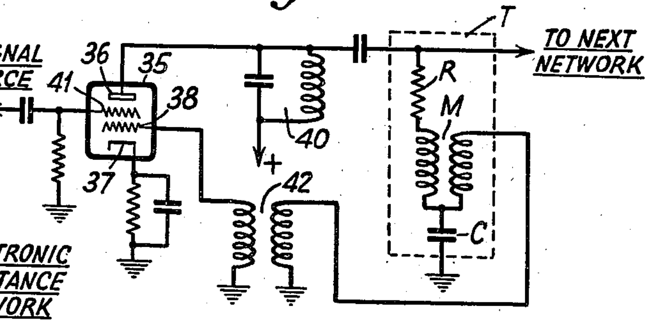


Fig. 4

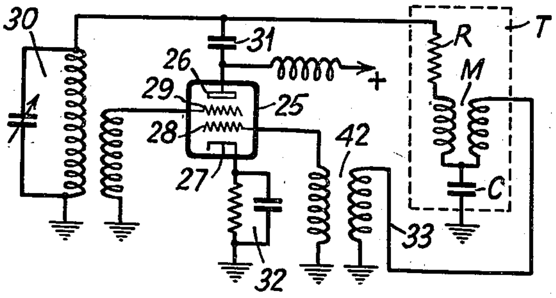
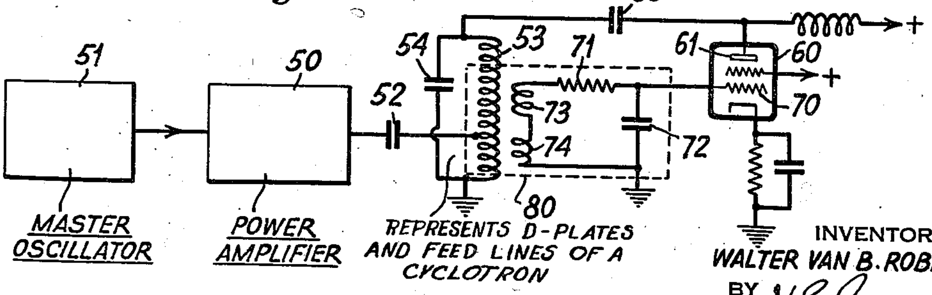


Fig. 5



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ELECTRONIC REACTANCE CIRCUITS

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7 Claims. (Cl. 250—40)

My present invention relates to electronic reactance simulation circuits, and more especially to circuits so arranged as to present to an applied voltage a reactance whose magnitude and sign are both determined by the frequency of the applied voltage.

One of the main objects of my invention is to alter the effective constants of an oscillatory circuit so that either a reduction or an increase occurs in the rapidity with which circuit phenomena vary with frequency.

Another important object is to provide an oscillation generator whose frequency is rendered substantially independent of variations in its constants, by the automatic application of compensation to its constants by means of the electronic reactance to be hereinafter described.

Another object of the invention is to maintain a circuit in a resonant condition to provide a large resonant voltage rise over a large range of frequencies, thereby making possible an amplifier stage having high gain and, at the same time, increased band width.

Still another object is to provide an electronic reactance network constructed and arranged to simulate inductive and capacity effects in dependence on the direction of frequency shift of energy from a predetermined frequency value.

Still other objects of my invention are to improve generally the efficiency and reliability of electronic reactance circuits, and more particularly to provide such reactance circuits in an economical manner.

The novel features which I believe to be characteristic of my invention are set forth in particularly in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 is a circuit diagram of an electronic reactance circuit employing the invention,

Fig. 2 shows a use of the reactance circuit,

Fig. 3 shows a signal amplifier embodying the invention, the amplifier functioning as part of the reactance circuit,

Fig. 4 shows an oscillation generator circuit whose tube functions as part of the reactance simulation network,

Fig. 5 shows the reactance circuit embodied in an amplifier for tuning stabilization.

Referring now to the accompanying drawing, wherein like reference characters in the different figures designate similar circuit elements, in Fig. 1 there is shown a tube **1** having a cathode **2**, a control grid **3** and a plate **4**. The alternating voltage input terminals are **5** and **6**, terminal **5** being connected to plate **4** through a direct current blocking condenser **7**. The cathode **2** is connected to ground through the usual bypassed grid bias resistor **8**, and the input terminal **6** is connected to ground. The positive voltage for the plate **4** is supplied through a radio frequency choke coil **9**, and a positive screen grid may preferably be employed adjacent the plate **4**. The dotted rectangle T designates an impedance network which is composed of a resistor R arranged in series with the primary winding **10** of a transformer M.

