Nov. 19, 1963 F. STOLTE 3,111,594

METHOD AND APPARATUS FOR GENERATING ELECTRICAL PULSES

Filed May 10, 1961

3 Sheets-Sheet 1

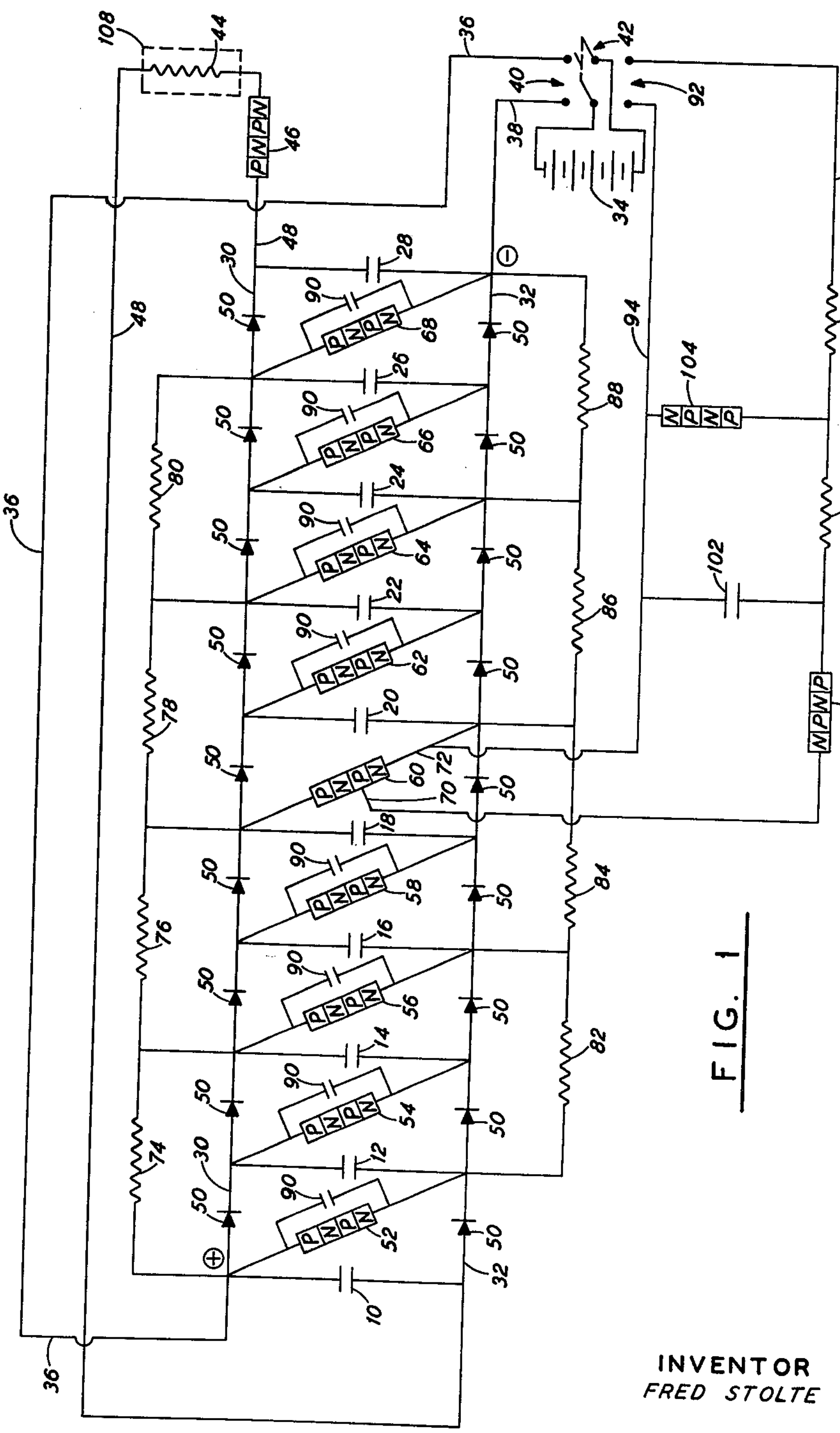

FIG. 1

INVENTOR
FRED STOLTE

BY Naylor & Neal
ATTORNEYS

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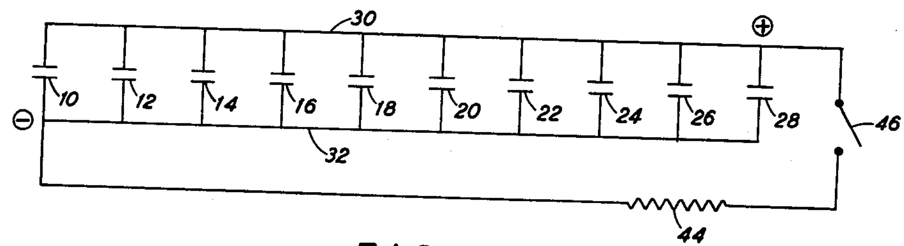

