Oct. 21, 1930. F. H. GRAHAM 1,779,126

NEGATIVE RESISTANCE CIRCUITS

Filed Aug. 1, 1927

FIG. 1.

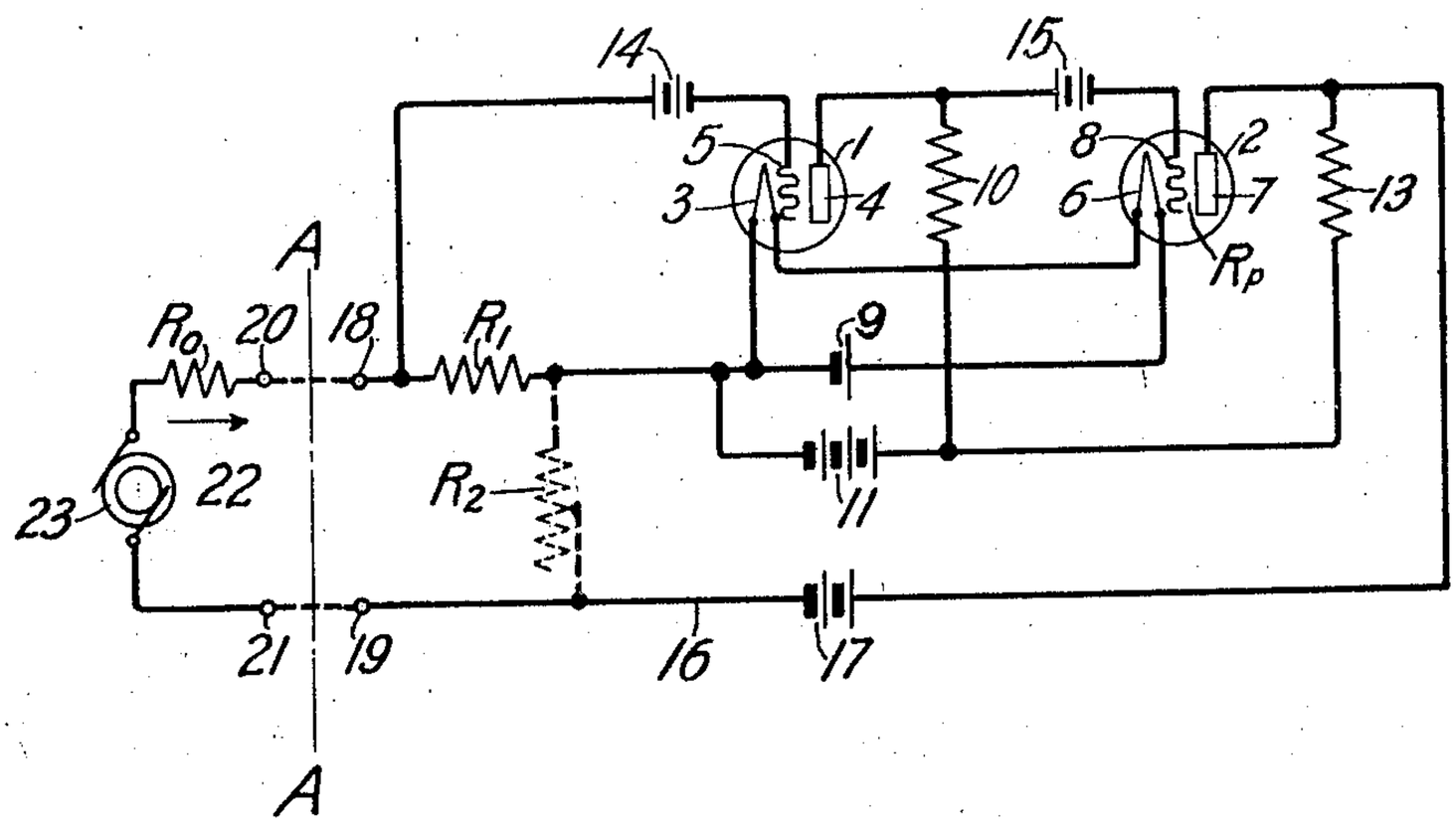
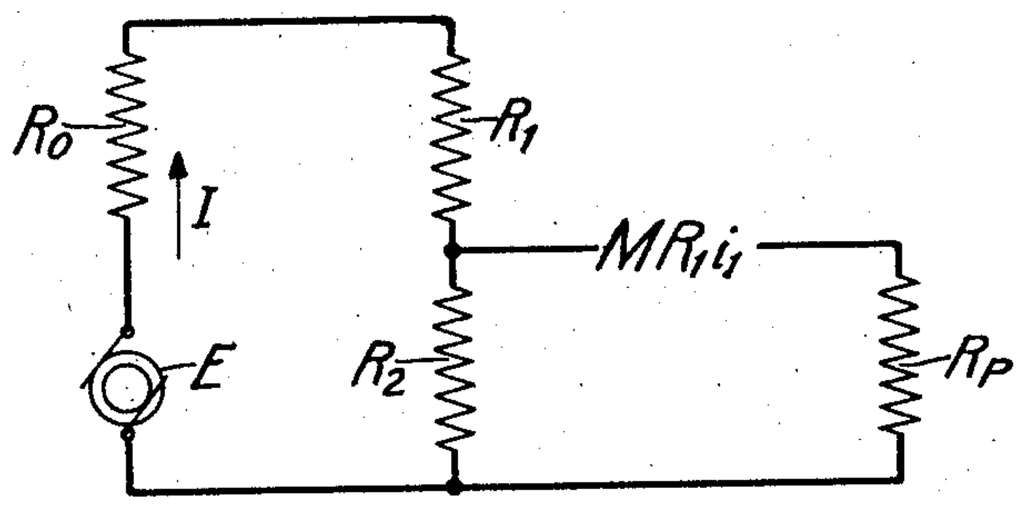


