

June 14, 1949.

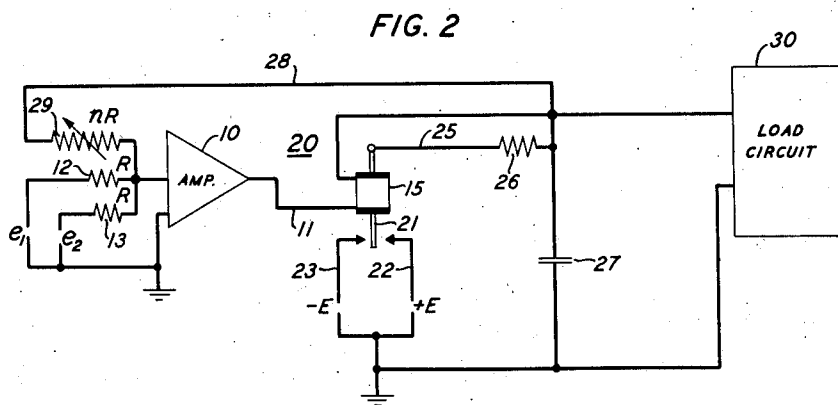
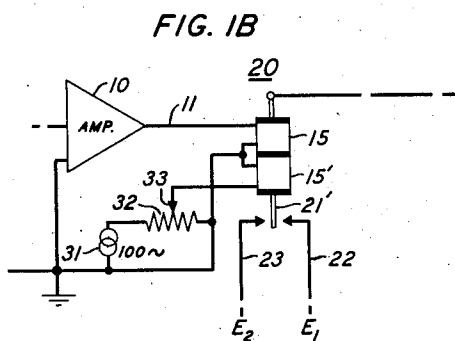
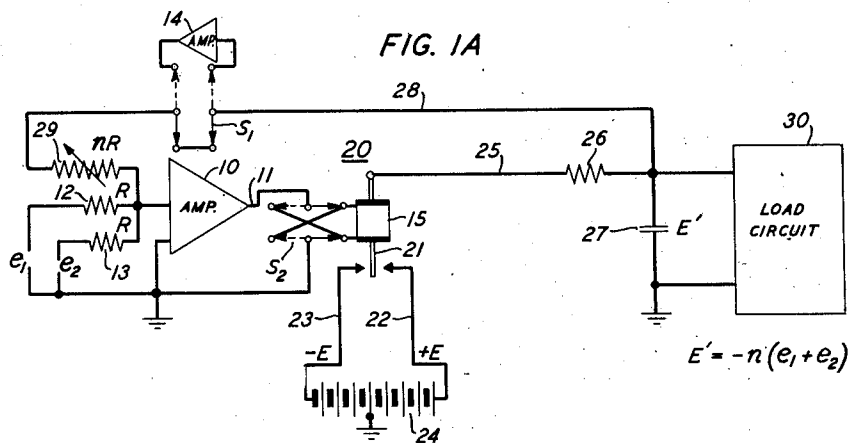
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2,473,414

