

June 30, 1953

G. C. SUMMERS

2,644,130

SQUARE WAVE PULSE GENERATING SYSTEM

Filed Jan. 24, 1949

4 Sheets-Sheet 2

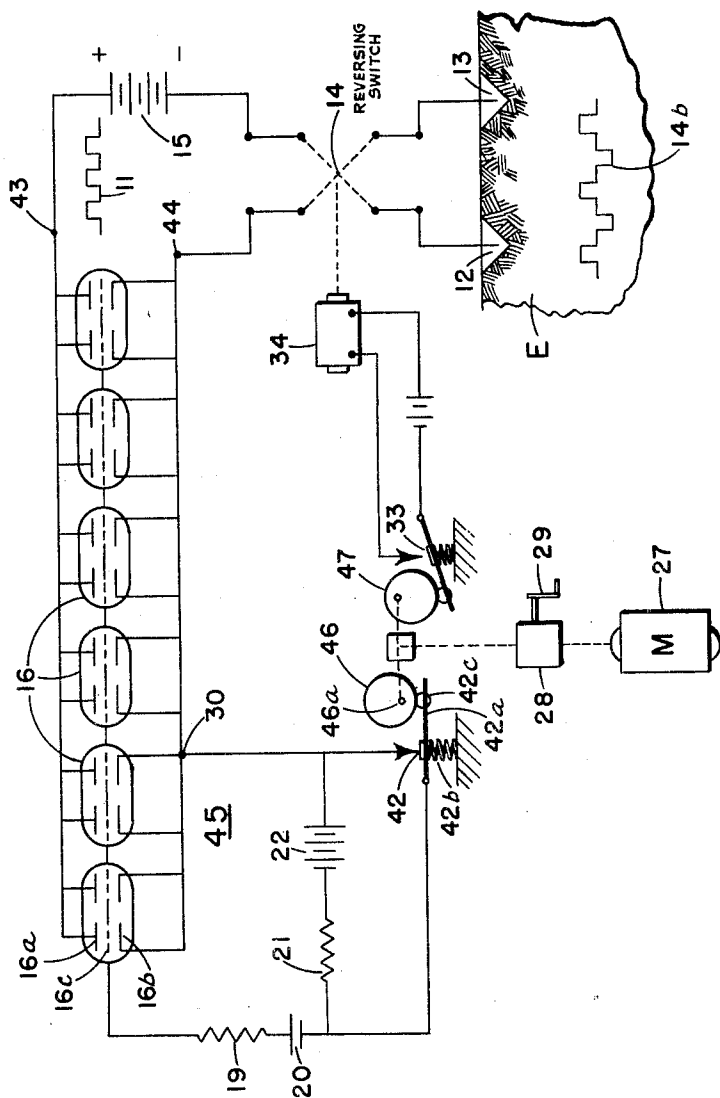


FIG. 2

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4 Sheets-Sheet 3

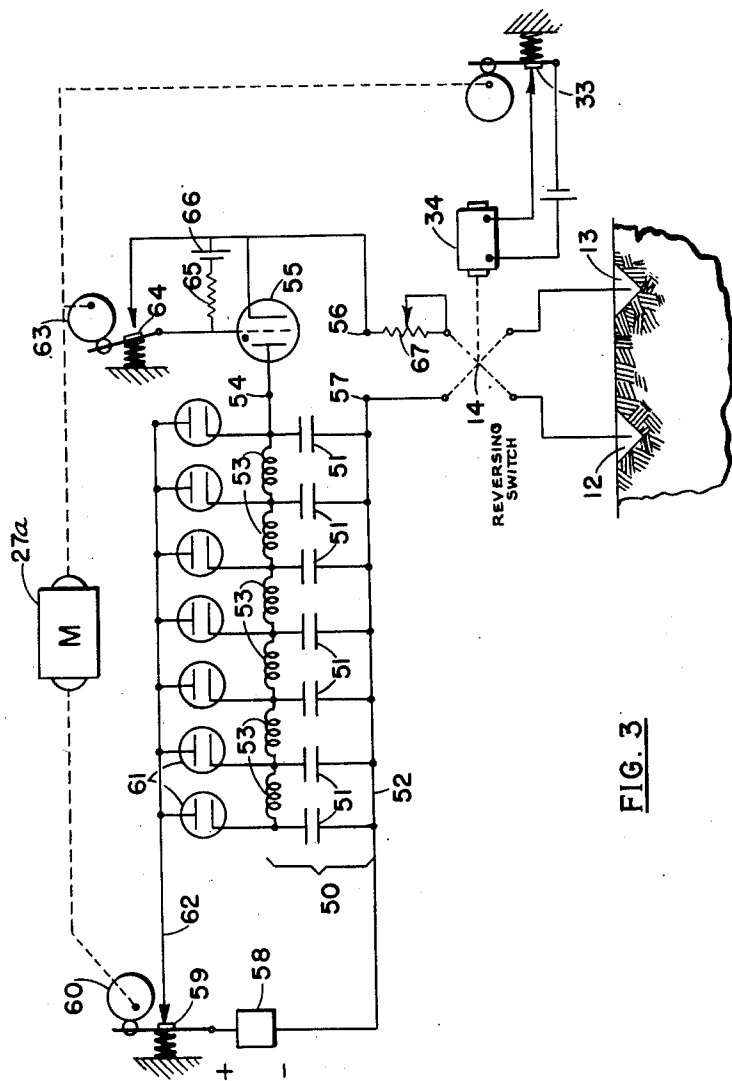


FIG. 3

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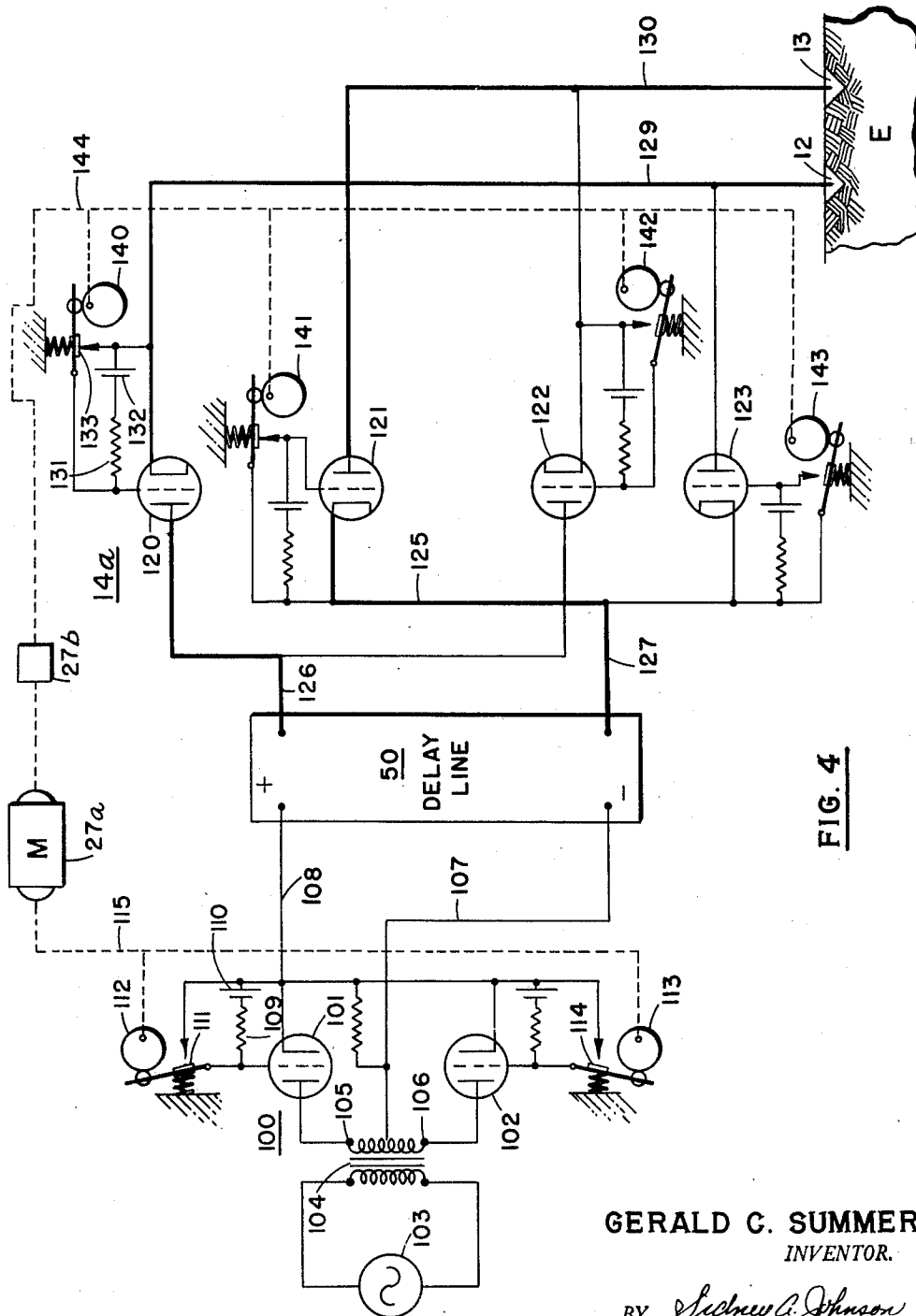


FIG. 4

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2,644,130

SQUARE WAVE PULSE GENERATING
SYSTEM

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Application January 24, 1949, Serial No. 72,363

19 Claims. (Cl. 324-1)

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This invention relates to electrical prospecting, more particularly to a system for generating current pulses of a desired form and frequency which are applied to an earth load for the purpose of obtaining information as to the character of subsurface strata.

In electrical prospecting methods it has been determined that the pulses must be of relatively high power, at frequencies variable in the range of 2, 4, 8, 16 cycles per second, more or less. It has heretofore been proposed to generate such signals by the opening and closing of circuit-breaker contacts driven by a variable speed motor. However, when the contacts must perform the work of making and breaking the high current flow, a certain amount of pitting and erosion takes place and the device does not remain precise over an appreciable period. More importantly, any arc forming upon the opening of the contacts represents current flow after the separation of the contacts. Hence, the length of each pulse represents an uncontrolled variable.

It has also been proposed to utilize gas discharge tubes of the thyatron type. However, the wave shape of the pulses from such tubes is not rectangular and with alternating current successive pulses are not alike except where the ratio of the frequency of the alternating current source to the frequency of commutation is a whole number.

