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2,614,140

TRIGGER CIRCUIT

Filed May 26, 1950

FIG. 1

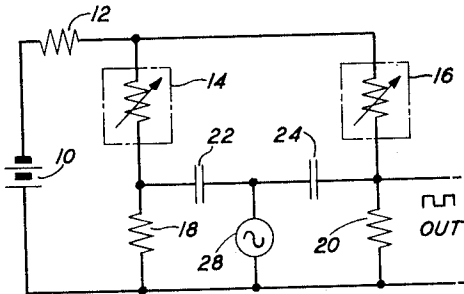


FIG. 2

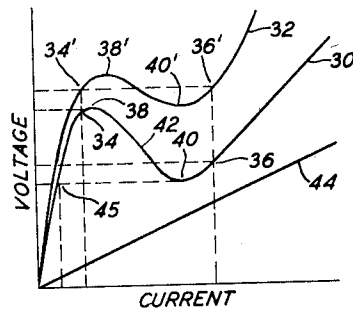


FIG. 3

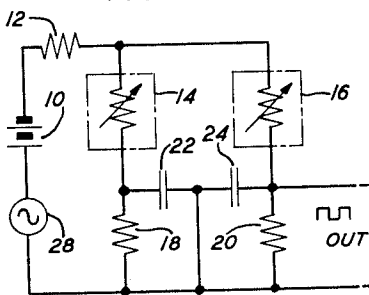


FIG. 4

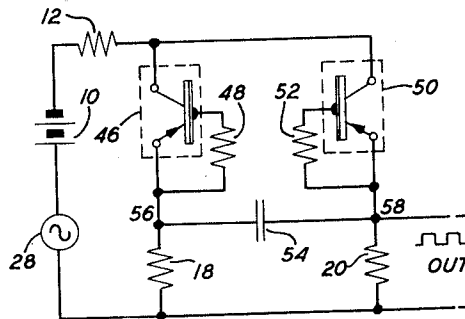


FIG. 5

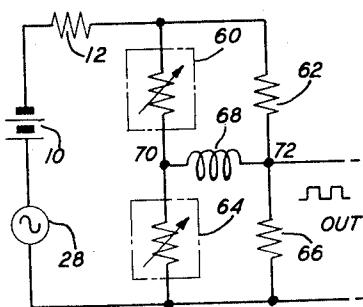
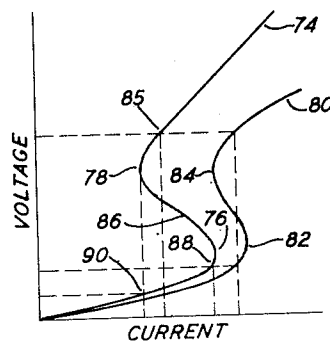


FIG. 6



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2,614,140

TRIGGER CIRCUIT

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17 Claims. (Cl. 171-97)

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This invention relates to signal translation systems using negative-resistance units as the active elements.

It is the general object of the invention to provide new and novel electric circuits of the type designated as trigger or double-stability circuits.

It is also an object of this invention to utilize small two-terminal negative-resistance units of the inert or passive type to produce a trigger circuit having two conditions of equilibrium.

It is notable of the double-stability circuits of this invention that they are capable of being repetitively triggered or changed from one to the other of their two conditions of equilibrium by successive impulses of the same polarity.

It is also a feature of the invention that two small inert or passive type negative-resistance units are utilized in double-stability circuit arrangements which require a minimum of space and power requirements for the production of suitably shaped discontinuous wave forms, such as rectangularly shaped waves.

The subject invention is characterized by its use of two current-conduction paths or circuit meshes in which electric currents flow continuously but in unequal amounts. Each of these paths includes a variable resistance unit that has a region of negative resistance over a portion of its variational characteristic, which region is flanked by two adjacent regions of positive resistance. The circuit parameters are so chosen that neither variable resistance unit will operate in its region of negative resistance; but one unit will operate in its positive-resistance region on one flank of the negative-resistance region while the other unit operates in its positive-resistance region on the other flank of the negative-resistance region. An energy storage or "memory" circuit interconnects these two circuit meshes or conducting paths and stores energy in accordance with the difference in the values of the currents flowing in the variable units. If a momentary circuit disturbance causes the current in each path to be changed to such a degree that both variable resistance units are simultaneously operated in their region of positive resistance on the same flank of the negative-resistance region, there is an unequal change in the currents flowing in the two branches and a consequent redistribution of the stored energy. At the termination of the momentary disturbance the total current flow in the two branches is restored to its previous value but the division of current between the branches is reversed. That is, the high-current path becomes the low-current path and vice

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versa. The operating conditions of the two variable resistance units are interchanged, and the energy is now stored in the memory circuit in the opposite sense or polarity to the original stored energy. This revised current-conduction condition is a stable one and will be maintained until a subsequent circuit disturbance in the form of a triggering impulse causes the circuit to revert to its original condition. Arrangements are made for extracting suitably shaped related voltage impulses.

The manner in which the invention accomplishes the above-mentioned objects will be more clearly apprehended from a consideration of the following descriptions of a few preferred embodiments thereof, when considered in conjunction with the drawings, in which:

Fig. 1 is a schematic circuit arrangement of one embodiment of the invention in which series-type negative-resistance elements are employed in the current-conduction paths, in which the source of reversing pulses is connected between the parallel conduction paths;

Figs. 2 and 6 are current-voltage and voltage-current characteristics, respectively, to which references are made in the following descriptions;

Fig. 3 is a schematic of a second embodiment of a double-stability circuit in accordance with the invention using series-type negative-resistance elements in which the source of reversing pulses is serially connected with the parallel conduction paths;

Fig. 4 is a schematic circuit of a double-stability circuit in accordance with the invention in which the negative-resistance elements are of the specific type known as "transistors," and in which a single energy storage unit is employed; and

Fig. 5 is a double-stability circuit arranged in accordance with the invention in which shunt-type negative-resistance elements are utilized.

