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F. G. MARBLE

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REACTANCE TUBE CIRCUIT

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FIG. 1

CIRCUIT OF THE PRIOR ART

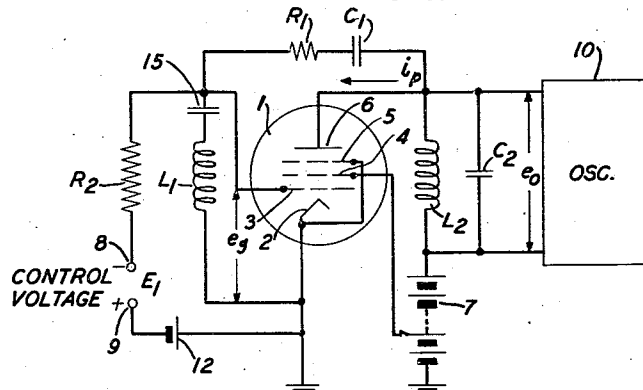
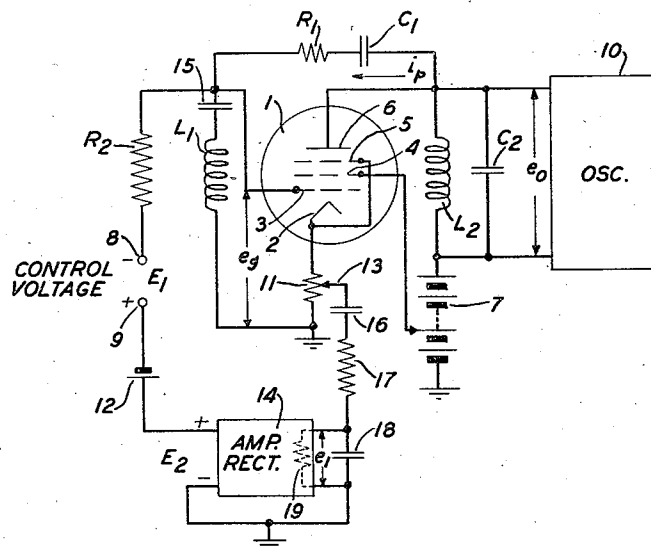


FIG. 2



INVENTOR  
F. G. MARBLE  
BY  
G. H. Heydt  
ATTORNEY

## UNITED STATES PATENT OFFICE

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## REACTANCE TUBE CIRCUIT

Frank G. Marble, West Orange, N. J., assignor to  
Bell Telephone Laboratories, Incorporated,  
New York, N. Y., a corporation of New York

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4 Claims. (Cl. 250—40)

This invention relates to an improvement in reactance tube circuits, particularly with reference to the use of such circuits as reactances varying with a direct current control voltage.

The object of the present invention is to provide a reactance tube circuit constituting a capacity capable of being varied in linear proportion to a unidirectional voltage applied to the input circuit of the reactance tube.

Numerous circuits known to the prior art provide electronic reactances varying with a control voltage and most commonly applied in the automatic frequency control of a radio receiving circuit local oscillator wherein the control voltage is derived by rectification of a portion of the intermediate frequency wave derived from the signal wave being received. It suffices for such use that the circuit operates to establish a definite intermediate frequency and no requirement exists that such frequency be approached linearly with variation in the controlling voltage. In other words, the trimming capacity must reach a desired value without specification of its approach thereto.

A stricter requirement must be fulfilled if the reactance tube circuit is to cause an effective capacity to vary linearly with a voltage representing a physical condition, a manner of capacity variation desired, for example in the vibration analyzer disclosed and claimed in the co-pending application Serial No. 483,129, filed April 15, 1943, by W. J. Brown. The analyzing circuit described by Brown includes an oscillator of which the tuning is varied by a voltage responsive device which varies the capacity in the frequency determining circuit of the oscillator linearly with a voltage proportional to the rotational speed of an airplane engine. The required variation in frequency is from 92,000 to 92,500 cycles per second, and over such a narrow range is sensibly linear with variation of the capacity in the tank circuit of the oscillator. It is clearly a saving in equipment to substitute for the voltage responsive device and the condenser thereby controlled a reactance tube constituting a capacity reactance directly controlled by the voltage proportional to the engine speed.