In still other systems, an electric commutator comprising gas discharge tubes capable of delivering rectangular pulses has been proposed. In such systems the termination of a positive pulse coincides with the initiation of a negative pulse. Such systems do not provide for the spacing of the successive pulses.

In carrying out the present invention in one form thereof, there is provided a method and system for generating pulses of relatively high power which are rectangular in shape, which are spaced one from the other, and all of which are of the same shape. More particularly, there is provided, in circuit with electrodes for applying current pulses to the earth load, a circuit-reversing device which is operated during the intervals between successive pulses. Accordingly, its operation does not affect the character or timing of the pulses carried thereby. The current flow is derived from a source capable of producing rectangular pulses under the control of an electric valve having a grid for controlling the conductivity thereof. The negligible current demand of the grid circuit makes feasible

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the use of a mechanical commutator in that circuit for controlling the impulses though, in the preferred form of the invention, the initiation of each impulse may be mechanical while the length thereof is electrically determined.

In a further preferred form of the invention, the length of each pulse is determined by an artificial transmission line having a plurality of capacitors arranged to be charged through circuits individual to one or more capacitors and to be discharged through a separate circuit forming a part of the artificial transmission line. That line may be connected to the earth electrodes either through a mechanical circuit-reversing device or through an electronic device, both being contemplated by the present invention.

