Feb. 24, 1948. J. M. MANLEY ET AL 2,436,395

PULSE GENERATOR

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FIG. 1

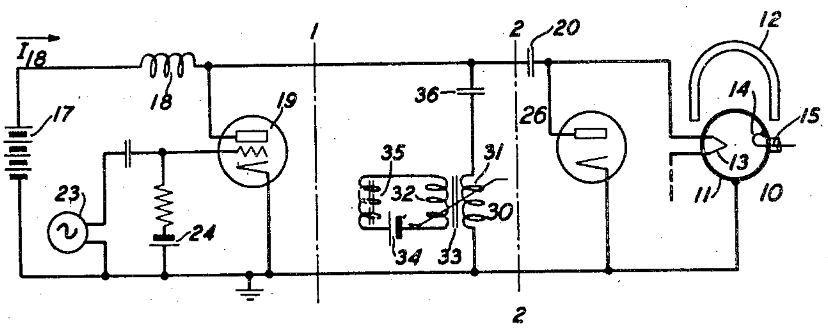


FIG. 2

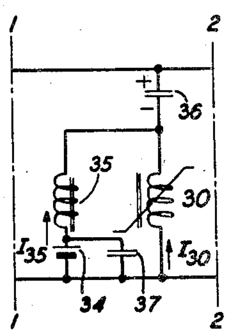
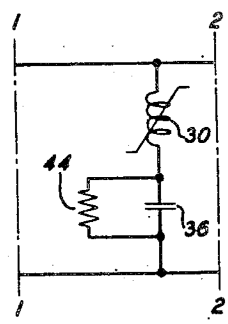


FIG. 3



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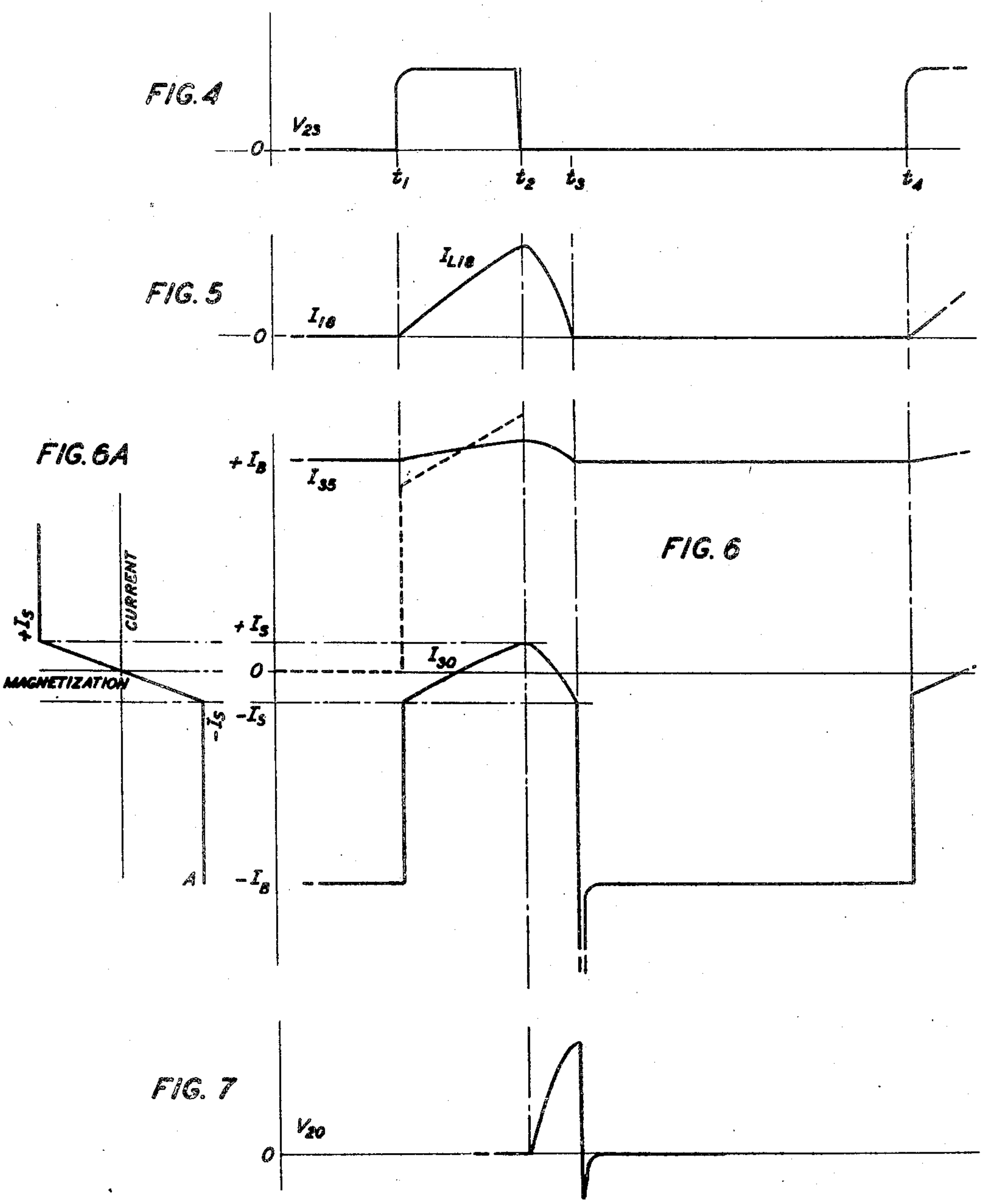

