Dec. 3, 1946. J. C. SCHELLENG 2,411,898

PULSE GENERATOR

Filed April 21, 1944

FIG. 1

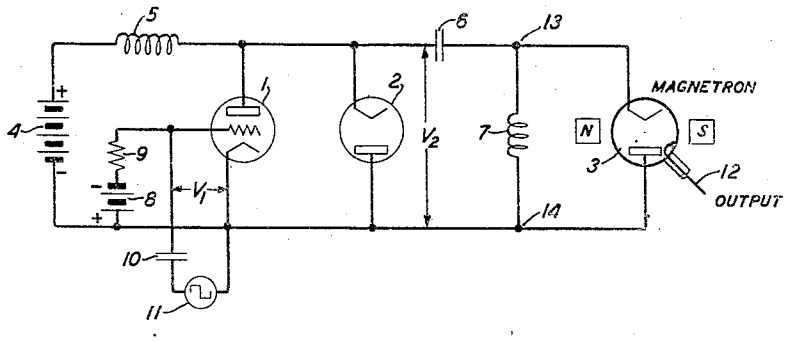


FIG. 2

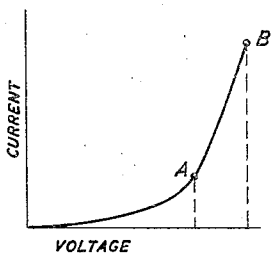


FIG. 3

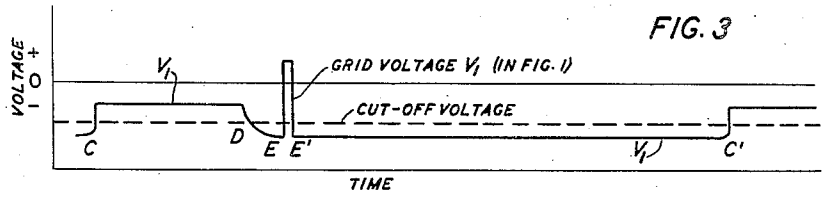
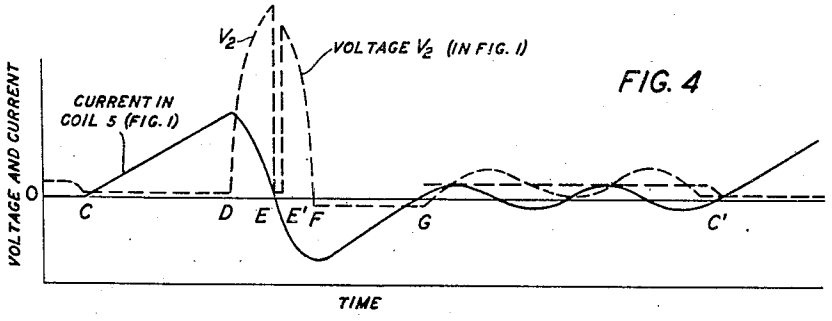


FIG. 4



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PULSE GENERATOR

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13 Claims. (Cl. 250—27)

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This invention relates to electrical pulse generators and particularly to such generators in which a capacitor is charged from a surge of high voltage produced by interrupting the flow of direct current through an inductance coil and then the high voltage of the capacitor is utilized by discharging the capacitor to the extent desired into a load circuit to produce a pulse of high voltage direct current power either for energizing a high frequency radio transmitter to transmit a short, high power pulse of radio frequency energy or for some other purpose. Since a common use for such a device is to produce series of pulses of radio frequency energy it will be described in that connection. It will be obvious that the invention may also be useful in other applications.

The principal object of the invention is to conserve the energy remaining in the capacitor at the end of a working pulse, that is, after the charge of the condenser has been utilized to the extent desired in producing a direct current power pulse. This is accomplished by providing a unidirectionally conducting current path between the capacitor and the direct current source whereby oscillatory discharge of the capacitor is damped and the remaining stored energy is returned to the direct current source.

Another object is to provide a circuit of the impulse type producing a high voltage from a relatively low voltage energy source and in which the energy pulse may be desirably shaped.