Therefore, it is another object of the invention to simply the circuit of a vibration analyzer.

The invention will be fully understood from the following description read with reference to the accompanying drawing in which:

Fig. 1 shows a circuit of the prior art in which a reactance tube circuit constitutes a variable capacity; and

Fig. 2 shows a circuit generally similar to that of Fig. 1 but including the improvement of the present invention. In both figures like numerals identify like elements. Alternating voltages and currents are represented by small letters, unidirectional voltages by capitals.

In Fig. 1 tube 1 is preferably a pentode such as the 6AC7, cathode 2 and control grid 3 are shunted by inductance  $L_1$  and condenser 15 while grid 3 and anode 6 are connected by the feedback path comprising resistor  $R_1$  in series with blocking condenser  $C_1$ . Cathode 2 is heated by the usual means not shown and is grounded. Suppressor grid 5 is joined to cathode 2 while screen grid 4 is connected to a suitable potential on battery 7 from which the supply of current to anode 6 is through inductance  $L_2$ . Grid 3 is negatively biased with respect to cathode 2 by means of battery 12. Inductance  $L_2$  and condenser  $C_2$  plus the capacity represented by tube 1 constitute the frequency determining circuit of oscillator 10 which generates a voltage of frequency say 100 kilocycles per second. The space current and so the mutual conductance of tube 1 is controlled by a direct current voltage across terminals 8 and 9 in series between battery 12 and grid 3, a high resistance  $R_2$  being included in series between terminal 8 and grid 3. Condenser 15 is a blocking condenser of large capacity. Resistances  $R_1$  and  $R_2$  are each of the order of 1 megohm. The capacity of condenser  $C_1$  is suitably of the order of 0.1 microfarad. The voltage on screen grid 4 and that of battery 7 are respectively of the order of 100 and 300 volts when tube 1 is a 6AC7. For the illustrative frequency of 100 kilocycles per second  $L_1$  and  $C_2$  plus the capacity represented by tube 1 may be 1 millihenry and 2530 micromicrofarads, respectively.

Circuits such as that of Fig. 1 are well known and reference may be made to the article by C. Travis entitled "Automatic frequency control" in the Proc. I. R. E. vol. 23, page 1125, October, 1935. It is necessary that the feedback resistance  $R_1$  and the internal resistance of tube 1 be very large in comparison with the resonant impedance of circuit  $L_2$  and  $C_2$  and that resistances  $R_1$  and  $R_2$  be both very large compared with the impedance of  $L_1$  at the resonant frequency. The tube and its associated circuit constitutes an effective condenser, shunting the tank circuit, of capacity

$$C = \frac{L_1 G_m}{R_1}$$

where  $G_m$  is the mutual conductance of tube 1.

A control voltage impressed across terminals 8 and 9 serves to determine the conductance  $G_m$  which accordingly varies with the variation of the control voltage itself.

In a practical case, the capacity of condenser  $C_2$  may be 2280 micromicrofarads and inductance  $L_2$  may be 1 millihenry. If  $R_1$  equals 1 megohm and  $L_1$  50 millihenries,  $G_m$  may readily be made 5000 micromhos so that the effective capacity

$$\frac{L_1 G_m}{R_1}$$

shunting tank circuit  $L_2 C_2$  becomes 250 micromicrofarads so that the total capacity of the tank circuit corresponds to a resonant frequency of 100 kilocycles per second. With the polarity of the control voltage shown in Fig. 1, an increase in magnitude of this voltage reduces the mutual conductance, and so the effective capacity shunting the tank circuit, thereby increasing the frequency of oscillator 10. If for inductance  $L_1$  a condenser of suitably small capacity is substituted the circuit of tube 1 becomes an effective inductance varying inversely with  $G_m$ , an arrangement which in some cases is desirable. For many purposes, an example being the vibration analyzer disclosed in the Brown application referred to, it is preferred to employ the circuit of Fig. 1 and vary the oscillator frequency by varying the total capacity of the tank circuit in accordance with a control voltage.