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PULSE GENERATOR

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7 Claims. (Cl. 171—97)

This invention relates to pulse generators, particularly 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 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 such applications is that of the copending application of William Shockley, Serial No. 460,328, filed October 1, 1942, Patent No. 2,416,718, of March 4, 1947. 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 magnetically and then transferred to a capacitor from which it is discharged to the load circuit. This requires two discrete switching operations or their equivalent; one for the transfer of the energy from the magnetic to the electric storage, and the other for the ultimate discharge to the load. Efficient operation requires a critical timing of the second switching or energy transfer so that the discharge of the capacitor occurs at the instant of maximum energy storage therein. One type of switching circuit for accomplishing this function as shown in the Shockley patent employs a non-linear inductor which is maintained in the non-saturated condition during the capacitor charging period but saturates at the end of that period to provide a low impedance path for the discharge of the capacitor to the load.

In the Shockley system it is necessary to employ a blocking capacitor in series with the non-linear coil in order to block the flow of current from the prime power source during the non-active period of the operating cycle. As a result this blocking capacitor provides a source of stored energy that will discharge through the tube used for establishing an inductive charging circuit. If uncontrolled this action not only results in a considerable waste of energy, but also, if the capacitor discharge is permitted to carry the non-linear coil into the saturated region may result in plate saturation of the tube and so limit the energy storage in the inductive system.

A further object of the invention is to improve the operation of such a non-linear inductor type of pulse generator.

In accordance with a feature of this invention

there is applied to the non-linear inductor a polarizing magnetizing force that magnetizes the core in the same sense as it is magnetized by the discharge current from the storage capacitor and to a degree sufficient to carry it into the saturation region. One effect of such a polarization or bias in which the core of the non-linear inductor is biased into the saturation region is to increase the energy that may be stored in the inductive system during the time required to carry the non-linear inductor through the non-saturated region; that is, from saturation in one sense to saturation in the opposite sense.

The amount by which the available inductive energy is augmented increases with the biasing current and, if the latter is made large compared with the current required to saturate the core and comparable to the peak current passed by the tube in the charging interval, substantial increases in the stored energy may be had.

The property of increased energy storage due to bias of the non-linear inductor into the saturation region may be briefly explained as due to the fact that the presence of the biasing current causes the inductive system to operate between two finite limits rather than from a value of zero. Thus, with such a polarization, upon closure of the inductive charging circuit the current will rise almost instantaneously to a value equal to the difference between the bias and the saturation values and the inductive charging will take place as the current rises from that value to the value that it reaches at the time the inductive charging circuit is opened.

