April 22, 1947. E. E. CRUMP ET AL 2,419,201

PULSE GENERATOR

Filed Nov. 30, 1943

FIG. 1

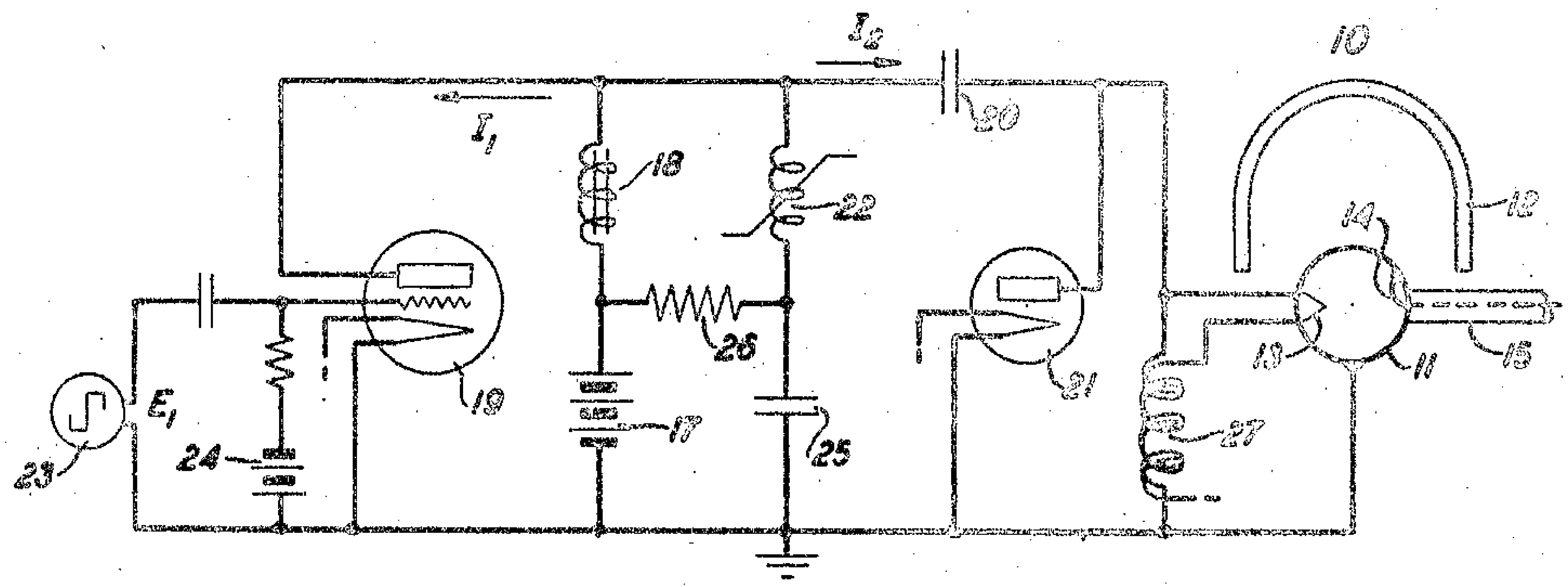



FIG. 2

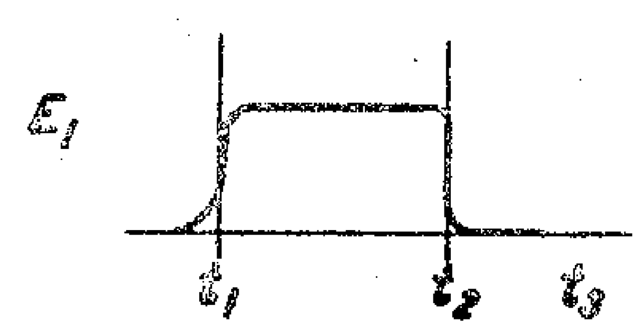
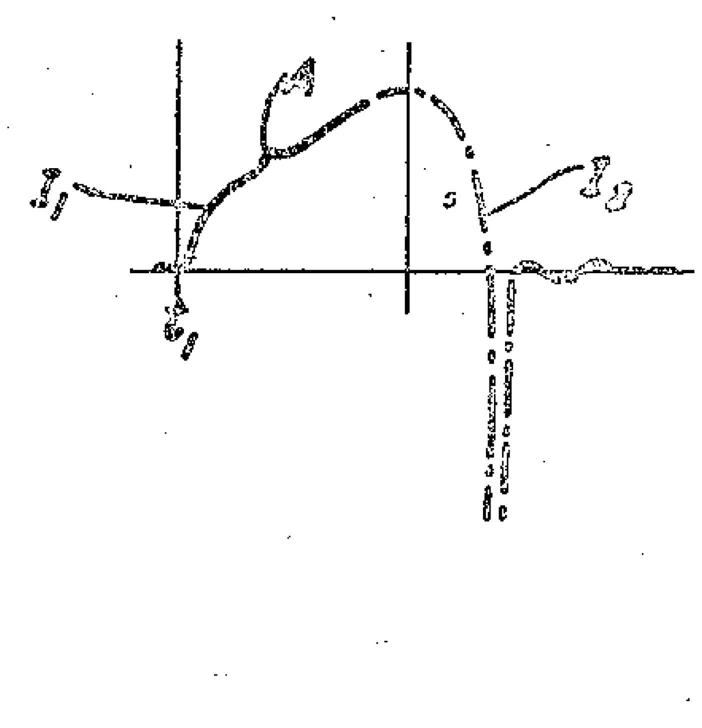



FIG. 3

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Patented Apr. 22, 1947 2,419,201

# UNITED STATES PATENT OFFICE

2,419,201

## PULSE GENERATOR

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Application November 30, 1943, Serial No. 512,294

15 Claims. (Cl. 171—97)

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This invention relates to pulse generators, particularly those for keying or modulating ultra-high frequency radio transmitters for the transmission of recurrent, short pulses of high power.

Various systems, for example, distance measuring and object locating systems employ high power recurrent pulses of ultra-high frequency radio waves. Such pulses may be of very short duration compared to the interval between pulses: Consequently, the average power demand on the prime power source is quite low even for very high peak power outputs. On the other hand, the system must be capable of meeting the high instantaneous power demands during the pulse interval.

An object of the invention is to provide an efficient and economical pulse generator.

One general type of pulse generating system that has been found useful in applications of the above type is that of the copending application of William Shockley, Serial No. 460,328 filed filed October 1, 1942. The basic principle of operation of this type of system is that of double energy storage, the energy from the prime source being first stored in the magnet field of an inductive system and then transferred to a storage capacitor from which it is discharged to the load circuit. Accordingly, the active portion of the cycle of operation comprises three periods, the inductance charging period, the capacitor charging period and the pulse period. In order to provide this cycle of operation there are required two discrete switching operations or their equivalents; first, for the transfer of the energy from the magnetic to the electric storage, and second, for the ultimate discharge to the load during the pulse period.

In the Shockley application one of the types of circuits for accomplishing the second switching or transfer operation employs a non-linear inductor. In the operation of such a system the non-linear inductor functions as a switch element controlled by the current flowing therethrough, by reason of the fact that its inductance undergoes a sharp change from a high to a negligibly low value as its core passes from the non-saturated to the saturated condition. The non-linear inductor has current supplied to it during the capacitor charging period and must be maintained in the unsaturated condition during this period. Efficient operation requires that it reach the saturation point at the time the storage capacitor assumes its maximum charge. This and other factors such as the limitation of the current drain through the non-linear inductor have

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required not only an accurate proportioning of circuit elements but also the use of auxiliary circuit features. In some systems of this general type the use of a supply of biasing current to the non-linear inductor has been found to give desirable results. The application of such systems may have some limitations particularly where power supply requirements are a controlling factor.

