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SUMMING AMPLIFIER

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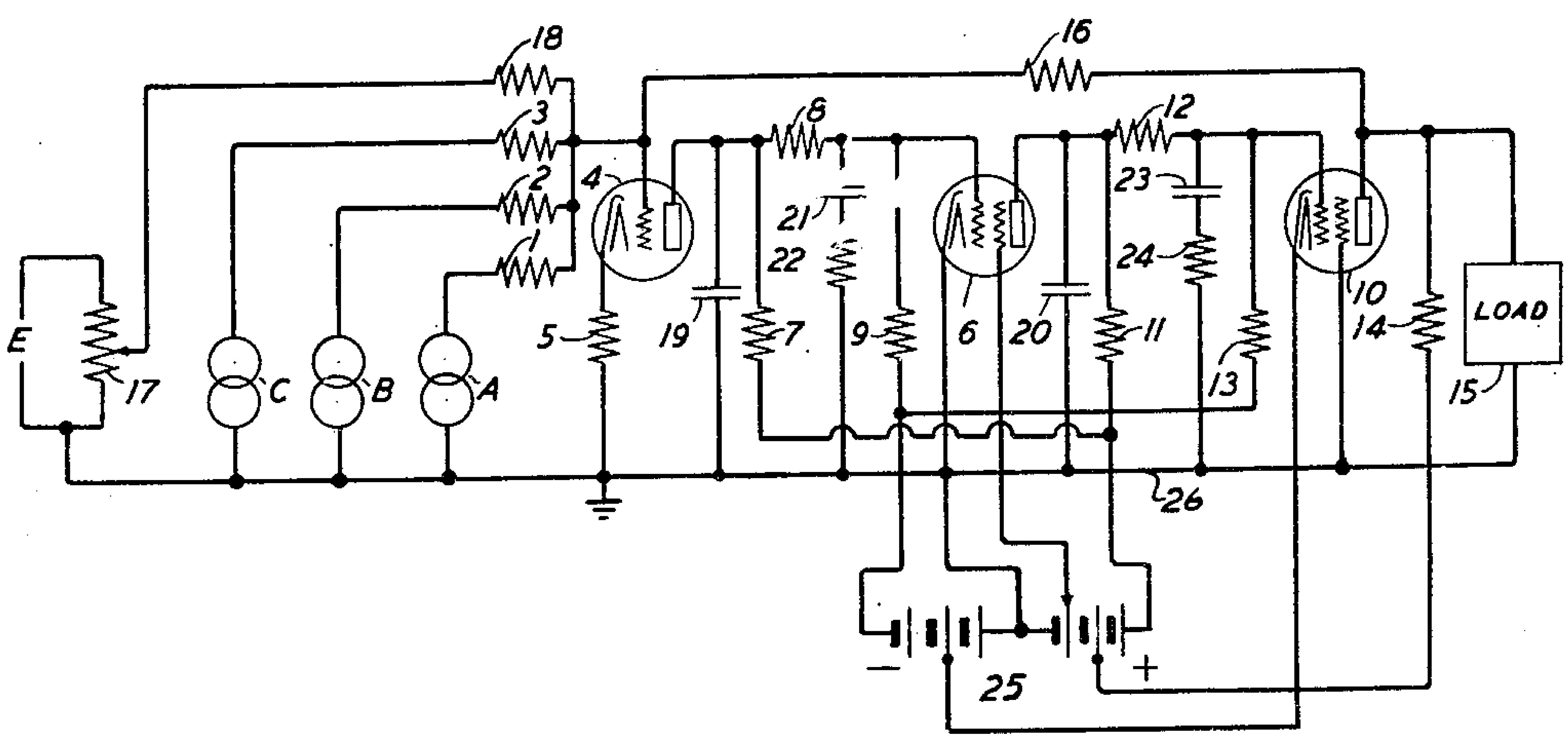

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SUMMING AMPLIFIER

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This invention relates to electrical calculating devices and particularly to a device for obtaining the sum of a plurality of electrical voltages.