These and other objects, features and aspects of the invention may 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;

Figs. 2 and 3 are schematic circuit diagrams of modifications of the portion of the circuit of Fig. 1 between the dash-dot lines 1—1 and 2—2; and

Figs. 4 to 7 are graphs illustrating the operation of the circuit of Fig. 1.

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 purpose of illustration, the ultra-high frequency generator is shown as a multicavity magnetron 10 of the type of United State Patent 2,063,342 to Samuel, December 8, 1936, for example. 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 remainder of the circuit of Fig. 1 constitutes the pulse generator circuit for producing high power recurrent pulses of short duration which are impressed between the anode 11 and cathode 12 for causing the production of corresponding pulses of ultra-high frequency oscillations.

The prime source of power is shown as a battery 17 though in most practical applications it would be a rectifier, direct current generator or the like. The positive terminal of the battery 17 is connected through an inductor 18 to the anode of a vacuum tube 19, the cathode of which is connected to the grounded negative terminal of the battery 17. A storage capacitor 20 is connected between the anode of the tube 19 and the cathode 12 of the magnetron 10.

The grid of the tube 19 is normally biased to cut-off or beyond by a battery 24. The operation of the tube 19 is controlled by a positive square wave supplied from the source 23. A charging diode 26 is connected in parallel to the space path of the magnetron 10 to provide a conductive path in the direction opposite to that provided by the magnetron space path.

Connected between the junction of the inductor 18 and the charging capacitor 20, in parallel to the space path of the tube 19, is a series circuit comprising the operating winding 31 of a non-linear inductor 30 and the blocking capacitor 36. The non-linear inductor 30 employs a core of magnetic material of such characteristics that the inductance is high for very low magnetizing forces but is readily saturable so that at a comparatively low magnetizing force the inductance drops to a very low value. This inductor 30 is also provided with a biasing winding 32 to which biasing current is supplied through the inductor 35 from a battery 34. The effect of this biasing current is to supply a polarizing magnetizing force to the core to permit operations over a desired portion of its characteristics. The value of the biasing current flowing under steady state condition will be determined by the voltage of the source 34 and the resistance of the circuit.

Fig. 2 shows a variation in the portion of the circuit of Fig. 1 between the dash-dot lines 1—1 and 2—2. This circuit shows a variation in the construction of the non-linear coil 30 with respect to the manner of supplying bias. In this modification the non-linear inductor has only one winding and the biasing current is supplied thereto from the battery 34 through the inductor 35. A filter capacitor 37 is included to smooth out the demand on the bias supply 34. As far as the system operation is concerned the circuits of Figs. 1 and 2 are equivalent. Fig. 1 is better suited to situations in which a high current, low voltage supply is available for bias and Fig. 2, where a high voltage, low current supply is available.

The operation will be described with particular reference to Fig. 2 since this somewhat simplifies the explanation with respect to the effect of the biasing current for the non-linear inductor 30. The same considerations are applicable to the circuit of Fig. 1 with proper weight given to the coupling between the operating winding 31 and the biasing winding 32.

In general the system operates by the periodical storage of energy in the inductive system, the transfer of that energy to the storage capacitor and finally the discharge of that energy to the load circuit. In the usual operation these energy transfers which constitute the working portion of the cycle occupy about one-tenth to one-quarter of the entire operating cycle. The building-up of energy in the inductive system is initiated by the positive voltage supplied to the grid of the tube 19 causing the space path to become conductive. Plate current to this tube is supplied from two sources, namely from the battery through the linear inductor 18 and from the blocking capacitor 36 which has become charged by the battery 17 during the idle period. This latter current flows through the non-linear inductor 30 and the bias inductor 35 in parallel. The plate current of the tube 19 is permitted to build up until the current through the inductor 30 reaches substantially the saturation point and then the tube is cut off. During this period when the tube is conducting the inductor 30 is operating in the unsaturated region where its inductance is high. Also the current in the inductors 18 and 35 has been building up with a consequent storage of energy in the magnetic fields. At the instant the tube 19 is cut off this energy begins to be transferred to the capacitor 20 through the charging diode 26. During this period of energy transfer the change in current through the non-linear inductor 30 causes it to approach saturation. The circuit is so designed that the saturation time of the non-linear inductor is equivalent to the charging time of the capacitor 20. When the full voltage is developed on the capacitor 20 the non-linear inductor 30 saturates and its inductance drops to a very low value providing a low impedance path for the discharge of the capacitor 20 to the magnetron oscillator 10.