FIG. 2

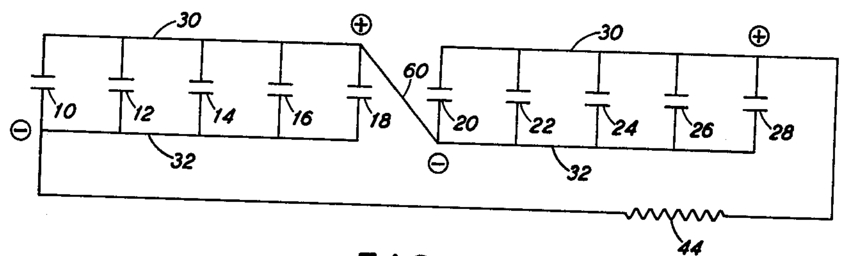

FIG. 3

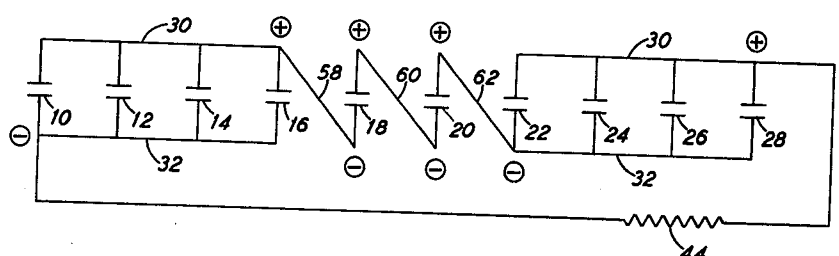

FIG. 4

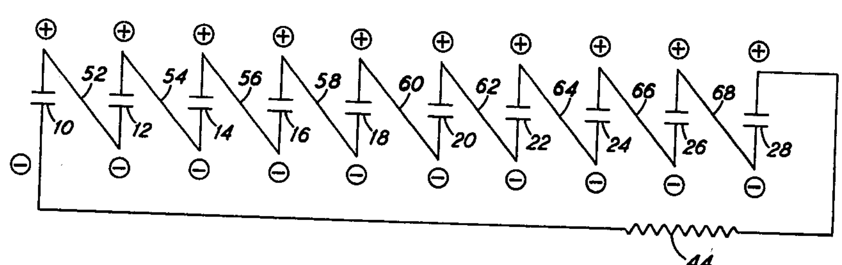

FIG. 5

INVENTOR
FRED STOLTE

BY Naylor & Neal
ATTORNEYS

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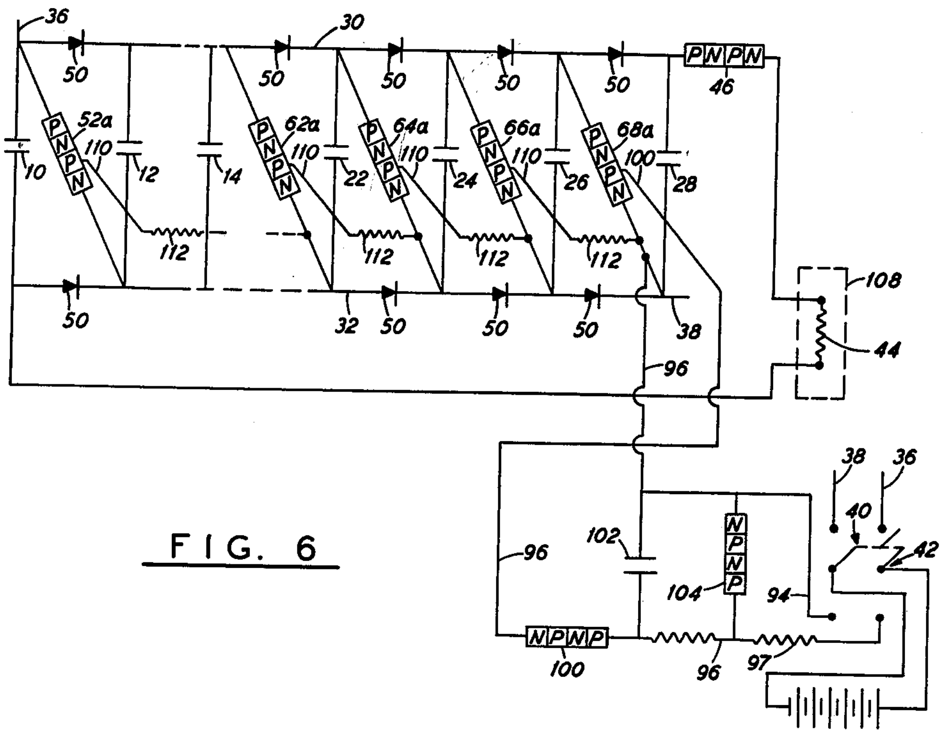

FIG. 6

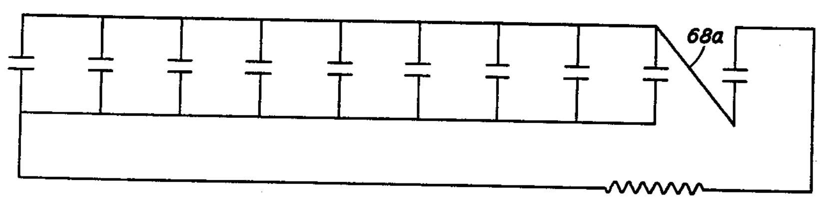

FIG. 7

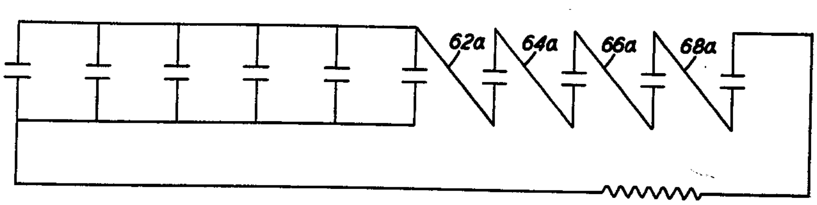

FIG. 8

INVENTOR
FRED STOLTE

BY Naylor & Neal
ATTORNEYS

United States Patent Office

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METHOD AND APPARATUS FOR GENERATING ELECTRICAL PULSES

Fred Stolte, 1213 Sunnyslope Road, Hollister, Calif.

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9 Claims. (Cl. 307—110)

This invention relates to power supplies and more particularly to power supplies for generating relatively short electrical pulses of high energy and fluctuating potential.

High energy electrical pulses are used in many devices to concentrate a large amount of energy into a small area in a short time. The energy so concentrated may be used, for instance, to ionize and illuminate the gas in a vapor lamp, thereby producing a very short and very intense flash of light; this practice is employed in large airports to produce light flashes which can be seen by pilots at great distances without blinding pilots closer to the airport, and the practice may be employed in the same manner on the highways to increase nighttime visibility of drivers without blinding oncoming drivers. The energy may also be used, for instance, in igniting insensitive propellant and/or explosive compositions, instead of using a train of successively higher energy explosive which starts with a highly sensitive one. The elimination of the highly sensitive explosive in the igniter results in an insensitive igniter that does not compromise the original safety of the insensitive propellant and/or explosive compositions; this practice is used in exploding bridgewire ignition systems where a large amount of energy is transferred by the pulse to a bridgewire in the form of heat and/or the potential energy of a compact plasma, the energy being transferred to the insensitive propellant and explosive compositions upon expansion of the exploded wire.

Many of these devices which employ relatively short pulses of high energy involve a load through which the pulse works where the load changes in its electrical properties during the course of the pulse; thus, the vapor in the lamp becomes ionized and then conducts current while its resistance to current flow changes substantially, and the exploding bridgewire changes sequentially through solid, liquid, vapor and plasma phases while undergoing very large changes in its resistance. As these materials undergo changes which alter their electrical properties, they generally demand increases in the potential of the electrical pulse which is to maintain current flow through the materials and transfer additional energy to the materials.