VOLTAGE MULTIPLYING CIRCUIT

Filed Nov. 7, 1947

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3

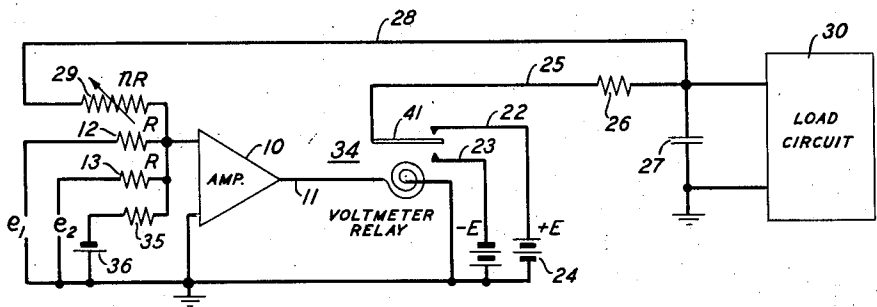
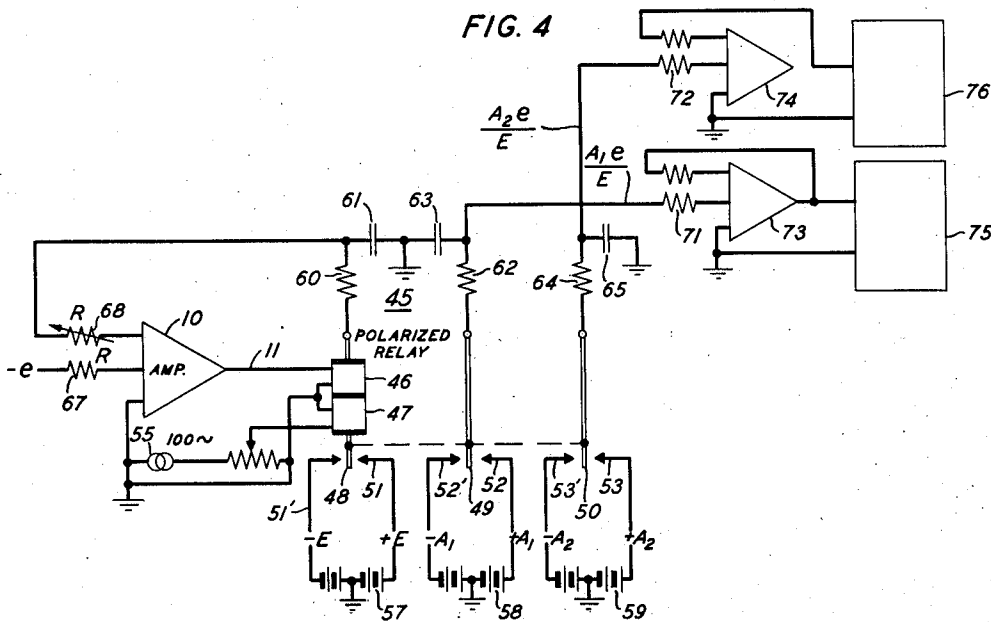


FIG. 4



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VOLTAGE MULTIPLYING CIRCUIT

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6 Claims. (Cl. 320-1)

1

This invention relates to an improved voltage multiplying circuit, useful where a load is to be driven by a voltage which is a desired multiple of a control voltage and, in one form, where the products of one voltage by other voltages are to be applied to utilization devices.

The invention uses low power amplifiers controlling relays to throttle independent voltage sources which themselves supply the load, and thus dispenses with the high power amplifiers which have heretofore been necessary unless servomotors are used in their place. It is therefore an object of the invention to provide a circuit wherein a low power amplifier with a relay thereby controlled may take the place of a high power amplifier.

The load circuit may require to be driven by a voltage much greater than the amplifier is designed to supply and the driving voltage may need to be a large multiple of the net amplifier input voltage. Another object of the invention is thus to provide a circuit whereby a control voltage is magnified in any desired ratio.

Another application of the basic circuit of the invention serves to provide for any desired purpose, such as the control of a load of any character, a voltage which is the product of an amplifier input voltage by another voltage. A further object of the invention is then to provide a circuit for the multiplication of voltages without the use of cascaded potentiometers such as it has been the practice to use.

Those acquainted with the art will recognize that the invention herein disclosed replaces the servomotors or the high power amplifiers commonly used to drive a load circuit in accordance with a control voltage and likewise permits the multiplication of voltages without the use of circuit elements which are electrically and spacially cumbersome.

The invention will be understood from the following description, reference being made to the accompanying drawings, in which:

Fig. 1A is a diagram of the basic circuit providing a useful voltage which is a desired multiple of a net control voltage;

Fig. 1B shows a relay drive alternative to the corresponding part of the circuit of Fig. 1A;

Fig. 2 is a diagram of a circuit alternative to that of Fig. 1A;

Fig. 3 is a diagram of a second circuit alternative to that of Fig. 1A; and

Fig. 4 is a diagram of a circuit for providing a plurality of product voltages.

2

In all figures, like elements are designated by like numerals or letters.

Referring to Fig. 1A, summing amplifier 10 operates to provide an output voltage on conductor 11 which is proportional to the algebraic sum of the voltages  $e_1$  and  $e_2$ . These input voltages are for the sake of illustration, shown as applied to the input circuit of amplifier 10 through resistors 12 and 13, respectively, which may be each of the order of 1 megohm. It may be arranged that the voltage on conductor 11 shall be any multiple of  $(e_1 + e_2)$ . The output circuit of amplifier 10 includes winding 15 of relay 20 in series between conductor 11 and ground.

Relay 20 may conveniently be a polarized relay; such a relay is disclosed in United States Patent 2,309,945, February 2, 1943, to J. S. Garvin. Armature 21 of relay 20, in the absence of current in winding 15, is in a neutral position between contacts 22 and 23; these contacts are connected respectively to positive and negative voltage sources  $+E$  and  $-E$ , illustratively shown as the terminals of battery 24 of which the mid-point is grounded.