The operation will now be described in more detail with reference to the explanatory diagrams of Figs. 4–7. Figs. 4, 5, 6 and 7 show various currents plotted against time. Fig. 6A shows an idealized magnetic characteristic of the non-linear inductor 30, hysteresis being neglected and the transition between the saturated and non-saturated conditions being treated as though it occurred abruptly.

Beginning at a time prior to t_1, a bias current ($-I_B$) is supplied from the battery 34 that causes the inductor 30 to operate at the point A of its idealized characteristic as indicated in Fig. 6A. Accordingly, there will be corresponding values of current flowing in the inductors 35 and 30 as indicated by the curves I_{35} and I_{30} of Fig. 6. At this same instant the current I_{18} through inductor 18 will be substantially zero (Fig. 5) and the blocking capacitor 36 will be charged to practically the voltage of the battery 17.

At the time t_1 the grid of the tube 19 is driven positive by the voltage from the source 23 as shown in Fig. 4 causing the space path to become conductive. This establishes a path for the flow of current from the battery 17 through the inductor 18 which takes place as shown in Fig. 5. This current (I_{18}) rises slowly as is the characteristic of an inductive circuit. At the same time the low impedance of the space path of the tube 19 affords a path for the discharge of the capacitor 36 through the inductors 35 and 30 in parallel. As shown in Fig. 6 the current I_{35} in the inductor 35 starts out at the value of the biasing current (I_B) and rises slowly. Since the inductor 30 is in the saturated region where its inductance is substantially zero, the current I_{30} therethrough changes almost instantaneously to the saturation value $-L_s$. From that point it rises slowly through the region where the inductance is high until it reaches the opposite saturation point ($+L_s$) at the time t_2. The system is so designed that at that instant, t_2, the voltage from the source 23 drops to zero and the tube 19 is cut off, as shown by the curve of Fig. 4.

The dotted line in Fig. 6 represents the sum of the currents I_{30} and I_{35} which is, of course, the current drawn by tube 19 from the non-linear coil and the biasing choke 35 together. This current rises sharply at the time t_1 to a value equal to the difference between the biasing current and the current value corresponding to magnetic saturation of the non-linear coil and after that time increases more slowly. Since the blocking condenser 36 may be made large enough so that the voltage across its terminals changes but little during the interval t_1-t_2, the growth of the total current takes place under a substantially constant voltage and the work done during this time is represented by the area under the curve. This work is done in changing the magnetization of the system and so represents energy that is recoverable from the system. It is evident from the drawing that the amount of this energy is substantially greater than if the total current were constrained to increase linearly from zero to same maximum value in the same time. Thus when the charging time and the maximum current are limited by other considerations, the use of a strong over-saturating bias provides a substantial increase in the stored magnetic energy.

At the instant t_2 at which the tube 19 is cut off the path for the flow of current from the battery 17 through the inductor 18 and for the flow of current from the capacitor 36 through the inductors 30 and 35 is opened. However, due to the inductive effect, the current through these circuits tends to continue and accordingly flows through the capacitor 20 and charging diode 26 in series. The energy stored in the magnetic field of the inductive system is thus transferred to the electric field of the capacitor 20 and by the proper proportioning of the circuit elements the resultant surge voltage developed across the capacitor 20 may be made many times that of the battery 17. This surge circuit is of an oscillatory character, being composed essentially of the capacitor 20 in parallel with the inductors 18, 30 and 35. Accordingly, the fall of current in each of the inductors follows a cosine law as shown by the curves of Figs. 5 and 6 and the rise of the voltage across the capacitor 20 is of a similar form, Fig. 7. At the time t_3 the current through each of the inductors 18 and 35 has dropped to its original value and the energy stored in their magnetic fields during the period the tube 19 was conducting has been transferred to the capacitor 20 which, at the same instant has reached its maximum voltage. At this same instant (t_3) the current in the non-linear inductor 30 will have changed to $-I_s$ corresponding to the other saturation point and the inductance of the inductor 30 will suddenly drop providing a low impedance path through which the high voltage charge on the capacitor 20 is discharged to the magnetron oscillator 10.

