Feb. 7, 1933. F. B. LLEWELLYN 1,896,781

CONSTANT FREQUENCY OSCILLATOR

Filed March 16, 1931 2 Sheets-Sheet 1

FIG. 1

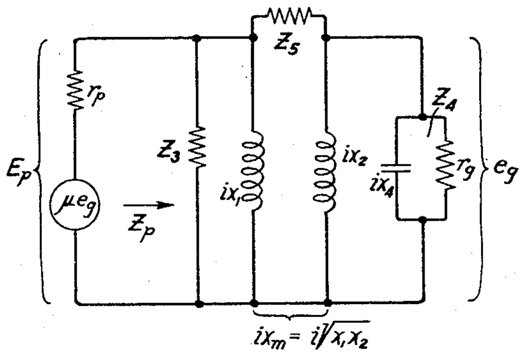


FIG. 2

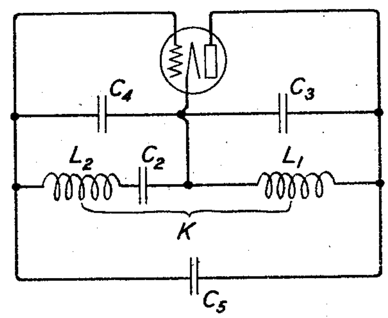


FIG. 3

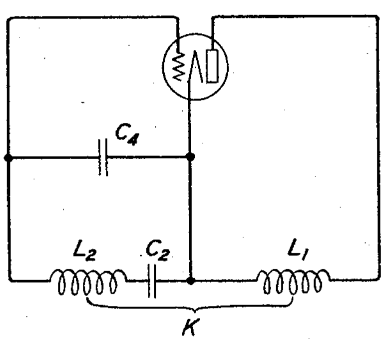


FIG. 4

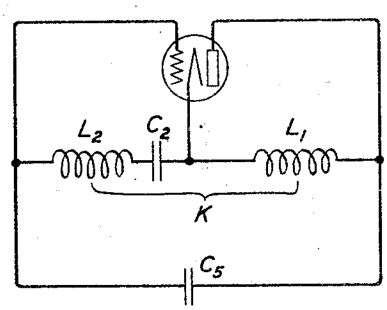


FIG. 5

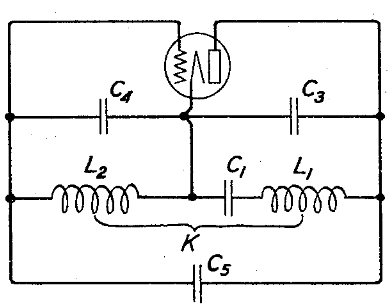
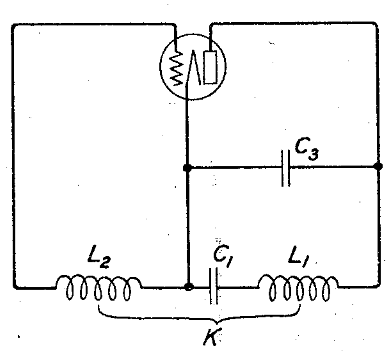


FIG. 6



INVENTOR
F. B. LLEWELLYN
BY Guy T. Morris
ATTORNEY

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CONSTANT FREQUENCY OSCILLATOR

