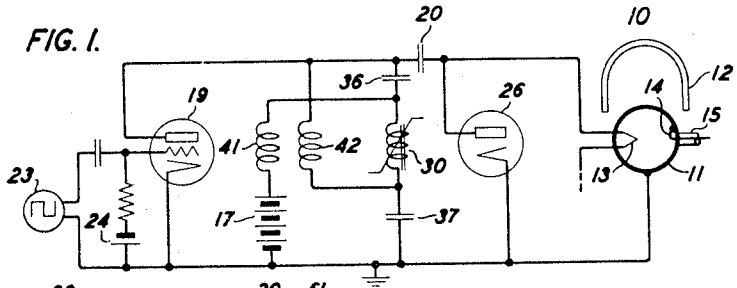
April 22, 1947. E. PETERSON 2,419,227

PULSE GENERATOR

Filed Nov. 17, 1943

FIG. 1.



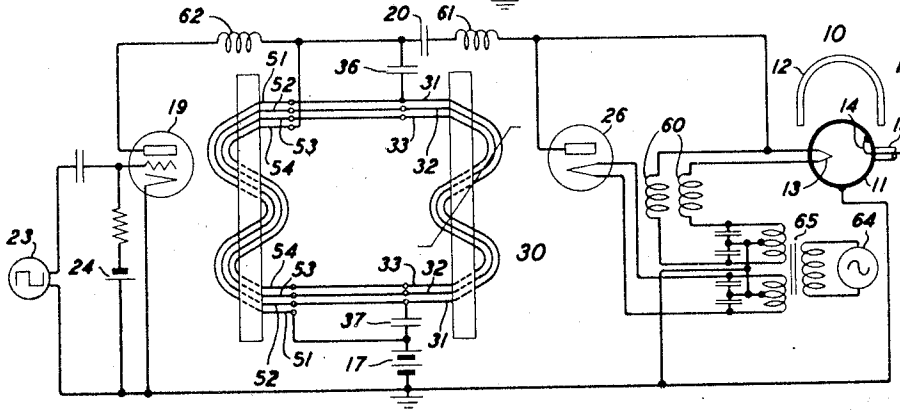


FIG. 2.

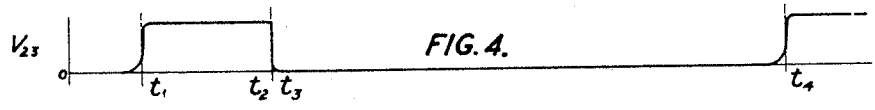


FIG. 4.

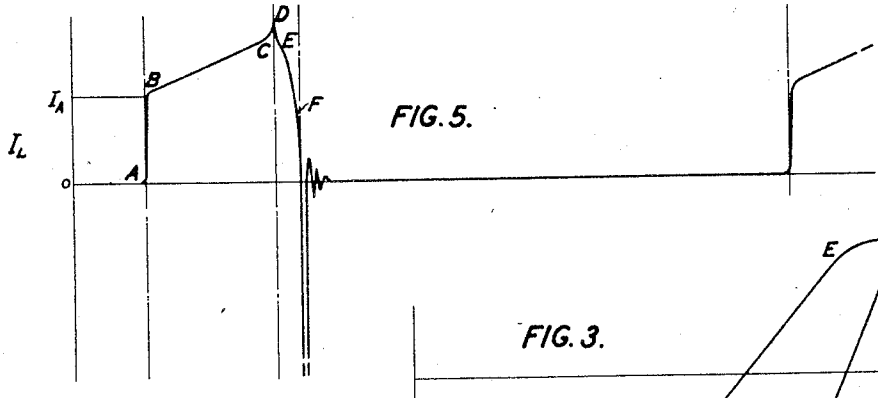


FIG. 5.

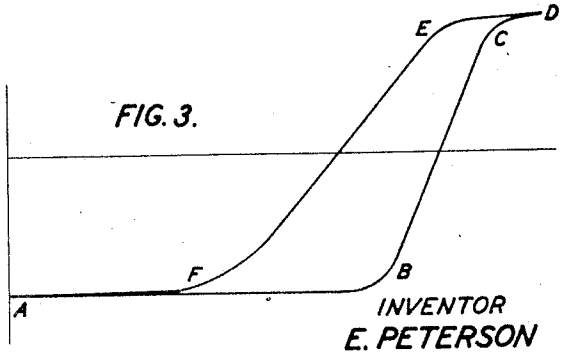


FIG. 3.

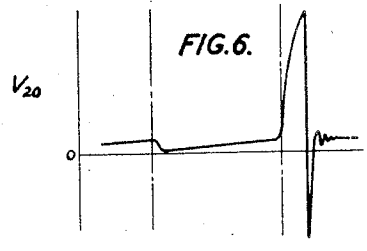


FIG. 6.