Several power sources have been employed in the past for generating the high energy pulses for devices of this type. These power sources generate pulses of sufficiently high potential that after the initial application of the high potential to the load, the potential is able to decay while the initial changes in the load are occurring and still have sufficiently high potentials left to effect the final transfer of energy to the load. However, several serious disadvantages have been encountered in employing the devices using these known power sources. For instance, the high potential used creates a hazard in itself since it is a voltage of from 1500 to 2500 volts. These voltages are still too low for reliable initiation and are too high for safety, causing dielectric failures and other malfunctions.

The devices using these power sources exhibit a characteristic behavior in their discharge pulse which causes irregularities and makes them less reliable. Of importance is the fact that the discharge pulse is characterized by a high magnetic pressure upon the exploded wire causing the ionized metal vapor to deionize and end the pulse, which then allows the exploded wire to expand until the conditions of voltage and pressure are such that reionization occur.

Accordingly, it is a principal object of this invention to provide a power supply for generating high energy

electrical pulses to be passed through a load and in which the instantaneous potential of the pulse may be changed in a controlled manner to maintain relatively continuous current through the load.

It is another object of the invention to provide a power supply for generating high energy electrical pulses in which the maximum potential employed during the pulse is reduced to a minimum, while the effect on the load caused by the pulse is raised to a maximum.

It is another object of the invention to provide a power supply for generating high energy electrical pulses in which the potential during the pulse is controlled to suit the pulse to the instantaneous needs of the load on which the pulse is working.

It is another object of this invention to provide a power supply for generating a high energy pulse to be applied to a load in which the instantaneous potential difference produced by the power source during the pulse increases in a sequence of controlled steps.

It is a further object of the invention to provide a power source for generating short electrical pulses in which the potential difference produced by the power source during the pulse increases in a plurality of steps and in which the increase in potential difference at each step and the frequency of the steps can be controlled.

It is another object of the invention to provide a method and apparatus for initiating insensitive propellant and/or explosive compositions possessing the safety of the insensitive initiators but free of the hazards and irregularities of the high voltage power supplies used heretofore.

It is another object of the invention to provide a method and apparatus for igniting insensitive propellant and/or explosive compositions by converting a small conductor rapidly and sequentially through solid, liquid, vapor and plasma phases while employing minimum potential differences across the conductor.

It is another object of the invention to provide such a method and apparatus for igniting an insensitive propellant and/or explosive compositions with an exploding bridgewire igniter in which energy is transferred to the bridgewire from a power supply with a discharge characteristic more suitable for the transfer of energy from the condensers to the explosive in a manner and a time that obviates the need for critical tolerances and that still operates reliably.

It is another object of the invention to provide such method and apparatus for igniting an insensitive propellant with an exploding bridgewire in which the potential of the high energy pulse employed to explode the bridgewire is controlled to suit the state of the bridgewire at each instant while the bridgewire is exploding.

It is another object of this invention to provide such a method and apparatus for igniting insensitive propellant and/or explosive compositions in which the shape of the discharge pulse is controlled by means other than the parameters of the discharge circuit.

It is another object of this invention to provide such a method and apparatus for igniting insensitive propellant and/or explosive compositions in which advantage is taken of the high energy storage density of low voltage electrolytic capacitors.

It is also another object of this invention to provide such a method and apparatus for igniting insensitive propellant and/or explosive compositions in which means are provided for protecting the triggering circuit from accidental firing by other than the firing signal.

Other objects and advantages of the present invention will become apparent from the following description read in conjunction with the attached drawings in which:

FIG. 1 is a circuit diagram of one form of power supply constructed in accordance with this invention and useful in practicing the method of this invention;

FIG. 2 is a schematic diagram of the circuit of FIG. 1 illustrating the condition of the circuit at a time prior to initiation of the electrical pulse produced by the power supply of FIG. 1;

FIG. 3 is a schematic diagram of the circuit of FIG. 1 illustrating the condition of the circuit at an intermediate time in the period of the pulse;

FIG. 4 is a schematic diagram similar to FIG. 3 illustrating the condition of the circuit a short time later but still prior to the end of the pulse;

FIG. 5 is a schematic diagram of the circuit of FIG. 1 illustrating the condition of the circuit at the instant before the pulse terminates;

FIG. 6 is a circuit diagram with portions thereof omitted, of an alternative form of power supply of the invention useful for practicing the method of the invention; and

FIGS. 7 and 8 are schematic diagrams of the circuit of FIG. 6 illustrating the conditions of the circuit respectively just after initiation of a pulse and a short time thereafter but still prior to the end of the pulse.