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FIG. 7

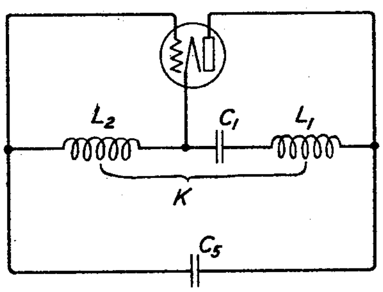


FIG. 8

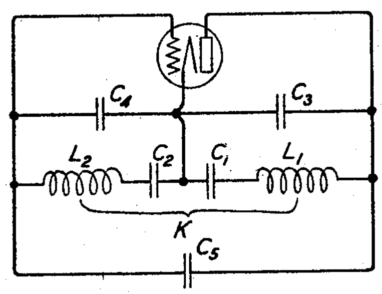


FIG. 9

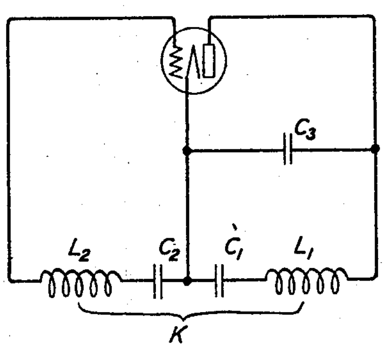


FIG. 10

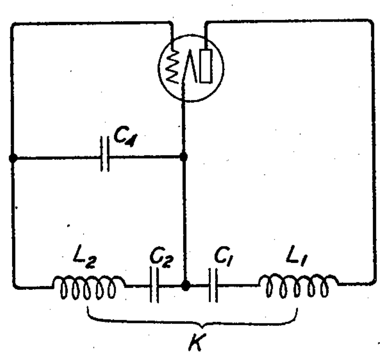


FIG. 11

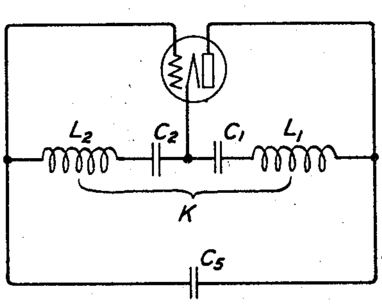
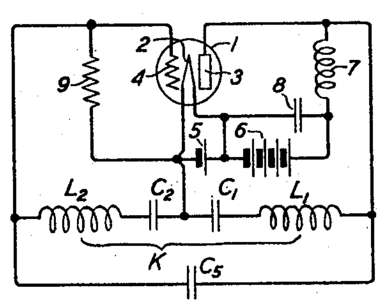


FIG. 12



INVENTOR
F. B. LLEWELLYN
BY Guy T. Morris

ATTORNEY

Patented Feb. 7, 1933

1,896,781

UNITED STATES PATENT OFFICE

FREDERICK B. LLEWELLYN, OF MONTCLAIR, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

CONSTANT FREQUENCY OSCILLATOR

Application filed March 16, 1931. Serial No. 522,941.

This invention relates to constant frequency electric discharge oscillators or, more specifically, to simple modifications of existing conventional types of electric discharge oscillators whereby their frequency stability is increased without detriment to their normal functions.

One object of the invention is to improve the frequency stability of conventional types of electric discharge oscillator circuits as affected especially by changes in operating or battery voltages or in load resistance, these being the more common contributing causes of frequency variation.

Another object of the invention is to evolve critical impedance relations in such conventional types of oscillators so as to achieve frequency stability as affected by changes in operating (for example, battery) voltages or of load resistance, or as affected jointly by such types of variations.

A further object of the invention is to achieve stabilization at frequencies at which inter-electrode capacities of the space discharge device employed in such oscillators produce an appreciable effect.

Still another object of the invention is to achieve frequency stabilization with respect to the above mentioned changes with maximum simplicity of circuit, economy of plant and reliability of function; and especially with avoidance of dependence on the parameters of the space discharge device employed in the conventional feed-back oscillator.

In my copending application, Serial No. 478,373, filed August 28, 1930, several oscillating systems are described in which frequency variations resulting from changes in battery voltages and load resistance are substantially eliminated by utilizing a critically valued reactance between the frequency determining circuit and the grid, or plate, or both. In the present invention frequency stabilization with respect to such changes is accomplished in magnetic feed-back oscillators by including a stabilizing reactance in the frequency determining circuit, the reactance being of such value that an effective unity coupling between the input and output circuits of the tube employed is obtained. One important advantage resulting from stabilizing feed-back oscillators in accordance with this invention is that the frequency of the oscillator may easily be stabilized at all frequencies, including relatively high frequencies at which the inter-electrode capacities of the space discharge device possess appreciable values.