One end of the resistor R is connected to the input terminal **5** through the direct current blocking condenser **7'**. The secondary winding **11** of transformer M has one end connected to the low potential end of winding **10**, while its high potential end is connected to the grid of the amplifier tube **12** through the direct current blocking condenser **13**. The junction of windings **10** and **11** is connected to ground through condenser C. The amplifier tube **12** may be of the screen grid type, and its cathode is connected to ground through a by-passed grid bias resistor. The input grid of tube **12** is connected to ground through a path which includes the choke coil **14** and the negative voltage source **15**. The latter includes some means for varying the value thereof thereby to provide gain control. The output electrode of amplifier tube **12** is connected to a source of positive potential through the primary winding **16** of transformer M_1, the winding **16** being shunted by the adjustable condenser **17**. The latter condenser is in turn shunted by a resistor **18**. The control grid **3** of tube **1** is connected by lead **20** to one terminal of the switch **21**, the opposite terminal of the switch **21** is established at ground potential, and the switch is arranged in circuit with the secondary winding **22** of transformer M_1.

In order to understand the functioning of the network shown in Fig. 1, the following theoretical explanation is given. It is to be understood that the purpose of the network is to simulate between terminals **5** and **6** a reactance effect which is either capacitative or inductive depending on the sense of frequency departure of alternating voltage impressed between the terminals **5** and **6** from a predetermined frequency value. The network T functions to provide, from a given impressed voltage, an output voltage whose phase relative to that of the impressed voltage is such as to cause any desired type of impedance to be simulated between terminals **5** and **6**, and whose magnitude varies with frequency in such a way as to make the simulated impedance a desired function of frequency. Let it be assumed now that alternating voltage is applied between terminals **5** and **6**. If secondary **11** is suitably poled relative to winding **10**, then at the frequency where the reactance of condenser C is equal and opposite to the mutual reactance of transformer M, the output voltage of the network T is zero. If resistor R is so large as to insure the current flowing therethrough being substantially in phase with the voltage between the terminals **5** and **6**, then upon a departure from the frequency mentioned above there will arise an output voltage from network T which will be 90° out of phase with the input voltage at **5**—**6**. Furthermore, the output voltage will have a magnitude proportional to the departure from the predetermined frequency. These statements correctly imply that the phase of the output voltage reverses as the frequency of the impressed alternating voltage passes through a critical frequency value.

Let it now be assumed that the radio frequency output from network T is fed back to the grid **3** of tube **1**. Then at frequencies above the predetermined critical frequency value tube **1** draws a leading current (assuming one position of switch **21**), and, hence, acts like a condenser whose capacity is proportional to the amount by which the frequency of the impressed alternating voltage exceeds the critical frequency value. Below the critical frequency value the tube acts like an inductance whose value decreases as the frequency falls.

This phenomenon could be used, for example, for the stabilizing of an oscillator. In the latter case suppose the tuned circuit of an oscillator is shunted between terminals **5** and **6**, and that the normal oscillator frequency is the aforementioned critical frequency value. Now suppose that the oscillation frequency tends to increase a small amount. If it does so then tube **1** will act like a condenser across a tuned circuit of the oscillator which, of course, tends to lower the oscillator frequency. By arranging the circuits so that the grid **3** gets sufficient voltage for a given frequency departure, then the frequency drift can be limited to any extent desired. A downward drift in frequency of the oscillator is limited in similar fashion by the resulting action of tube **1** as an inductance in shunt to the oscillator tuned circuit. The stiffness of the control action may be adjusted by varying the amount of voltage applied to grid **3**, or by the design of the selective network T.

In the circuit arrangement of Fig. 1, the winding **10** and condenser C are preferably arranged to resonate at the same frequency as the resonant frequency of the mutual inductance of transformer M and capacity C, so as to cause minimum possible plase shift in the current flowing through resistor R. The output circuit of amplifier **12**, if tuned, is preferably made to tune broadly by the shunt resistors **18**, and this is done for the same reason as stated in connection with the elements of network T, that is to minimize phase shift. In other words, for minimizing phase shift effects circuits **17**—**16**, **10**—C and M—C are each tuned to the predetermined critical frequency value. For very best results it is preferable that the phase errors introduced by the reactances of winding **10** and condenser C be balanced by equal and opposite effects in some other part of the transmission path to the grid **3**. Such phase errors introduce positive or negative resistance components into the effective impedance of the reactance tube, and while these effects in some cases may be desired, it is also often desired to avoid it. The switch means **21** is included for the purpose of permitting the action of tube **1** to be reversed. In other words, by throwing switch **21** into the dotted line position, it is possible to reverse the sign of the reactance simulated between terminals **5** and **6**.