FIG. 2.



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NEGATIVE RESISTANCE CIRCUITS

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This invention relates to a method of and means for obtaining negative resistance and particularly to a method and means for obtaining a negative resistance utilizing space discharge devices.

In the prior art, circuits using vacuum tube amplifiers for securing negative resistances have been known for some time. Various vacuum tube circuits for this purpose are shown, for example, in an article entitled "Resistance neutralization—an application of thermionic amplifier circuits," by Bennett and Peters, pages 234 to 248 of the Journal of the A. I. E. E. vol. 41 (1922). These circuits, however, as they all utilize inductive feed-back arrangements for this purpose, produce a negative resistance which is a function of frequency.

In accordance with the present invention a new circuit arrangement for obtaining negative resistance which is independent of frequency over a wide range of frequencies is provided. This circuit arrangement in a preferred embodiment comprises an amplifier circuit having two vacuum tube stages, resistance-coupled, and a feed-back resistance coupling between the output circuit of the last stage and the input circuit of the first stage. In this circuit, between terminals connected respectively to the grid of the first tube and the plate of the last tube, a negative resistance is obtained which is a function of the constants of the circuit and which may be expressed in terms of the plate circuit resistance of the last tube, the resistance in the input circuit of the first tube and the net voltage amplification of the amplifier circuit. The negative resistance thus obtained is advantageous in that it remains stable over a wide range of frequencies, and may easily be made to vary between widely different limiting values by suitably adjusting the elements of the circuit.

The various features and objects of the invention will be better understood from the following detailed description thereof when read in connection with the accompanying drawing, in which:

Fig. 1 shows diagrammatically one embodiment of the circuit of the invention as applied to the neutralization of resistance in an electrical circuit; and

Fig. 2 is a simplified circuit illustrating the theory and operation of the circuit of Fig. 1.

In Fig. 1, to the right of the dot-dash line A—A, is shown an arrangement in accordance with the invention for obtaining a negative resistance, comprising a resistance-coupled amplifier circuit of two stages, the first stage comprising a space discharge device 1 having a cathode or a filament 3, an anode or plate 4, and a control electrode or grid 5, and the second stage comprising a space discharge device 2 having a cathode or filament 6, an anode or plate 7 and a control electrode or grid 8. The cathodes, 3 and 6, respectively, of tubes 1 and 2 are connected together and may be heated by a common battery 9. The output circuit of tube 1 and the input circuit of tube 2 are coupled through coupling resistance 10, common to the two circuits. The space current for tube 1 is supplied by battery 11 through coupling resistance 10 to the plate 4 of tube 1. Similarly, space current for tube 2 is supplied by battery 11 through battery feed resistance 13 to the plate 7 of the tube 2. The grid potentials of tubes 1 and 2 respectively, are adjusted to any suitable values by the grid batteries 14 and 15 in the respective input circuits of the tubes. The grid 5 of tube 1 is connected through grid battery 14 and resistance R_1 to cathode 3 of tube 1, and through grid battery 14, resistance R_1, variable resistance R_2, conductor 16, and battery 17 to the plate 7 of tube 2. Battery 17 is poled so as to oppose plate battery 11 and its potential is adjusted so that for the condition in the circuit, when no external voltage is impressed upon resistances R_1 and R_2, there is no current flowing in conductor 16. Terminals 18 and 19 are connected respectively to the remote ends of resistances R_1 and R_2.