Now if a voltage is required opposite in sign to the algebraic sum of voltages  $e_1$  and  $e_2$  and this sum is negative, switch  $S_1$  is closed downward and winding 15 is so connected that when switch  $S_2$  is closed right armature 21 is moved to contact 22. Contact 23 is then made by armature 21 when the net input voltage is positive. It will be noted that the input voltage of amplifier 10 is in each case of the opposite polarity to that selected by relay 20.

The voltage selected is applied through armature 21 and conductor 25 to a resistance-capacity filter comprising resistor 26 and condenser 27; the terminal of condenser 27 remote from resistor 26 is grounded and load circuit 30 is shunted across condenser 27. From the junction of resistor 26 and condenser 27, a reverse feedback path is provided via conductor 28 and adjustable resistor 29, to the input of amplifier 10.

Switch  $S_1$  is shown in Fig. 1A in a position to make continuous conductor 28 from load circuit 30 to resistor 29. By throwing this switch to the opposite position indicated by dotted lines, conductor 28 is interrupted to include amplifier 14, a single-stage reversing amplifier of unit gain. When this is done, the connection of conductor 11 to winding 15 is reversed (by operating switch  $S_2$  left) and armature 21 selects the voltage source of the same polarity as the input voltage. The voltage on conductor 28 now is reversed by amplifier 14 and though resistor 29 opposes the sum of

3

voltages  $e_1$  and  $e_2$  on the input circuit of amplifier 10. The discussion which follows relates to the provision of a load voltage which is a negative multiple of the sum of the given voltages; it is unnecessary to repeat the discussion with the obvious changes which apply to the provision of a positive multiple voltage.

It is well known that the net voltage input to amplifier 10 is proportional to the algebraic sum of the quotients

$$\frac{e_i}{R_i}$$

where  $e_1$  is the voltage which reaches the input of amplifier 10 through resistor  $R_1$ . If in Fig. 1A, the resistance of each of resistors 12 and 13 is  $R$  while that of resistor 29 is adjusted to be  $nR$ , condenser 27 will be charged to a voltage equal to  $n$  times the algebraic sum of  $e_1$  and  $e_2$  but opposite in sign thereto; when this occurs, the reverse feedback voltage  $E'$  will be  $-n(e_1+e_2)$ , which makes zero the total input voltage to amplifier 10 and armature 21 returns to neutral. The voltage on condenser 27 is then left to drive the load circuit 30. Load circuit 30 is thus driven from the power supply of battery 24, at a voltage therefrom equal to a desired multiple of the aggregate of voltages  $e_1$  and  $e_2$ . As condenser 27 discharges through the load, relay 20 is again called into operation to reconnect battery 24 in the appropriate polarity, the voltage fluctuations being subdued by the filter composed of resistor 26 and condenser 27. It will be evident that the net input voltage to amplifier 10 is a measure of the momentary departure of the load voltage from the chosen multiple,

$$-n(e_1+e_2)$$

and that armature 21 or (21') operates to select for application to the load the voltage source of polarity appropriate to reduce the departure.

Relay 20 may be, as shown in Fig. 1B, a relay with two windings, the operating winding 15 and the auxiliary winding 15' supplied with alternating current from any convenient source 31 of suitable frequency, say 100 cycles per second. Source 31 may be shunted to ground by potentiometer 32 and by tap 33 a suitable fraction of the voltage of source 31 may be applied across winding 15'; armature 21 then spends equal times on contacts 22 and 23 in the absence of a voltage on conductor 11. Contacts 22 and 23 are, respectively, here connected to voltages  $E_1$  and  $E_2$ , which are of opposite sign but need not be equal in magnitude.

An output voltage from amplifier 10 causes armature 21 to spend more time on one or the other of contacts 22 and 23 as determined by the polarity and magnitude of the voltage on conductor 11. Anticipating the discussion of Fig. 4 we may call  $k$  the fraction of a cycle of the voltage from source 31 that is spent on contact 22 by armature 21. In this case also the voltage across condenser 27 is  $n$  times the net voltage of  $e_1$  and  $e_2$ , the filter serving to eliminate voltage fluctuation.

The same effect can be obtained by using the single winding relay at Fig. 1A, but adding a little alternating current to the input of amplifier 10.