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PULSE GENERATOR

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Application November 17, 1943, Serial No. 510,643

8 Claims. (Cl. 171—97)

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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. The principle of operation of the Shockley 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 impulsively through the load circuit. This requires two discrete switching operations or their equivalent; first, for the transfer of energy from the magnetic to the electric storage, and second, for the ultimate discharge to the load. In the above-mentioned Shockley application, one of the circuits shown for accomplishing this second switching or energy transfer operation employs a non-linear inductor. In the operation of this circuit the sharp drop in the impedance of such an inductor as its magnetic core passes from the non-saturated to the saturated condition is utilized to achieve this switching function. In the copending application of Manley and Peterson Serial No. 502,282, filed April 14, 1943, it is brought out that the operation of such a pulse generating system is improved by the application to the non-linear inductor of a substantial polarizing magnetizing force.

Another object of the invention is to improve the method of applying such a polarizing bias to the non-linear inductor.

A further object of the invention is to provide a circuit arrangement for efficiently supplying the required bias from the high voltage source from which the pulse energy is derived.

A still further object of the invention is to prevent the development of excess voltages in the windings of the non-linear inductor.

In accordance with a feature of the present invention the direct current component from the

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main supply source is utilized as a biasing current to provide the required polarizing magnetizing force by connecting the winding of the non-linear coil to the prime source through separate paths for the alternating or surge current and for the direct current. In this way a large polarizing magnetizing force is obtained as a result of the fact that the path through the winding of the non-linear inductor for the surge currents serves also as a path for circulating currents that are sustained in the period following the output discharge. Such connections may be provided by the use of circuits of the lattice or bridge type composed of inductors and capacitors.

In accordance with another feature of the invention the winding of the non-linear coil is of the multiple strand or multifilar type. These strands are connected in series for the biasing direct current component but only a single strand is included in the surge path. In this way the magnetic polarizing effect of the biasing current is multiplied by the number of strands used, while the inductance and consequently the impedance of the discharge path to the load is not similarly increased. Similarly, it permits a large polarizing effect to be obtained from a low current without the production of a large surge voltage across the winding. In order to keep the paths for the two current components separate, an inductor is included in the connections between each two strands in addition to the two inductors connected between the respective terminal strands of the series circuit and the supply. Since corresponding points of the windings of all of these inductors are at the same alternating current potentials and differ only by the direct current drops therein, they also may be formed as a multiple strand winding of the multifilar type.

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;

Fig. 2 is a schematic circuit diagram of a second embodiment of the invention; and

Figs. 3, 4, 5, and 6 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 purpose of illustration, the ultra-high frequency generator is shown as a multicavity magnetron 10 of the type of United States Pat-

ent 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 therefrom is controlled by the vacuum tube 19. This tube is normally biased to cut-off by the negative voltage applied to its grid by the battery 24. The operation of the circuit is regulated by the voltage supplied to the grid of tube 19 from the square wave generator 23.

When the tube 19 becomes conducting upon the application of a positive voltage to its grid from the source 23, current is drawn from the battery 17. The path of this current may be traced from the positive terminal of the battery 17 through the linear inductor 41, the non-linear inductor 30, the linear inductor 42 and the space path of tube 19 to the negative terminal of the battery 17. At the end of the positive portion of the cycle of the output from the source 23, the tube 19 is cut off, opening the circuit for the supply of current from battery 17 to the inductive circuit. However, owing to the inductance of the circuit, the current will tend to continue to flow, a surge path being provided through the storage capacitor 20 and the charging diode 26. During this portion of the cycle the energy stored in the magnetic field while the tube 19 was conducting is transferred to the capacitor 20 which becomes charged to the high surge voltage thus produced. In this period the current flowing through the non-linear inductor 30 will be changing and consequently the condition of its magnetic core will be varied. The constants of the circuit are so proportioned that at substantially the instant that the voltage on the capacitor reaches its maximum value the core of the non-linear inductor 30 becomes saturated and the inductance drops to a very low value. This provides a low impedance path for the discharge of capacitor 20 to the magnetron 10. This discharge path may be traced from the right-hand (positive) terminal of capacitor 20 through the blocking capacitor 36, non-linear inductor 30, blocking capacitor 37 and anode-cathode path of the magnetron 10 to the left-hand terminal of capacitor 20.

In general, the operation of this circuit may be considered equivalent to that of the circuit described in the application of Manley and Peterson referred to above, but with the biasing current for the non-linear inductor 30 supplied by the pulsating current from battery 17. It may be considered that the bias current is produced because the currents flowing in the loops formed by the inductors 30, 41 and 42, and the capacitors 36 and 37 continuing to circulate after the pulse discharge. A complete cycle of operation will be considered in more detail in connection with the operation of the embodiment of the invention shown in Fig. 2.

It may be readily seen that the biasing current for the inductor 30 is determined by certain factors of which the pulse rate and the time that the tube 19 is conducting are important. Within certain limits these factors are determined by other operating requirements. Accordingly the required biasing effect is obtained by controlling the number of turns of the winding of the inductor 30. In general, in object locating and distance measuring systems to which this invention is particularly directed, it is found that this results in a winding of such a large number of turns that an excessive voltage is developed across its terminals during the passage of the impulse. From another point of view, it may be considered that such a coil has too high an inductance in the saturation region and consequently offers a higher impedance to the capacitor discharge than is tolerable with efficient operation. In the circuit of Fig. 2, there is shown a modification of the invention in which such difficulties are overcome.