In Fig. 2 there is shown a use to which the electronic reactance network of Fig. 1 may be applied. In this case the signal collector **23** is coupled to a signal-tuned circuit **24**. The terminals **5** and **6** of the network in Fig. 1 are connected across the tuned circuit. Let it now be assumed that signal voltage, subject to small departures from a normal frequency, is impressed on circuit **24** which is fixedly tuned to said normal frequency. If the frequency of the signal voltage is too high for the circuit an inductance should be shunted across the tuned circuit **24** to bring it into tune. However, by connecting the network of Fig. 1 across tuned circuit **24**, the elements of Fig. 1 being tuned to said normal frequency, it has been shown that on a rise of impressed frequency there is simulated between terminals **5** and **6** a capacity effect. However, this action can be reversed by reversing the phase of the alternating voltage fed to the grid **3**. In other words, it is possible to change the reactance simulated between terminals **5** and **6** by reversing the switch **21**. Hence, with the reversed phase and with properly adjusted stiffness of action the reactance network of Fig. 1 will automatically keep the fixedly tuned circuit **24** resonant to the frequency of the signal voltage applied thereto over a considerably increased range of frequencies. Such a circuit could be used, for example, with a police receiver having fixed tuning and varying antenna reactions.

By superposing a voltage 180° different from the applied voltage on a grid of the reactance tube, as by putting the former voltage on another grid, a negative resistance may be applied to a tuned circuit along with frequency control. Thus, for example, in Fig. 4 there is shown an oscillation-production circuit which comprises tube **25** provided with a plate **26**, a cathode **27**, a control grid **28** with an oscillation grid **29**. The resonant tank circuit of the oscillator tube is denoted by numeral **30**, and the high potential side thereof is connected to plate **26** through the direct current blocking condenser **31**, the low potential side of the tank circuit **30** being grounded. The oscillation grid **29** is inductively coupled to the tank circuit **30**, and the cathode **27** is connected to ground through a self-biasing resistor network **32**. The network T has its resistor R included in series with the primary winding of transformer M and oscillator plate **26**. The secondary winding of transformer M is connected by lead **33** to the control grid **28** through a transformer **42**.

By virtue of the network T and the control grid **28** the oscillator has its frequency maintained as stable as is desired by providing adequate stiffness of control from the network T. Between the plate and cathode of tube **25** there is simulated both a reactive effect having a polarity or sign which depends on the sense of frequency departure of the oscillation voltage from a predetermined critical frequency value, and also a negative resistance effect which maintains oscillations in tank circuit **30**. In other words, tube **25** functions both as an electronic reactance tube, and as an oscillator tube whose frequency is maintained at substantially the resonant frequency determined by C and the inductance of the secondary of transformer M even in the presence of considerable change in the constants of circuit **30**. The reversing transformer **42** is so poled as to produce the desired sign of simulated reactance.

In Fig. 3 there is shown a tube **35** used simultaneously as a signal voltage amplifier and as an electronic reactance tube. The plate **36** of tube **35** has included in its circuit therewith a fixedly tuned circuit **40**. Upon the signal input grid **41** is impressed signal voltage. The cathode **37** is connected to ground through the usual grid biasing network, and the control grid **38** is coupled by transformer **42** to the secondary winding of transformer M of the network T. The network T and the control grid **38** function in this case to maintain the resonant plate circuit **40** in tune with the signal voltage of varying frequency. The network T in this case applies to grid **38** a reversed, 90° phase-displaced voltage derived from the signal voltage. In this case the functioning is similar to that in Fig. 2, except that tube **35** functions simultaneously both as a signal amplifier and as an electronic reactance-simulation tube. It will be understood that in Fig. 3 the network T functions to produce across tuned circuit **40** either a capacity effect, or an inductance effect, depending upon the direction of frequency shift with respect to a predetermined critical frequency value of the signal voltage applied to grid **41**.

The invention has particular use in connection with a device of the type known in the art as a "cyclotron." Since this type of oscillation-production device is well known in the art at the present time, it is not believed necessary to show it in detail. It is sufficient to point out that a "cyclotron" is a device of the magnetron type wherein electric charges within the interior of a tube are whirled around in a curvilinear path until a very high speed is attained, the moving charges then being utilized as a so-called "beam." In a cyclotron the enclosure within which charges are whirled around is usually composed of D-shaped plates. If for whirling the charges a self-excited oscillator is used whose frequency depends on the capacity of the D-shaped plates together with the lines leading thereto, then changes in the capacities of the D-shaped plates, due to heating, cause frequency changes which require correction to keep the beam strength maximum. The reactance tube, connected as described heretofore, may be arranged to limit frequency variations from this cause to a value that is admissible. Furthermore, this can be done without the delay involved in mechanically correcting the constants of the oscillator circuit. This is especially important where rapid cyclic changes in effective D-capacities are encountered as sometimes occurs in practice.