As mentioned above an important use of pulse generators is to energize radio transmitters in a manner to transmit pulses of radio frequency energy. Various types of electron tubes may be employed in such transmitters and energized by the pulse generator. One type commonly used is the magnetron. It is well known that in electron discharge devices such as the magnetron the electron discharge current falls off very rapidly as the voltage is reduced. This is illustrated in Fig. 2 showing the general nature of a magnetron characteristic. The useful part of the characteristic is the upper part roughly indicated as from A to B. It can be seen that when the applied voltage is a pulse produced from the discharge of a capacitor as in the type of pulse generator under discussion it may not be desirable to allow the capacitor to approach complete discharging during a pulse because at the lower voltages so little power is delivered. Also, when a very short pulse is required the capacitor may not have time to discharge appreciably during the period of the pulse. In either of these

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cases there may be considerable energy remaining in the capacitor at the end of a working pulse which is ordinarily dissipated in an oscillatory discharge or otherwise. This is wasteful of energy and may be objectionable in other respects.

By this invention the residual energy in the capacitor at the end of a working pulse is returned to the low voltage source and therefore not wasted or objectionably dissipated. This is accomplished by providing current paths which permit the energy in the capacitor to return to the inductance coil and then in another step to the original energy source. The invention is explained in more detail by the following description and the accompanying drawing in which:

Fig. 1 is the circuit arrangement, and

Figs. 2, 3 and 4 are explanatory diagrams.

Fig. 1 illustrating the circuit of the invention shows three electron tubes designated 1, 2 and 3. Tube 1 is a triode in which the current path between the cathode and anode may be made either substantially an open circuit or a relatively low impedance by varying the electric potential of the grid to make it respectively more negative or more positive with respect to the cathode potential and its magnitude suitably related to the potential applied to the anode. The manner of so using a triode as an electric switch is well known. Tube 2 is a two-element diode or valve which provides a unidirectional conducting path presenting always a substantially open circuit to potentials applied in one direction and a relatively low impedance circuit to potentials applied in the other direction. Tube 3 is shown as a magnetron of which the evacuated envelope comprises an electrically resonant cavity within which high frequency waves may be generated and from which high frequency energy may be delivered to a load circuit through the shielded lead 12 which forms a coupling loop within the cavity in a well-known manner. A tube of this general type is described in United States Patent 2,063,342, issued December 8, 1936, to A. L. Samuel. The showing of tube 3 in Fig. 1 is in schematic form as it is merely to illustrate a typical load for the pulse generator. The output terminals of the pulse generator proper may be considered to be at the terminals of the inductance coil 7 which are designated for reference 13 and 14. Any other load which it may be desired to pulse may be connected to the terminals 13 and 14 in place of the tube 3. Obviously anything connected between the points 13 and 14

may be regarded as "load" and the inductor 7 may be considered either as part of the load or as another part of the circuit.

Other circuit elements of Fig. 1 are: direct current energy source 4, inductance coil 5 of relatively high inductance so that a high voltage is induced in it when the current through it is sharply reduced, capacitor 6 which is charged to a high voltage from the inductance coil 5 and delivers high voltage pulses to the load circuit such as tube 3, inductance coil 7 which is of relatively low inductance and provides a low frequency current path for charging and discharging the capacitor 6 but sustains the high voltage of a short pulse, direct current source 8 and resistor 9 for biasing the grid of tube 1, and the square wave generator 11 with blocking condenser 10 for timing and initiating the pulses by varying the potential of the grid of tube 1. Suitable means for heating the cathodes of tubes 1, 2 and 3 are required but for simplification of the diagram are not shown. They may be provided in various known manners. It may be pointed out, however, that the cathode heating means should not introduce a large capacitance across the tube 2 to absorb energy from the high voltage pulse.

The operation of the circuit is as follows: Refer first to Fig. 3 which shows the operation of the square wave generator on the grid voltage of tube 1. This figure is a plot of voltage against time. The zero horizontal base-line from which voltages are measured is near the top of the graph. The horizontal broken line marked "cut-off voltage" indicates the negative grid voltage required to bias the tube 1 to cut-off for the particular anode voltage applied from source 4. The solid line curve shows the voltage V_1 between the grid and the cathode which results from the combination of the voltage from the bias source 8 and the voltage from the square wave generator 11. Its shape is that of the generator voltage and it may be noted that in this particular showing this curve is generally below the zero voltage base-line, varying above and below the line of cut-off voltage and rising above the zero voltage line once each cycle. Various points of interest along the time scale are indicated at C, D, E, E' and C'. It may be noted that a complete cycle of operation extends from C to C'.

