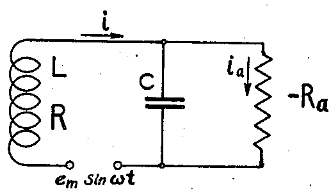
Jan. 10, 1939. L. M. CRAFT 2,142,999

OSCILLATION SYSTEM

Filed July 31, 1935

FIG. 1.



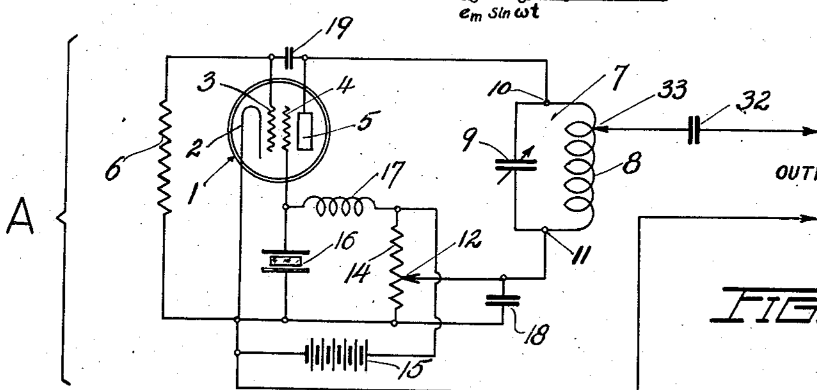


FIG. 2.

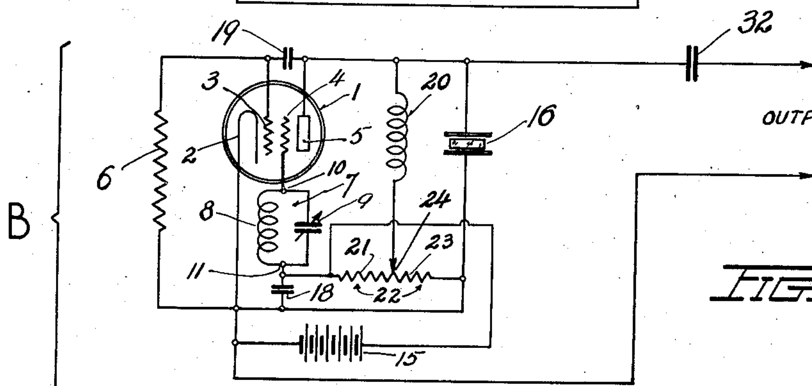


FIG. 3.

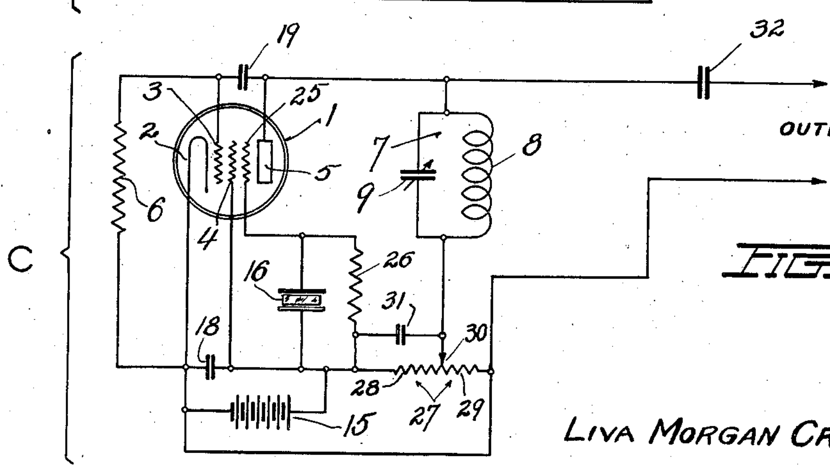


FIG. 4.