Since the changes in operating (for example battery) voltages and load resistance are the principal factors in the frequency change, an oscillator whose frequency is stable so far as affected by such changes may be regarded as a frequency stable oscillator for all practical purposes except as the reactive frequency determining elements may be affected by temperature changes. It happens in accordance with this invention that an oscillator whose frequency is stable with respect to changes in voltages may, by the use of means to be described, be made stable with respect to load resistance.

Other advantages and aspects of the invention will be apparent from the following description, when read in connection with the accompanying drawings in which:

Fig. 1 illustrates a diagrammatic circuit which is useful for mathematical analysis of the circuits shown in the other figures;

Fig. 2 illustrates a generalized circuit arranged for input or grid stabilization;

Fig. 3 illustrates a feed-back oscillator with grid stabilization;

Fig. 4 is a Hartley oscillator arranged for grid stabilization;

Fig. 5 illustrates a generalized circuit arranged for output or plate stabilization;

Fig. 6 illustrates a reversed feed-back oscillator with plate stabilization;

Fig. 7 illustrates a Hartley oscillator with plate stabilization;

Fig. 8 illustrates a generalized circuit arranged for both grid and plate stabilization;

Fig. 9 illustrates a reversed feed-back oscillator arranged for both grid and plate stabilization;

Fig. 10 illustrates a feed-back circuit having both the grid and plate circuits stabilized;

Fig. 11 illustrates a Hartley oscillator with both grid and plate stabilized; and

Fig. 12 is a wiring diagram of an oscillator having both grid and plate stabilized in accordance with the invention.

Referring to Fig. 1, the mathematical theory underlying the invention will be considered in detail, the designations listed below being used uniformly throughout the subsequent analysis:

E_p, output voltage
e_g, input voltage
μ, the amplification factor
r_p, the plate resistance of the vacuum tube
r_g, the grid resistance in the vacuum tube
M, mutual inductance
ω, angle frequency
Z_p, impedance locking out of plate side of tube
L, self inductance
C, capacitance
X, reactance corresponding to L, M or C
Z_3, impedance associated with the output circuit
Z_4, impedance associated with the input circuit; and
Z_5, plate-grid impedance

In Fig. 1 the two windings of the transformer with effective unity coupling are shown by reactances X_1 and X_2. From the properties of unity coupled coils, at either low or high frequencies, we have

$$e_g = -E_p\sqrt{\frac{X_2}{X_1}} \qquad (1)$$

Then, since

$$E_p = -\frac{\mu e_g Z_p}{r_p + Z_p}, \qquad (2)$$

where Z_p is the impedance as seen looking out of the plate side of the tube, we have, from (1) and (2)

$$\frac{1}{Z_p} = \frac{1}{r_p}\left[\mu\sqrt{\frac{X_2}{X_1}} - 1\right] \qquad (3)$$

This equation completely expresses the operation of the oscillator insofar as impedance relations for the fundamental current component are concerned. By ordinary circuit anaylsis, it may be shown that Z_p is given by the following expression:

$$\frac{1}{Z_p} = \frac{1}{Z_3} + \frac{1}{Z_4}\left(\frac{X_2}{X_1}\right) + \frac{1}{iX_1} + \frac{1}{Z_5}\left(1+\sqrt{\frac{X_2}{X_1}}\right)^2 \qquad (4)$$

Substitution of this into (3) gives

$$\frac{1}{Z_3} + \frac{1}{Z_4}\left(\frac{X_2}{X_1}\right) + \frac{1}{iX_1} + \frac{1}{Z_5}\left(1+\sqrt{\frac{X_2}{X_1}}\right)^2 = \frac{1}{r_p}\left[\mu\sqrt{\frac{X_2}{X_1}} - 1\right]$$