In accordance with a feature of the present invention the operation of the non-linear inductor of a pulse generating system of the type of the above Shockley application is controlled by the use of a capacitor-resistor combination. The capacitor provides a low impedance path for supplying the output pulse to the load. At the same time its capacity is made low enough so that it does not carry the non-linear inductor far into the saturated region during the inductive charging period which would otherwise waste energy and impose operating limitations on the vacuum tube used to provide that current path. The resistor functions during the inductance charging period to hold the current in the non-linear inductor to such a value that the saturation time of the coil will correspond to the time required to for the storage capacitor to assume its maximum charge, and in addition to provide sufficient resistance to limit that current to a value below saturation. These requirements for both the capacitor and resistor can be met with relatively uncritical values.

These and other objects, features and aspects of the invention will be better understood by reference to the following detailed description in connection with the drawing, in which:

Fig. 1 is a schematic circuit diagram of one embodiment of the invention, and

Figs. 2 and 3 are graphs illustrating the operation of the invention.

In the system of Fig. 1 the invention is employed for producing recurrent short pulses of high power ultra-high frequency radio waves. For the purposes of illustration, the ultra-high frequency generator is shown as a multicavity magnetron 10 of the type disclosed in United States Patent 2,063,342 to Samuel, December 8, 1936. In this type of oscillator the anode 11 forms an external sheath or enclosure which it is desirable to maintain at ground potential. When the tube is subjected to a magnetic field supplied by the magnet 12 and a high direct current voltage is impressed between the anode 11 and the electron emitting cathode 13, there are produced high power oscillations of a frequency determined by the internal structure of the device as described in more detail in the Samuel patent. These oscillations may be picked up by a loop 14 and transmitted through a coaxial line 15 to an antenna (not shown).

The purpose of the remainder of the circuit is to produce the recurrent direct current pulses that are impressed between the anode 11 and cathode 12 for causing the corresponding pulses of ultra-high frequency oscillations. It is to this pulse generating circuit that this invention is particularly directed.

The prime power source is the battery 17, though obviously some other source such as a generator or rectifier will be found preferable in most practical applications of the invention. The flow of current from the battery 17 is controlled by the vacuum tube 19 whose essential function in the system is that of a switching element. This tube is normally biased to plate current cut-off by the negative voltage applied to its grid by the battery 24. The operation of the tube is controlled by the positive voltage supplied to the grid of tube 9 by the square wave generator 23. (Alternatively the tube 19 might be maintained in the cut-off condition by a negative voltage from the square wave generator 23 and rendered conductive during the portion of the cycle in which the voltage is zero or positive.)

A linear inductor 18 is connected in series with the battery 17 in the plate circuit of the tube 19. During the inductive charging period energy is stored in the magnetic field of this inductor. After the tube 19 is cut off this energy is transferred to the storage capacitor 20. A diode 21 provides a path for this charging current and prevents pulses of incorrect polarity from appearing across the magnetron.

A non-linear inductor 22 is provided for accomplishing the second switching or energy transfer operation namely, the discharge of the storage capacitor 20 through the magnetron 10. This inductor 22 has the special characteristic that its inductance is high for low flux densities and changes quite sharply to negligibly low value in its saturation condition. One type of construction for such an inductor may comprise a toroidal winding on a core of spirally wound tape of the molybdenum permalloy type.

A capacitor 25 is connected in series with the inductor 22 and a resistor 26 is connected between the positive terminal of the battery 17 and one terminal of the inductor 22. This capacitor and resistor function to aid in the control of the non-linear inductor 22 in performing the switching function in a manner to give the desired operation. This action will be explained in the detailed description of a cycle of operation of the system which will be given below.

The bifilar inductor 27 provides a means for supplying heating current to the cathode 13 of the magnetron without the use of a more expensive insulating transformer. This inductor has a high impedance for high frequencies representing the pulse length and a low impedance at the low power frequency of the alternating current source furnishing the heating current. The inductor also functions in combination with the charging diode 21 to prevent oscillations in the pulse circuit as is explained in the Shockley application referred to above.