Referring now in detail to the drawings and particularly to FIG. 1, a bank of capacitors **10—28** are connected in parallel between leads **30** and **32**, and a D.C. power source **34** is connected across the leads **30** and **32** by leads **36** and **38**, respectively, through the contacts **40** of a double pole, double throw switch **42**. Upon the closing of switch **42** onto contacts **40**, all of the capacitors **10—28** are charged in parallel to the potential of source **34**.

A load **44**, illustrated as being a small electrical conductor such as a bridgewire, is connected across the leads **30** and **32** in series with a potential sensitive switch **46** by means of leads **48**. A suitable potential sensitive switch **46** is the four layer diode illustrated which is constructed to be open, preventing any substantial current flow therethrough, until a potential difference is applied across the switch **46** which is greater than the potential of the D.C. power source **34**. Accordingly, the switch **46** is open, preventing current flow through the bridgewire **44** from the capacitors **10—28** when the capacitors **10—28** are connected in parallel as for instance when they are being charged as described above. This condition of the circuit of FIG. 1 in which the capacitors **10—28** are connected in parallel and the switch **46** is open as illustrated in FIG. 2.

For reasons that will appear hereinafter, the points of connection of adjacent capacitors **10—28** to the leads **30** and **32** are separated by rectifiers **50** through which the current in leads **30** and **32** must pass. The current passing direction of the rectifier **50** is arranged to permit all of the capacitors **10–28** to be charged in parallel by the power source **34** as illustrated in FIG. 1. The positive side of each of the capacitors **10—26** is connected to the negative side of the adjacent capacitors **12—28** by means of semiconductor switches **52—68**. The switches **52—58** and **62—68** are potential sensitive switches made of four layer diodes as illustrated and constructed to switch to an on-current passing condition when each of the diodes is subjected to a potential difference greater than the potential of power source **34**. The switching potential of the diodes **58** and **62** is less than twice the potential of source **34**, and as explained hereinafter, the switching potentials of the diodes **52—56** and **64—68** may or may not be below twice the potential of the source **34**. The semi-conductor switch **60** is a suitable gated switch such as a silicon controlled rectifier having a gate terminal **70**. The switch **60** is constructed to prevent current flow therethrough except when a positive potential is applied to the gate terminal **70** with respect to the adjacent terminal **72**. The positive sides of the capacitors **10, 14, 18, 22** and **26** are connected by high resistances **74—80**, and the negative sides of the capacitors **12, 16, 20, 24** and **28** are connected by high resistances **82—88**. A capacitor **90** is connected in parallel with each of the four layer diodes **52—58** and **62—68**.

When the capacitors **10—28** have been charged to the potential of the D.C. power source **34** by connection of the double throw switch **42** to the terminals **40**, the circuit of FIG. 1 is triggered by reversing the switch **42** to connect the power source **34** to the terminals **92** of switch **42**, thereby connecting the negative side of source **34** through a lead **94** to the terminal **72** of the silicon controlled rectifier **60**; at the same time the switch **42** connects the positive terminal of source **34** through a lead **96**, resistors **97** and **98**, and a potential sensitive switch **100** to the gate terminal **70** of the silicon controlled rectifier **60**. A potential sensitive switch **104** is connected between lead **94** and lead **96** at a point between resistor **97** and resistor **98** to divert potentials from being applied to the switch **100** if they are substantially greater than the potential of the firing signal which herein is **34**. A capacitor **102** is connected between the lead **94** and lead **96** at a point between the resistor **98** and the potential sensitive switch **100** to provide a delay between the application of the potential to switch **104** and the application of the potential to switch **100** so that switch **104** may close if necessary before switch **100** closes. Also capacitor **102** is used to provide the necessary current for triggering switch **60**. Switch **100** is used to prevent potentials from being applied to the gate of switch **60** if they are substantially lower than the potential of the firing signal which herein is **34**.