It is obvious that relay 20 does not have to have a stable neutral position when used in the circuit of Fig. 1B, for the alternating current in winding 15' transfers the armature rapidly from one contact to the other. It is also possible to use a relay with no neutral position, in the cir-

4

cuit of Fig. 1A, although one with a neutral position may be preferable. With no stable neutral position the relay armature moves back and forth between contacts 22 and 23, even though there is no added alternating current winding, at a frequency determined by the time constants of the circuit.

A non-polar relay may be used instead of a polar type, although the polar type may be preferable. If a non-polar relay is used, amplifier 10 must be limited by overload conditions such that substantial output voltages can be produced in one direction only. For instance, positive input voltages may produce substantial positive output voltages, while negative input voltages produce very little output voltage at all; in particular, insufficient to operate the relay. Then with positive input voltages the relay is operated, and with negative input voltages, released. Best operation calls for a zero adjustment such that output voltage is equal to operate voltage when net input voltage is zero, but this is not necessary if a high gain amplifier is used.

When the circuit must handle voltages between limits which are not equal in magnitude and opposite in sign, voltages  $+E$  and  $-E$  can be advantageously replaced as illustrated in Fig. 1B by  $E_1$  and  $E_2$  where  $E_2$  is not equal to  $-E_1$ . For instance, if it is required to handle only positive input voltages,  $+E$  can be replaced by a ground connection.  $E_1$  may be greater,  $E_2$  less, than the chosen multiple of the input voltage.

In Fig. 2 a circuit is shown, equivalent in function to those described but with only trivial fluctuations in voltage caused by the perhaps intermittent relay operation. Here winding 15, at its terminal remote from conductor 11, is connected directly to the ungrounded terminal of load circuit 30 and also in the feedback path including resistance 29. The filter includes resistor 26 and condenser 27 as before while the feedback is taken as before from the ungrounded terminal of the load through resistor 29. The output circuit of amplifier 10 is completed to ground through load circuit 30.

Fig. 3 is a diagram of a circuit in accordance with the invention but using a voltmeter relay 34 normally supplied with a suitable current in its winding. For this purpose amplifier 10 receives on its input through resistor 35 the voltage from battery 36 which is chosen to produce, in the absence of another input voltage, a current through winding 40 just sufficient to hold in neutral position armature 41. Relay 34 may suitably be of the type disclosed by L. E. Lawrence in United States Patent 1,927,346, September 19, 1933.

In each of the circuits of Figs. 1, 2 and 3, condenser 27 may itself constitute the load. The ratio  $n$  may be unity or less as well as greater than unity, whatever its value, when resistor 29 is correspondingly adjusted there are compared in the input circuit of amplifier 10 a voltage proportional to  $e_1$  (or  $e_2$ , or their sum) and a voltage similarly proportional to  $1/n$ th of that on condenser 27.

In this case, the output current of amplifier 10 varies from the normal value due to battery 36 as the sum of the input voltages via resistors 12 and 13 adds to or subtracts from the input voltage via resistor 35. The operation of the relay produces as in the circuits before described a voltage across condenser 27 which is a desired multiple of the algebraic sum of the voltages via resistors 12 and 13, and opposite in sign thereto.

5

The invention is not limited to the multiplication of the input voltage by a factor set by adjustment of the resistance of resistor 29. By the use of a multicontact relay, means are provided for obtaining voltages proportional to the products of the input voltage by other and independent voltages.

Referring now to Fig. 4, relay 45 is provided with two windings 46 and 47 as is relay 20 in Fig. 1B and with three armatures 48, 49 and 50, simultaneously operating in the same direction between contacts 51—51', 52—52' and 53—53', respectively. Winding 46 is traversed by the output current from amplifier 10. In the absence of this current the three armatures are vibrated by alternating current in winding 47 between their respective left and right contacts to spend equal times alternately on the two contacts. Conveniently, the connection of amplifier 10 to winding 46 is so made that for a negative input voltage the three armatures shall operate for a longer time to the right, making contacts 48 with 51, 49 with 52 and 50 with 53, selecting thereby the voltages +E, +A<sub>1</sub> and +A<sub>2</sub>. Direct current sources providing voltages +E and -E, +A<sub>1</sub> and -A<sub>1</sub>, +A<sub>2</sub> and -A<sub>2</sub> are symbolized by batteries 57, 58 and 59, respectively, each of which is grounded at its mid-point.