The variable resistance units that are utilized in this invention are well known in the art and may take a variety of forms. Although this invention is primarily concerned with the use of small inert or passive type negative-resistance units because of their extremely small size and low power requirements, it will be understood that it may be practiced equally well through the use of ionic or electronic discharge devices, or for that matter with arc discharges. In the following descriptions the invention will be set forth in terms of two main classifications of negative-resistance units, rather with reference to a specific unit. However, there will be described one tested embodiment of the invention in which

small flake-type "thermistors" were utilized. these units will be more completely identified in connection with the description of Fig. 1.

Negative-resistance units have been generally classified as series- or shunt-type units, and will be so referred to herein. The series type of unit is often referred to as an open-circuit stable or current-controlled unit. A graph of its current-voltage characteristic is an N-shaped curve which shows a region of negative resistance in which an increase in the current flowing through the unit is accompanied by a decrease in the voltage drop across it. This region is flanked on the left and right by regions of positive resistance in which an increase in current flow is accompanied by an increase in voltage drop across the unit. Thus, for a given value of voltage drop across the unit there may be as many as three appropriate values of current. If this type of unit is serially connected to a positive resistance the value of which is at all times greater than the maximum value of the negative resistance, the unit is stable, hence its classification as an open-circuit stable unit. If the connected resistor is less than this maximum negative value the unit is unstable and the current flowing through it will never come to rest at a value corresponding to the negative-resistance region but will quickly traverse this region and come to rest in the positive-resistance region to the left or right of the negative region. These left and right regions of positive resistance will be referred to herein as the first and second regions, respectively.

The shunt type of unit is said to be voltage-controlled or short-circuit stable. A plot of the values of current flowing in the unit for various values of voltage impressed across the unit has the general shape of an S curve. This curve shows a region of negative resistance that is flanked on the bottom and top by regions of positive resistance; which regions may be referred to herein as the first and second positive-resistance regions, respectively. This shunt type of unit is in nearly all respects the converse of the series type of unit. Thus, in the region of negative resistance an increase in the impressed voltage is accompanied by a decrease in the current flowing through the unit, and for a given value of current flow there may be as many as three values of voltage across the unit. If this type of unit is connected in parallel with a positive resistance which is at all times less than the minimum value of the variable resistance in its negative region, the unit is stable. If so connected with a resistor of value greater than this minimum value, the unit is unstable, and the voltage across the unit will never come to rest in the negative-resistance region; but will quickly traverse this region to rest in its first or second region of positive resistance depending upon whether the disturbance is an addition or reduction in magnitude of the impressed voltage.

In Fig. 1 there is shown the circuit arrangement of a double-stability or trigger circuit in accordance with the invention in which the variable or negative-resistance units are of the series- or current-controlled type. Therefore, in order to utilize the unstable characteristic of these units, each is connected in series with a padding resistor the magnitude of which is less than the maximum value of the variable unit in its negative portion of its variational characteristic.

In this tested arrangement, the negative-

resistance units 14, 16 which are here shown as variable resistors in a broken line rectangle, were a species of the general class of variable resistors that has been named varistor, and specifically is called a thermistor because of its property of changing its resistance in accordance with changes in its temperature. The tested units were substantially identical flake-type or thin-film type thermistors similar to those described in Patent 2,414,793, January 28, 1947, to J. A. Becker. They could equally well have been bead-type thermistors, point-type rectifiers such as the germanium crystal diode; or, as will be explained in connection with Fig. 4, they could be the more recently publicized semiconductor arrangement that has come to be known as transistor.

Each of resistance units 14, 16 has a variational resistance characteristic of the type indicated by the current-voltage graph 30 of Fig. 2. Current source or battery 10 together with current-limiting series resistor 12 is connected across the parallel current-conducting paths comprising variable resistors 14, 16 and their connected padding resistors 18, 20. A pair of capacitors 22, 24 are connected in series between the junctions of the fixed and variable resistance units; and a pulse generator 28 is connected between the junction of resistors 18, 20 and the junction of capacitors 22, 24. Generator 28 is connected so that its pulses as they pass through variable resistors 14 and 16 are in opposed polarity to the current from source 10. Output terminals designated Out are connected across padding resistor 20.

The general principles governing the choice of suitable values for current source or battery 10, limiting resistor 12 and padding resistors 18, 20 will be explained with reference to the current-voltage characteristic curves of Fig. 2. Referring to that figure, curve or graph 30 indicates the manner in which the voltage across a series-type or current-controlled negative-resistance unit changes as the current flowing through the unit is varied. This curve is representative of the general class of series-type units and is not individual to any specific unit. It is indicative of the variation that would be noted if a thin-film resistor composed of one or more of the oxides of manganese, nickel, cobalt or other suitable metal, such as is described by Becker in the previously referred to Patent 2,414,793, were connected in series with a source of variable unidirectional current and a large-valued stabilizing resistor. The variation in voltage or voltage drop across the thermistor would be similar to that shown on curve 30 if the current flowing in the resistor were varied.