The object of the invention is to obtain the sum of a number of electrical voltages, one pole of each of the voltages being grounded.

A feature of the invention is an electrical amplifier having a feedback of power from the output circuit to the input circuit of the amplifier of such magnitude and phase as to reduce the input impedance of the amplifier to a small value and to make the over-all gain of the amplifier a predetermined quantity.

In prior electrical circuits for the addition of quantities represented by electrical voltages, it has been necessary to place the voltages to be added in serial relationship in order to obtain the sum of these voltages. Such a connection has the serious practical disadvantage that only one of the voltages can be connected to ground. In accordance with the present invention all of the sources of voltages may be connected to a common point, preferably to ground, and supplied through individual high impedances to the input of an electrical network.

The voltages to be added may be of any desired frequencies, and may have zero cycles, that is, a direct voltage, as one limit. The network is designed to amplify voltages within the desired frequency range, without distortion or instability, and has a feedback from the output circuit to the input circuit of such polarity and magnitude as to render the impedance of the input circuit, as viewed from the voltage sources, low compared to the impedances in series with the sources, without rendering the amplifier unstable. In the specific embodiment of the invention disclosed in the present application, the network is capable of amplifying voltages from zero cycles to a comparatively high frequency, but the invention is in no way limited to this specific disclosure, as the interstage coupling networks of the amplifier may be designed by known methods to amplify any other desired range of frequencies. The network is further adjusted so that the over-all gain is a predetermined quantity, and during the operation of the circuit, the network will tend automatically to maintain this relationship. Thus the sum of the voltages will be reproduced across the output load, without any interaction of one source of voltage upon another. Further, by adjustment of the impedances connected in series with the various sources of voltage, any one or more of the sources may be, in effect, multiplied by any desired factor and this voltage, multiplied by such factor, will be included as one element of the summation of voltages in the output circuit.

The drawing diagrammatically illustrates a circuit embodying the invention.

In the drawing the generators A, B, and C, diagrammatically symbolizing three sources of voltages to be added, are respectively connected in serial relationship with one of the impedances 1, 2, 3, each having a relatively high impedance compared to the effective input impedance of the amplifier. The impedances 1, 2, 3 will normally be resistors, unless the added voltages are to be modified in accordance with frequency, in which case the impedances may have any desired frequency characteristic.

The voltage sources, and their serially connected impedances, are connected in parallel relationship to the input of a thermionic vacuum tube 4. This vacuum tube may, if desired, have the usual grid biasing resistor 5. The vacuum tube 4 is coupled to the vacuum tube 6 by means of an interstage coupling network comprising the three resistors 7, 8 and 9. This coupling network is of the type disclosed in U. S. Patent 1,751,527, March 25, 1930, H. Nyquist, but any other form of coupling network capable of operation without distortion for voltages covering the frequency range desired may be used in place of the network shown. The vacuum tube 6 is coupled to the vacuum tube 10 by a similar network comprising the resistors 11, 12 and 13, respectively. The vacuum tube 10 is coupled by means of a resistor 14 to the load 15. The anode of the vacuum tube 10 is coupled by an impedance 16 to the control electrode, or grid, of the vacuum tube 4, feeding back energy from the output circuit of the vacuum tube 10 to the input circuit of the vacuum tube 4. As this amplifier comprises an odd number of stages of amplification the energy fed back will be in the proper phase to oppose the voltage applied to the input of the vacuum tube 4, thus forming a reverse feedback.

An intermediate tap of the battery 25, or other suitable source of voltage, is connected to the grounded connection 26. Positive potential from source 25 is supplied through resistors 7, 11, to the anodes of vacuum tubes 4, 6, and negative potential from the source 25 is supplied through resistors 9, 13 to the control electrodes of vacuum tubes 6, 10. The screen grid of vacuum tube 6 is connected to a suitable tap in the source 25. Positive potential is supplied through coupling resistor 14 to the anode of vacuum tube 10, and negative potential from the source 25 is supplied to the cathode of vacuum tube 10. The screen grid of vacuum tube 10 is grounded, thus making the screen positive with respect to the cathode of vacuum tube 10.