On their right contacts, armatures 48, 49 and 50 are connected respectively to voltages +E, +A<sub>1</sub> and +A<sub>2</sub>. On their left contacts the armatures are connected to the opposite polarities -E, -A<sub>1</sub>, and -A<sub>2</sub>. In either case, the voltage on armature 48 is applied to the filter comprising resistor 60 in series with condenser 61 to ground. A similar filter, resistor 62 in series with condenser 63, is in shunt between armature 49 and ground, while resistor 64 and condenser 65 are connected between ground and armature 50.

For simplicity, amplifier 10 is here shown with only one input voltage -e supplied through resistor 67 of resistance R. In this situation winding 46 is so connected that the relay armatures are operated right for more than half a cycle of the alternating current from source 55; let the corresponding fraction of the cycle be denoted by k, ranging between 0.5 and 1.0 as the voltage -e is varied between zero and a value great enough to lock up the relay. Condenser 61 then is charged to a positive voltage, as in the circuit of Figs. 1A and 1B, and this voltage is fed back to the input of amplifier 10 through adjustable resistor 68. For the time being, assume that resistor 68 is adjusted to have the same resistance R as resistor 67.

Condenser 61 now charges to a voltage +e, the output voltage of amplifier 10 is zero and relay armatures again spend equal times on the left and right contacts except for unbalances (which can be kept small) required to maintain the charge on condenser 61. The value of k is determined by the equation  $e = k(+E) + (1-k)(-E)$ , or  $(2k-1)E = e$ , k being the fraction of a cycle that armature 48 is connected to +E. Since the three armatures operate together condenser 63 charges to a voltage  $(2k-1)A_1$  and condenser 65 to a voltage  $(2k-1)A_2$  (except for possible constant factors if series resistors 60, 62, 64 are not small compared with input resistors 68, 71, 72). Then,

$$(2k-1) = \frac{e}{E}$$

6

and the voltage of condenser 63 is

$$\frac{A_1 e}{E}$$

and that of condenser 65 is

$$\frac{A_2 e}{E}$$

If resistor 68 is adjusted to the resistance 10R, the voltage applied to it when the output voltage of amplifier 10 is zero becomes  $(2k-1)E = 10e$  and

$$(2k-1) = \frac{10e}{E}$$

the voltages of condensers 63 and 65 are correspondingly increased. Whatever the adjustment of resistor 68 the voltage of condenser 63 (or 65) becomes proportional directly to the product of e and A<sub>1</sub> (or e and A<sub>2</sub>) and inversely to E. The invention thus enables a voltage e to be multiplied directly by another voltage with a constant factor which is proportional to the ratio of resistances of resistors 68 and 67, divided by the voltage E.

As shown in the circuit of Fig. 4 via resistors 71 and 72 voltages

$$\frac{A_1 e}{E} \text{ and } \frac{A_2 e}{E}$$

may be connected through individual amplifiers 73, 74, to separate load circuits 75, 76. While the circuit has been described with connections such that these voltages are of the same polarity, it is obvious that their polarities can be made opposite to each other or both opposite to E by suitable interchanges of the connections between batteries 58 and 59 and the corresponding relay contacts. It is likewise obvious that the switching means controlled by the output current of amplifier 10 may be a non-polar relay, as previously indicated in connection with the description of Fig. 2. Also, as described in connection with Fig. 1B, the voltages of the several pairs need not be of equal magnitude and opposite in sign; it suffices that in each pair there be the same ratio of the voltage selected in the first position to that selected in the second position of armatures 48, 49 and 50. The voltages replacing +E and -E may be algebraically one greater, the other less than a chosen multiple of the input voltage, while the voltages of each other pair are proportional but by different factors to the corresponding other given voltage.

What is claimed is:

1. A system of apparatus for charging a condenser to a direct-current voltage numerically proportional in a desired ratio to a given direct-current voltage and of prescribed polarity relative thereto comprising a summing amplifier having an input and an output circuit, a first and a second resistance of arbitrarily fixed values, a third resistance proportional in the desired ratio to the first resistance, means for applying the given voltage to the input circuit through the first resistance, a pair of sources of direct-current voltage of opposite polarities, selection means for applying one or the other of the sources to charge the condenser through the second resistance, means included in the output circuit controlling the selection means to select that one of the sources of prescribed polarity relative to the given voltage and means for applying the voltage of the condenser through the third resistance to the input circuit in opposite polarity to the given voltage.