From this curve it will be noted that the unit has a region 38 to 40 of negative resistance in which an increase of current produces a corresponding decrease in voltage across the unit. This region of negative resistance is flanked on the left by a first region of positive resistance extending from zero to reference numeral 38, and is flanked on the right by a second region of positive resistance to the right of reference numeral 40. These first and second regions are occasionally referred to as the low-current and high-current regions of positive resistance, respectively. There is only one appropriate value of voltage or voltage drop for any specific value of current flowing through the device, but, for any given value of voltage drop there may be as many as three appropriate values of current flow in

the unit. The curve portion between reference numerals 38, 40 is a region in which a change in the current flowing through the device produces an oppositely directed change in the voltage across the device. This, therefore, is a region of instability and is not one in which the current flow will come to rest unless the unit is in series connection with a stabilizing resistor of sufficiently great value. If the stabilizing resistor is greater than the maximum negative resistance of the negative-resistance unit, any current value may be stably maintained. This maximum negative resistance occurs at a current corresponding to the point 42 at which curve 30 has its maximum negative slope.

The constant slope curve 44 (Fig. 2) indicates the potential drop across one of the padding resistors 18, 20 as the current through the resistor is increased. The combined current-voltage characteristic of a serially connected series-type negative-resistance element 14, 16 and its associated padding resistors 18, 20 is shown by curve 32 of Fig. 2. It will be noted from this curve that the negative-resistance region, as indicated by curve portion 38', 40' is constricted from that for the negative-resistance unit alone, as indicated by the curve portion 38', 40' of curve 30. This compression of the negative-resistance region is caused by the addition of the padding resistor, and is a function of the magnitude of this resistor. If the associated padding resistor is less than the above-described maximum negative resistance, the curve 32 will include such a region as indicated by the numerals 38', 40'. Any change in current that brings the operation within the curve portions 38', 40' promotes the regenerative action that is inherent in the device and causes the current to quickly traverse this region of negative resistance and to come to rest at an appropriate value in its first, low-current or second, high-current region of positive resistance. It is this characteristic of the negative-resistance element that is employed to useful purpose in the subject invention.

It may be seen that the padding resistor should not be of such value that the negative-resistance portion of curve 32 is completely eliminated. In actual practice, the padding resistor should be sufficiently below this limiting value to allow a suitably large or extended negative-resistance region, as seen on the current-voltage characteristic curve of the negative-resistance element, to permit the desired trigger action. One consideration to be borne in mind is that increased stability with respect to extraneous voltage impulses may be expected to accompany an extended negative-resistance range.

An analogous situation exists in the shunt-type voltage-controlled or short-circuit stable unit in which the current varies as the voltage across the unit is varied. This characteristic of the shunt-type unit will be later discussed with relation to Fig. 6. It is mentioned at this time in order to emphasize that each type of unit has a negative-resistance region of instability for electrical quantities within a predetermined or specified range of values.

Current source or battery 10 and current-limiting resistor 12 may be suitably proportioned over a rather wide range of values, the choice of which will to a large extent determine the magnitude of the pulse from source 28 that provides the desired trigger action. In general, for a given operating condition, a reduction in the potential of

battery 10 and in the magnitude of resistor 12 will also reduce the required magnitude of the reversing pulses from source 28. Current source 10 and resistor 12 are chosen of such values that when connected in series with the parallel conducting paths including negative-resistance units 14 and 16, the total current flowing through resistor 12 lies between the values of twice the current value corresponding to the voltage maximum 38' across the combined resistors and twice the current value at the voltage minimum 40' across the combined resistors. From an inspection of curve 32 it will be seen that, when the total current in the circuit is maintained between these two limiting values, negative-resistance units 14, 16 may not both be simultaneously operating in their high-current or low-current positive voltage regions. Therefore, one of these negative-resistance units must necessarily operate in its low-current positive resistance region to the left of point 38' at the same time that the other is operating in its high-current positive-resistance region to the right of point 40'.

Capacitors 22 and 24 may be suitably chosen of equal value. They are preferably of such size that a substantial fraction of the potential difference that exists across these units at the beginning of the reversing pulse from source 28 continues to exist across them at the end of the pulse period. The maintenance of this potential differential is desirable in order that the current conduction state of each negative-resistance unit 14 and 16 will be reversed after each pulse interval.

Pulse source 28 is of sufficient magnitude and is so poled that it momentarily reduces (to a value less than the minimum value 40) the voltage across negative-resistance unit 14 or 16, whichever is conducting high current. The pulse from source 28 is preferably of a duration that is a substantial fraction of the time required for the negative-resistance units 14 and 16 to reverse their current-conduction states. Therefore, the duration of this pulse may be increased when slow-speed units are used and decreased when high-speed units are used.

In one tested embodiment of the invention, suitable values for the designated components were as follows:

Battery 10	60 volts
Current-limiting resistor 12	10,000 ohms
Capacitors 20, 24	3,000 microfarads
Resistors 18, 20	3,300 ohms
Pulse source 28	33 volts

Negative-resistance units 14, 16 were flake-type thermistor units composed of nickel, manganese, and cobalt oxides such as are described in the previously mentioned J. A. Becker Patent 2,414,793. Their thickness was such that they had a time constant of about 100 milliseconds or less and a current-voltage characteristic such that a maximum voltage (point 38, curve 30) of about 18 volts coincided with a current voltage of about .18 milliamperes and a minimum voltage (point 40) of about 4.5 volts corresponded to a current value of 10 milliamperes.

Although in the above-described embodiment the values of components in the two current-conduction paths have been shown to be substantially similar, modifications of this circuit are conceivable in which the characteristics of the two negative-resistance units 14, 16 and the values of their series-connected resistors 18, 20 differ substantially from each other. This also applies to the circuits to be described hereinafter.

It is interesting to note that had the potential of source 10, in this tested embodiment of the invention, been reduced to about 25 volts and the magnitude of the resistor 12 had been reduced to about 1,500 ohms, a magnitude of only 8 or 9 volts would be required for the pulses from source 28 to insure reversal of the double-stability unit.