When a triggering potential is applied to the gate terminal **70** of the silicon controlled rectifier **60**, as described above, the switch **60** closes connecting the positive side of the capacitor **18** to the negative side of the capacitor **20** and thus doubling the potential difference applied across the voltage sensitive switch **46**. It should be noted that this closing of the switch **60** applies reverse bias to the rectifiers **50** which connect similar sides of the capacitors **18** and **20** thereby effectively breaking each of the leads **30** and **32** into two halves, as illustrated in FIG. 3.

Referring to FIGS. 1 and 3, the doubling of the potential difference between the righthand half of the lead **30** and the lefthand half of the lead **32** causes the switch **46** to close, thereby initiating the discharge of the capacitors **10—28** through the bridgewire **44**. The switch **46** may be selected to close at any multiple of the potential difference between leads **30** and **32** herein selected to be double. The resulting flow of current through the bridgewire **44** will heat up and start to melt the bridgewire **44**.

The closing of switch **60** also places the combined potential differences of the capacitors **16** and **18** in series with the diode **58** and the high resistance **84** so that the switching potential of the diode **58** is exceeded and the diode **58** closes, thereby connecting the positive side of the capacitor **16** to the negative side of the capacitor **18**. At the same time, the closing of switch **60** places the capacitors **20** and **22** in series with the high resistance **78** across the potential sensitive diode **62**, thereby exceeding the switching potential of diode **62**, closing diode **62** and connecting the positive side of capacitor **20** to the negative side of the capacitor **22**. With the closing of the switches **58** and **62**, the potential difference between the righthand side of the lead **30** and the lefthand side of the lead **32** has been increased to approximately four times the potential difference of the power source **34**. The proper choice of the capacities of the capacitors **90** in parallel with the diodes **58** and **62** permits proper regulation of the timing between the closing of the switch **60** and the closing of the switches **58** and **62**, since the capacitors **90** are in resistance-capacitance circuits across the switches **58** and **62** and the resistances **84** and **78**.

In similar manner, the potential sensitive switches **52—56** and **64—68** will close sequentially after the closing of the switches **58** and **62** until all of the capacitors **10—28** are in series applying across the terminals of the bridgewire **44** a potential difference which is the sum of the potential differences remaining in the capacitors **10—**

28. It should be noted, for instance, that upon the closing of switch 58, the potentials of capacitors 16 and 18 are applied in series across the switch 56 to cause the switch to close if its switching potential is less than twice the potential of source 34.

While the capacitors 10—28 are switching from the circuit configuration of FIG. 3 to the series configuration of FIG. 5, current is flowing through the bridgewire 44 transferring energy to the bridgewire 44 so that the bridgewire passes sequentially through solid, liquid, vapor and plasma phases. During this phase changing period while energy is being absorbed by the bridgewire 44, the resistance of the bridgewire 44 is increasing substantially, but at the same time a stepwise increasing potential difference is being applied across the bridgewire 44 as more of the capacitors 10—28 are switched into series. In this manner the potential difference across the bridgewire 44 is increased to match the increasing resistance of the bridgewire 44 so that a continuous current passes through the bridgewire 44 until the capacitors 10—28 are discharged. This operation of the power source of this invention eliminates "dark time" in the bridgewire. Conveniently, the bridgewire 44 is mounted in a detonator cap, illustrated schematically at 108 in FIG. 1, which may be screwed or otherwise inserted into the container housing a body of the insensitive propellant to be ignited.