The operation of vacuum tube 10 may be explained in different ways, some of which are set forth hereinafter but the scope of the invention is not thereby limited to these theories of operation. In the absence of an applied signal, the constants of the circuit may be so adjusted that the positive potential from the source 25 is completely used up in driving the anode current through resistor 14 so that no voltage is applied to the anode of vacuum tube 10, which is thus at ground potential. The anode current of vacuum tube 10 is maintained by the negative potential from the source 25 applied to the cathode of vacuum tube 10. When a negative voltage is applied to the control electrode of vacuum tube 4, the amplified voltage will cause the control electrode of vacuum tube 10 to become more negative, reducing the anode current and the voltage drop in resistor 14, and applying a positive voltage to the load 15. When a positive voltage is applied to the control electrode of vacuum tube 4, the amplified voltage will cause the control electrode of vacuum tube 10 to become less negative, permitting the negative voltage applied to the cathode of vacuum tube 10 to increase the anode current, making the voltage drop in resistor 14 larger than the applied positive potential from the source 25, and applying a negative voltage to the load.

From another point of view, a current can flow from the positive tap of the source 25 through resistor 14, down through load 15, and connection 26 back to the source 25. Another current can flow from the tap of source 25, by connection 26 up through load 15, anode to cathode of vacuum tube 10 to the negative tap of source 25. By adjusting the bias on the control electrode of vacuum tube 10, these currents, in the absence of a signal, may be made equal. Thus no current will flow in the load 15, and the anode of vacuum tube 10 will be at ground potential. When an amplified signal is applied to the control electrode of vacuum tube 10, the balance of these theoretical currents is disturbed, and a resultant current will flow in the load 15.

Let quantities relating to the sources A, B, C be designated by subscripts *a*, *b*, *c*, and those relating to the output circuit by subscript *d*.

The control electrode, or grid, of vacuum tube 4 has a potential, preferably negative, such that the control electrode does not draw any appreciable current.

Applying the Kirchoff relationship to the node at the control electrode of vacuum tube 4,

$$i_a+i_b+i_c=-i_d \qquad (1)$$

or

$$i_a+i_b+i_c+i_d=0 \qquad (2)$$

Let the impedances 1, 2, 3, 16 be resistances R_1, R_2, R_3, R_{16}, the potential of the control electrode of vacuum tube 4 be e_g and the voltage across the output circuit be e_d, then

$$-e_g=e_a-i_ar_1=e_b-i_br_2=e_c-i_cr_3=e_d-i_dr_{16} \qquad (3)$$

Solving Equation 3 for i_a, i_b, i_c and i_d and substituting in Equation 2,

$$e_d=-\frac{e_a\frac{r_{16}}{r_1}+e_b\frac{r_{16}}{r_2}+e_c\frac{r_{16}}{r_3}}{1+\frac{1}{\mu}\left[1+\frac{r_{16}}{r_1}+\frac{r_{16}}{r_2}+\frac{r_{16}}{r_3}\right]} \qquad (4)$$

where μ is the voltage amplification ratio of the amplifier.

If μ be large compared to unity, the bracketed quantity is small, and the output voltage is very nearly

$$e_o=-r_{16}\left(\frac{e_a}{r_1}+\frac{e_b}{r_2}+\frac{e_c}{r_3}\right) \qquad (5)$$

Assuming the gain factors

$$\frac{r_{16}}{r_1},\ \frac{r_{16}}{r_2},\ \frac{r_{16}}{r_3}$$

are unity, and that the ratio μ is 6×10^4, the denominator of Equation 4 will be

$$1+\frac{4}{\mu}$$

which differs from unity by about .007 per cent.