Connected to the terminals 20 and 21 to the left of the dot-dash line A—A is shown diagrammatically an electrical circuit 22, in which the generator 23 represents a source of electromotive force which is assumed to have zero internal impedance, and R_0 repre-

sents the net positive resistance of circuit 22.

When the terminals 20 and 21 are joined through a suitable electric circuit, the generator 23 drives a current in the direction indicated by the arrow through the resistance R_0, the magnitude of which is dependent on the value of the resistance in the circuit. It is desired to insert in the electrical circuit across the terminals 20 and 21 a network which will act as a negative resistance, that is, act in a sense to effectively neutralize the effect of a part of the positive resistance R_0 in the circuit so that the current flowing therein will be larger than the current which is produced by the generator 23 alone. In accordance with the invention, this result is accomplished by connecting the terminals 18 and 19 of the amplifier circuit by suitable means to the terminals 20 and 21 of circuit 22, which provides a negative resistance between those terminals which is a function only of the constants of the amplifier circuit, i. e. of the value of the elements R_1, R_2, the anode to cathode resistance of tube 2 and the net voltage amplification of the amplifier circuit, and is independent of the value of the electromotive force produced by generator 23 in the circuit. By adjusting the values of the elements referred to, it has been found that a negative resistance of any desired value may be obtained, this negative resistance being independent of frequency over a wide range of frequencies and also independent of the external circuit electromotive force and impedance.

In order that the negative resistance thus obtained should be stable and free from so-called "singing effects", it is necessary, as will be explained below, to select the elements of the circuit so that the negative resistance is at all times less than the positive resistance which it faces, that is, so that the net impedance of the circuit as a whole is positive.

The operation of the circuit of Fig. 1 will now be described: Let it be assumed that the alternating current produced by generator 23 will flow through the resistances R_0, R_1 and R_2 in a direction indicated by the arrow. The drop in potential in resistance R_1 due to the current flowing through it will cause a decrease in the negative voltage applied to the grid 5 of tube 1 and a resultant increase in the average current flowing through resistance 10 in the output circuit of tube 1. The resultant drop in potential in the resistance 10 will cause an increase in the negative potential applied to grid 8 of tube 2, and thus a decrease in the average current in the output circuit of the tube which due to the impedance thereto offered by resistance 13 will be fed back through conductor 16 in the direction indicated by the dotted arrow to electrical circuit 22 and will be in phase with the current produced in that circuit by the generator 23. The magnitude of this superposed current will depend on the value of the resistance R_2 in that circuit, and a maximum value for this current will be obtained by making R_2 infinite. It may be desired, however, to limit the amount of superposed current, and this may be done by adjusting resistance R_2 to a suitable value.

By inserting the circuit arrangement shown to the right of the dot-dash line A—A in circuit 22, therefore, the current flowing in the latter circuit may be increased without necessitating an increase in the potential of generator 23. It appears, therefore, that the network inserted between terminals 20 and 21 of circuit 22 will act as a negative resistance, as in effect neutralizes a part of the positive resistance in circuit 22.

The theory on which the invention is based will be clear from the following explanation in connection with Fig. 2, which shows a simplified representation of the circuit of Fig. 1. In Fig. 2, the elements R_0, R_1 and R_2 correspond to the similarly characterized elements in the circuit of Fig. 1; R_p represents the A. C. plate circuit resistance of the space discharge device 2; E represents the voltage of the generator 23; M represents the net voltage amplification for the circuit of Fig. 1 from the grid of tube 1 into the plate circuit of tube 2; MR_1i_1 represent the voltage reproduced in the anode circuit of tube 2 due to M, R_1 and i_1 where i_1 is the current driven through the circuit by the voltage E of generator 23; and I is the resultant current flowing through the resistance R_0 due to the voltage E and the various electromotive forces in the circuit of Fig. 1 to the right of the dot-dash line.