In each form of the present invention the power pulses, because identical and spaced one from the other, make possible the detection of electrical signals with such accuracy that important subsurface information as to the character of subsurface strata may be obtained. The signal-level of such reflected signals is quite low and the change in character, due to subsurface strata of differing electrical properties, is of course of a still lower order. Hence, it is important that the power pulses both as to shape and duration shall be more nearly the same than the variations in acoustic pulses by which seismic information is derived.

For a more complete description of the invention and for further objects and advantages thereof, reference should be had to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 diagrammatically illustrates in simplified form a system embodying the present invention;

Fig. 2 is a schematic diagram of another form of the invention and includes a grid-controlled high-vacuum switch as the source of pulses;

Fig. 3 is a schematic diagram of a generating system utilizing a delay line as the source of impulses; and

Fig. 4 illustrates a modification of Fig. 3.

Referring now to Fig. 1, the system of the present invention includes a source 10 of spaced unidirectional low-frequency pulses 11. The pulses are applied to the earth E by way of electrodes 12 and 13. A circuit-reversing device such as a reversing relay or switch 14 is connected between the electrodes 12 and 13 and the source of unidirectional pulses for reversing the connections between the source 10 and the electrodes to

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convert the unidirectional pulses 11 to pulses 14b alternately of opposite polarity. The unidirectional pulses 11, each of rectangular shape, and each spaced an interval one from the other, are obtained by reason of flow of current from a unidirectional source, such as a battery 15 having adequate capacity to supply unidirectional pulses. The battery 15 is connected to the anode 16a of an electric valve 16 having a cathode 16b and a control grid 16c. The grid circuit includes a grid resistor 19, a bias battery 20, a resistor 21 and a second bias battery 22, all connected in series between the grid and the cathode 16b. A pair of conductors 23 and 24 form a part of the circuit of a control switch 25 for removing from the circuit the battery 22 which normally negatively biases the valve 16 to prevent flow of current therethrough. The switch 25 is operated by a cam 26 driven by a variable speed driving device such as a motor 27 drive-connected to cam 26 through a speed-changing device 28 such as a Reeves drive having a control crank or wheel 29. The motor 27 also drives through device 23 a cam 30 in timed relation with the cam 26 in order to operate the reversing relay 14 during intervals between each of the rectangular pulses 11.

Assuming the line switch 31 of motor 27 closed and the motor rotating in a direction to drive the cams in a counter-clockwise direction, it will be seen that the upper contacts of switch 25 are closed. With the upper contacts of switch 25 closed, the bias battery 22 and the resistor 21 are effectively removed from the circuit. Accordingly, the bias battery 20 effectively applies a positive potential in the grid circuit to render conductive the valve 16. Current flows from battery 15 through valve 16, by way of conductor 15a to the lower contact of switch 14, and thence to the earth electrode 13. The return circuit is by way of the other earth electrode 12, the upper contact of reversing switch 14, and thence by conductor 15b to the battery 15.

The current rises immediately to its maximum value and flows for a time interval determined by the length of time the switch 25 remains in its uppermost circuit-closing position. For the purpose of the present description and not by way of limitation, cam 26 shaped as illustrated maintains the switch 25 closed through 70° rotation. Thereupon, the operation of the cam 26 opens the by-pass circuit through its upper contacts to make effective in the control circuit of valve 16 the powerful bias battery 22 to render non-conductive valve 16 immediately to interrupt the current flow. In this manner the first electrical pulse, of seventy degrees duration, is applied between electrodes 12 and 13. There is then provided a time interval by travel of the cam 26 through one hundred and ten degrees, at which time the outer level of cam 26 operates switch 25 to its lowermost position.

The reversing switch 14 is operated under the control of the cam-operated switch 33 arranged to control energization of its operating coil 34 from supply lines 35 and 36. More specifically, after switch 25 has opened to render valve 16 non-conductive the cam 30, during rotation of cam 26 through its one hundred and ten degree section, closes switch 33 to energize the operating coil 34. The reversing switch 14 is then operated from one circuit-closing position to a reverse circuit-closing position during the interval of no current flow following the first of pulses 11. Accordingly, there is no chance for arcing at the

contacts of switch 14. There is neither erosion nor pitting of the contacts. Even if there were, it would have no effect upon the wave shape or time of the current of the next cycle since initiation and termination is under the control of the electric valve 16.

With the reversing switch 14 in its upper position to reverse the direction of current flow through earth electrodes 12 and 13, the cam 26 operates the switch 25 to its lowermost circuit-closing position, again to remove the bias battery 22 and resistor 21 from the grid circuit of the valve 16 and to apply the positive bias of battery 20 thereto. Current again flows from battery 15 to produce the second of the rectangular pulses 11. The outer level of cam 26 also extends for seventy degrees so that the second pulse is identical in length with the first. The cam 26 then moves switch 25 to its intermediate open-circuit position to make battery 22 effective to render the valve 16 non-conductive. In the subsequent interval of no current flow as controlled by the additional one hundred and ten degree intermediate level of cam 26, the cam 30 is rotated to open the switch 33 to deenergize reversing coil 34. The switch 14 thereupon reverses the current path to the current electrodes 12 and 13 during a period of no current flow.

The foregoing operations are then repeated to produce a series of identical current pulses 11, each of rectangular shape and each spaced one from the other by a predetermined time interval. During each such time interval the reversing switch 14 is moved first to one and then to the other of its positions to convert the identical rectangular pulses of unidirectional polarity to pulses 14b successively of opposite polarity. The succession of pulses of alternating polarity are applied to the earth through the current electrodes 12 and 13.

By means of detecting electrodes 37 and 38, located a substantial distance from the current electrodes, electrical signals 39 are detected and recorded on a device 40, the recorded signals being useful in yielding information as to the character of the subsurface strata. As pointed out in Clewell Patent No. 2,454,911, the reflected signals such as appear in the interval between current pulses 14b, or variations in the electrical field, detected or received by electrodes 37 and 38 are exceedingly small in magnitude, of the order of millivolts. Accordingly, the device 40 preferably includes suitable amplifying equipment to elevate the detected signals to a magnitude adequate for actuation of the recording device. Since the signals themselves are small and require great amplification, it will be apparent that the pulses 14b applied to the earth must have great uniformity. If successive pulses differ from preceding pulses, the differences themselves might account for variations in the electrical field which could be confused with signals due to subsurface anomalies. Thus, with pulses of varying character the system as a whole would not be satisfactory. The importance of the application to the earth of uniform signals produced in accordance with the present invention may not be over-emphasized.