The coupling impedance formed by the input circuit of vacuum tube 4 may be shown to be

$$\frac{r_{16}}{1+\mu}$$

If μ is 6×10^4, and r_{16} is 1 megohm, the coupling impedance is about 15 ohms. If the input resistors are of the order of 1 megohm each, the interaction between the sources A, B, C is negligible.

The output impedance of the vacuum tube 10 is reduced by the factor

$$\frac{\frac{r_{16}}{r_1}+\frac{r_{16}}{r_2}+\frac{r_{16}}{r_3}}{\left(\frac{r_{16}}{r_1}+\frac{r_{16}}{r_2}+\frac{r_{16}}{r_3}\right)+\mu}$$

and is effectively less than 10 ohms. The amplifier, in effect, forms a voltage source of very low impedance, thus variations in the load impedance have little effect on the accuracy of the summation.

As the effective gain for each source is controlled by the ratio of the feedback resistor to the input resistor, the voltages from the sources may have different gains, thus multiplying or dividing one voltage with respect to the others.

For the purpose of illustrating the flexibility and utility of the invention and not as any limitation thereon, let the impedances 1, 2, 3 be resistances R_1, R_2, R_3, and let the impedance 16 be a resistance R_4, and let D be the voltage across the load 15.

If $R_1=R_2=R_3=R_4$, then $-D=A+B+C$

If $R_1=R_2=R_3=\frac{R_4}{x}$, then $-D=x(A+B+C)$

If $R_1=R_2=\frac{R_3}{x}=R_4$, then $-D=A+B+\frac{C}{x}$

If $R_1=R_2=xR_3=R_4$, then $-D=A+B+xC$

where x is any desired factor. Thus, if R be the feedback impedance, and R_i be the input impedance for the voltage E_i, the voltage gain G for that input will be

$$G=\frac{-R}{R_i}$$

and this relationship will apply simultaneously and independently for all inputs, thus for any number of inputs

$$D=-\frac{AR}{R_1}-\frac{BR}{R_2}-\frac{CR}{R_3}-\,-\frac{E_iR}{R_i}-\,-\frac{E_nR}{R_n}=-R\sum_{n}^{1}\frac{E_i}{R_i}$$

When the network is designed for use with voltages having frequencies which may go down to zero cycles, preferably the circuit constants are so chosen that in the absence of an input voltage the potential of the anode of the vacuum tube 10 is substantially that of the ground, or zero voltage. When voltages are applied to the input circuit of the vacuum tube 4 the potential of the anode of the vacuum tube 10 will swing above or below the ground potential in accordance with the sum of the voltages applied to the input of the vacuum tube 4, consideration being taken of the signs of the voltages applied.

In order to adjust the potential of the anode of the vacuum tube 10 exactly to zero or ground potential, a correcting circuit comprising any convenient source of voltage E supplied to the potentiometer 17 may be connected through a serial resistance 18 to the input of the vacuum tube 4, and, in the absence of other applied voltages, the potentiometer may be adjusted to bring the potential of the anode of the vacuum tube 10 exactly to the zero or ground potential. As the effective gain of the complete network depends upon the ratio of the resistance of the resistor in series with any source of voltage compared to the resistance of the feedback resistor 16, in order to secure a more accurate control of the adjustment, the resistance of the resistor 18 is preferably made say three or four times the resistance of the resistor 16. This relationship will also improve the direct current noise situation.

In a practical embodiment of the invention the resistors 1, 2 and 3 were 1 megohm. The potentiometer 17 was of the order of 10,000 ohms and the resistor 18 was 3 megohms. The vacuum tubes 4, 6 and 10 were commercial vacuum tubes having the type designations respectively 6SC7, 6SJ7, and 6Y6G. The resistor 5 was 1,500 ohms, the resistors 7, 8 and 9 were respectively ½, ¾ and 2 megohms. The resistors 11, 12 and 13 were respectively ¼, 1¼ and 1 megohms. The resistor 14 was 6,000 ohms and the load 15 was also 6,000 ohms. The resistor 16 was 1 megohm. A 700-volt battery grounded at the mid-point was used, plus 350 volts being supplied to the anodes of the vacuum tubes 4 and 6, plus 250 volts to the anode of the vacuum tube 10, plus 75 volts to the screen of the vacuum tube 6, ground or zero volts to the cathode of the vacuum tube 6 and the screen grid of the vacuum tube 10, minus 135 volts to the cathode of the vacuum tube 10, and minus 350 volts to the grid biasing resistors of the vacuum tubes 6 and 10.

