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NEGATIVE RESISTANCE DEVICE

Filed Aug. 4, 1930

FIG. 1.

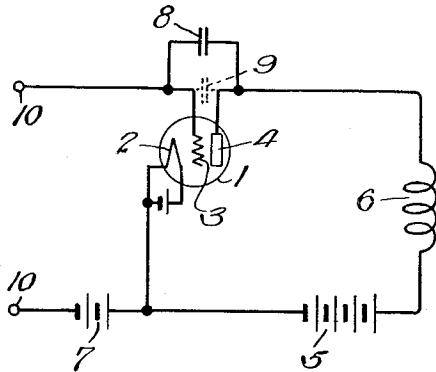


FIG. 4.

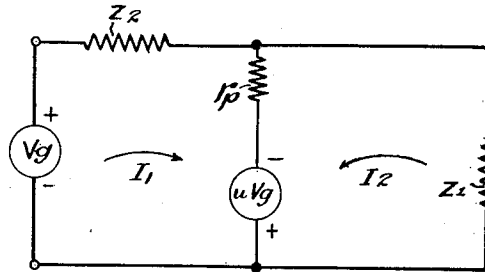


FIG. 2

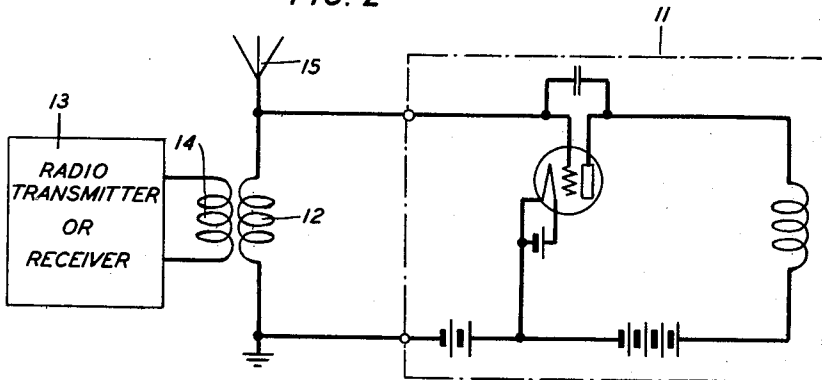
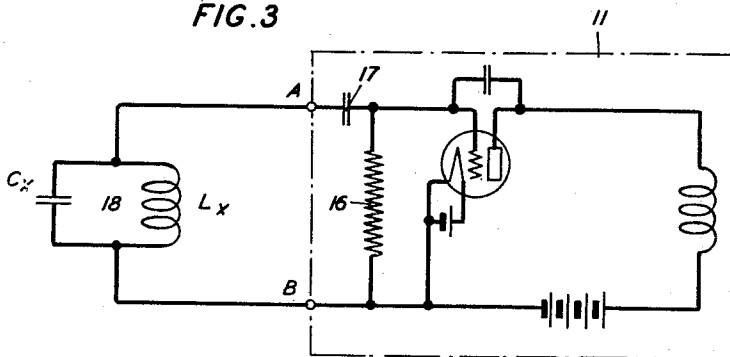


FIG. 3



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NEGATIVE RESISTANCE DEVICE

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8 Claims. (Cl. 178-44)

Detailed description

This invention relates to negative resistances, and more particularly to negative resistances employing, for obtaining the negative resistance effect, a vacuum tube of the three-electrode type operating without secondary electron emission.

A number of types of negative resistance are known. Among these are those utilizing special vacuum tube arrangements employing more than three electrodes, those making use of secondary electron emission effects and others utilizing three-electrode tubes without secondary emission.

The present invention relates to the third class. Its object is to simplify the circuit arrangements employed, particularly to reduce the number of tubes required; to render the circuits employing negative resistances free from self-oscillation at all frequencies; to render the negative resistance constant with frequency and limited numerically to a definite value; to render the negative resistance effective at high frequencies; and to free the negative resistance from the variations in value with changes in frequency that are imposed by inductive coupling.

Another object is to render an oscillating circuit less sensitive to frequency variation with changes of battery potentials.