The manner in which the double-stability unit of Fig. 1 operates to alternately change from maximum current conduction to minimum current conduction in each path may be best apprehended if an initial set of current conditions is assumed. For this purpose, assume that the total current from battery 10 is limited to the sum of the two values corresponding to points 34' and 36' on curve 32 and that the negative resistance 14 and padding resistor 18 initially constitute the maximum current-conduction path. Under these conditions, the current flowing in negative-resistance unit 16 is less than that in unit 14, but the voltage across unit 16 is greater than the voltage across unit 14. The voltage drop across padding resistor 18 exceeds the drop across resistor 20, and capacitors 22, 24 are charged with the negative terminal connected to resistor 18. If source 28 now supplies a voltage impulse between the common terminal of resistors 18, 20 and the common terminal of capacitors 22, 24 the polarity of which with respect to the common terminal of resistors 18, 20 is the same as the polarity of source 10, the voltage across negative-resistance unit 14 is changed to a value less than its voltage minimum 40 (curve 30, Fig. 2). Referring to this curve, it will be noted that when the voltage across the negative-resistance unit is reduced below the voltage minimum value 40, the unit is brought within its range of instability. The current in the unit cannot rest between reference points 38 and 40 (curve 30), so it quickly traverses this region to rest at a value in the low-current positive-resistance region corresponding to the new voltage value 45 (curve 30). During the period just preceding the pulse interval in question, negative-resistance unit 16 was operating at point 34 in its low-current positive-resistance range, and the voltage across it was greater than that across unit 14. Upon the application of the voltage pulse from source 28, the voltage across this unit is lowered by the same amount as that across unit 14; however, because it was initially operating in its low-current positive-resistance range, its current conduction is only slightly lowered and remains at a higher value than the revised value for unit 14 (represented by point 45). Capacitor 22 discharges through resistor 18 and temporarily maintains the voltage across resistance unit 14 at a lesser value than that across 16. At the termination of the pulse, the full potential of source 10 again becomes effective to increase the current flowing in both units. Because the voltage across unit 16 is now greater than that across unit 14 and this difference tends to be maintained by the discharge of capacitor 22 as the currents through the negative-resistance units 14 and 16 simultaneously increase, it is apparent that unit 16 will reach its point of voltage maximum (point 38) before unit 14 reaches this point. Therefore, as the current continues to increase, unit 16 is forced through its negative resistance region (30-40) and into conduction in its high-current positive-resistance region to the right of point 40 (curve 30). This action results in a sudden increase in the total current flowing in the circuit, which increase is limited by the voltage drop across current-limiting resistor 12 in such fashion that the

total current in the circuit is again maintained at a value that is less than twice the current flowing in either negative-resistance unit at its point 40 of voltage minimum. Hence, the current conduction through unit 14 is limited to its low-current stage. During the interval of the reversing pulse from source 28 and immediately following the cessation of this pulse, the potential difference across capacitors 22 and 24 is redistributed, that is, capacitor 22 discharges and capacitor 24 charges in such fashion that the potential difference that previously existed between these units is maintained in magnitude but is reversed in direction by the now larger current flow through padding resistor 20. Thus, a half cycle of operation is completed, and the main current carrying path is changed from resistance unit 14 to resistance unit 16. In addition to acting as a padding resistor, resistor 20 also functions as a load resistor. At the time of each change in the magnitude of the current flowing through negative-resistance unit 16, there is a corresponding change in the potential drop across resistor 20, which change is available at the output terminals designated Out in the form of a rectangularly shaped voltage wave. These current-conduction conditions are maintained until the next succeeding impulse from source 28 causes unit 16 to revert to its low-current positive voltage region of operation and unit 14 to change to its high-current positive voltage condition in the manner which has been previously described.

As described in the foregoing paragraphs, the pulse source 28 is poled in a direction to reduce the potential across the variable-resistance current-conduction paths. However, it will be apparent from a study of curves 30 and 32 of Fig. 2, that the circuit of Fig. 1 could also be operated with the polarity of pulse source 28 reversed, the added pulses being of sufficient magnitude to enable both variable-resistance units to operate on the upper positive portions of the current-voltage characteristic for the duration of the pulse.

Fig. 3 shows the schematic arrangement of a slightly different embodiment of the invention in which the source 28 of reversing voltage impulses is connected between one terminal of the current source or battery 10 and the common junction of padding resistors 18, 20 instead of in the manner shown in Fig. 1. As in the arrangement of Fig. 1, the polarity of the voltage pulses from source 28 are chosen to be in opposition to the polarity of battery 10. Therefore, the required polarity with respect to the common junction of resistors 18, 20 is reversed from that of Fig. 1. Under certain operating conditions, this may be found to be a convenient form of the invention; such as, where certain grounding arrangements must be observed. In addition to the foregoing consideration, the arrangement of Fig. 2 also differs from that of Fig. 1 in that the impedance termination of source 28 is slightly different in the two arrangements. In most instances, this will not be a material consideration.