In Fig. 1, condenser  $C_2$  is shunted by the effective capacity

$$\frac{L_1 G_m}{R_1}$$

An alternating current  $i_p$  flows in the anode circuit of tube 1 due principally to the alternating voltage  $e_s$  which appears between grid 3 and ground. This voltage  $e_s$  on grid 3 is the alternating component

$$e_s = \frac{e_o \omega L_1}{R_1}$$

where  $\omega$  is  $2\pi$  times the instantaneous frequency of  $e_o$  the voltage across oscillator 10. The ratio  $i_p/e_s$ , or  $G_m$ , depends on the bias voltage of grid 3 and this is the voltage of battery 12 together with the external control voltage  $E_1$  between terminals 8 and 9. A deliberate variation of  $E_1$ , therefore results in a variation in  $G_m$ , entailing a variation in the frequency generated by oscillator 10 resulting from the capacity variation of the reactance circuit, a capacity variation which would be linear with that of  $E_1$ , were the characteristic of mutual conductance vs. grid voltage a straight line.

The advantage for the above purpose of the circuit of Fig. 1 is its greater compactness as compared with mechanical devices. On the other hand, since the curve of mutual conductance vs. grid voltage is S-shaped there is the disadvantage that the effective capacity of a reactance tube is not a linear function of the control voltage except over a very narrow range. This disadvantage is largely removed by the present invention and the manner of its removal will appear from the description of the circuit of Fig. 2.

Referring now to Fig. 2 a small resistance 11 is inserted between ground and cathode 2. From a suitable point on resistor 11 a connection 13 is taken to amplifier 14, the rectified output of which is introduced in series between ground and terminal 9 and is so poled as to be in opposition to the control voltage applied between terminals 8 and 9. Resistor 11 is traversed by a complex current composed of the unidirectional space current

of tube 1 together with an alternating current due to the fraction of the oscillator voltage from tank circuit  $L_2 C_2$  introduced across  $L_1$ . Under the assumptions made above the magnitude of this alternating component depends on the mutual conductance of tube 1 as does the effective capacity presented by the circuit of Fig. 1. As the control voltage increases in magnitude, grid 3 goes more negative, the mutual conductance decreases and the alternating component of the current in resistor 11 decreases. The corresponding alternating voltage applied by connection 13 to amplifier rectifier 14 emerges as a unidirectional voltage introduced in opposition to the control voltage.

Resistor 11 is chosen to be a sufficiently low resistance, say 25 ohms to avoid the introduction of negative feedback other than that it is desired to introduce by the circuit connection including amplifier rectifier 14. Only the alternating component of the current traversing resistor 11 is useful for the purpose of the invention, for which reason blocking condenser 16, of large capacity, is included in series between tap 13 and the voltage divider consisting of resistor 17 in series with condenser 18 to ground. Across condenser 18 is connected the input to amplifier rectifier 14, the input resistance 19 of which is represented in dotted line. This input resistance is of the order of 1 megohm, large compared to the reactance of condenser 18 and it is convenient to make the resistance of resistor 17 25,000 ohms. The capacity  $C_{18}$  of condenser 18 is suitably chosen to be equal to

$$\frac{1}{R_{17} \omega_1}$$

where  $R_{17}$  is the resistance in series with condensers 16 and 18 and  $\omega$  is  $2\pi$  times the frequency one octave lower than the lowest operating frequency of oscillator 10. It may be shown that under these conditions, for variations in frequency of oscillator 10 above the lowest operating frequency, the ratio  $e_1/e_s$  of the voltage  $e_1$  across condenser 18 to the grid voltage  $e_s$  involves the operating frequency inversely as does the voltage ratio  $e_s/e_o$ , wherefore the ratio  $e_1/e_o$  is independent of the oscillator frequency over the range assumed.