A negative resistance in accordance with the present invention comprises the impedance presented by the grid filament terminals of an ordinary vacuum tube under the following conditions:

1. Plate circuit impedance substantially inductive.
2. Impedance between the grid and plate substantially capacitive.
3. External plate circuit reactance less than the grid-plate reactance.
4. External plate reactance small as compared with the internal plate resistance of the tube.

Under these conditions one may obtain, by the use of a single tube, and without the necessity of an external coupling, the effect of a negative resistance in series with a capacity.

With the limitation that the external plate circuit reactance is small as compared with the grid-plate reactance, the capacity becomes constant over a large frequency range and moreover it is approximately constant irrespective of the value of the internal plate resistance of the vacuum tube. If, in addition, the external plate circuit reactance is made small as compared with the internal plate resistance of the tube, the negative resistance also becomes constant over a wide range of frequencies and is never larger in magnitude than it is in the said range of frequencies.

The optimum condition for constancy of capacity and negative resistance is that the plate circuit and grid-plate impedances be as nearly as possible purely inductive and capacitive, respectively.

The various features and characteristics of the negative impedance device of this invention will be better understood by reading the following description in connection with the accompanying drawing, in which:

Fig. 1 is a schematic diagram of a circuit in accordance with the invention;

Fig. 2 shows an application of the invention to a radio transmitting or receiving system;

Fig. 3 shows a constant frequency oscillator utilizing the invention; and

Fig. 4 represents the equivalent electrical network of the circuit of Fig. 1 in a form useful in the mathematical analysis of such circuit.

Referring to Fig. 1 of the drawing, the negative impedance device shown therein comprises a space discharge device 1 having a cathode or filament 2, a grid or control electrode 3 and an anode or plate 4. The space current of discharge device 1 may be supplied by battery 5 through inductance 6. The grid potential is adjusted to a suitable negative value by means of biasing battery 7. Between grid and plate electrodes is connected condenser 8.

In explaining the operation of this circuit it will be assumed that element 6 is a pure inductance of value L ; that the grid-plate impedance is a pure capacity C . The internal or plate resistance of the discharge device will be assumed a pure resistance of value r_p . The shunt capacity and resistance of the input circuit may be disregarded since they are effectively in parallel with the impedance of the external circuit and may be considered as a part thereof. Similarly, the grid-plate inter-electrode capacity of the tube is included in the capacity represented by C . In fact, in many cases, especially where the particular value of C_0 is of little concern, the external feed-back condenser 8 may be dispensed with, R_0 being adjusted by the proportioning of other elements determining its value, the terms C_0 and R_0 representing respectively the capacitive and resistance components of the input impedance Z_1 .

It can be shown that with these assumptions

$$R_0 = \frac{r_p \left[(1 + \mu) \omega^2 L^2 - \frac{\mu L}{C} \right]}{r_p^2 + (1 + \mu)^2 \omega^2 L^2} \quad 110$$

$$C_0 = \frac{r_p^2 + (1 + \mu)^2 \omega^2 L^2}{\omega^2 \left[\frac{L^2}{C} (1 + \mu) - r_p^2 L \right] + \frac{r_p^2}{C}} \quad 115$$

The above equations may be derived as follows with the assistance of the equivalent electrical network of Fig. 4:

In determinant form the circuit equations are: smaller than r_p , we may neglect the last term of both numerator and denominator, giving

$$\begin{vmatrix} \frac{I_1}{r_p + Z_2} & \frac{I_2}{r_p} \\ r_p & r_p + Z_1 \end{vmatrix} = \frac{(1+\mu)V_g}{\mu V_g} \quad (3)$$

whence

$$I_1 = V_g \left[\frac{(\mu+1)Z_1 + r_p}{r_p Z_1 + r_p Z_2 + Z_1 Z_2} \right]$$

Now

$$Z_0 = \frac{V_g}{I_1}$$

Putting

$$Z_2 = -\frac{i}{\omega C} Z_1 = i\omega L$$

we get

$$Z_0 = \frac{\frac{L}{C} + i\left(\omega L - \frac{1}{\omega C}\right)r_p}{r_p + i(1+\mu)\omega L}$$