Though as above described each of the pulses 11 has a length of seventy degrees, it is to be understood they may be of any selected length or duration. The cam 26 may be adjustable to change the relative lengths of the three levels thereof or different cams may be substituted therefor. Similarly, cam 30 may be adjustable

or it may be replaced or angularly adjusted on the drive shaft to produce operation of reversing switch 14 during a period of no current flow. The switches 25 and 33 are preferably biased against cams 26 and 30 though they may be mechanically connected thereto for positive actuation in both directions if desired.

By adjusting the crank or wheel 29, the speed of the drive shaft may be varied or where a variable speed motor is used, the device 28 may be dispensed with. The pulses 11 may be produced at any selected rate from around one-half cycle per second to thirty cycles per second, each cycle representing a positive pulse, an interval, a negative pulse and a second interval. As explained in said Clewell patent, the electrical survey may be conducted by varying the frequency through a selected range and noting the character of the detected signals. For some locations signals of one length may be preferred over signals of a different length. Nevertheless, these severe requirements are satisfactorily met by the present invention.

As further explained in said Clewell patent, the signals 39 are detected during selected time intervals preferably in an intermediate portion of each interval between pulses 14b. This may be readily accomplished by a commutator driven in synchronism from or by the drive shaft as indicated by the dotted line 41. Referring now to Fig. 2, a modified form of the invention has been shown for producing pulses 14b between the earth electrodes 12 and 13. A plurality of electric valves or triodes 16 are connected in parallel and are so controlled as to function as a precise circuit controller. Each electric valve or triode 16 is provided with an anode 16a, a cathode 16b, and a control grid 16c. The anodes are connected in parallel with each other and in series with a source of unidirectional current such as the battery 15, the circuit being completed through a reversing switch 14, electrodes 12 and 13, and the cathodes 17 which are also connected in parallel with each other.

The grids 16c of the triodes 16 are also connected together and to a common grid-controlling circuit 45 which, it will be observed, includes a grid resistor 19, a source of biasing potential such as the battery 20, a grid resistor 21, and a second source of biasing potential such as the battery 22. As in Fig. 1, the resistor 21 and the battery 22 may be effectively inserted and removed from the grid-control circuit by closure of a control switch 42 to complete a by-pass circuit. The battery is not short-circuited by switch 42 due to the relatively high value of the resistor 21.

Though vacuum tubes or electric valves of other types may be utilized providing they have suitable characteristics, triodes of the 6AS7-G type have been found particularly suitable for the invention. By using a sufficient number of such triodes in parallel, the voltage drop between the anodes and cathodes, as for example between the output conductors 43 and 44, when the current is of the order of two amperes, will be satisfactorily low; that is, about fifty-five volts for twelve triodes. By utilizing the high vacuum type of tube, there is attained not only control of the initiation of each pulse, but also control of the termination thereof. The low plate drop of the tube also makes it particularly desirable in conjunction with a direct-current source for the production of spaced rectangular pulses without prohibitive power loss in the tube. This will be recognized as important since electrical

prospecting for oil generally takes place over areas remote from sources of current and it is, therefore, necessary to rely upon transportable sources such as storage batteries and the like. However, such operational limitations on the equipment are satisfactorily met by the present invention.

The parameters of the grid-control circuit 45, for satisfactory operation, may not be determined by the usually accepted empirical relations. They would indicate that for an anode voltage, battery 20 of 230 volts, the cut-off bias would be of the order of 142 volts. For the 6AS7-G type tube whose amplification factor is 2.1, it has been found, where the plate voltage is 230 volts, that in order to meet the requirements of the present invention it is necessary to utilize an effective negative bias from battery 22 of at least 200 volts. Such negative bias is necessary to reduce the plate current to a value below that which would prevent interference with, or effect upon, detected signals. A reduction below one microampere has been found satisfactory. Moreover, it has been found that a valve or triode 16 is not effective for production of rectangular current pulses of uniform current value unless the grid during each period of conduction is made positive. Accordingly, the battery 20 is necessary to yield rectangular pulses having flat tops indicating lack of current variation during each conductivity period. A battery 20 of 22½ volts has been utilized and found to be satisfactory in conjunction with a battery 22 or other source of biasing potential of the order of 270 volts. The resistor 19 of one-tenth of a megohm and the resistor 21 of one megohm were satisfactory. The resistance values of resistors 19 and 21 are not particularly critical. Those given are exemplary and satisfactory. The switch 42 is preferably of the type in which the contact carrying arm 42a is biased as by spring 42b in its closed position. Additionally there is included a roller member, preferably a small ball bearing 42c, carried by contact arm 42a. Cam 46 operatively engaging bearing 42c serves to open switch 42a. By adjustment of the distance between shaft 46a carrying cam 46, and arm 42a, the period of closure of switch during each revolution of cam 46 may be selected and/or controlled.

With the foregoing arrangement, the current flowing through the control switch 42, when closed, was less than 500 microamperes, a wholly negligible value as regards wear or arcing, or other damage to the switch contacts. Accordingly, the switch 42 may be and has been operated by the cam 46 over long periods of time with great precision, and with negligible wear and no arcing or pitting of the contacts.

The cam 46 is driven by the motor 27 under the control of the speed-changing device 23. The motor and speed changer also drive the cam 47 which controls the operation of the switch 33 for energization of the operating coil 34 of the reversing switch 14. The cam 43 is spaced from the contact arm 42a periodically to close and to open the switch 42 for production of the rectangular pulses 11 with selected time intervals therebetween. Similarly, the cam 47 is spaced from its associated contact arm for closure and opening of the switch 33 during a time interval between the rectangular pulses 11. The drive of the cams 46 and 47 in timed relation one with the other results in the series of pulses 14b, each of identical shape with the other and of alternating polarity.