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OSCILLATION SYSTEM

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17 Claims. (Cl. 250—36)

My invention relates broadly to oscillation systems and more particularly to a circuit arrangement for a constant frequency oscillator operating according to the principle of negative resistance.

One of the objects of my invention is to provide a method of controlling the frequency of a negative resistance device whereby changes in power supply voltage have minimum effect on the constancy of frequency of oscillations generated thereby.

Another object of my invention is to provide a circuit arrangement for producing oscillations using a negative resistance device having means for more readily establishing a condition of oscillation in the circuit of the device than has heretofore been accomplished.

Still another object of my invention is to provide a circuit arrangement for a negative resistance device having the circuits thereof controlled as to frequency by means of an electromechanical vibrator wherein the frequency of the generated oscillation is chiefly determined by the operation of the electromechanical vibrator.

A further object of my invention is to provide a circuit arrangement for a negative resistance device in which a piezo-electric crystal is employed for determining the frequency of oscillation of the negative resistance device.

A still further object of my invention is to provide an oscillation circuit which includes a negative resistance device constituted by an electron tube including a cathode, a plate, an inner grid electrode, and a positive grid, and/or an outer grid electrode, with a piezo-electric crystal connected in circuit with either the inner grid, the positive grid, or the outer grid electrode for maintaining the frequency of oscillation of the negative resistance device substantially constant.

Other and further objects of my invention reside in the circuit arrangements for the system of my invention as set forth in the accompanying drawing in which:

Figure 1 is a theoretical circuit diagram for illustrating the principles of operation of my invention; Fig. 2 diagrammatically illustrates one embodiment of my invention; Fig. 3 shows a modified circuit arrangement for the system of my invention; and Fig. 4 shows a still further modified form of the circuit of my invention.

My invention contemplates the generation of oscillations employing a negative resistance device constituted by an electron tube containing a cathode, an inner grid, a plate, and a positive or an outer grid connected in circuit for the generation of oscillations without feed-back or regeneration. The circuits of my invention operate wholly upon the principle of negative resistance.

If a negative resistance device be connected to a resonant circuit, sustained oscillations can be produced. Certain factors in the negative resistance device and in the resonant circuit determine the frequency of oscillation, the stability of the frequency, and the range of frequency adjustment. A number of systems are known in the art for producing high frequency oscillations in a negative resistance characteristic circuit.

The theory of the negative resistance oscillator may best be understood by considering the circuit of Fig. 1 in which a resonant combination is represented by inductance L and capacity C, the inherent resistance of the resonant combination by R, and the negative resistance by $-R_a$. The negative resistance is shown connected in parallel with the resonant circuit. Assuming an instantaneous voltage $e_m \sin \omega t$ connected to the terminals shown in Fig. 1, and acting in the circuit to produce currents i and i_a as shown, the current i in the closed circuit can be found from the equation:

$$\{R-R_a(1-\omega^2LC)+j\omega(L-CRR_a)\}i=(1-j\omega CR_a)e \quad (1)$$

which is a development of Ohm's law applied to the circuit of Fig. 1.

The condition for self oscillation of the circuit is $e=0$ which requires that the resistance and reactance components of the left-hand side of the Equation (1) above shall be zero, i. e.:

$$R-R_a\ (1-\omega^2LC)=0 \quad (2)$$

$$\text{and } L-CRR_a=0 \quad (3)$$

By Equation (2) the frequency of oscillation is found to be:

$$\omega=\frac{1}{\sqrt{LC}}\cdot\sqrt{1-\frac{R}{R_a}} \quad (4)$$

or very approximately,

$$\omega\approx\frac{1}{LC}\cdot\left(1-\frac{R}{2R_a}\right)$$

Equation (3) above gives as the resistance condition for oscillation

$$R_a=\frac{L}{CR} \text{ or } R-\frac{L}{CR_a}=0 \quad (5)$$

the physical significance of which is that the resistance R is effectively cancelled by the negative series resistance L/CR_a which is equivalent to the negative shunt resistance R_a. R_a is in shunt with the oscillatory circuit, so that the smaller R_a, the larger is the negative resistance it effectively produces in series with the oscillatory circuit. That is, the smaller R_a, the greater the current rise for a given decrease in voltage, and conversely, the greater the current decrease for a given rise in voltage; which means a larger effective negative resistance.