It will be recognized that the disposition of apparatus shown in Fig. 2 makes use of a special kind of inverse feedback. In the usual feedback circuit a portion of the output voltage of an amplifier is fed back in reverse phase to the input circuit thereof and thereby deformities in the output energy are corrected so that the output energy becomes a more faithful enlargement of the input energy. In the circuit of the present invention the deformation to be corrected arises from the characteristic of the reactance tube and is represented in the alternating current traversing resistor 11. Since the variation of a unidirectional control voltage is to be preformed to compensate in advance for the tube characteristic, rectification is required of the compensating alternating voltage and the required reversal of phase is obtained by poling the rectified voltage in series opposition to the control voltage which it is desired to modify. The magnitude of the compensating voltage may be altered either by altering the point of connection 13 on resistor 11 or by a gain control in amplifier rectifier 14, whichever is more convenient. In practice it is a simple matter to determine the required compensation for a tube of given type by plotting a family of curves of control voltage vs. anode cur-

rent for various adjustments of the compensating voltages. Once this determination is made, the anode current and so the mutual conductance of the tube over a wide range vary linearly with respect to the control voltage ( $E_1$  in Figs. 1 and 2) although not so with respect to the total grid to cathode voltage ( $E_1 - E_2$ , Fig. 2). The effective capacity of the reactance in the circuit of Fig. 2 likewise varies over the same range linearly with the control voltage thereby attaining the object of the invention.

What is claimed is:

1. In an electronic reactance circuit including a thermionic vacuum tube provided at least with a control grid, a cathode and an anode and controlled by a unidirectional voltage applied in series between said control grid and ground, means for varying the mutual conductance of said tube linearly with said voltage comprising a source of alternating voltage connected between said anode and ground, a resistance in series between said cathode and ground, means for rectifying and amplifying a desired portion of the alternating component of the voltage across said resistance and means for introducing said rectified fractional voltage in series with and in opposition to said unidirectional voltage.

2. An electronic reactance circuit adapted to be controlled by a unidirectional external voltage, comprising a thermionic vacuum tube provided at least with a control grid, a cathode and an anode, power supply for said tube, coupling comprising a first resistance in series with a capacity between said control grid and said anode, a first reactive impedance connected between said control grid and ground, a second resistance in series between said cathode and ground, an output circuit for said tube including a second reactive impedance connected between said anode and ground, an input circuit for said tube shunting said first reactive impedance and including

a third resistance, means for rectifying a desired portion of the voltage across said second resistance and means for introducing in series with said third resistance said external voltage in series with and in opposition to said rectified voltage.

3. An electronic reactance circuit adapted to be controlled by a unidirectional voltage, comprising a thermionic vacuum tube provided at least with a control grid, a cathode and an anode, power supply for said tube, an impedance coupling said control grid and said anode, a source of alternating voltage connected between said anode and ground, a resistance in series between said cathode and ground, means for rectifying the voltage across said resistance, an input circuit for said tube including a second impedance and means for introducing in series with said second impedance said external voltage and said rectified voltage in mutual opposition.

4. Means for controlling the tuning of the frequency-determining circuit of an oscillator linearly with the magnitude of a unidirectional control voltage comprising a thermionic vacuum tube provided at least with a control grid, a cathode and anode, power supply for said tube, an output circuit for said tube, means for connecting said frequency-determining circuit in parallel with said output circuit, coupling including a first resistance in series with a capacity between said anode and said control grid, an inductance connected between said control grid and ground, a second resistance in series between said cathode and ground, an input circuit for said tube including a third resistance, means for rectifying a desired portion of the voltage across said second resistance and means for connecting said control voltage and said rectified voltage in mutual opposition in series between said third resistance and ground.

FRANK G. MARBLE.