To improve the stability of the amplifier, and to obviate high frequency singing due to parasitic capacitances, small capacitors 19, 20 may be connected from the anodes of the vacuum tubes 4 and 6 to the cathode circuit, and small capacitors 21, 23, respectively, in serial relationship with resistors 22, 24, may be connected across the input circuits of the vacuum tubes 6 and 10. The capacitors 19, 20, 21, 23 were respectively .25, .0001, .001, .03 microfarad and the resistors 22, 24 were 100,000 ohms.

What is claimed is:

1. In combination, a plurality of voltage sources, a plurality of high impedances respectively in serial relationship with said sources, an amplifying device having an input and an output circuit, said sources and impedances being connected in parallel relationship to said input circuit, a load impedance in said output circuit, and means for feeding back energy from said output circuit to said input circuit to make the impedance of said input circuit small compared to said input impedances and the over-all gain of said amplifier substantially unity.

2. In combination, a plurality of voltage sources, a plurality of high resistances respectively in serial relationship with said sources, an amplifying device having an input and an output circuit, said sources and resistances being connected in parallel relationship to said input circuit, a load resistor in said output circuit, and means including a high resistance for feeding back energy from said output circuit to said input circuit to make the over-all gain of said amplifier for any one of said sources substantially equal to the ratio between the resistance feeding back energy and the resistance connected in serial relationship with that one of said sources.

3. In combination, a thermionic device having a cathode, an anode and a control electrode, a coupling impedance, a source of current connected to said cathode and through said coupling impedance to said anode and having an intermediate tap, an output circuit connected to said anode and said intermediate tap, two impedances connected in serial relationship across said output circuit, and a connection from the junction of said two impedances to said control electrode.

4. The combination in claim 3 with amplifying means in said connection from the junction of said two impedances to said control electrode.

5. The combination in claim 3 with a source of control voltage in serial relationship with said two impedances.

6. In combination, an electron discharge device having at least a cathode and an anode, a source of direct current having the negative pole connected to said cathode and the positive pole to said anode, an output circuit connected to said anode and an intermediate point in said source, two impedances connected in serial relationship across said output circuit, said intermediate point being so chosen that the currents from said source flowing in said impedances are substantially equal and opposite and the voltage across said output circuit is substantially zero.

7. The combination in claim 6 with a connection from the junction of said serially connected impedances to a control electrode in said electron discharge device.

8. The combination in claim 6 with a source of voltage in serial relationship with said serially connected impedances adjusted to make the voltage across said output circuit more nearly equal to zero.

9. In combination, an electron discharge device having at least a cathode and an anode, a source of direct current having the negative pole connected to said cathode and the positive pole connected to said anode, an output circuit connected to said anode and an intermediate point in said source, a plurality of voltage sources, a plurality of impedances respectively in serial relationship with said voltage sources, said impedances and voltage sources being connected in parallel relationship, and another impedance connected in serial relationship with said parallel connected impedances and voltage sources across said output circuit.

10. The combination in claim 9 with a connection from the junction of said serially connected impedances to a control electrode in said electron discharge device.

11. A network having a plurality of input and output terminals, a potential divider connected in serial relationship with a plurality of said input terminals and one of said output terminals, said divider having a plurality of impedances in parallel relationship connected in serial relationship with a single impedance, an electron discharge device having at least a cathode, an anode and a control electrode, a direct connection from the junction of said plurality of impedances and said single impedance to said control electrode, a connection from said anode to said one output terminal, and a connection from said cathode to an input terminal and the remaining output terminal.

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