From the foregoing it will be appreciated that even though the systems of Figs. 1 and 2 may be satisfactory, they leave something to be desired because of the voltage and power limitation of the vacuum tubes such as valves 16. In the further modification of the invention illustrated in Fig. 3, a system is disclosed in which the pulses of greater power magnitude are produced, the duration of each pulse being independent of any switch and dependent entirely upon circuit constants of a pulse-producing network. The foregoing is accomplished by the provision of a transmission line 50 formed by a plurality of condensers 51, each of which has one terminal connected to a common output conductor 52. The other terminals of the condensers 51 are interconnected through series-inductances 53 to the other output conductor 54. The line 50 is connected by conductor 54 and a gas discharge tube or thyatron 55 to output terminals 56 and 57 leading to the reversing switch 14. The elements forming the line 50 are chosen in number and size to form a transmission line having a time constant equal to one-half the period of the desired pulse length. If such a line is terminated in an impedance equal to the surge impedance of the line, a current pulse will flow through the load which will be rectangular in shape upon discharge of the line. If the line condensers 51 are charged and the thyatron 55 is initially non-conductive, a trigger voltage applied to the grid renders it conductive and initiates the discharge. Following the initiation of discharge, a transient travels down the line toward the open end. The transient is reflected at the open end out of phase and upon arrival at the output end causes the plate voltage of the thyatron 55 to be zero. Consequently, the thyatron becomes non-conductive and the flow of current to the earth load connected to the terminals 56 and 57 is abruptly terminated.

In order to provide sufficient capacity in the line to deliver high current pulses and to provide for the charging of the line during each pulse interval, which in some instances may be of the order of the discharge period, special considerations must be given to the charging circuit. In accordance with the present invention, a charging circuit is provided for each of the condensers or capacitors 51 of the transmission line 50. The charging circuit includes a source of D. C. potential 58 connected through a switch 59, operable by cam 60, to the plates of a plurality of diodes 61. The plates of the diodes are connected together and to the switch 59 by a conductor 62. The cathode of each of the diodes 61 is connected to one terminal of each of the condensers 51. Upon closure of the switch 59, as by the cam 60, current flows to the condensers 51, charging them to a potential approaching that of the source 58.

Inasmuch as all condensers 51 are simultaneously charged through parallel circuits, each including a diode 61, and each directly including a capacitor to the exclusion of the associated inductances, it will be seen that all capacitors or condensers 51 at any instant during the charging period will be at the same potential. If the line 50 were to be charged from one or both ends, there would be present during the charging period different voltages at the several condensers 51. The line 50 would not be stable. However, by using the separate charging circuits, the line 50 is at all times stable. The charging circuit may be opened at any time with assurance the condensers will be uniformly or equally charged

with a resultant stabilized transmission line 50 ready for discharge to produce the next earth-exploring impulse. Hence, the charging period may be less than the length of an impulse.

The use of a transmission line also makes possible a high voltage source of supply 58. A rectifier or other source may have a voltage of the order of three thousand volts or more. The higher voltage of the source produces impulses of greater magnitude. The greater the electrical energy delivered to the earth, the greater will be the magnitude of the reflected or detected signals. Improved records and depth-ranges are thereby secured. Since the source 58 is not connected to the line 50 during discharge, its regulation does not affect the character of the pulse.

The output of the line 50 is connected by way of a reversing switch 14 to earth electrodes. As illustrated, the points 56 and 57 are connected to one pair of terminals of the reversing switch 14. The switch 14 reverses circuit connections for flow of current in the earth circuit during intervals between the pulses delivered by the line 50. More particularly, the switch 14 is reversed by energization of its operating coil 34 upon closure of the switch 33. The switch 33 is actuated by the cam 47 driven by a variable speed motor 27a. The motor 27a also drives the cams 60 and 63, the latter operating a switch 64 to control the grid circuit of the thyatron 55 at predetermined instants. The grid circuit of the thyatron 55 includes a resistor 65 and source of potential such as a bias battery 66 connected in series between the grid and cathode. The switch 64 connected between the grid and cathode of the thyatron 55 effectively removes the bias battery 66 from the grid circuit to initiate discharge of the line 50.

The operation of the thyatron 55 in conjunction with the line 50 is satisfactory while generally they are not satisfactory for control of initiation and termination of impulses. More particularly, when a high voltage source of the order of a thousand volts, is used, there is no problem as at low voltages, or delay, in ionizing the thyatron even at relatively low temperatures. Hence, in conjunction with a high voltage transmission line the thyatron has proved to be a satisfactory electronic switching device.

Assuming now that condensers 51 are initially charged, the switches as illustrated in Fig. 3, and the motor 27a operating at a selected speed, the cam 60 will open switch 59 to interrupt or disconnect the charging circuit. The cam 63 operates the switch 64 to remove the negative bias on the grid of the thyatron 55. The thyatron is thereby made conductive for flow of current from output conductor 54 of the capacitive storage elements 51 in the line 50 through thyatron 55 to the electrodes 12 and 13 and thence to the other output conductor 57. The current flows for a period equal to twice the electrical length of the transmission line 50. Following termination of the pulse, the charging circuit is again closed through switch 59 to recharge each of the condensers 51 to the voltage of the source 58 or to a predetermined fraction thereof. Simultaneously, and during the charging period, switch 64 is momentarily closed to cause the switch 14 to reverse the connections between the output conductors 54 and 57 and the electrodes 12 and 13. Thereafter, the switch 59 is opened and switch 64 closed to discharge the line a second time, the direction of current flow between the electrodes 12 and 13 being reversed from the

direction of the first pulse. Following the reversed polarity pulse, the condensers of line 50 are again recharged, the switch 14 again actuated, and the switch 64 closed for delivery of a pulse of opposite polarity to the earth load. The operation continues, as described.