Fig. 4 shows the variations with time of the current through coil 5 of Fig. 1 and of the voltage V_2 across the tube 2 of Fig. 1. The time scale and the points indicated on it are the same as in Fig. 3 with the addition of points F and G. At C (the beginning of a cycle) the generator 11 causes the grid voltage V_1 of tube 1 to rise above the cut-off voltage so that current begins to flow through the coil 5 and the tube 1 from the source 4. This current increases energizing the coil 5 until the time D when the generator voltage reverses and the voltage V_1 impressed on the grid of tube 1 drops below cut-off so that the flow of current through tube 1 is stopped. This opening of the circuit through the tube 1 in effect connects the capacitor 6 and coil 7 in the place of tube 1, in series with the coil 5 and source 4, and permits the transfer of energy from coil 5 to the capacitor 6. It may be noted that with the circuits through tube 1 and tube 2 open the capacitor 6 and coil 5 are connected together through the potential source 4 and coil 7 to form a low frequency resonant circuit. The source 4 and coil 7 are unimportant in this connection on account of their low impedances at the resonant frequency. The

transfer of energy from the coil 5 to the capacitor 6 which starts at the time D, therefore, is the beginning of an oscillatory interchange of energy between this coil and capacitor which may persist until the energy is utilized or dissipated. Due to the inductance of coil 5 the current continues therethrough and through coil 7 during the period between D and E (Fig. 4) charging the capacitor 6 and by the time the current has decreased to zero at E (or approximately E) a high voltage is developed across the capacitor 6. During the period from C to E neither tube 3 nor tube 2 has been in operation, tube 3 because of lack of anode voltage (it being short-circuited by the coil 7 for direct current or relatively low frequencies) and tube 2 because its anode has been negative with respect to the cathode. At E about the time that V_2 reaches its maximum the voltage of generator 11 again reverses (as shown in Fig. 3) driving the grid voltage V_1 positive (above cut-off) or at least in that direction so that the tube 1 again becomes conducting with a relatively low impedance and allows the capacitor 6 to discharge with a steep wave front through the tube 3 causing it to operate and deliver high frequency energy through the output lead 12. Due to the steep wave front the energy is not at once diverted from the tube 3 by the shunting coil 7 through which the capacitor was charged during the period DE. At E' a short time (for instance one microsecond) after E the generator voltage again reverses and the grid voltage V_1 is driven below cut-off so that the capacitor discharge through tube 3 is stopped and the voltage V_2 (Fig. 4) returns to a value nearly its peak value at E. During the interval EE' a pulse of high frequency energy has been delivered by the tube 3 as the result of a pulse of high voltage energy being delivered to it by the pulsing circuit. In this case the tube 3 is the load circuit of the pulsing device and obviously the high voltage pulse could be similarly delivered to any suitable load circuit. The problem now is to arrange for recharging the capacitor 6 to its peak voltage for delivering a subsequent high voltage pulse. It is in this part of the cycle that the particular advantages of the applicant's circuit and method of operation are realized. The situation (as denoted at the time E') is that the capacitor is still charged to a relatively high voltage and such that it may discharge back through coil 5, source 4 and coil 7. None of the tubes is operative. Tube 1 is biased below cut-off, tube 2 is not poled to pass current and tube 3 is effectively short-circuited by the low inductance coil 7. An oscillatory discharge therefore starts between the capacitor 6 and the coil 5 through the circuit including also the source 4 and the coil 7. After one-quarter cycle of this natural oscillation (at F Fig. 4) the capacitor 6 is discharged and a maximum of current is built up through the coil 5 in a direction opposite to that at D, that is, in such a direction as to feed energy back into the source 4. At this point for the first time the voltage V_2 across the tube 2 is in the direction to permit current to flow through tube 2. Since tube 2 has a very low impedance in the conducting direction it substantially short-circuits the capacitor 6 and coil 7 and allows the energy stored in the coil 5 to flow into the source 4 without materially recharging the capacitor 6 and when none remains in the coil the current in the coil and tube 2 becomes zero and the tube 2 becomes non-conducting. This occurs at the time G on Fig. 4. The tube 2 by thus preventing a substantial recharge of the