The resultant current I may be represented in the form of a series,

$$I = i_1 + i_2 + i_3 \text{ ---------- } (1)$$

where the current produced in the electrical circuit due to the voltage E is

$$i_1 = \frac{E}{R_0 + R_1 + \frac{R_2 R_p}{R_2 + R_p}} \text{ -------- } (2)$$

Then the current produced in the circuit due to the potential drop produced by current i_1 in R_1 is

$$i_2 = \frac{MR_1E}{\left[R_0 + R_1 + \frac{R_2R_p}{R_2+R_p}\right]\left[R_p + \frac{R_2(R_0+R_1)}{R_0+R_1+R_2}\right]} \times \frac{R_2}{R_0+R_1+R_2} = \frac{MR_1R_2}{[R_p(R_0+R_1+R_2)+R_2(R_0+R_1)]} \times \frac{E}{R_0+R_1+\frac{R_2R_p}{R_2+R_p}} \text{ ---------- } (3)$$

Then the current produced in the circuit

due to the potential drop produced by current i_2 in R_1 is

$$i_3=\left[\frac{MR_1R_2}{R_p(R_0+R_1+R_2)+R_2(R_0+R_1)}\right]^2\times\frac{E}{R_0+R_1+\frac{R_2R_p}{R_2+R_p}} \quad (4)$$

and the current produced in the circuit due to MR_1i_3 is

$$i_4=\left[\frac{MR_1R_2}{R_p(R_0+R_1+R_2)+R_2(R_0+R_1)}\right]^3\times\frac{E}{R_0+R_1+\frac{R_2R_p}{R_2+R_p}} \quad (5)$$

$$\text{Let } r=\frac{MR_1R_2}{R_p(R_0+R_1+R_2)+R_2(R_0+R_1)} \quad (6)$$

Then

$$I=i_1+ri_1+r^2i_1+r^3i_1=i_1(1+r+r^2+r^3+\cdots) \quad (7)$$

For I to be finite, the series must be convergent, that is

$$r=\frac{MR_1R_2}{R_p(R_0+R_1+R_2)+R_2(R_0+R_1)} \text{ must be } <I \quad (8)$$

The summation of the series is

$$S_n=\frac{rl-a}{r-l} \quad (9)$$

where r=ratio of terms, a=first term and $l=ar^{n-1}$=last term. Where $n=\infty$

$$S_n=\frac{a}{l-r}=\frac{E}{R_0+R_1+\frac{R_2R_p}{R_2+R_p}}\times\left(\frac{1}{l-r}\right) \quad (10)$$

Let R_N=negative resistance across the terminals 18, 19 of Fig. 1. Then

$$I=\frac{E}{R_0+R_N}=\frac{E}{R_0+R_1\ \frac{R_2R_p}{R_2+R_p}}\left(\frac{1}{l-r}\right) \quad (11)$$

Therefore

$$R_0+R_N=R_0+R_1+\frac{R_2R_p}{R_2+R_p}-M\frac{R_1R_2}{R_2+R_p} \quad (12)$$

or

$$R_N=R_1+\frac{R_2R_p}{R_2+R_p}-M\frac{R_1R_2}{R_2+R_p} \quad (13)$$

For maximum I, $R_2=\infty$, then

$$R_N=R_1+R_p-MR_1=R_p+(1-M)R \quad (14)$$

The negative resistance obtained in the circuit of the invention as given by Equation (13), is a function of the variables R_1, R_2, R_p and M in the circuit. This negative resistance may be adjusted, therefore, to any desired value by adjusting the value of any of these variables by suitable means. When used in an electrical circuit for neutralizing the effect of positive resistance, in order to prevent the circuit from developing "singing tendencies," the elements should be so selected as shown by Equation (8) so that the ratio

$$\frac{MR_1R_2}{R_p(R_0+R_1)+R_2(R_0+R_1)}<l.$$

The circuit of the invention as described above produces a negative resistance which is substantially independent of frequencies since its value is determined largely, as shown by the above equation, by elements which are substantially pure resistances, which circuit is within wide limits stable and non-oscillatory, and which may be adjusted within wide limits.