The real part of this is R_0 and the imaginary part is

$$X_0 = -\frac{i}{\omega C_0}$$

Thus:

$$R_0 = \frac{r_p \left[(1+\mu)\omega^2 L^2 - \mu \frac{L}{C} \right]}{r_p^2 + (1+\mu)^2 \omega^2 L^2} \quad (1)$$

$$X_0 = -\frac{1}{\omega C_0} = \frac{r_p^2 \left(\omega L - \frac{1}{\omega C} \right) - \frac{\omega L^2}{C} (1+\mu)}{r_p^2 + (1+\mu)^2 \omega^2 L^2}$$

So that

$$C_0 = \frac{r_p^2 + (1+\mu)^2 \omega^2 L^2}{\omega^2 \left[\frac{L^2}{C} (1+\mu) - r_p^2 L \right] + \frac{r_p^2}{C}} \quad (2)$$

(1) and (2) are the required relations.

Assume that the plate circuit reactance ωL be considerably less than the grid-plate reactance

$$\frac{1}{\omega C}$$

and that the amplification factor μ , multiplied by the external plate circuit reactance ωL , is substantially less than the internal plate circuit resistance r_p .

With the assumptions given in the above paragraph the following relations are easily seen to be true from the above equations:

$$C_0 = C \text{ and } R_0 = \frac{\mu L}{Cr_p}$$

The above equations for C_0 and R_0 may be obtained from Equations (1) and (2) as follows:

Let

$$\omega L \ll \frac{1}{\omega C} \left\{ \begin{array}{l} \text{then } \omega^2 LC \ll 1 \\ \text{and } \omega^2 L^2 \ll \frac{L}{C} \end{array} \right.$$

The denominator of (2) may be written

$$\frac{1}{C} [r_p^2 (1 - \omega^2 LC) + \omega^2 L^2 (1 + \mu)]$$

which is nearly

$$\left[\frac{1}{C} r_p^2 + \omega^2 L^2 (1 + \mu) \right]$$

since $\omega^2 LC \ll 1$. Thus (2) becomes:

$$C_0 = C \left[\frac{r_p^2 + (1 + \mu)^2 \omega^2 L^2}{r_p^2 + (1 + \mu) \omega^2 L^2} \right], \text{ nearly}$$

In practical cases, this is nearly independent of frequency. However, when

$$(1 + \mu)\omega L \ll r_p$$

which means that the anode reactance is much

Again, in (1) when, as above,

$$(1 + \mu)\omega L \ll r_p$$

we may neglect the last term in the denominator giving

$$R_0 = \frac{1}{r_p} \left[(1 + \mu)\omega^2 L^2 - \mu \frac{L}{C} \right]$$

But the first term of this may be neglected in comparison with the second because

$$\omega^2 L^2 \ll \frac{L}{C}$$

as stated above. This gives

$$R_0 = -\frac{\mu L}{Cr_p} \quad (4)$$

(3) and (4) are the required relations.

By properly proportioning the various constants of the circuit, practically any combination of negative resistance and positive capacity may be obtained. So far as stability is concerned, high frequency is no limitation, for the stability of the circuit is dependent, not on the absolute value of C_0 and R_0 , but on the ratio of

$$\frac{1}{\omega C} \text{ to } \omega L,$$

the latter quantities being variable at will. Not only are the capacity and negative resistance constant over a given range of frequencies for which the circuit may be designed, but at no frequency outside the selected range will the resistance become more negative than the selected value. Hence, when the device is associated with a resonant circuit, its negative resistance may be held constant at some value less than the positive resistance of the reactive circuit so that the total resistance of the circuit will be always a positive value. Oscillations then, due to the combination of a negative resistance and a resonant circuit, can never develop.

The above described feature of the invention is utilized in the radio transmitting or receiving system of Fig. 2, where the negative impedance circuit 11 is associated with the antenna coupling coil 12 to reduce its resistance to signal currents flowing in the antenna circuit. To avoid the development of an oscillating condition in the circuit comprising the negative resistance and coil 12, the total resistance in that circuit must always be positive. Hence it is essential that the negative resistance of circuit 11 never exceed the positive resistance of the coil. The characteristic of the negative impedance device of this invention being such that its negative resistance is never greater (i. e., in negative value) outside the frequency range for which it is designed than it is within that range, the circuit of Fig. 2, therefore, will not "sing" at any frequency.