capacitor 6 damps the oscillation between the capacitor and coil 5 and causes energy remaining in the capacitor after the working pulse to be returned to the source 4. Substantial natural oscillations between the coil 5 and capacitor 6 are thus restricted to a period of about one-half cycle (between D and F' of Fig. 4). Without further oscillation the voltage V_2 would then assume the steady voltage of the source 4 as it was prior to the time C and as indicated by the horizontal broken line between G and C' on Fig. 4. Actually there will be a small oscillation remaining between the capacitor 6 and the coil 5 as shown by the broken line wave depicting the voltage V_2 and the solid line wave depicting the current in coil 5 between G and C' in Fig. 4. This however represents a relatively small amount of energy and even it may be recovered (if it is not dissipated in circuit resistance) by timing the beginning of the next cycle of operation to occur when conditions are as shown at C' where the current and the voltage V_2 are both substantially zero.

As previously mentioned the operating cycle described is completely at the time designated C' on Fig. 4 where the conditions are the same as at C and a similar succeeding cycle may start.

The curves of Figs. 3 and 4 are solely for explanatory purposes. They are drawn and proportioned in a manner to facilitate the explanation given of the circuit operation. The relative proportions therefore have no other significance. For instance, the time interval EE' is made large enough to be distinguishable though actually it may be so short in proportion to the other intervals shown that it would be indistinguishable if drawn to the same scale.

The invention, a circuit arrangement comprising means for generating high voltage electrical pulses wherein high voltage energy remaining in a capacitor at the termination of a pulse is recovered has been described in connection with a magnetron type of high frequency generator to which the pulses are delivered for the purpose of producing pu'ses of high frequency energy. It is obvious that the arrangement may be used with any type of high frequency generator which may be so energized and also as a source of high voltage pulses for any other appropriate purpose. It is intended therefore that the invention is not limited by the particular specific disclosure but only by the appended claims.

What is claimed is:

1. The method of producing and utilizing pulses of electrical energy which comprises the steps of transferring electrical energy from a source to a reactive element of a resonant circuit, transferring part of such transferred energy to a load circuit in a pulse shorter in time than one-fourth of the natural period of the said resonant circuit and returning a substantial part of the energy then remaining in the reactive element back to the source.

2. In a start-stop electrical circuit having a cycle of operation, and comprising a source, a load circuit and a resonant circuit including a reactive element, control means responsive to signals produced independently of the said resonant circuit for determining the said cycle of operation, means comprising said control means for transferring energy from the source to the reactive element in the first part of the cycle, means comprising the said control means for delivering a portion of the said energy to the said load circuit in a pulse shorter in time than one-fourth of the natural period of the said resonant circuit and means for restoring part of said energy to the source in the latter part of the cycle.

3. A circuit comprising a source of voltage and an inductance, means for applying said source of voltage to said inductance whereby energy is stored in the inductance, means for coupling said inductance with a capacitance to form a resonant circuit whereby a relatively high voltage is momentarily produced across said capacitance, means for applying the said momentarily produced high voltage to a load circuit for a period less than one-fourth the natural period of the said resonant circuit whereby a portion of the said energy is transferred to the load circuit and means whereby a substantial part of the remainder of said energy is restored to said source of voltage.

4. A circuit comprising an electrical source, a reactance element, means for applying said electrical source to said reactance element whereby energy is stored in the reactance element, a second reactance element, means for coupling the second reactance element with said first named reactance element to form a resonant circuit and to initiate an electrical oscillation in the resonant circuit, means for connecting a load circuit to the said resonant circuit during the persistence of the said electrical oscillation for a period less than one-fourth the period of the oscillation whereby a portion of the said energy is delivered to the load circuit and means for restoring part of said energy to said electrical source.