The system above illustrated and described should be construed merely as typical and not as limiting the invention, the scope of which is defined in the appended claims.

What is claimed is:

1. An electrical network for securing a negative resistance which is independent of frequency, comprising a resistance coupled amplifier having an even number of stages each including a space discharge device having an input and an output circuit, each device having a cathode, an anode and a control electrode, a common source of space current for both of said devices, a resistance connected in the input circuit of the first space discharge device in said amplifier between the control electrode and the cathode thereof, a second resistance connected in the output circuit of the last space discharge device in said amplifier between the anode thereof and said source, a terminal connected to a point in the input circuit of said first device between the control electrode thereof and said resistance in said input circuit, a second terminal, a connection between said second terminal and a point in the output circuit of said last space discharge device between the anode thereof and said second resistance, and means in said connection allowing transmission therethrough of the amplified current variations while preventing transmission therethrough of direct current from the output circuit of said last device, said network producing between the first mentioned terminal and said second terminal when an external electromotive force is applied therebetween a negative resistance which is a function solely of the constants of the amplifier circuit and independent of the value of said external electromotive force.

2. In combination, an amplifier circuit comprising two space discharge devices, each having an input and an output circuit, and each having a cathode, anode and a control electrode, the output circuit of one of said devices being coupled to the input circuit of the other of said devices through a resistance, a single source of space current for both

of said devices, a second resistance connected in the input circuit of said one device between the control electrode and anode thereof, a third resistance connected in the output circuit of said other device between the anode thereof and said source, a terminal connected to the input circuit of said one device between the control electrode thereof and said one resistance, a second terminal, and a conductor connecting said second terminal to the output circuit of said other device between the anode thereof and said third resistance, and means in said conductor for preventing flow in said conductor of direct current from the output circuit of said other device.

3. In combination, an amplifier circuit comprising two space discharge devices, each having an input and an output circuit, and each having a cathode, anode and a control electrode, the output circuit of one of said devices being coupled to the input circuit of the other of said devices through a resistance, a common source of space current for said devices, a second resistance connected in the input circuit of said one device between the control electrode and anode thereof, a third resistance connected in the output circuit of said other device between the anode thereof and said source, a terminal connected to the input circuit of said one device between the control electrode thereof and the first-mentioned resistance, a second terminal, a conductor of low resistance to alternating currents connecting said second terminal to the output circuit of said other device between the anode thereof and said third resistance, and means in said conductor for preventing flow in said conductor of direct current from the output circuit of said other device, said means comprising a source of direct current electromotive force poled so as to oppose the action of the common source of space current for said devices.

4. In combination, a two stage amplifier circuit comprising two space discharge devices, each having an input and an output circuit, and a cathode, anode and control electrode, the output circuit of one of said devices being coupled to the input circuit of the other of said devices through a resistance, a single source of space current for both of said devices, a second resistance connected between the control electrode and the cathode of said one device, a terminal connected between said second resistance and the control electrode of said one device, a third resistance connected in the output circuit of said other device between the anode thereof and said single source of space current, a second terminal, a conductor connecting said second terminal to a point in said output circuit for said other device between said third resistance and the anode of said other device, and means in said conductor offering a high resistance to flow therein of direct current from the space current source in the output circuit of said last device and low resistance to flow of the amplified current variations from said output circuit.

5. An electrical network for securing a negative impedance between two terminals of an electrical circuit including a source of alternating current waves, said network comprising a resistance coupled amplifier having an even number of stages each including a space discharge device having a cathode, an anode and a control electrode, and each having an input and an output circuit, a common source of space current for both devices, an impedance in the input circuit of the first discharge device in said amplifier connected between the cathode and control electrode thereof, a connection from one of said terminals to a point in the input circuit of said first discharge device between the control electrode thereof and said impedance, a connection between the other of said terminals and a point in the output circuit of the last space discharge device in said amplifier between the anode thereof and said source of alternating current waves, and means in the last-mentioned connection for preventing direct current from the output circuit of said last space discharge from being transmitted to said electrical circuit.

In witness whereof, I hereunto subscribe my name this 28th day of July, A. D. 1927.

FRANK HOWARD GRAHAM.