There is a limit to the smallness of R_a below which oscillation will not occur even though R is effectively cancelled by the negative series resistance L/CR_a. Extraneous parasitic conditions apparently prevent oscillation in such cases. The system of my invention is adapted to extend this limit, whereby oscillations of very high frequency may be generated, and the frequency range of the system thereby be broadened, while maintaining stability in the oscillations.

Fig. 2 of the drawing shows one embodiment of my invention comprising a tube **1** which may have a direct or indirectly heated cathode **2**, an inner grid **3**, a positive grid **4**, and a plate **5**. A resistor **6** connects between the cathode **2** and the inner grid **3** for biasing the inner grid **3**. A condenser **19** is connected between plate **5** and inner grid **3** to provide an external path between these electrodes. A tank circuit **7** comprising inductance **8** and variable condenser **9** has one terminal **10** thereof connected to plate **5**. The opposite terminal **11** of resonant tank circuit **7** connects to a tap **12** on potentiometer **14**. The potentiometer **14** is connected in circuit with positive grid **4** and cathode **2**. A high potential battery or other source **15** of the order of one hundred volts or more connects between the cathode **2** and the positive grid **4**.

The frequency control means comprises a piezo crystal **16** disposed in circuit between the cathode **2** and the positive grid **4**. A high frequency choke coil **17** is connected between the positive grid end of potentiometer **14** and the positive grid **4**. A by-pass condenser **18** is connected across that portion of potentiometer **14** which is included between the tap **12** and the cathode end of the potentiometer.

The operation of the circuit is as follows:

Secondary electrons are emitted from the plate **5** and form a current flowing back to the positive grid **4** by reason of the fact that the plate potential is adjusted to a value lower than that of the positive grid **4**. If the impedance in the circuit of positive grid **4** is large, the negative resistance appearing across tank circuit **7** will be large and only weak oscillations or no oscillations will occur. However, as the tank circuit is tuned through the frequency of the crystal, the circuit abruptly assumes the crystal frequency and tuning of the resonant tank circuit produces a negligible change in frequency over a limited range of adjustment. The frequency of oscillation is apparently such that the crystal presents a low impedance in the oscillation currents. The circuit has the advantage over a non-crystal controlled dynatron in that the frequency is chiefly determined by the crystal and minor changes in the resonant tank circuit have negligible effects. The circuit has the advantage over the feed-back type of crystal oscillator in that oscillations are more readily obtained and that changes in supply voltage have less effect on the generated frequency.

I have designated the form of oscillator heretofore described as form A of my invention. Forms B and C for the circuit of my invention are illustrated in Figs. 3 and 4.

In Fig. 3, the tank circuit **7** has the terminal **10** thereof connected to the positive grid **4** while the electro-mechanical vibrator or piezo-electric crystal **16** is connected to the plate **5**. The potential supplied to the plate **5** from battery source **15** is supplied through a series path which includes the high frequency choke coil **20**. The potential for the positive grid **4** is supplied directly from the source **15**. A potentiometer **22** is connected across the source **15** and divided into portions **21** and **23** by the tap connection **24**. The potential for the plate **5** is supplied from the tap **24** through the drop in the portion **21** of the potentiometer **22**. The inner grid **3** is connected with the cathode **2** through the leak resistor **6**. By-pass condenser **19** functions as heretofore explained in connection with form A of my invention.