If, on the other hand, the cyclotron is driven from a master oscillator and an amplifier, then the aforesaid changes in the capacities of the D-plates throw the resonant connecting lines out of tune with the fixed frequency. In this case sufficient and delayless correction may be made to the tuning of the D-lines by utilizing a reactance tube excited by a voltage proportional to the departure of the tuning of the D-line from the condition of unity power factor. This is shown in Fig. 5 wherein the numeral **50** is a power amplifier which is fed by a master oscillator **51**, said power amplifier feeding through the coupling capacity **52** to an intermediate point on the tank circuit inductance **53**. It is to be understood that the numerals **54** and **53** designate the tank circuit of a cyclotron. In other words, the coil **53** and condenser **54** are an electrical representation of the usual D-plates and the feed lines thereto of a cyclotron.

The reactance simulation tube is designated by numeral **60**, and the plate **61** thereof is connected to a point on the high potential side of tank circuit **53—54** by the direct current blocking condenser **55**, the low potential side of the tank circuit being at ground potential. The cathode of tube **60** is at ground radio frequency potential but at a suitable direct current biasing potential, while the grid **70** thereof is connected to the junction of resistor **71** and condenser **72**. The opposite end of condenser **72** is at ground potential, while in shunt with resistor **71** and condenser **72** are arranged a pair of coils **73** and **74** wound in opposite directions. The coil **73** is coupled to winding **53** on one side of the intermediate tap point, while coil **74** is coupled to winding **53** on the opposite side of the tap point. The rectangle **80** includes within its boundary the elements which are included in the selective phase shift network. Between the plate and cathode terminals of tube **60** is simulated the reactance which functions to control the frequency of tank circuit **54—53**.

When the tank circuit **54—53** is correctly tuned the currents flowing in the winding **53**, those above and below the intermediate tap point, are substantially equal since in a cyclotron the resonance of the tank circuit is very sharp. Therefore, the equal and oppositely poled coils **73** and **74** will receive substantially no net voltage. However, if the tank circuit gets out of resonance the aforementioned net voltage is no longer zero, but has a value that increases with the amount of detuning and has a phase that is reversed as the sense of the detuning is reversed. This net voltage is in phase with the voltage across the tank so that when applied to the grid **70** through the resonant circuit shown it becomes 90° out of phase with the voltage across the tank with the result that tube **60** acts like a reactance. Suitable choice of the polarities of the coils **73** and **74** will insure that the effect of the automatic reactance is to compensate for changes in tank capacity, and just keep the tank in tune to an exactness limited only by the stiffness of control provided. The power amplifier **50** can be made to provide both amplification and tuning control as pointed out in connection with Figs. 3 and 4.

If the above mentioned polarities were reversed the effect would be that an extremely slight detuning of the tank circuit **54—53** would react to cause a further detuning. Similarly, in Figs. 2 and 3, a reversal of the feedback would make the response of the circuits in question much sharper than normal, since any slight shift in frequency would introduce changes in the tuning of the circuits that would accentuate the difference between the critical frequency value and the circuit tuning. This effect may be employed in place of regeneration for the artificial sharpening of resonance curves. It has the advantage that the sharpening can be made very large without the danger of a large increase in gain of the system setting up oscillations, as is the case in highly regenerative systems.

It will be understood that the phase shifting circuit shown in Fig. 1 is merely illustrative, as well as the amplifying and reversing arrangements shown. What is common to the various circuits shown in this application is the fact that there has been provided an alternating voltage resonant circuit which has an electron discharge tube electrically associated therewith, and the tube is excited by an alternating voltage in quadrature with, and derived from, the alternating voltage existing across the resonant circuit, means being provided for causing the quadrature voltage to have an amplitude algebraically proportional to the difference between the frequency of the quadrature voltage and a predetermined critical frequency value of the resonant circuit.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In a high frequency network, a resonant circuit tuned to a predetermined frequency value, an electron discharge tube having input and output electrodes, means coupling said output electrodes across said resonant circuit, a phase shifter circuit having capacitative and inductive elements balanced at said frequency value, means for impressing high frequency voltage appearing across said tuned circuit upon said phase shifter circuit, an auxiliary electrode within said tube, means impressing high frequency voltage on said auxiliary electrode, and means impressing phase-shifted high frequency output voltage of said shifter upon said input electrodes whereby a reactive effect is produced between said output electrodes whose sign and magnitude are dependent upon respectively the sense and extent of departure of said high frequency voltage frequency from said predetermined frequency value.