In the foregoing operation of the system, it is to be understood the variable resistor 67 has been set to a value such that the characteristic impedance of the line 50 is equal or substantially equal to that of the earth load between electrodes 12 and 13. Theoretically, the earth load or the resistance of the earth between points spaced, for example, 500' apart is in the order of 1 ohm. However, using electrodes of practical nature (porous pots containing a copper sulphate solution) tests made over widely scattered areas indicate that the resistance between such electrodes 12 and 13 spaced 500 feet apart is generally slightly less than 100 ohms. Accordingly, the line 50 is designed for a characteristic impedance of around 100 ohms. The resistor 67 is then adjusted to add to the earth load resistance increasing the impedance of output circuit substantially to equal the line impedance of 100 ohms. In this manner the line 50 may be used over widely distributed areas without changing the circuit constants and yet with matched impedance for best operating conditions.

Where the impedance match between line and load is close, the line will completely discharge to produce a rectangular pulse. Hence, the pulse will be self-terminating. However, if there is slight mismatch, there will be continued current flow after expiration of the selected pulse period, equal to twice the time constant of the line 50. If the mismatch results from a load resistance greater than the line, there will be flow of current from the line in the positive direction, through the thyatron 55. A reverse mismatch tends to produce current flow in the opposite direction. However, in both cases the magnitude of current flow through the thyatron drops very rapidly. As soon as the voltage drops below the thyatron ionizing voltage (approximately twelve volts), the thyatron 55 becomes non-conductive. Since the deionization time of thyatrons is in the order of .001 second it is preferable that the load impedance is adjusted to equal or be slightly less than the surge impedance of the line to assure an abrupt termination of the pulse current and following quiescent period. This permits detection of reflected signals in the pulse interval unaffected by any continued current flow between electrodes 12 and 13. The detected signals for pulses of two amperes at two hundred volts vary from around five to twenty or more microvolts depending upon the electrical characteristics of the subsurface strata. For pulses of higher power, as from the transmission line, the received signals will be of correspondingly greater magnitude. The condensers used in line 50 may permit a voltage of the order of several thousand volts which results in a decided increase in pulse power.

It has been found that for a given frequency, the relative values of the high-frequency components and low-frequency components of the energy delivered to the earth are determined by the pulse length. For longer pulse lengths, the low-frequency energy is predominant and permits greater penetration in the earth. The transmission line included in the present invention may be operated, as by suitable selection of circuit parameters, to produce pulses of variable length.

As those skilled in the art understand, the pulse length for any given line will be determined by the time constant of its constituent impedances. Factors to be considered in designing a line of the desired pulse length include the impedance into which the line is to work and the magnitude of the current desired. In a typical embodiment of the invention for producing electrical impulses each of rectangular shape and of 10 milliseconds duration, the characteristic impedance of the line was selected as 100 ohms. The inductance of each section of a ten-section line was 25 millihenrys, and the capacity of each section 2.5 microfarads. With a source of supply of, for example, 1000 volts for charging the line with an internal resistance of 900 ohms, and with conventional charging from one end of the line, the voltage on the line would rise to about 200 volts during a time interval equal to the discharge period. However, by using the diode system of charging, the voltage would be of the order of 360 volts and there would be absent transients which arise with conventional charging methods. Further information about design of transmission lines and operation thereof will be found in standard texts, such as "Principles of Radar" by the M. I. T. Radar School Staff (second edition 1946, McGraw-Hill) chapters 2 and 6.

Referring now to Fig. 4, there is disclosed a system for charging the delay line 50 from an alternating current source. More particularly, a full wave thyatron rectifier 100 comprising thyatrons 101 and 102 are energized from an A. C. source 103 connected to primary terminals of a transformer 104. The anodes of thyatrons 101 and 102 are connected to the secondary terminals 105 and 106 respectively of the transformer 104. Conductor 107 is connected between the center top of transformer 104 and the negative terminal of delay line 50. The cathodes of thyatrons 101 and 102 are connected together and to the positive terminal of delay line 50 by way of conductor 108. A resistor 109 and bias battery 110 are connected in series between grid and cathode of thyatron 101. A similar circuit is provided for tube 102. A switch 111 under control of cam 112 serves effectively to remove battery 110 from the grid circuit of tube 101 rendering it conductive over the positive half of the potential cycle of source 100. Similarly, cam 113 driven in synchronism with cam 112 from motor 27a actuates switch 114 to control the conduction period of tube 102. In order to eliminate the possibility of the charging circuit being energized during any portion of the discharge period, the switches 111 and 114 must be opened by action of cams 112 and 113 prior to the initiation of discharge from the delay line 50 at a time at least equal to, and preferably greater than, the period of one-half cycle of the voltage from source 100. The manner in which this is accomplished will be explained after describing an electronic reversing switch used in this modification of the invention.

In the modification of Fig. 4, the discharge path for the delay line has been illustrated as including an electronic or gas tube reversing switch or circuit controller 14a.

The gas tube circuit reversing means 14a includes four thyatrons 120, 121, 122 and 123. The plates of the thyatrons 120 and 122 are interconnected by conductor 125. One terminal of the output side of the delay line 50 is connected to the plates 120 and 122 by conductor 126.

In a similar manner, the cathodes of tubes 121

and 123 are connected together and to the other output terminal of the delay line 50 by conductor 127. The cathode of tube 120 and the plate of tube 123 are interconnected and coupled by way of conductor 129 to the electrode 12. Likewise the plate of tube 121 and cathode of tube 122 are interconnected and in circuit with the electrode 13 by way of conductor 130. The grid-cathode circuit of each of the tubes 120—123 includes a resistance in series with a source of bias voltage, such as the resistor 131 and battery 132 included in the grid-cathode circuit of tube 120. There is further provided a shorting or bias disabling circuit including switch 133, the terminals of which are connected between grid and cathode. Further, for each grid circuit there is a switch-actuating mechanism driven through a speed reduction mechanism 27b by the motor 27a. The speed reduction mechanism 27b causes the shaft represented by dotted line 144 to rotate at one-half the speed of motor 27a. The actuating mechanisms of Fig. 4 have been illustrated as cam surfaces 140, 141, 142 and 143 coupled by way of driving connection 144 to the motor 27a. Upon rotation of the cams or cam surfaces 140—143, grid-shortening switches, such as the switch 133 in each of the grid circuits of the gas tube switch, are closed for conduction through the tube associated with each cam. The cams 140—143 preferably are phased so that switches actuated by cams 140 and 141 are actuated, that is, closed or opened 180° from those closed or opened by cams 142 and 143. Further, the cams are spaced from the contact carrying arms of their associated switches so that the bias batteries 132 are but momentarily effectively removed from the grid circuit during each rotation. The action is such that thyratrons 120 and 121 will conduct simultaneously and during the period in which thyratrons 122 and 123 are non-conductive. The heavy line circuit illustrates paths of current flow upon energization of thyratrons 120 and 121. A current pulse will flow from the transmission line 50 through conductor 126, thyatron 120, conductor 129 to electrode 12. The current then flows through the earth to the electrode 13, through conductor 130, thyatron 121, and conductor 127 to the other terminal of the delay line 50. During the second half of the cycle and for reversed direction of current flow between electrodes 12 and 13, the thyratrons 122 and 123 are conductive.