The operation of the system will now be described with reference to the explanatory diagrams of Figs. 2 and 3 in which various voltages and currents in the system are plotted against



time. In this description it is assumed that the circuit has been operating for several cycles prior to the time $t_1$ at which the active period of an operating cycle begins. During the non-working portion of the cycle prior to $t_1$ the tube 19 has been blocked and the capacitor 25 has become charged substantially to the voltage of the battery 17. At the time $t_1$ the voltage from the source 23 becomes positive and remains positive until the time $t_2$, as shown in Fig. 2. During this period, from $t_1$ to $t_2$, the tube 19 is conductive and current flows through its space path. This current ($I_1$ of Fig. 3) builds up slowly owing to the high inductance provided by the inductors 18 and 22 in the plate circuit of tube 19. The main component of this current is supplied by the battery 17 through the inductor 18. The component through the inductor 22 is first supplied mainly by the charge on the capacitor 25. The capacity of this element is so chosen that its charge is quickly dissipated without carrying the inductor 22 far into the saturation region. The effect of this discharge of the capacitor 25 is shown by the hook (A) in the current curve of Fig. 3. From this point on the current through the inductor 22 is determined by the resistor 26 which is given such a value as to hold the current through inductor 22 at about the saturation point or just below.

At the time $t_2$ the grid of the tube 19 is driven to such a negative value that the plate path is cut off sharply. The inductive current must find another path namely through the storage capacitor 20 and the charging diode 21. As a result the capacitor 20 is charged by the energy stored in the inductor 18 during the previous period. During this period the current in the non-linear inductor 22 is also changing. The voltage building up on the capacitor 20 first decreases the current in inductor 22, then reverses it, finally driving the inductor 22 into its saturation region in the sense opposite to that which it approached during the time the tube 19 was conducting. As soon as this saturation condition is reached the impedance of the non-linear inductor 22 drops to a very low value providing a low impedance path for the discharge of the capacitor 20 to the magnetron 10.

The non-linear inductor 22 is so designed that the time that is required for the current change from the point at which it is held by the resistor 26 during the on-time of the tube 19 to the point of saturation is equal to the time required for the capacitor 20 to assume its maximum charge. This can be done by the proper proportioning of the volume and cross-sectional area of the core and number of turns of the winding, and these dimensions may be so chosen that the magnetization of the coil changes from substantially saturation in one direction to saturation in the direction during the energy transfer interval.

It will be observed that the values of the capacitor 25 and resistor 26 must each be a compromise. Thus the capacitor 25 must be small enough that the charge it accumulates during the time the tube 19 is cut off will not drive the non-linear inductor 22 very far into the saturated region when dissipated during the on-time of the tube 19. Also the capacitor 25 must be sufficiently large compared to the capacitor 20 so that appreciable energy will not be lost during the pulse discharge. Similarly resistor 26 must be sufficiently large to limit the on-time current through the inductor 22 to a value below saturation and yet have a sufficiently low resistance to permit the current to build up to a point approaching that saturation value. It is possible to meet these requirements with relatively uncritical values for both elements.

In one embodiment of the invention which has given highly satisfactory operation in actual practice the following circuit constants were used:

Source or battery 17=1200 volts

Inductor 18=220 millihenries

Inductor 22 in unsaturated region=1–1.3 henries

Inductor 22 in saturated region=negligible

Capacitor 20=220 micromicrofarads

Capacitor 25=0.0025 microfarad

Resistor 26=18,000 ohms

Charging period $(t_1-t_2)$=approximately 170 microseconds

Pulse rate=approximately 1650 per second.

What is claimed is:

1. In a recurrent pulse generator, a source of direct current, a first inductor, a storage capacitor, switching means for intermittently establishing a flow of current from said source through said inductor, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said flow of current, a second inductor having a readily saturable core, circuit connections including a by-pass capacitor for discharging said storage capacitor to the load through said second inductor, the capacity of said second capacitor being sufficiently low that said second inductor does not become saturated during the period of said flow of current, and a resistor connecting said source to said second inductor to supply current thereto through said switching means.