This last expression is next separated into its real and imaginary components. Assuming, as in my copending application mentioned above, that the losses in the external circuit elements are small compared with those occasioned by the grid resistance of the tube, $_4$ may be separated into two parts, the one iX_4, in parallel with the other which constitutes the grid resistance r_g. Both Z_3 and Z_5 are taken as pure reactances. Thus the last expression yields the two equations:

$$\frac{1}{X_3} + \frac{1}{X_4}\left(\frac{X_2}{X_1}\right) + \frac{1}{X_1} + \frac{1}{X_5}\left(1+\sqrt{\frac{X_2}{X_1}}\right)^2 = 0 \qquad (5)$$

$$\frac{1}{r_g}\left(\frac{X_2}{X_1}\right) = \frac{1}{r_p}\left[\mu\sqrt{\frac{X_2}{X_1}} - 1\right] \qquad (6)$$

Equation (5) contains neither r_p, r_g, nor μ, so that we reach the important conclusion that the frequency of an oscillator with unity coupling between the plate and grid circuits depends only upon the inductances and capacities in the circuit, and not at all upon the tube parameters, r_p, r_g, and μ; provided, however, that the losses in the external circuit are small, and the harmonic voltages across the tube are small enough to allow r_p and r_g to be considered as pure resistances. In this connection it is important to note that the interelectrode capacities may be grouped with the external circuit elements forming X_3, X_4 and X_5, so that no high frequency difficulty is to be anticipated from them.

Equation (6) contains the relation between r_p, r_g, and μ necessary to insure the presence of oscillation. In practice, the amplitude of the oscillations builds up until this relation is satisfied.

The foregoing theory of the action of a unity coupled oscillator demonstrates, therefore, the independence of frequency and operating voltages.

The conditions necessary for securing unity coupling will now be considered. The first thing to notice, however, in this connection is that our theory does not require that the unity coupling condition,

$$M = \sqrt{L_1 L_2}$$

should be obtained, where L_1 and L_2 represent inductances corresponding to reactances X_1 and X_2, respectively. What actually is required is the much less rigid condition:

$$X_m = \sqrt{X_1 X_2} \qquad (7)$$

Thus, imagine one of the impedances, say X_2, to consist of a coil, L_2, in series with a condenser, C_2, as shown in Fig. 2. We have then, by (7):

$$\omega^2 M^2 = \omega L_1\left(\omega L_2 - \frac{1}{\omega C_2}\right) \qquad (8)$$

or; writing

$$M = k\sqrt{L_1 L_2}$$

where k may now be less than one, we have from (8)

$$C_2=\frac{1}{\omega^2 L_2(1-k^2)} \qquad (9)$$

which gives the value of C_2 necessary to provide unity coupling between the plate and grid circuits at the operating frequency. Condenser C_2 is shown connected between L_1 and L_2 but this is not necessary. The result will be accomplished if C_2 be positioned at the other side of L_2.

The value of

$$\frac{X_2}{X_1}$$

is thus

$$\frac{X_2}{X_1}=\frac{\omega L_2-\frac{1}{\omega C_2}}{\omega L_1}=\frac{\omega L_2-\omega L_2(1-k^2)}{\omega L_1}=k^2\frac{L_2}{L_1} \qquad (10)$$

In practice, X_3, X_4 and X_5 would usually be capacities, such as the elements C_3, C_4 and C_5, respectively, in Fig. 2. With this arrangement, and the relation given by (10) we have the frequency from (5):

$$\omega^2=\frac{1}{L_1\left[C_3+k^2C_4\frac{L_2}{L_1}+C_5\left(1+k\sqrt{\frac{L_2}{L_1}}\right)^2\right]} \qquad (11)$$

The value of C_2 is thus written from (9) and (11) as follows:

$$C_2=\left(\frac{L_1}{L_2}\right)\left[\frac{C_3+k^2C_4\frac{L_2}{L_1}+C_5\left(1+k\sqrt{\frac{L_2}{L_1}}\right)^2}{1-k^2}\right] \qquad (12)$$

This is the general value of C_2 needed to stabilize the oscillator.

It will be seen from the above analysis that the invention possesses two distinct advantages, one advantage being that the interelectrode capacities are taken into account, as in Equation (12) and another being that a more readily interpreted picture of the relation required for stability, namely the "unity coupling" condition of Equation (7), is obtained.