Fig. 4 shows a schematic arrangement of a third embodiment of the invention in which each negative-resistance unit 46, 50, comprises a semiconductor triode of the type which has become commonly known as a transistor; and which is described and claimed in Patent 2,524,035 of John Bardeen and W. H. Brattain, issued October 3, 1950. Each of these units comprises a small block of semiconductor material, such as N-type germanium, with which are associated three electrodes. One of these, known as the base elec-

trode, makes low-resistance contact with one face of the germanium block. It may be a plated metal film. The others, one termed "emitter" and the other "collector" preferably make point-type contact with the other face of the block. The unit is connected in the manner disclosed and claimed in H. L. Barney Patent 2,585,078, issued February 12, 1952, in which a resistor 48 or 52 is connected between the base electrode and the emitter electrode. As is there described, this transistor is characterized by a ratio of short-circuit collector current increments to corresponding emitter current increments which substantially exceeds unity for electrode current-voltage conditions within a preassigned range of values. When such a semiconductor triode is connected, as shown in Fig. 4, the points 38 and 40 (curve 39, Fig. 2) of voltage maximum and minimum are functions of the magnitude of the shunting resistor 48 or 52. Thus, changes in the magnitude of this resistor permit placing the points 38 and 40 of voltage maximum and minimum at the desired values. These negative-resistance transistor circuits are serially connected with padding resistors 18 and 20 to form parallel conduction paths across which are connected a third circuit branch made up of current source or battery 10, current-limiting resistor 12, and a source of voltage impulses 28. As in the previously described embodiments, pulse source 28 is poled in such manner that its pulses opposite in polarity the potential of battery 10. Capacitor 54 is connected between the junction point 56 of transistor 46 and resistor 18 and junction point 53 of transistor 50 and resistor 20. Transistor units 46 and 50, when arranged as shown, constitute series-type negative-resistance units having a representative current-voltage characteristic, as shown by curve 30 of Fig. 2. The same considerations control the choice of magnitudes for battery 10, current-limiting resistor 12, and padding resistors 18 and 20, as was described in connection with the circuit arrangement of Fig. 1. As was previously explained, by limiting the total current flow in the circuit to a value which lies between the two limiting values, of less than twice the current corresponding to the voltage minimum 40' across the combined negative resistance and padding resistor and more than twice the current corresponding to the voltage maximum 38' across these units, the stable current-conduction states in the two parallel circuit branches comprising the transistors 46, 50 are unequal. If it is assumed that transistor 46 is at a given instant conducting a high-current value, transistor 50 will be conducting a low-current value, and the potential drop across padding resistor 18 will exceed that across resistor 20. Capacitor 54 will have a positive potential charge on its plate adjacent to point 56. If now a reversing voltage impulse is applied from source 28 so as to reduce the potential across transistor 46 to a value less than its minimum value 40, capacitor 54 will drive circulating current around the loop made up of capacitor 54 and resistors 18 and 20 in such a way as to tend to maintain the potential difference between reference points 56 and 58. Hence, the current through transistor 50 will be greater than that through transistor 46, and if the pulse is removed before condenser 54 is discharged, transistor 50 will transfer to the high-current state. Capacitor 54 will then discharge and recharge in the reverse direction in which its terminal adjacent junction 58 is

positive. At the same time of the next reversing voltage impulse from source 26, the same cycle of events takes place, but in the reverse direction, and transistor 46 is returned to the high-current state, while transistor 50 returns to the low-current state, thus completing a full cycle of operation. Simultaneously, currents flowing in resistor 20 produce changed potential drops across resistor 20 which are available at the output terminals designated Out in the form of rectangular voltage impulses.

In Fig. 4 the output is shown as connected across padding resistor 20. It is equally possible to connect the output across either resistor 48 or 52.

Fig. 5 is a schematic of a circuit in accordance with the invention in which the negative-resistance units 60, 64 are shunt-type negative-resistance elements. Each of these elements 60, 64 may have a current-voltage characteristic such as is shown by the representative curve 74 of Fig. 6. This characteristic is distinguished by the fact that as the voltage across the negative-resistance unit is increased from zero, the current through the unit first increases until it reaches a maximum value indicated at reference point 76. A further increase of the voltage across this unit causes the current to decrease until it reaches a minimum value at point 78, after which further increase of voltage causes increased current. It is thus seen that each of these elements possesses a region of negative resistance between reference points 76 and 78 which is enclosed by a first or low-voltage region of positive resistance and a second or high-voltage region of positive resistance. These units are distinguishable from those described in connection with Fig. 1 in that there is only one related value of current corresponding to each value of voltage across the unit; whereas there may be as many as three values of related voltage across the unit for a single value of current.

This characteristic is the reverse of the series-type characteristic exemplified by curve 30 of Fig. 2. These shunt-type negative-resistance elements 60, 64 are connected in series with potential source or battery 10, voltage dropping resistor 12, and pulse source 28, as indicated. Resistors 62, 66 are connected in series and are shunted across the negative-resistance units. An inductor 68 is connected between junction point 70 of the negative-resistance units and junction point 72 of resistors 62, 66.

The considerations governing the choice of magnitudes for the various components of the arrangement of Fig. 5 are similar to those that have been described in connection with the arrangement of Fig. 1. Resistors 62, 66 are preferably equal, or nearly equal. Each may be chosen from a wide range of values subject to the limitation that it shall not be less than the minimum negative resistance of the shunt-type element (approximately indicated at point 86, curve 74) so that the current-voltage characteristic 80 of the combination of one of these resistors in parallel with its associated negative-resistance unit 60 or 64 has a negative slope or negative-resistance portion, as is shown by the maximum and minimum current reference points 82, 84. The potential of battery 10 and the resistance of resistor 12 are chosen so that the potential difference across the serially connected negative-resistance units 60, 64 shall always be greater than twice the voltage across the combination of one of these units and its paralleled fixed re-

sistor at the point 82 of current maximum and less than twice the voltage across the combination at point 84 of current minimum.