In the interval from t_3 to t_4 the system is essentially quiescent except for the restoration of the charge on the capacitor 36. At the time t_4 another active period of the operating cycle is commenced.

The curves of Figs. 5 to 7 are based on somewhat idealized conditions and show qualitatively the nature of the operation of the circuit. Other factors such as the effect of hysteresis on the inductor 30, surge currents through the inductor 18 during the cut-off period of tube 19, etc. will produce effects of secondary character.

Fig. 3 shows a second modification of the manner of biasing the non-linear inductor 30. In this circuit the blocking capacitor 36 is shunted by a resistor 44. The biasing current is supplied to the single winding of the non-linear inductor 30 as in the circuit of Fig. 2. However, the biasing current is drawn from the main source 17 through the resistor 44. This circuit may be found useful in cases where a separate biasing source is not readily available and where the power capacity of the main source is adequate.

What is claimed is:

1. In an impulse generator, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core, circuit connections for providing a path for the surge discharge of said capacitor to a load through said inductor, switching means for intermittently establishing a path for the flow of direct current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for polarizing said core by a magnetizing force in the same sense as that produced by the discharge of said capacitor through said inductor and of at least such value as to saturate said core.

2. In an impulse generator, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core, circuit connections for providing a path for the surge discharge of said capacitor to a load through said inductor, switching means for intermittently establishing a path for the flow of direct current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for supplying a direct current to said inductor to produce a polarizing magnetizing force in the same direction as that produced by the discharge of said capacitor and of at least such value as to saturate said core.

3. In an impulse generator, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core, circuit connections for providing a path for the surge discharge of said capacitor to a load through said inductor, switching means for intermittently establishing a path for the flow of direct current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for polarizing said core by a magnetizing force in the same sense as that produced by the discharge of said capacitor through said inductor and of a value at least several times that required to saturate said core.

4. In an impulse generator for supplying a unilateral conducting load circuit, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core of high permeability and flux densities below saturation, circuit connections for providing a path for the discharge of said capacitor to said load circuit through said inductor including a blocking capacitor, switching means for intermittently establishing a path for the flow of current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for

polarizing said core by a magnetizing force in the same sense as that produced by said discharge of said capacitor through said inductor and of at least such magnitude as to saturate said core.

5. An impulse generator comprising a first inductor, a source of direct current, a storage capacitor, a second inductor having a core with high permeability at low magnetizing forces and readily saturable at higher magnetizing forces, a load circuit, a blocking capacitor, circuit connections establishing a series circuit including said storage capacitor, said load circuit, said second inductor and said blocking capacitor, circuit connections including intermittently operated switching means for supplying current from said source to said first inductor and for interrupting said flow of current, circuit connections for charging said storage capacitor by the surge voltage developed upon said interruption of said flow of current, and means for so biasing the core of said second inductor that at the instant of establishing said flow of current from said source to said first inductor the magnetizing force is of the order of at least ten times that required for saturation.

6. In an impulse generator, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core, circuit connections for providing a path for the surge discharge of said capacitor to a load through said inductor, switching means for intermittently establishing a path for the flow of direct current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for so polarizing said core that during the charging period of said capacitor the flux therein varies from substantial saturation in one sense to saturation in the opposite sense.

7. In an impulse generator for supplying a unilateral conducting load circuit, a source of direct current, a storage capacitor, an inductor having a readily saturable magnetic core of high permeability and flux densities below saturation, circuit connections for providing a path for the discharge of said capacitor to said load circuit through said inductor including a blocking capacitor, switching means for intermittently establishing a path for the flow of current from said source through an inductive circuit whereby said capacitor is charged by the surge developed upon the interruption of said path, and means for so polarizing said core that during the period of charging said capacitor the magnetization varies from substantially the saturation point in one direction to the saturation point in the opposite direction.

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