In Form C of my invention, the frequency control element **16** is connected in circuit with the outer grid **25** disposed between the positive grid **4** and the plate **5**. In this arrangement, as illustrated in Fig. 4, the tank circuit **7** is connected in circuit with the plate **5**. The piezo-electric crystal **16** is shunted by means of a resistor **26**. The plate potential is obtained from source **15**, the value of the potential being determined by the potentiometer **27** having portions **28**, **29** tapped at **30** with a connection leading through resonant circuit **7** to plate **5**. By-pass condenser **31** is disposed across portion **28** of the potentiometer.

In the several circuits which I have illustrated, it is possible to eliminate the inner grid **3** and the condenser **19** and still secure oscillations having a high degree of stability. The output of the oscillator may be taken off through a condenser connected to the plate or other electrode or across the piezo-electric crystal. In form A of my invention illustrated in Fig. 2, I have shown the output circuit coupled through condenser **32** which connects to a tap **33** on inductance **8** of resonant circuit **7**, the opposite side of the output circuit being connected to cathode **2**. In form B of my invention, illustrated in Fig. 3, the output circuit connects across piezo-electric crystal **15** as illustrated. In form C of my invention, coupling condenser **32** connects to the plate **5**, the other side of the output circuit being connected to the cathode **2**.

The condenser **19** in all forms of the circuit of my invention which provides an external path between plate **5** and inner grid **3** serves as a means for neutralizing interelectrode capacity and preventing feed-back interference in the oscillating system.

Inasmuch as the current through positive grid **4** decreases as the positive grid potential increases, and the potential decreases as the current increases, the grid-cathode path is said to have a negative resistance as far as current and voltage changes are concerned. If Equation (5) above is satisfied, the circuits illustrated will oscillate at a frequency determined by the elements in the circuit as provided in Equation (4) above. R_a is the negative resistance of the grid-cathode path and R the resistance in the external circuit, which is substantially that of the inductance L. The resonant circuit has a shunt impedance less than the negative impedance of the grid-cathode path.

The arrangement in the system of my invention whereby, in effect, the oscillatory circuit is employed merely to control the quantity of electrons sent to the anode relieves the resonant tank circuit of a varying load which would adversely affect the stability of the oscillations generated.

The oscillating system of my invention is able to produce oscillations of ultra-high frequencies, and is stable in operation, producing waves of uniform shape and constant frequency. The frequency of oscillation is adjustable over a very broad range of frequency, which makes the system of my invention applicable to a large number of uses. The circuit of my invention is simple in arrangement and operation, and extremely practical in use as an oscillation generator in any of the instances where such is required.

While I have shown and described my invention in certain of its preferred embodiments, I desire that it be understood that modifications may be made and that no limitations upon my invention are intended other than may be imposed by the scope of the appended claims.

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

1. An oscillation system comprising an electron tube including a cathode, an inner grid, a second grid, and a plate, a resonant circuit connected between the plate and cathode, a frequency stabilizing element connected between said second grid and said cathode, a resistance connected between said inner grid and said cathode, means for supplying a positive potential to said plate and a higher positive potential to said second grid whereby the plate-cathode path in said electron tube has a negative resistance, a neutralizing condenser connected between said anode and said inner grid, and an output circuit connected with said cathode and a point in said resonant circuit.

2. An oscillation generator comprising an electron tube including a cathode, an inner grid, a second grid, and a plate, a resonant circuit connected between said second grid and said cathode, a frequency stabilizing element connected between said plate and said cathode, a resistance connected between said inner grid and said cathode, means for supplying a positive potential to said plate and a higher positive potential to said second grid whereby the plate-cathode path in said electron tube has a negative resistance, a neutralizing condenser connected between said anode and said inner grid, and an output circuit connected across said frequency stabilizing element.