When the values of battery 10 and current-limiting resistor 12 are chosen to produce a voltage condition within these limits, there will be a total current T (Fig. 5) flowing in the circuit. This current T corresponds to three possible voltage conditions across the negative-resistance units. One condition (point 85, curve 74) corresponds to the high-voltage operating condition of the negative-resistance unit. A second condition (point 88) corresponds to the low-voltage operating condition of the negative-resistance unit. The third condition falls within the negative voltage range of the negative-resistance unit. Since this is a region of instability, it will not come to rest in this condition. Under these conditions, there will not be a stable rest state in which the voltage across one negative-resistance unit is equal to that across the other unit. Analogous to the series-type arrangement, one of these shunt-type negative-resistance units will operate in its high-voltage positive-resistance region at point 85 on curve 74, while the other is operating in its low-voltage region at point 88 on this curve. The sum of the currents through negative-resistance unit 60 and its shunt resistor 62 will always equal the sum of the currents through negative resistance 64 and its shunt resistance 66.

The manner of operation of this arrangement is similar to that which has been previously described for the series-type negative-resistance units. Assume an initial condition in which negative resistance 60 is operating at point 85 in its high-voltage state and negative resistance 64 is operating at point 88 in its low-voltage state. A relatively high value of current will flow through negative resistance 64 and resistor 62, and a relatively low value of current will flow through negative resistance 60 and resistor 66. The difference between these two values of current flows through inductor 68. Because of the energy that is stored in the magnetic field around inductor 68, the current conduction through inductor 68 cannot change instantaneously. Therefore, if an impulse is supplied from source 28, the currents flowing through negative-resistance units 60 and 64 will also be reduced in such manner that the difference between the currents flowing through these units remains substantially unchanged. This current reduction reduces the current through negative resistance 60 to a value less than its current minimum 78, and this unit reverts to its low-voltage operating condition at point 90 in which the current through it is less than that through negative-resistance unit 64. At the termination of the pulse from source 28, the current through negative resistances 60, 64 starts to increase uniformly, and negative resistance 64 reaches its current maximum condition 76 and is forced through the negative-resistance portion of its characteristic before unit 60 reaches its current maximum condition. Resistance unit 64, therefore, transfers to its high-voltage low-current state (point 85, curve 74), and unit 60 is maintained in its low-voltage high-current state at point 88 on this curve. Current flow through inductor 68 decreases to zero and then builds up to a stable value in the reversed direction consistent with the revised current conditions. At a later instant when a second current pulse is supplied from source 28, the previously described redistribution of potentials with its consequent

change in current flow is performed in the reverse direction, thus restoring the circuit to its initial condition and completing a full cycle of operation. At the time of each potential change, there is a revision in the current flowing through padding resistor 66 which also serves as an output load resistor. These revised current conditions produce square wave voltage impulses which are available at the output terminals designated Out.

It is evident from the preceding description that the subject invention may be practiced through the use of a variety of circuit arrangements, a few preferred ones of which have been described herein. It should be appreciated that there exist several suitable negative-resistance units, either of the series- or shunt-type, which may be used with equal facility to those that have been described herein in carrying out this invention. In view of this, it is to be expected that variations of the invention which do not depart from its spirit and scope will present themselves to those skilled in the related art.

What is claimed is:

1. A double-stability trigger circuit which comprises a pair of variable resistance elements each of which possesses a negative resistance over a restricted portion of its current-voltage range having a minimum and a maximum voltage value, a pair of fixed resistance elements each connected in series with a respective one of said variable elements to form a pair of branches, a capacitive circuit connected between the common points of said respective variable and fixed resistance elements, a source of potential, current-limiting means connecting said source across both of said series-connected resistance branches and effective to limit the current from said source to a value less than the sum of the currents corresponding to said minimum voltage values and greater than the sum of the currents corresponding to said maximum voltage values, and means for momentarily reducing the current in said branches to a value less than the sum corresponding to said maximum voltage values comprising a source of unidirectional voltage impulses connected intermediate said source of potential and said variable resistance elements.

2. A double-stability trigger circuit which comprises a pair of variable impedance elements each of which possesses a negative impedance over a restricted portion of its current-voltage range having a minimum and a maximum voltage value, a pair of fixed impedance elements each connected in series with a respective one of said variable impedance elements to form a pair of impedance branches, energy storage means interconnecting said respective variable and fixed impedance elements, a source of potential connected across both series-connected impedance branches, said source being limited to a current less than the sum of the currents corresponding to said minimum voltage values, and greater than the sum of the currents corresponding to said maximum voltage values, and means for momentarily reducing the current flow through said impedance branches to a total value less than a predetermined minimum value.

3. An electrical trigger circuit comprising a pair of variable resistance elements and a pair of connected fixed resistors forming therewith a pair of current-conduction paths, each of said variable resistance elements in combination with each said fixed resistor having a variational resistance characteristic which is represented by a first region in which one stable operating state obtains exclusively for a given set of conditions,

and a second region in which another stable operating state obtains exclusively for a given set of conditions, and a region intermediate said first region and said second region in which either of said stable operating states obtains for a given set of conditions, an impedance element connected to each of said elements and forming therewith a current conduction path, an external network interconnecting said current conduction paths, said network including a source of energy the magnitude of which is such that both of said elements are operated in said intermediate region simultaneously, whereby each of said elements stabilizes in a different one of said stable operating states, said network including a source of unidirectional electric pulses, and energy storage means coupling said current-conduction paths to store energy in accordance with the difference in said current-voltage operating conditions of said variable resistance elements, said stored energy effecting an interchange of the operating conditions in said elements at the termination of each pulse from said source.