The proper choice of the values of the circuit elements shown in FIG. 1 permits proper regulation of the timing of the closing of switches 52—68 to produce a stepwise increasing voltage having any desired voltage increase at each step and desired time interval between steps. In one particular embodiment of the invention in which the circuit configuration of FIG. 1 is employed, the following specific elements are employed: 50 microfarad capacitors are employed for the capacitors 10—28; a 45 volt battery is employed for the charging and triggering battery 34; 1N2069 rectifiers are employed for the rectifiers 50; a 4G100 diode having a switching potential of 100 volts is employed for the switch 46; 4D50M diodes having switching potentials of 50 volts are employed for the switches 52—58 and 62—68; a 3B100S triode having a switching potential of 100 volts and a gate-triggering potential of 0.4 to 2.5 volts is employed as the triggering switch 60; 4700 ohm resistors are used for each of the resistors 74—88, and 680 microfarad capacitors are employed for the capacitors 90. The values of the elements 98—106 are chosen independently to provide proper safety levels in the triggering circuit for each particular application. Adjustment of the capacities of the capacitors 90 and adjustment of values of the resistances 74—88 would adjust the timing between the closing of switch 60 and the switches 58 and 62 etc., since the capacitors 90 are in resistance-capacitance circuits with the resistances 84 and 78 and in parallel with the switches 58 and 62. Thus, when switch 60 is closed, the elements 16, 58, 18, 60 and 84 are placed in series and a capacitor 90 is in parallel with the switch 58; the time constants of this circuit regulate the closing of switch 58. When the value of the resistance 84 is increased the time delay between the closings of switches 60 and 58 is increased, and when the capacity of the capacitor 90 is increased, the time delay is increased.

It should be noted that the values of the resistances 74—88 need not be equal, and the values of the capacitors 90 need not be equal. For instance, the values of resistances 76 and 78 and/or the capacitor 90 in parallel switch 56 may be changed to close switch 56 by the closing of switch 60 rather than by the closing of switch 58 since the closing of switch 60 establishes a timing circuit by placing in series the elements 18, 60, 20, 50, 78, 76, 56 and 50 with a capacitor 90 and capacitor 14 in parallel with the switch 56. This timing circuit may close the switch 56 simultaneously with the closing of switch 58. In the above circuit in which the resistances 74—88 are equal and the capacitors 90 are equal, this timing circuit does not close the switch 56 until after the switch 58 has closed, and the closing of switch 58 closes the switch 56 through the series connection of elements 16, 58, 18, 76 and 56 with a capacitor 90 in parallel with switch 56.

The alternative form of the apparatus of this invention illustrated in FIGS. 6–8 is substantially identical to the apparatus of FIG. 1 except that the high resistors 74—88 have been eliminated; the capacitors 90 have been eliminated, and the semiconductor switches 52—68 have all been constructed of gated switches 52*a*—68*a* which are conveniently silicon controlled rectifiers such as the switch 60 in FIG. 1. The gate terminals 110 of the switches 52*a*—66*a* are connected to the negative sides of the capacitors 14—28, respectively, through high resistances 112, and the triggering leads 94 and 96 are connected respectively to the negative side of the capacitor 28 and the gate terminal 110 of the switch 68*a*.

The operation of the device of FIGS. 6–8 is substantially the same as the operation of the device of FIGS. 1–5, except that in FIG. 6 the triggering potential is applied at one end of the bank of capacitors instead of in the middle, thereby closing the switch 68*a* at one end of the bank of condensers. The closing of the switch 68*a* connects the positive side of the capacitor 26 to the gate 110 of the switch 66*a*, thereby closing the switch 66*a* so that the capacitors are sequentially switched into series starting at the righthand side of the capacitor bank of FIG. 6 and proceeding to the left until all of the capacitors are in series. FIG. 7 illustrates the condition of the circuit of FIG. 6 immediately after the triggering potential has been applied to the switch 68*a*, and FIG. 8 illustrates the condition of the circuit of FIG. 6 when the switches 62*a*—68*a* have closed.

The two specific devices illustrated in the drawings and described above are particularly useful in practicing the method of this invention and are illustrative of power supplies constructed in accordance with this invention for producing high energy pulses while controlling the variation of the potential of the pulses. With these devices of the invention the instantaneous values of the potential difference produced by the power source can be controlled within wide limits to suit the conditions of the load on which the source is used. With the power sources of the invention, continuous currents may be maintained through the loads during the pulses, and effects can be produced in the loads with pulses of low maximum potentials which heretofore required pulses of very high potentials.

While the two specific devices illustrated in the drawings and described above are particularly useful in exploding bridgewire systems, the specific arrangements of parts are subject to substantial change within the spirit and scope of the invention in order to adapt the power supplies to more efficient use in other devices and more efficient use in specific exploding bridgewire problems. Obviously, substantial flexibility in designing a particular power supply of the invention for a specific need is provided in the free choice of the values of resistors and timing capacitors and in the choice of potentials at which potential sensitive switches close. In the same manner, the proper choice of capacity for the capacitors, or replacement of each capacitor by a battery, provides great flexibility in satisfying the current demands of different loads.