3. A high frequency oscillation generator comprising an electron tube device including plate, cathode, inner grid and grid electrodes, means whereby said plate in said device is operative to produce secondary electron emission; a resonant circuit comprising a condenser and an inductance disposed in parallel, said resonant circuit being connected in series between said grid and cathode electrodes and operative to sustain oscillations produced therein by virtue of said secondary electron emission from said plate, a piezo-electric device connected in circuit between said plate and said cathode and operative to stabilize such oscillations at the natural frequency of vibration of said piezo-electric device and a condenser disposed in circuit between said inner grid and said plate electrode.

4. A high frequency oscillation generator comprising an electron tube device including plate, cathode, inner grid and grid electrodes, means whereby the plate electrode in said device is operative to produce secondary electron emission; a resonant circuit comprising a condenser and an inductance disposed in parallel, said circuit being connected in series between said grid and cathode electrodes and operative to sustain oscillations produced therein by virtue of said secondary electron emission from said plate, a frequency determining element connected in circuit between said plate and said cathode and operative to stabilize such oscillations at the natural frequency of vibration of said frequency determining element and a neutralizing condenser connected between said inner grid and said plate electrode.

5. A high frequency oscillation generator comprising an electron tube device including a cathode, a plate, an inner grid, and a second grid electrode; a source of potential, said second grid being supplied with a high positive potential and said plate with a lower positive potential from said source of potential, the negative terminal of said source of potential being connected to said cathode; a resonant device connected in series between said positive grid and said cathode, said plate being operative to produce secondary electron emission whereby sustained oscillations are produced in said resonant device, an inductance having one terminal connected with said plate and the other terminal connected through a high frequency path to said cathode, a condenser connected to the terminals of said inductance and forming therewith a resonant circuit, another condenser having one capacity area thereof connected to said inner grid and the other capacity area thereof connected to the terminal of said inductance in common with the plate connection thereto, whereby the interelectrode capacity between said plate and grid electrodes is neutralized and feed-back interference in the oscillating grid circuit prevented.

6. An oscillation generator comprising an electron tube having a cathode, a grid, an inner grid, and a plate electrode, means for supplying a positive potential to said grid electrode and a lower positive potential to said plate electrode with respect to said cathode, a frequency control device disposed in series between said grid and said cathode electrode, a resonant circuit disposed in series between said plate and said cathode electrodes, said plate operating to emit secondary electrons with respect to said grid whereby oscillations are produced in said resonant circuit stabilized by said frequency control device and a circuit connected between said inner grid and said plate and including a device for neutralizing interelectrode capacities in said electron tube.

7. A generator comprising an electron tube having cathode, grid, inner grid and plate electrodes, means for supplying potentials to said electrodes, and applying a positive charge to said grid in excess of a positive potential impressed upon said plate, a tuned circuit disposed in series between said grid and said cathode, a piezo-electric device disposed in circuit between said plate and said cathode and a neutralizing condenser connected between said inner grid and said plate electrode.

8. A generator comprising an electron tube having cathode, grid, inner grid, and plate electrodes, means for supplying potentials to said electrodes, and applying a positive charge to said grid in excess of a positive potential impressed upon said plate, a tuned circuit disposed in series between said grid and said cathode, an electromechanical vibrator disposed in circuit between said plate and said cathode and a condenser connected between said inner grid and said plate electrode for neutralizing interelectrode capacities in said electron tube.

9. In a high frequency generator, an electron

tube including a cathode, a grid, an inner grid and a plate, a potentiometer device, means for supplying a voltage across said potentiometer device, and connections from said potentiometer device to said plate and said grid for impressing a higher positive potential on said grid than on said plate with respect to said cathode, a frequency control device in circuit between said plate and said cathode, a tunable resonant circuit connected between said grid and said cathode and a condenser connected between said inner grid and said plate electrode.