It is to be understood that the cams 112 and 113 driven by the motor 27a will also be phased for closure of switches 111 and 114 following the termination of each of the pulses flowing through the earth E to energize the line-charging circuit during the interval between pulses. In such case, shaft 115 would rotate at a speed twice that of shaft 144.

It is evident that modifications and substitutions may be made in the systems above described. For example, the reversing switch or circuit-controller 14 may be replaced by the gas tube circuit-controller 14a. Further, the members which control the production of the spaced pulses have been illustrated in each of the modifications as mechanically driven cam surfaces. This has been done for convenience and should not be taken as a limitation since it is well understood by those skilled in the art that timed electrical pulses from other sources may be utilized to initiate conduction in the thyatron tubes included in the present invention.

It is to be understood that in electrical pros-

pecting methods, it is the practice to make measurements at several frequencies for each location. For example, such measurements may be made at 2, 4, 8 and 16 cycles per second. In order for the system of Figs. 3 and 4 so to operate some means must be provided for varying the length of the delay line 50 in order that pulses of different lengths may be produced. This is readily accomplished, Fig. 3, by removing or adding, as by a multi-terminal switch, sections of the line 50. For example, the line may be made up in sectional units for ease in switching operations.

Though the invention has been illustrated by several modifications, it is to be understood that further modifications within the scope of the appended claims may now suggest themselves to those skilled in the art.

What is claimed is:

1. A system for generating spaced low-frequency current pulses of alternating polarity which comprises a source of spaced unidirectional current pulses, a pair of current electrodes, means intermediate said source and said electrodes for reversing the connections therebetween, and means for actuating said reversing means in the interval between spaced unidirectional pulses whereby pulses of one polarity and then of a reverse polarity flow through said electrodes.

2. A system for generating spaced low-frequency rectangular current pulses alternately of opposite polarity which comprises a source of spaced unidirectional rectangular current pulses, a pair of current electrodes, means intermediate said source and said electrodes for reversing the connections therebetween, and means for actuating said reversing means in the interval between said spaced unidirectional pulses whereby said pulses of alternately reverse polarity flow through said electrodes.

3. A system for generating spaced low-frequency pulses alternately of opposite polarity for current flow between a pair of spaced electrodes which comprises a direct current circuit, a reversing circuit-controller intermediate said direct current circuit and said electrodes and a commutator associated with both said direct current circuit and said reversing controller for energizing said direct current circuit during predetermined intervals and to actuate said reversing controller in the interval between periods of energization of said direct current circuit to produce rectangular current pulses of alternating polarity between said electrodes.

4. In a system for generating low-frequency pulses alternately of opposite polarity for current flow between a pair of current electrodes, the combination which comprises direct current switching means, a thyatron circuit connected between said switching means and said electrodes, a motor-driven commutator, means coupling said commutator and said switching means to produce upon rotation of said commutator a series of unidirectional pulses spaced one from the other, means coupling said commutator and said thyatron circuit to energize said circuit in the interval between adjacent current pulses to reverse the connection between said electrodes and said switching means thereby to produce current pulses alternately of opposite polarity through said electrodes.

5. In a system for generating spaced low-frequency current pulses alternately of opposite polarity for current flow between a pair of elec-

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trodes in geophysical prospecting the combination which comprises an electron discharge path, a grid circuit including a source of potential for maintaining said discharge path normally non-conductive, circuit-reversing means intermediate said discharge path and said electrodes, actuating means for removing a portion of said source of potential from said grid circuit to render said discharge path conductive at spaced intervals, a coupling between said actuating means and said reversing means for reversing the connections between said electrodes and said discharge path in the interval between repeated removals of said source of potential for flow of current pulses alternately of opposite polarity through said electrodes.

6. A system having low power controlling requirements for delivering high-power, low-frequency, spaced, rectangular current pulses to a load impedance comprising a grid-controlled source of unidirectional spaced rectangular current pulses, a reversing circuit-controller connecting said load impedance to said source, and control means for energizing said grid-controlled source to produce said spaced pulses and for synchronously energizing said circuit-controller during the interval between said pulses for flow of spaced rectangular pulses alternately of opposite polarity through said load impedance.

7. A system having low power controlling requirements for delivering low-frequency, spaced, rectangular current pulses to a load impedance comprising a vacuum discharge path, a source of potential and a pair of output terminals in series circuit relation, means in the grid circuit of said discharge path to maintain said path normally non-conductive, a reversing circuit-controller connecting said load impedance to said output terminals, and a commutator driven at said low-frequency to remove a portion of said potential from said grid circuit to produce spaced unidirectional current pulses through said path and for energizing said controller during the interval between said spaced current pulses for flow of current pulses alternately of opposite polarity through said load impedance.