4. An electrical trigger circuit comprising a pair of negative-resistance elements each of which is characterized by a variational resistance characteristic which is represented by a first region in which a first stable operating state obtains exclusively for a given operating condition, a second region in which a second stable operating state obtains exclusively for a given operating condition, and a region intermediate said first and said second regions in which either of said first or said second stable states obtains for a given operating condition, a fixed resistance connected to each of said elements and forming therewith a current-conduction path, an external network interconnecting said current-conduction paths, said network including a unidirectional source of electrical energy of such a magnitude as to operate each of said elements in said intermediate region simultaneously, whereby each of said elements stabilizes in a different one of said operating states, said network also including a source of unidirectional electrical pulses for changing the effective value of said electrical source to give rise to a condition of the system in which each of said elements is in the same stable operating state, and energy storage means interconnecting said conducting branches.

5. An electrical double-stability circuit comprising a pair of variable resistance units, a pair of fixed resistance units each of which is connected to a respective one of said variable units, each of said connected combinations being characterized by a variational resistance characteristic having a predetermined range of electrical quantities within which either of two stable rest states obtains for a given set of conditions and outside of which only a single stable rest state obtains for a given set of conditions, a source of continuous unidirectional energy interconnecting said connected resistance units, the energy of said source limited in magnitude to values within said predetermined range of electrical quantities for both of said elements, whereby each of said elements stabilizes in a different one of said stable rest states, a source of unidirectional voltage pulses connected between said energy source and said variable resistance units the magnitude of said pulses being sufficient to change during their duration the effective value of said unidirectional energy source to a value which gives rise to operation outside of said predetermined range for both of said elements

simultaneously whereby each of said elements is momentarily in the same stable operating state, and a reactance element interconnecting the junctions of said fixed and variable resistance units.

6. An electrical double-stability circuit comprising a pair of variable resistance units and a respective fixed resistance unit connected to each, each of said connected variable and fixed units having a current-voltage characteristic that is characterized by a first region in which one stable operating condition obtains exclusively for any given condition, a second region in which another stable operating state obtains exclusively for any given condition, and an intermediate region between said first and said second regions in which either one or the other of said stable operating conditions obtains for any given condition, an external network interconnecting said combined units, said network including a source of continuous unidirectional energy the magnitude of which is equal to twice the value required to produce in one of said combinations the current-voltage conditions corresponding to said intermediate region and a source of unidirectional energy impulses the polarities of which are opposed to the polarity of said continuous energy source, the magnitude of said impulses being sufficient to momentarily bring both resistance combinations within the current-voltage conditions corresponding to one of said regions outside said intermediate region, and a reactive member coupling said fixed and variable resistance combinations.

7. An electrical double-stability circuit comprising a pair of variable resistance units and a pair of respective fixed resistance units connected thereto, each of said variable resistance units and its respective connected fixed resistance units having a current-voltage characteristic that is characterized by a first region in which one stable operating state obtains, a second region in which another stable operating state obtains, and a region intermediate between said first and second regions in which either one or the other of said stable operating states obtains, an external network interconnecting said connected resistances, said network including a source of continuous unidirectional energy, said source of continuous energy having a value sufficient to produce current-voltage conditions corresponding to said intermediate region in each of said variable resistance units simultaneously, and a source of intermittent pulses, said pulse energy source having a value sufficient to reduce the effective value of said continuous energy source to a value insufficient to produce current-voltage conditions corresponding to said intermediate region in each of said variable resistance units simultaneously, and a reactive member coupling said connected fixed and variable resistance units.

8. An electrical double-stability circuit comprising a pair of variable resistance units, a pair of fixed resistance units connected to respective ones of said variable units, each of said connected fixed and variable units in combination being characterized by a region of negative resistance within a predetermined range of current-voltage conditions in which operation in either of two stable states is possible, and by first and second regions of positive resistances within adjacent ranges of current-voltage conditions wherein operation in only one stable state is possible, a source of continuous uni-

directional energy connected across said fixed and variable resistance units, said source being limited in magnitude to a normal value that is less than that required to maintain simultaneously both connected fixed and variable resistance combinations in their second positive resistance region and greater than is required to maintain simultaneously both of said combinations in their first positive-resistance region, means to momentarily reduce the magnitude of said source to a value sufficient only to maintain said connected combinations in their first region of positive resistance, and energy storage means interconnecting said fixed and variable resistance unit combinations.

9. An electrical trigger circuit comprising a pair of variable resistance units, each of which is in series connection with a respective fixed resistance unit, each of said combined fixed and variable units being characterized by a variational resistance characteristic having a predetermined range of current-voltage conditions within which operation in either of two stable states is possible for a given set of conditions and outside of which operation in only one of said stable states is possible for a given set of conditions, a capacitive coupling between the junctions of said fixed and variable units, a source of continuous unidirectional current and a current-limiting resistance in series therewith, said serially connected source and resistance being connected across and interconnecting said fixed and variable resistance units and being of such values that the maximum current flow therefrom equals but does not exceed the current flow sufficient to produce currents within said predetermined range for each of said variable resistance units simultaneously, and a source of unidirectional voltage pulses coupled across each of said fixed resistance units, said pulse source being opposed in polarity to said continuous current source and being of magnitude sufficient to momentarily reduce the current flow from said source to a value less than that sufficient to produce said predetermined range in each of said variable resistance units simultaneously.

10. A double-stability circuit comprising a pair of series-type negative-resistance elements, each of which is paired in series connection with a fixed resistance element, each of said paired resistance elements being characterized by a similar variational resistance characteristic having a predetermined range of current-voltage conditions within which operation occurs in either of two stable states for a given set of conditions and outside of which operation occurs in only one of said stable states for a given set of conditions, a continuous current source connected across and interconnecting said resistance combinations, said source being of such magnitude that the maximum current therefrom corresponds to roughly twice a current value within said predetermined range of current-voltage conditions in one of said negative-resistance elements, a source of unidirectional current pulses the magnitude of which is sufficient to momentarily change the current flow in each of said series-type negative-resistance elements to a value corresponding to current values outside of said predetermined range of current-voltage conditions, and a capacitive circuit interconnecting the junction points of said series-type negative-resistance elements and said fixed resistance elements.