10. A dynatron oscillating circuit comprising an electron tube device having plate, cathode and at least two grid electrodes, means for maintaining one of said grid electrodes and said plate at respectively higher and lower positive potentials with respect to said cathode, and a resonant circuit connected between said plate and said cathode, whereby oscillations are produced in said resonant circuit by virtue of negative internal resistance between the plate and cathode of said electron tube device; means for stabilizing the oscillations in said resonant circuit including an electromechanical vibratory device connected with the said one of the grid electrodes and with said resonant circuit and said cathode; means for biasing another of said grid electrodes at a static potential with respect to said cathode for governing the operation of said oscillating circuit, and a condenser connected between said last mentioned grid electrode and said plate.

11. A dynatron oscillating circuit comprising an electron tube device including plate, cathode, inner grid, and grid electrodes, means for maintaining said grid electrode and said plate at respectively higher and lower positive potentials with respect to said cathode whereby said electron tube device exhibits a negative resistance between cathode and plate electrodes, a resonant circuit connected in parallel with the negative resistance whereby oscillations are produced in said resonant circuit, a series circuit including said resonant circuit and a frequency stabilizing device connected between said plate and the said grid electrode whereby the oscillations produced in said resonant circuit are stabilized by the operation of said frequency stabilizing device and an impedance element connected between said inner grid and said plate electrode.

12. A dynatron oscillating circuit comprising an electron tube device having plate, cathode and a plurality of grid electrodes, means for maintaining a first of said grid electrodes and said plate at respectively higher and lower positive potentials with respect to said cathode, and a resonant circuit connected between said plate and said cathode, whereby oscillations are produced in said resonant circuit by virtue of negative internal resistance between the plate and cathode of said electron tube device; means for stabilizing the oscillations in said resonant circuit including an electromechanical vibratory device connected with the said first of said grid electrodes and with said resonant circuit and said cathode; means for biasing a second of said grid electrodes at a higher positive potential than the said first of said grid electrodes with respect to said cathode for controlling the negative internal resistance characteristic of said electron tube device; means for biasing a third of said grid electrodes at a static negative potential with respect to said cathode for governing the operation of said oscillating circuit, and a condenser connected between said last mentioned grid electrode and said plate.

13. A stabilized dynatron oscillation system comprising an electron tube device having plate, cathode, and at least two grid electrodes, means for maintaining one of said grid electrodes and said plate at respectively higher and lower positive potentials with respect to said cathode whereby said electron tube device is operative with an internal negative resistance between plate and cathode, a series circuit including a resonant circuit and an electromechanical frequency stabilizing device connected between said plate and said one of the grid electrodes, a connection from a point intermediate said resonant circuit and said stabilizing device to said cathode, means for biasing another of said grid electrodes at a static potential with respect to said cathode for governing the operation of said oscillation system and a condenser connected between said last mentioned grid electrode and said plate.

14. A dynatron oscillation system comprising an electron tube device having plate, cathode, grid and inner grid electrodes, means for maintaining said grid electrode and said plate at respectively higher and lower positive potentials with respect to said cathode, a series circuit including a resonant circuit and a piezo-electric crystal connected between said plate and said grid electrode and a capacity neutralizing condenser connected between said inner grid electrode and said plate.

15. A dynatron oscillating circuit comprising an electron tube device including cathode, grid, inner grid, and plate electrodes, means for maintaining said grid electrode and said plate at respectively higher and lower positive potentials with respect to said cathode whereby said electron tube device exhibits a negative resistance between cathode and plate electrodes, a resonant circuit connected between plate and cathode, an electromechanical resonant device connected between said grid and cathode whereby a high impedance is presented to alternating currents in the plate cathode circuit and the impedance between grid and cathode is sufficiently low at the resonant frequency of the crystal to sustain oscillations at a frequency determined by the natural period of the crystal and an impedance connected between said inner grid and said plate.

16. A dynatron oscillating circuit as set forth in claim 15 and including, in combination therewith, means for biasing said inner grid at a lower potential than the said positively charged grid.

17. A dynatron oscillating circuit as set forth in claim 15 and wherein said impedance which connects between said inner grid and said plate is constituted by a neutralizing condenser.

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