8. In a geophysical prospecting system where low-frequency current pulses alternately of opposite polarity flow between a pair of electrodes which comprises a vacuum discharge path, a grid circuit for said vacuum discharge path including a positive source and a negative source of potential, a reversing circuit-controller intermediate said discharge path and electrodes, a commutator, means coupling said commutator and said grid circuit of said discharge path for removing said negative source of potential from said circuit to render said discharge path conductive at spaced intervals, and means coupling said commutator and said reversing controller for reversing the connection between said electrodes and said discharge path in the interval during which said source of negative potential is in said control circuit, thereby to produce flow of spaced current pulses alternately of opposite polarity between said electrodes.

9. A system for generating low-frequency pulses alternately of opposite polarity for current flow between a pair of spaced electrodes in geophysical prospecting which comprises a source of potential, a high vacuum switch and a pair of output terminals in series with said source, a control circuit for said high vacuum switch including a second source of potential, a reversing circuit-controller connecting said electrodes to said out-

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put terminals, a device for removing said second source of potential from said control circuit during spaced intervals at said low frequency to produce a series of spaced unidirectional current pulses flowing to said output terminals, a coupling between said device and said controller for reversing the connections between said output terminals during the interval between each of said unidirectional pulses to produce pulsed current flow through said electrodes alternately of opposite polarity.

10. A system for generating low-frequency current pulses alternately of opposite polarity for flow in a load which comprises a delay-line source of spaced unidirectional current pulses, a reversing switch intermediate said delay-line source and said load, and means for actuating said reversing switch in the interval between said spaced unidirectional pulses to reverse the connections between said load and said delay-line source for flow of pulses alternately of opposite polarity through said load.

11. A system for generating low-frequency current pulses alternately of opposite polarity for flow in a load which comprises a plurality of series inductances and shunt condensers forming an artificial transmission line, a normally open charging circuit for said line including a source of potential, diodes individually in circuit with each of said condensers and said source of potential, circuit-reversing means intermediate said line and said load, and a circuit-controller for closing said charging circuit and for energizing said reversing means at twice the frequency of said current pulses alternately to charge said line from said source and to discharge said line through said load.

12. A system for generating low-frequency current pulses alternately of opposite polarity for flow in a load which comprises a delay line including a plurality of capacitive elements, a circuit including a plurality of diodes for individually charging each capacitive element in said delay line to a predetermined voltage, a thyatron connected to said delay line for controlling discharge thereof, a reversing circuit-controller connecting said load through said thyatron to said delay line, a control device for alternately energizing said thyatron and said charging circuit at a rate twice that of said low-frequency impulses, and means for operating said controller to reverse said connection between said electrodes and said delay line during energization of said charging circuit.

13. A square wave-pulse generating circuit comprising a transmission line having a plurality of charge-storing elements for forming and determining the duration of said pulses, a normally open circuit including a source of potential, an electron discharge path connected between each of said storing elements of said line and said source of potential, a load impedance and an electron discharge device having a conductive atmosphere connected in series with each other and with said line, means associated with both said normally open circuit and said second-named discharge device alternately to close said normally open circuit to charge said line from said source and to discharge said line through said load impedance, circuit-reversing means interposed between said line and said load impedance, and means for actuating said circuit-reversing means during the period of charging of said line.

14. A circuit for generating a series of pulses comprising a transmission line including a plu-

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rality of energy-storing elements for determining said pulse period, a charging circuit including a source of potential, an electron discharge device connected between each of said elements and said source of potential, a load impedance and a thyatron in series circuit with said line, a circuit-controller for alternately closing said charging circuit and rendering said thyatron conductive to produce said series of pulses in said load impedance, circuit-reversing means connected between said load impedance and said thyatron, and means for actuating said circuit-reversing means during the time of closure of said charging circuit.

15. A circuit for generating a series of pulses comprising a plurality of shunt condensers and series inductances forming a transmission line, a charging circuit for said line including a source of potential, switching means, and diodes equal in number to said condensers with their plates connected in parallel, a connection between each of said condensers and the cathode of one of said diodes, a discharge circuit for said line including a load impedance and a thyatron, circuit-controlling means alternately to connect said diodes and said condensers to said source to charge said line and to fire said thyatron for discharge of said line through said load impedance, circuit-reversing means connected between said load impedance and said thyatron, and means for actuating said circuit-reversing means during the charging of said line and prior to the firing of said thyatron.

16. A current-supply system for electrical prospecting which comprises a load, a source of current supply for said load, a reversing circuit-controller connected between said current source and said load, said source including electric valve means for producing a succession of rectangular current pulses each spaced one from the other by a predetermined time interval, and means for operating said reversing controller during each said time interval for application to said load of rectangular impulses of successively opposite polarity.

17. A current-supply system which comprises a reversing circuit-controller for reversing the connections to a load, a transmission line having output terminals connected to said reversing controller and comprising a plurality of interconnected capacitors and inductances, a charging circuit individual to each of said capacitors, a discharge circuit separate from said individual charging circuits and including said reversing controller, said capacitors and inductances predetermining the length of a current impulse delivered to said charging circuit, means for repeatedly closing said discharge circuit with time intervals between each closure thereof, means for

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operating said reversing controller during each interval of time between successive closures of said discharge circuit, and means for completing said individual charging circuits during said spaced intervals of time.

18. A current-supply system which comprises a source of current supply for a load, a reversing switch connected between said current source and said load, said source including electric valve means for producing a succession of rectangular current pulses each spaced one from the other by a predetermined time interval, and means operating said reversing switch from one position to the other during each said time interval for application to said load of rectangular impulses of successively opposite polarity.

19. A current-supply system which comprises a reversing switch for reversing the connections to a load, a transmission line having output terminals connected to said reversing switch and comprising a plurality of interconnected capacitors and inductances, a charging circuit individual to each of said capacitors, a discharge circuit separate from said individual charging circuits and including said reversing switch and said load, said capacitors and inductances predetermining the length of a current impulse delivered to said load, means for repeatedly closing said circuit to said load with time intervals between each closure thereof, means for operating said reversing switch for movement from one position to the other during each interval of time between successive closures of said load discharge circuit, and means simultaneously completing said individual charging circuits during said spaced intervals of time for uniformly elevating the voltage on all of the capacitors of said line for producing upon closure of said load circuit at any time an electrical pulse of rectangular shape.

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