Equation (12) is also applicable to the "tuned plate-tuned grid" type of oscillator, when there is magnetic coupling between the input and output circuits. Thus, when L_1 and L_2 are equal, as also are C_3 and C_4, we have from (12):

$$C_2=C_3\frac{(1+k^2)}{(1-k^2)}+C_5\frac{(1+k)}{(1-k)} \qquad (13)$$

Hence, if tuning is done by "ganging" C_3 and C_4 together and varying them simultaneously, the stability may be maintained for all frequencies by making C_2 to consist of two parts; the one a fixed capacity equal to

$$C_5\frac{(1+k)}{(1-k)}$$

and the other a variable capacity "ganged" together with C_3 and equal to

$$C_3\frac{(1+k^2)}{(1-k^2)}$$

In order to insure fulfillment of the requirements of this theory the oscillator should be relatively free from harmonics, in order that r_p and r_g may be taken as pure resistances.

Referring to the drawings it will be seen that the feed-back type of oscillator illustrated in Fig. 3 is obtained from the general circuit of Fig. 2 by regarding C_3 and C_5 as zero. Substituting zero for C_3 and C_5 in Equation (12) the value of C_2 in the feed-back oscillator of Fig. 3 will be

$$C_2=C_4\frac{k^2}{1-k^2} \qquad (14)$$

When C_3 and C_4 in Fig. 2 are zero the Hartley oscillator shown in Fig. 4 results. The value of C_2 in the Hartley oscillator of Fig. 4 obtained by substituting zero for C_3 and C_4 in Equation (12) will be

$$C_2=C_5\frac{L_1\left(1+k\sqrt{\frac{L_2}{L_1}}\right)^2}{L_2\ (1-k^2)} \qquad (15)$$

If C_4 and C_5 in Fig. 2 are small enough to be neglected the equivalent circuit of the reversed feed-back oscillator with grid stabilization disclosed in my copending application mentioned above is obtained, the value of C_2 in such an oscillator as derived from Equation (12), or as derived in the said copending application, being

$$C_2=\frac{L_1C_3}{L_2(1-k^2)} \qquad (16)$$

Besides the general circuit of Fig. 2 where stabilization is accomplished by imposing a critical value on C_2, there is the alternative shown on Fig. 5 where the stabilizing element is a condenser C_1 located in series with L_1, and of such value as to cancel the leakage reactance between L_1 and L_2. In other words, Fig. 5 illustrates the general circuit for plate or anode stabilization and corresponds to Fig. 2 which illustrates the general circuit for grid or control electrode stabilization.

The equation giving the value of C_1 in terms of the other circuit constants is obtained in the manner Equation (12) was obtained and this value is

$$C_1=\frac{L_2}{L_1}\left[\frac{C_3k^2\frac{L_1}{L_2}+C_4+C_5\left(1+k\sqrt{\frac{L_1}{L_2}}\right)^2}{1-k^2}\right] \qquad (17)$$

The circuits shown in Figs. 6 and 7 may be derived from the general circuit shown in Fig. 5 in the same manner in which Figs. 3 and 4 were derived from Fig. 2.

In Fig. 6 a feed-back oscillator having plate stabilization is illustrated, C_4 and C_5

being regarded as zero. Substituting zero for C_4 and C_5 in Equation (17) the value of C_1 is

$$C_1 = C_3 \frac{k^2}{1-k^2} \quad (18)$$

In Fig. 7 a Hartley oscillator having plate stabilization is illustrated, C_3 and C_4 being made equal to zero. The value of C_1 obtained from Equation (17) for this oscillator is

$$C_1 = \frac{L_2}{L_1} \frac{C_5\left(1-k\sqrt{\frac{L_1}{L_2}}\right)^2}{(1-k^2)} \quad (19)$$