11. An electrical trigger circuit comprising a

pair of shunt-type negative-resistance units in series connection, a pair of series-connected fixed resistors in parallel connection with said shunt-type units, an inductor connected between the junctions of said fixed and shunt-type resistance units, each of said shunt-type units and its parallel-connected fixed resistor being characterized by a variational resistance characteristic that is negative within a predetermined range of current-voltage conditions within which operation occurs in either of two stable states, and outside of which operation occurs in only one of said stable states, and an external network connected across said parallel combination, said network including a source of continuous voltage of a given polarity, a series-connected source of intermittent voltage pulses, and means to limit the normal current flow from said continuous voltage source to a value sufficient to produce currents within said predetermined range of current-voltage conditions in each of said negative-resistance units simultaneously.

12. An electrical trigger circuit comprising a pair of shunt-type negative-resistance units in series connection, a pair of series-connected fixed resistors respectively in parallel combination with each said shunt-type unit, a reactive impedance connected between the junctions of said fixed and said shunt-type resistance units, each of said shunt-type units and its parallel-connected fixed resistor being characterized by a variational resistance characteristic having a predetermined range of current-voltage conditions within which operation occurs in either of two stable states and outside of which operation occurs in only one of said stable states, and an external network connected across said parallel combinations, said network comprising a current-limiting resistor, a source of continuous voltage of a given polarity, and a source of intermittent voltage, said current-limiting resistor being of such value that the maximum current from said continuous voltage source is limited to a current value corresponding to values within said predetermined range of current-voltage conditions in each of said negative resistance units simultaneously.

13. An electrical trigger circuit comprising a pair of similar shunt-type negative-resistance elements in series connection, a pair of series-connected fixed resistors connected in parallel with said negative-resistance elements, each of said fixed resistors being of smaller value than the minimum negative resistance of said shunt-type elements, an inductor connected between the junction of said shunt-type elements and the junction of said fixed resistors, and an external network connected across said parallel combination, said network comprising a current-limited source of continuous current and a source of intermittent current pulses, said current-limited source being restricted to a value of current equal to roughly twice a value within the range of values at which said shunt-type elements display their negative-resistance characteristics.

14. An electrical trigger circuit comprising a pair of series-connected shunt-type negative-resistance elements, each of said elements having a region of negative resistance over a portion of its current-voltage characteristic, within which operation occurs in either of two stable states for a given set of conditions, a pair of series-connected fixed resistors respectively in parallel connection with said shunt-type elements, each of said fixed resistors being of value less than

the minimum negative-resistance value of said shunt-type elements, an impedance connection between the junction of said shunt-type elements and the junction of said fixed resistors, a current-limited source of continuous current of a given polarity connected across said parallel combinations, said source being limited to a maximum current value sufficient to produce the values of current within said negative-resistance portion of said current-voltage characteristics in each of said units simultaneously, and pulse producing means connected to said combination to momentarily reduce the currents through said shunt-type negative-resistance elements to values below those in said negative-resistance portion of their current-voltage characteristic.

15. An electrical trigger circuit comprising a pair of current-conductive paths, each of said paths including a series-type negative-resistance element connected to a fixed resistor, each of said series-type elements having a region of negative resistance for current values within a portion of its current-voltage characteristic within which region operation occurs in either of two stable states in response to a given set of conditions, and having regions of positive resistance for current values outside of said portion within which operation occurs in only one stable state in response to a given set of conditions, each of said fixed resistors being of a value less than the maximum negative resistance of series-type element, an impedance path connected between the junction of said fixed resistor and said series-type element in each current-conductive path, a source of continuous current of given potential connected across and interconnecting said pair of paths, said source being limited to a maximum current equal to the sum of the currents in said current-conductive paths corresponding to said region of negative resistance of said series-type negative-resistance elements, and pulsing means to intermittently change the current in said negative-resistance elements to values outside of those corresponding to said negative-resistance region.

16. An electrical trigger circuit comprising a pair of current-conducting paths, each of said paths including a variable impedance element which is characterized by a variational resistance characteristic having a predetermined

range of current-voltage conditions within which operation occurs in either of two stable states, and outside of which operation occurs in only one stable state, a storage circuit connected to intercouple said current-conducting paths, an external network connected across said current-conduction paths, said network including a continuous unidirectional source of energy the magnitude of which is sufficient to give rise to said predetermined range of current-voltage conditions in each of said current-conducting paths simultaneously, said network also including a source of unidirectional electrical pulses the magnitude of which is sufficient to momentarily change the current through said current-conducting paths to a value outside said predetermined range of current-voltage conditions.

17. An electrical trigger circuit comprising in combination a pair of variable resistance elements and a pair of connected auxiliary impedance elements forming therewith a pair of current-conduction paths, each of said variable resistance elements in combination with said auxiliary impedance elements having a variational resistance characteristic wherein operation occurs in either of two stable states within a predetermined range of electrical quantities, and wherein operation occurs in only one stable state for electrical quantities outside of said range, an energy storage circuit interconnecting said current-conduction paths, an external network connected across said current-conduction paths, said network including a continuous unidirectional source of energy the magnitude of which is sufficient to give rise to quantities within said predetermined range in each of said current-conducting paths simultaneously, said network also including a source of unidirectional electrical pulses the magnitude of which is sufficient to momentarily change the current through said current-conducting paths to a value outside of said predetermined range.

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The following references are of record in the file of this patent:

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