Many other additional modifications may be employed in the power supplies of the invention to suit particular applications thereof, but one example of which being the replacement of the switch 42 by electronically time flip-flop switches to effect recurrent pulses as for producing recurrent timed intense flashes of a lamp. Accordingly, the above-mentioned features of the invention are merely illustrative of the variations which may be employed within the spirit and scope of the invention.

The term "propellant" used in the claims is intended to means both propellant and/or explosive compositions.

What is claimed is:

1. A power supply for generating a high energy pulse adapted to be applied to a load which comprises a plurality of electrical energy storage means each having an energy substantially less than the energy of said pulse, circuit means interconnecting said energy storage means, with said energy storage means normally connected in parallel, triggering means for initiating the switching of said energy storage means into series, and automatic switch means including switch conductors interconnecting said energy storage means for sequentially switching said energy storage means into series at a controlled rate after actuation of said triggering means.

2. The power supply of claim 1 characterized further in that said circuit means includes low resistance circuit means for discharging said energy storage means in parallel, and said automatic switch means comprises means for sequentially switching said energy storage means into series at a controlled rate while said energy storage means are discharging in parallel through said low resistance circuit means.

3. The power source of claim 1 characterized further in that said automatic switch means comprises normally open switch means connecting one side of one of said energy storage means to the side of opposite potential of another of said energy storage means, rectifier means connecting the sides of like potential of said one and other energy storage means, and automatic means for closing said normally open switch means responsive to and in timed relation to the placing of said one energy storage means in series with a third energy storage means.

4. The power supply of claim 3 in which said energy storage means is adapted to store electrical energy at a predetermined potential difference; said normally open switch means is a potential sensitive diode which closes when subjected to a potential difference greater than said predetermined potential difference but less than twice said predetermined potential difference, and said automatic means comprises a high resistance conductor connected to said one and said other of said energy storage means to place said one and said other of said energy storage means in series across said potential sensitive diode when said one and said third one of said energy storage means are placed in series.

5. The power supply of claim 4 characterized further by the inclusion of a capacitor connected in parallel with said potential sensitive diode and in series with said high resistance conductor for controlling the lapse of time between the placing of said one and third energy storage means in series and the closing of said potential sensitive diode switch.

6. The power source of claim 3 in which said normally open switch is a triode having first and second terminals, connected respectively to the positive side of said other storage means and the negative side of said one storage

means, and a gate which closes said switch when a positive potential is applied to said gate with respect to said second terminal, and said automatic means comprises a high resistance conductor connected between said gate and the negative side of said third one of said energy storage means.

7. A power supply for generating a high energy pulse adapted to be applied to a load which comprises a plurality of electrical storage means each having an energy substantially less than the energy of said pulse, low resistance circuit means interconnecting said energy storage means, with said energy storage means normally connected in parallel for discharging their energies in parallel, and switch means for sequentially switching said energy storage means into series for discharging their energies in series while said energy storage means are discharging their energies in parallel through said low resistance circuit means.

8. A power supply for generating a high energy pulse adapted to be applied to a load which comprises a plurality of capacitors each being adapted to be charged to a charged voltage substantially less than the maximum voltage of said pulse and to carry an electrical charge at said charged voltage substantially less than the cumulative current of said pulse, low resistance circuit means interconnecting said capacitors and including rectifiers connecting the sides of like polarity of said capacitors for discharging said capacitors in parallel, and switch means connecting the sides of opposite polarity of said capacitors for switching said capacitors into series for discharge in series while said capacitors are discharging in parallel.

9. A power supply for generating a high energy pulse adapted to be applied to a load which comprises a plurality of capacitors each being adapted to be charged to a charged voltage substantially less than the maximum voltage of said pulse and to carry an electrical charge at said charged voltage substantially less than the cumulative current of said pulse, low resistance circuit means interconnecting said capacitors and including rectifiers connecting the sides of like polarity of said capacitors for discharging said capacitors in parallel, triggering means for initiating the switching of said capacitors into series, and automatic switch means connecting the sides of opposite polarity of said capacitors for sequentially switching said capacitors into series after actuation of said triggering means for discharge in series while said capacitors are discharging in parallel.

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