If C_3 and C_5 in Fig. 5 are regarded as zero the feed-back oscillator with plate stabilization disclosed in my copending application is obtained, the value of C_1 as obtained from Equation (17), or as derived in the copending application, being

$$C_1 = \frac{L_2}{L_1} \frac{C_4}{1-k^2} \quad (20)$$

A combination of the features of Figs. 2 and 5 may be employed in the manner shown in Fig. 8 where condensers C_1 and C_2 are placed in series with L_1 and L_2, respectively. In this case the equation for the required size of C_1 and C_2 becomes quite cumbersome when expressed only in terms of the other circuit constants. Since, however, the frequency is usually known approximately, we may use the relation

$$X_m^2 = X_1 X_2$$

for finding C_1 and C_2 in terms of ω and get:

$$\omega^2 k^2 L_1 L_2 = \left(\omega L_1 - \frac{1}{\omega C_1}\right)\left(\omega L_2 - \frac{1}{\omega C_2}\right) \quad (21)$$

As in the case of Figs. 2 and 5, so also may the circuit of Fig. 8 be modified to correspond to the reversed feed-back, the feed-back and the Hartley types of oscillators, stabilization being achieved both in the plate and grid circuits.

These circuits are illustrated in Figs. 9, 10 and 11, respectively. In Fig. 9, C_4 and C_5 are regarded as zero; in Fig. 10, C_3 and C_5 are regarded as zero; and in Fig. 11, C_3 and C_4 are regarded as zero.

Since, as shown above, the frequency of an oscillator may be rendered constant independently of the tube parameters r_p and r_g, in accordance with this invention, it is evident that external resistances connected between the anode and cathode and between the control electrode and the cathode, may be regarded as forming a part of r_p and r_g, respectively. Consequently, variable resistance loads may be connected in these positions without affecting the frequency stabilization.

Figs. 1 to 11 represent, of course, schematic circuit arrangements. Fig. 12 illustrates a complete oscillator wiring diagram in which the invention is employed, the oscillator being schematically shown in Fig. 11. This wiring arrangement is, of course, only one of several that may be employed and of course similar arrangements may be applied to the other schematic circuits shown on the drawings.

In Fig. 12 reference numeral 1 designates a space discharge device having a cathode 2, an anode 3, and a control electrode 4. The cathode is energized by means of battery 5 and a positive potential is impressed upon the anode by means of battery 6. Reference numeral 7 represents a radio frequency choke coil which functions to prevent radio frequency current from flowing through battery 6. Numeral 8 designates a by-pass condenser connected across battery 6. A high resistance 9 of the order of 8000 ohms is connected across the input circuit for the purpose of permitting electrons to escape from the cathode. As in the schematic figures on the drawings L_1 and L_2 designate transformer windings magnetically coupled, and included in the output and input circuits, respectively. C_5 is an inter-electrode condenser and C_1 and C_2 designate, respectively the plate and grid stabilizing reactances. The operation of the oscillator, is, of course, obvious and well known and will not be described here. The values of C_1 and C_2 may be determined from Equation (21).

Although the invention has been described in connection with certain specific embodiments it should be understood that it is not to be limited to these embodiments and that the invention may be applied to other type oscillators including push-pull oscillators. Moreover, the stabilizing means may be any suitable type of impedance and it may be associated with the coupling means in various ways for the purpose of accomplishing effective unity coupling without exceeding the scope of the invention.

What is claimed is:

1. An oscillator comprising an electric discharge device, input and output circuits therefor, a transformer having a plurality of windings for inductively coupling said circuits, and reactive means connected to at least one winding of said transformer for rendering the effective coefficient of coupling substantially equal to unity.

2. An oscillator comprising a space discharge device having a cathode, anode and impedance control electrode, input and output circuits therefor, an inductance included in each of said circuits, said inductances being coupled, and a reactance connected to at least one of the said inductances, the value of the reactance being such as to cancel the leakage reactance between said inductances whereby the coefficient of coupling between said circuits is equal to unity, substantially.

3. An oscillator comprising an electric discharge device having a cathode, anode and impedance control electrode, input and output circuits therefor, a frequency determining circuit energetically related to said input and output circuits, and a frequency stabilizing reactance included in said frequency determining circuit.