5. A circuit comprising an electrical source, a reactance element, means for applying said electrical source to said reactance element whereby energy is stored in the reactance element, a second reactance element, means for coupling the second reactance element with the first named reactance element to form a resonant circuit and to initiate an electrical oscillation in the resonant circuit, means for connecting a load circuit to the said resonant circuit during the persistence of the said electrical oscillation for a period less than one-fourth the period of the oscillation whereby a portion of the said energy may be delivered to the load circuit and means comprising a unidirectionally conducting device connected effectively in parallel with one of the reactance elements for restoring at least part of said energy to said electrical source.

6. A circuit comprising an electrical source, a reactance element, means for applying said electrical source to said reactance element whereby energy is stored in said reactance element, a second reactance element, means for coupling the second reactance element with said first named reactance element to form a resonant circuit and to initiate an electrical oscillation in said resonant circuit, means for connecting a load circuit to the said resonant circuit during the persistence of the said electrical oscillation for a period less than one-fourth the period of the oscillation whereby a portion of the said energy may be delivered to the load circuit and means for substantially suppressing the electrical oscillation in the resonant circuit comprising the two reactance elements before the completion of a cycle and for returning a substantial part of the oscillation energy to the said electrical source.

7. A circuit according to claim 6 in which the means for suppressing an electrical oscillation in the resonant circuit and returning a substantial part of the oscillation energy to the electrical

source comprises a unidirectionally conducting device effectively shunting one of the reactance elements.

8. A pulse generator comprising a source of direct current, an inductor, a capacitor, and a load circuit capable of passing direct current in either direction connected in series with each other in the order named, a unidirectionally conducting path bridging the said direct current source and inductor in series and arranged to be non-conducting to current from the said source, switching means for first establishing a flow of current from the said source through the said inductor, next interrupting the flow of current through the inductor without opening the said series connection of the inductor and capacitor, whereby the capacitor is charged to a high voltage by the energy stored in the inductor by the said flow of current from the source, next for closing a path for discharge of the capacitor through the load circuit and finally for opening the said discharge path without opening the said series connection of the inductor and capacitor whereby the residual energy of the capacitor charge is returned to the inductor and thence through the said unidirectionally connecting path to the direct current source.

9. A pulse generator according to claim 8 in which the load circuit comprises a pulse energy absorbing member and a member connected in parallel therewith which presents a high impedance to the pulse current but a relatively low impedance to low frequency and direct current.

10. A pulse generator according to claim 8 in which the load circuit comprises an inductor connected between the load circuit terminals.

11. A pulse generator comprising a source of direct current, a relatively high impedance inductor, a capacitor and a relatively low impedance inductor arranged in a series circuit in the order named, a unidirectionally conducting current path bridging both the said relatively high impedance inductor and the direct current source and arranged to be non-conducting to current from the said source, an electronic switch connected in parallel with the said unidirectionally conducting path and arranged when desired to conduct current from the said source, means for controlling the electronic switch in a desired sequence and a load circuit for the generated pulses connected in parallel with the said relatively low impedance inductor.

12. A pulse generator of the type in which a capacitor arranged to deliver power to a load circuit in pulses of which the periodicity and duration are determined by a timing wave is charged to a high voltage by the interruption of current flowing from a direct current source through an inductor and in which a low impedance unidirectional path is connected to form with the direct current source and said inductor a closed circuit and to bridge the said capacitor independently of the said source and inductor and is so poled as to effectively isolate the capacitor from the said inductor and source when a voltage is generated in the inductor of such a polarity as to pass a reverse current through said source.

13. The method of producing and utilizing pulses of electrical energy which comprises the steps of transferring electrical energy from a direct current source to a reactive element of an electrically resonant circuit, allowing the said transferred energy to initiate an electrical oscillation in the said resonant circuit whereby there is produced through resonance therein a voltage surge, connecting a load circuit to the said resonant circuit for a limited period during the time of the said voltage surge whereby a pulse of energy is delivered to the load circuit from the resonant circuit, the length of the pulse being shorter than a period of oscillation of the resonant circuit and too short to permit delivery to the load circuit of all the energy in the resonant circuit, and returning a substantial part of the energy then remaining in the resonant circuit back to the said energy source.

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