The variation of phase relation in an inductively coupled feed-back circuit, an inherent limitation of the frequency range of certain types of negative impedance circuits, is avoided in the present invention. Capacity between the grid and plate of the vacuum tube has no detrimental action in applicant's circuit, in fact, it is used alone or as a supplement to a condenser connected between these two electrodes.

Fig. 3 shows a constant frequency oscillator comprising a negative impedance circuit 11 and

an anti-resonant circuit 18 connected across its terminals. One of the conditions for oscillation is that the effective resistance of the anti-resonant circuit 18 be equal to the negative resistance across the terminals A-B. The other condition is that the reactance of the circuit to the right of A-B be equal and opposite to that presented by the anti-resonant circuit. A grid leak 16 and blocking condenser 17 are provided to maintain grid 3 at a negative potential.

In order that the frequency of oscillation be constant it is essential that the values of the various reactive elements of the oscillatory circuit, viz. C_0 , C_x and L_x , be invariable. C_x and L_x satisfy this condition, and it has been found that C_0 is practically independent of both L and r_p . With the frequency thus independent of r_p , fluctuations in battery potential, which would tend to alter the latter quantity, have practically no effect in altering the frequency of the oscillator.

In a specific case where L is 0.01 henry, C is 50 mmf. and r_p is 5000 ohms, a change of 10% in the latter quantity results in a change in C_0 of only 0.1 mmf. In applicant's oscillatory circuit where C_0 is only a part of the total capacity, the change in C_0 has much less than a proportionate effect on the frequency.

From the foregoing description of a particular embodiment of applicant's invention, may be understood the novel features of the invention as pointed out by the appended claims.

What is claimed is:

1. An impedance device having a negative resistance component comprising a space discharge tube having an anode, a cathode, and a control electrode, a condenser between said anode and said control electrode, a positive reactance device located in the anode circuit of said tube and having a reactance magnitude which is considerably less than the reactance of said condenser and which is less than the internal anode circuit resistance of said tube.

2. A circuit having a negative resistance component comprising a space discharge device having an anode, a cathode and a control electrode, a reactance in the output circuit of said discharge device of a value which is considerably less than the anode-control electrode reactance and which when multiplied by the amplification factor is substantially less than the internal plate resistance of said discharge device, and terminals for connecting said cathode and control electrode to an external circuit.

3. An impedance device containing a negative resistance component comprising a three-electrode vacuum tube, a condenser between the anode and control electrode thereof, a positive reactance in the anode circuit of said tube which is considerably less than the anode-control electrode reactance and which when multiplied by the amplification factor is substantially less than the internal anode circuit resistance of said tube and which remains positive over a wide range of working frequencies.

4. A negative resistance device comprising a space discharge device having an anode, a cathode, and a control electrode, capacity between said control electrode and anode, an impedance in the anode circuit of said device whose resistance is low and whose reactance is considerably less than the anode-control electrode reactance and when multiplied by the amplification factor is substantially less than r_p , where r_p is the internal anode circuit resistance of said discharge device, and two terminals connected to said cathode and control electrodes across which the desired negative impedance is to be presented.

5. An impedance device having a negative resistance component comprising a single space discharge tube having an anode, a cathode and a control electrode, a capacitive reactance between said anode and control electrodes, and an inductive reactance in the anode circuit of said tube which is substantially less than the internal resistance of said tube and said capacitive reactance.

6. A circuit comprising a three-element vacuum tube for producing at its input terminals the effect of a negative resistance and a positive capacity in series, said vacuum tube having a condenser between its plate and grid electrode, the output circuit of said tube being of low resistance and of a reactance which is considerably less than the plate-grid reactance and when multiplied by the amplification factor is small compared with the internal plate circuit impedance of said tube.

7. A constant frequency oscillator comprising the negative impedance device of claim 5 and 120 an anti-resonant circuit connected to the input terminals thereof.

8. The combination of a negative impedance in accordance with claim 5 and an inductive element associated with the input terminals thereof, for producing oscillations having a frequency substantially independent of plate battery voltage fluctuations.

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