4. An oscillator comprising an electric discharge device having a cathode, anode and impedance control electrode, input and output circuits therefor, a frequency determining circuit energetically related to said input and output circuits, and a frequency stabilizing reactance included in said frequency determining circuit between the control electrode and cathode.

5. An oscillator comprising an electric discharge device having a cathode, anode and impedance control electrode, input and output circuits therefor, a frequency determining circuit energetically related to said input and output circuits, and a frequency stabilizing reactance included in said frequency determining circuit between said anode and cathode.

6. An oscillator comprising an electric discharge device having a cathode, anode and impedance control electrode, input and output circuits therefor, a frequency determining circuit energetically related to said input and output circuits, a plurality of frequency stabilizing reactances included in said frequency determining circuit, one reactance being positioned between the anode and cathode and another reactance being positioned between the control electrode and cathode.

7. An oscillator comprising a space discharge device having output and input circuits, an anti-resonant circuit included in said input circuit, means to transfer energy from said output circuit to said input circuit, and frequency stabilizing means comprising a reactance included in said anti-resonant circuit.

8. An oscillator comprising a space discharge device having input and output circuits each including an anti-resonant circuit, a frequency stabilizing reactance included in the input anti-resonant circuit.

9. An oscillator comprising a space discharge device having a cathode, anode and control electrode, an anti-resonant circuit included between said anode and cathode, an anti-resonant circuit included between said control electrode and cathode, a frequency stabilizing reactance included in the last mentioned anti-resonant circuit, and a reactance included between said anode and control electrode.

10. An oscillator comprising a space discharge device having output and input circuits, an anti-resonant circuit included in said output circuit, means to transfer energy from said output circuit to said input circuit, and frequency stabilizing means comprising a reactance included in said anti-resonant circuit.

11. An oscillator comprising a space discharge device having input and output circuits each including an anti-resonant circuit, a frequency stabilizing reactance included in the output anti-resonant circuit.

12. An oscillator comprising a space discharge device having a cathode, anode and control electrode, an anti-resonant circuit included between said anode and cathode, an anti-resonant circuit included between said control electrode and cathode, a frequency stabilizing reactance included in the first mentioned anti-resonant circuit, and a reactance included between said anode and control electrode.

13. An oscillator comprising a space discharge device having output and input circuits, an anti-resonant circuit included in said output circuit, means to transfer energy from said output circuit to said input circuit, a plurality of frequency stabilizing means each comprising a reactance, one of the said stabilizing means being included in the anti-resonant circuit and another of the stabilizing means being included in the input circuit.

14. An oscillator comprising a space discharge device having output and input circuits, an anti-resonant circuit included in said input circuit, means to transfer energy from said output circuit to said input circuit, a plurality of frequency stabilizing means each comprising a reactance, one of the stabilizing means included in said anti-resonant circuit and another of the stabilizing means included in the output circuit.

15. An oscillator comprising a space discharge device having input and output circuits each including an anti-resonant circuit, a frequency stabilizing reactance included in the anti-resonant circuits.

16. An oscillator comprising a space discharge device having a cathode, anode and a cathode control, input and output circuits therefor, an anti-resonant circuit comprising an inductance and capacity included between said anode and control electrode, a portion of said inductance being included in the input circuit and another portion of said inductance being included in the output circuit, and a frequency stabilizing reactance included in said anti-resonant circuit between said portions of the inductance.

17. An oscillator comprising a space discharge device having a cathode, anode and control electrode, input and output circuits therefor, means to energize said cathode, a source of energy for said output circuit, a high frequency choke coil included between said anode and said source, a high resistance included between said control electrode and said cathode, a high frequency pass condenser included between said anode and cathode,

a frequency determining circuit energetically related to said input and output circuits, and a frequency stabilizing reactance included in said frequency determining circuit.

In witness whereof, I hereunto subscribe my name this 13th day of March, 1931.

FREDERICK B. LLEWELLYN.