2. A system of apparatus for charging a condenser to a direct-current voltage numerically proportional in a desired ratio to a given direct-current voltage and opposite in polarity thereto comprising a summing amplifier having an input and an output circuit, a first and a second resistance of arbitrarily fixed values, a third resistance proportional in the desired ratio to the first resistance, means for applying the given voltage to the input circuit through the first resistance, a pair of sources of direct-current voltage of opposite polarities, selection means for applying one or the other of the sources to charge the condenser through the second resistance, means included in the output circuit controlling the selection means to select that one of the sources opposite in polarity to the given voltage and means for applying the voltage of the condenser to the input circuit through the third resistance.

3. A system of apparatus for charging a condenser to a direct-current voltage of the same polarity as a given direct-current voltage and proportional thereto in a desired ratio comprising a summing amplifier having an input and an output circuit, a first and a second resistance of arbitrarily fixed values, a third resistance proportional in the desired ratio to the first resistance, means for applying the given voltage through the first resistance to the input circuit, a pair of sources of direct-current voltage of opposite polarities, selection means for applying one or the other of the voltage sources to charge the condenser through the second resistance, means included in the output circuit controlling the selection means to select that one of the sources of the same polarity as the input voltage and means including a polarity-reversing amplifier for applying the voltage of the condenser with reversed polarity to the input circuit through the third resistance.

4. A voltage multiplying circuit for charging a condenser to a direct-current voltage adjustably related numerically to a given direct-current voltage comprising a summing amplifier having an input and an output circuit and providing therebetween an odd number of phase reversals, a first, a second and a third resistance of arbitrary values, a fourth resistance of value adjustably related to that of the first resistance, a source of constant direct-current voltage, means for applying the constant voltage through the first resistance to the input circuit to produce in the output circuit a normal current, means for applying the given voltage through the second resistance to the input circuit to vary correspondingly in amount and oppositely in sense the output current, a pair of sources of direct-current voltage of opposite polarities, selection means for applying a selected one of the sources to charge the condenser through the third resistance, means responsive to variation of the output current and controlling the selection means to select the source of positive polarity when the output current rises above the normal current and to select the source of negative polarity when the output current falls below the normal current, means for applying the selected source through the third resistance to charge the condenser and means for applying the voltage of the condenser through the fourth resistance to the input circuit in opposite polarity to the given voltage.

5. A voltage-multiplying circuit for charging a condenser to a direct-current voltage equal to a given direct-current voltage multiplied by a chosen quantity comprising a summing ampli-

fier having an input circuit and an output circuit, a relay provided with two windings and an armature operable between a pair of contacts responsively to currents in the windings, one winding being included in the output circuit, a voltage source supplying alternating current in the other winding to control the armature in the absence of direct current in the one winding to make contact for equal intervals alternately with one and with the other of the contacts, a pair of sources of direct-current voltage of opposite polarities connected individually to the contacts, means including a first series resistance for applying the given voltage to the input circuit to produce a corresponding current in the output circuit rendering unequal the alternate intervals of contact made by the armature, means including a second series resistance for connecting the condenser in series with the armature and alternately with one and with the other direct-current voltage source, and means for applying the voltage of the condenser to the input circuit in opposite polarity to the given voltage, the last named means including a third series resistance equal to the first resistance multiplied by the chosen quantity.

6. A voltage-multiplying circuit for charging a load condenser to a direct-current voltage numerically proportional to a given direct voltage multiplied by a first direct-current voltage divided by a second direct-current voltage comprising a summing amplifier having an input and an output circuit, a first and a second pair of direct-current voltage sources of opposite polarities and numerically equal respectively to the first and to the second voltage, a relay having a first winding included in the output circuit, an auxiliary winding and two armatures simultaneously operable responsively to currents in the windings respectively between contacts connected to the voltage sources of the first pair and between contacts connected to the voltage sources of the second pair, a voltage source supplying alternating current in the auxiliary winding to control the armatures in the absence of current in the first winding to make contact for equal intervals alternately with one and with the other of the voltage sources of each pair, means for applying the given voltage through a first resistance to the input circuit to produce in the output circuit a corresponding current rendering unequal the alternate intervals of contacts made by the armatures, an auxiliary condenser, means including a second series resistance for connecting the auxiliary condenser in series with one of the armatures and alternately one and the other source of the second pair, means including a third series resistance for applying the voltage of the auxiliary condenser to the input circuit in opposite polarity to the given voltage and a fourth series resistance for connecting the load condenser in series with the other of the armatures and alternately one and the other source of the first pair.

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