2. In a high frequency network, a resonant circuit tuned to a predetermined frequency value, an electron discharge tube having input and output electrodes, means coupling said output electrodes directly across said resonant circuit, a phase shifter circuit having capacitative and inductive elements balanced at said frequency value, means coupling said shifter circuit across said resonant circuit whereby high frequency voltage appearing across said tuned circuit is directly applied upon said phase shifter circuit, a control electrode within said tube, means for applying high frequency energy of said predetermined frequency to said control electrode, and means impressing phase-shifted high frequency output voltage of said shifter upon said input electrodes whereby a reactive effect is produced between said output electrodes whose sign is dependent upon the sense of departure of said high frequency voltage frequency from said predetermined frequency value, said phase shifter circuit including a resistive element in circuit with the reactive elements.

3. In combination, a high frequency voltage circuit, an electron discharge tube having output and input electrodes, the tube output electrodes being directly connected across said circuit, means impressing between the tube input electrodes a high frequency voltage in quadrature with, and derived from, the voltage across said circuit, an auxiliary control grid in said tube, means applying to said grid a high frequency voltage derived from said circuit, said impressing means being constructed to cause said quadrature voltage to have an amplitude algebraically proportional to the difference between its frequency and a critical, predetermined frequency value of said circuit, said impressing means comprising a phase shifter circuit coupled directly to said high frequency circuit and being provided with reactances of opposite sign, said reactances being balanced at said critical frequency value.

4. In combination, a high frequency voltage circuit, an electron discharge tube having output and input electrodes, the tube output electrodes being directly connected across said circuit, means impressing between the tube input electrodes a high frequency voltage in quadrature with, and derived from, the voltage across said circuit, a source of high frequency energy, an auxiliary input grid in said tube, means coupling said grid to said source whereby said tube acts as an amplifier, said impressing means being constructed to cause said quadrature voltage to have an amplitude algebraically proportional to the difference between its frequency and a critical, predetermined frequency value of said circuit, said impressing means comprising a reactive network coupled directly to said high frequency circuit and being series resonant to said critical frequency value.

5. In combination with a source of alternating current of high frequency and a resonant circuit tuned to the frequency of said source, means for maintaining synchronism between the frequency of said resonant circuit and the frequency of said source current, said means comprising an electron discharge tube provided with at least a cathode, an input grid, a control grid and output electrode, means coupling the output electrode of said tube to said resonant circuit, means for applying current from said source to said input grid, means for deriving from said circuit a voltage substantially co-linear in phase with the current in said circuit and proportional to the frequency thereof, means for deriving from said circuit a second voltage substantially co-linear in phase with the current in said circuit and inversely proportional to the frequency thereof, means for combining said two voltages in opposition to provide a resultant voltage, and means for impressing said resultant voltage on the control grid of said tube.

6. In a high frequency network comprising a pair of terminals adapted to be connected across a high frequency circuit whose frequency is to be controlled, an electron discharge tube having input and output electrodes, means connecting the tube output electrodes between said terminals, a reactive path connected between the said terminals, said path comprising a resistor in series with a reactance network, said resistor having a resistance sufficiently high in comparison with the impedance of said reactance network to assure current through the latter having a phase and magnitude determined substantially solely by the resistance of said resistor over a range of frequencies, said reactance network comprising a transformer in series with a condenser the

mutual inductance between the transformer windings and the condenser being resonated to a predetermined high frequency, means for deriving from said reactance network a high frequency voltage in quadrature with the high frequency voltage between said terminals, means for applying said quadrature voltage to said tube input electrodes whereby there is developed between said terminals a reactive effect whose magnitude and sign are determined by the extent and sense of frequency difference between the frequency of the voltage from said circuit and the said predetermined frequency.

7. In combination with an electron discharge tube having input and output electrodes, means for simulating between the said output electrodes a reactance effect whose sign and magnitude depends upon the sense and amount of frequency shift of alternating voltage from an assigned frequency value, an auxiliary input electrode in said tube, a resonant circuit tuned to said frequency value connected between the output electrodes, means for applying to said auxiliary electrode voltage of said frequency value, said simulating means comprising an alternating voltage feedback path common to said output and input electrodes, said path including reactances of constants such that the feedback voltage is substantially zero at said assigned frequency value, said reactances being arranged to produce a quadrature phase relation between alternating voltage at said input and output electrodes and a resistor in circuit with said reactances of such magnitude that the phase of the current through said reactances is maintained constant.

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