2. A recurrent pulse generator comprising a load, a source of direct current, a linear inductor, a storage capacitor, switching means for intermittently establishing a flow of current from said source through said linear inductor, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said flow of current, a non-linear inductor, a resistor connecting said non-linear inductor to said source through said switching means, said resistor being of such a value as to limit the current through said non-linear inductor to approximately the saturation value, and circuit connections including a by-pass capacitor for discharging said storage capacitor to the load.

3. A recurrent pulse generator in accordance with claim 2 in which said blocking capacitor is of such value that the charge accumulated thereby during the inactive portion of the cycle of operation is readily dissipated through said switching means during the active period.

4. A recurrent pulse generator comprising a load, a source of direct current, a linear inductor, a non-linear inductor, switching means for intermittently establishing a flow of current from said source through said inductors in parallel, a storage capacitor, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said flow of current, and other circuit connections for discharging said storage capacitor to the load through said non-linear inductor.

5. A recurrent pulse generator according to claim 4 including a resistor connected in series with said non-linear inductor for the flow of current from said source and having such a value as to limit the current flow through said non-linear inductor from said source to a value approximating the saturation value.

6. A recurrent pulse generator according to claim 4 including in said other circuit connections a by-pass capacitor in series with said non-linear inductor.

7. A recurrent pulse generator in accordance with claim 4 including a resistor connected in series with said non-linear inductor for the flow of current from said source and having such a value as to limit the current flow through said non-linear inductor to approximately the saturation value and further including a by-pass capacitor connected in series with said non-linear inductor for the discharge current from said storage capacitor.

8. A recurrent pulse generator comprising a source of direct current, a linear inductor, a storage capacitor, a load circuit having an asymmetrical conduction characteristic, a charging circuit having an asymmetrical conductor characteristic and so connected in shunt to said load circuit as to provide a path for current in the direction opposite to that provided by said load circuit, switching means for periodically causing a current from said source through said linear inductor to store energy therein and for interrupting said flow of current whereby said energy is transferred to said storage capacitor through said charging circuit, a non-linear inductor, a direct current circuit for supplying current from said source to said non-linear inductor through said switching means, and a surge circuit for discharging said storage capacitor through said non-linear inductor to said load circuit.

9. A recurrent pulse generator according to claim 8 including in said direct current circuit a resistor of such a value as to limit the direct current from said source through said non-linear inductor to approximately the saturation value.

10. A recurrent pulse generator according to claim 8 including in said surge circuit a capacitor of such value that its charge is readily dissipated during the period of current flow from said source to said linear inductor.

11. A recurrent pulse generator according to claim 8 including in said direct current circuit a resistor for limiting the current from said source through said non-linear inductor and further including in said surge circuit a capacitor of such value that its charge dissipates during the period of current flow from said source to said linear inductor.

12. A recurrent pulse generator comprising a source of direct current, a linear inductor, a storage capacitor, a non-linear inductor, a resistor, said non-linear inductor and said resistor being connected in series with each other in parallel to said linear inductor, switching means for intermittently establishing a flow of direct current from said source through said inductors in parallel, the value of said resistor being such as to limit the current through said non-linear inductor to approximately the saturation point in one sense, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said flow of current, and circuit connections including a by-pass capacitor for discharging said storage capacitor to the load through said non-linear inductor.

13. A recurrent pulse generator according to claim 12 in which said resistor has a value limiting the current flow from said source through said non-linear inductor to approximately the saturation value.

14. A recurrent pulse generator according to

claim 12 in which said by-pass capacitor has a value sufficiently low to dissipate its charge during the period of current flow from said source to said inductors but several times the capacity of said storage capacitor.

15. A recurrent pulse generator according to claim 12 in which said resistor has such a value as to limit the current flow from said source to said non-linear inductor to approximately the saturation point and in which said by-pass capacitor has such a value that its charge is dissipated during the period of current flow from said source to said inductor.

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