In the circuit modification of Fig. 2, the same reference numerals are used for corresponding elements of the circuit of Fig. 1. The main difference between the two circuits is that instead of the single winding non-linear coil used in Fig. 1, the non-linear coil of Fig. 2 has three windings 31, 32 and 33. In order to achieve the full advantages of this multiwinding inductor a corresponding larger number of linear inductors is used. There are other incidental circuit features that differ from the circuit of Fig. 1 and will be discussed hereinafter.

The windings 31, 32 and 33 of the non-linear inductor 30 are of the multifilar type being wound as a single multiple strand winding. The linear inductors 51, 52, 53 and 54 are of the same type. The inductor circuit may be traced from the positive pole of battery 17 through linear conductor 51, non-linear inductor 31, linear conductor 52, non-linear inductor 32, linear inductor 53, non-linear inductor 33, and linear inductor 54, to the common connection to the anode of tube 19 and the storage capacitor 20. Thus not only are the windings of the non-linear inductor separated from the circuit on each side by a linear inductor but also each winding of the non-linear inductor is separated from its adjacently connected winding by a linear inductor. The circuit for the surge currents is made through the blocking capacitors 36 and 37 to the winding 31 only, though it is immaterial which of the three windings 31, 32 or 33 is so connected.

The graphs of Figs. 3, 4, 5 and 6 show the operating characteristics of a typical circuit of the type of Fig. 2. The operation of such a circuit will be discussed in detail in connection with these graphs. Fig. 3 shows the effective B—H loop of the coil 30. Figs. 4, 5 and 6 show, respectively, the voltage from the generator 23 applied to the grid of tube 19, the surge component I_L of the current through the inductors 30 and 50, and the voltage of the capacitor 20, all plotted against time.

It will be noted from Fig. 4 that the voltage from the source 23 is positive between the times

t_1 and t_2 during which the tube 19 will be conducting and after which the tube is blocked by the voltage from the battery 24 until the beginning of a new cycle at the time t_4. The curves of Figs. 3 and 5 have been lettered to indicate the manner in which the B—H loop of the inductor 30 is traversed and the corresponding values of currents through the inductive system.

The direct current component of the current through all of the inductors 30 and 50 in series may be considered as being maintained fairly constant throughout the cycle due to the effect of the inductance of the windings 51 to 54 and the capacity of the blocking capacitors 36 and 37. This current provides a bias for the non-linear inductor 30 so that the B—H curve may be considered as shifted to the origin, A.

Tracing through a complete cycle of operation we start at the point A at the time t_1, when the tube 19 is cut off. As the voltage applied to the grid rises (Fig. 4) the tube 19 begins to conduct and the current I_L rises rapidly to the value I_A corresponding to the point B of Fig. 3. This rise in current takes place very rapidly since the core of the non-linear inductor 30 is saturated in this region and the inductance is correspondingly low. At the point B the inductance begins to increase and rises to a high value. Accordingly, the current rises more slowly until the core begins to saturate in the opposite direction at the point C. It is in the interval between points B and C that energy supplied by the battery 17 is stored in the magnetic field. After the point C the inductance is again small due to saturation of the core and the current rises rapidly until the point D is reached at which point plate saturation of the tube 19 prevents any further rise. At this time the tube 19 is cut off by the drop in the voltage V_{23} and the current I_L drops rapidly to the point E. At this time the inductance again rises, although not to a value as large as before. The tube 19 is now open and a large current exists in the inductors 30 and 50. This causes an oscillation to be set up between the inductors 30 and 50 and the capacitor 20 through the diode tube 26 which has a fairly low resistance so that the current variation follows very closely a sinusoidal form. The current falls during the first quarter cycle of this oscillation as we go from point E to point F (Figs. 3 and 5) and the voltage on the capacitor 20 rises (Fig. 6). At about the end of this quarter cycle oscillation, when the voltage on capacitor 20 would reach a maximum, the core of inductor 30 again begins to saturate at point F and the inductance drops to a low value. This allows the capacitor 20 to discharge to the magnetron 10 through the path including the capacitors 36 and 37 and the very low impedance offered by the single winding 31 when the core of inductor 30 is saturated.

The inductors 61 and 62 are included in the circuit to shape the pulse during the discharge of the capacitor 20. The effect of the inductor 62 is due to the fact that it is connected in circuit with the plate capacitance of the tube 19. The effect of the inductance of the winding 31 in the saturation region of itself is to give the pulse a sinusoidal rise. By the use of the additional elements forming supplementary branches tuned to frequencies that are harmonics of the frequency of which the pulse length represents a half wave; it is possible to obtain a pulse shape closely approximating a square weave.

The bifilar inductor 60 provides a means of supplying heating current to the cathode 13 of the magnetron 10 without the use of a more expensive insulating transformer. The cathode heating current is obtained from an alternating current source 64 through a transformer 65. An additional secondary on the transformer 65 supplies heating current to the cathode of the diode 26. The inductor 60 has a high impedance at high frequencies representing the pulse length but a low impedance at the low frequency of the source 65 furnishing the heating current. This inductor and the charging diode 26 also function to prevent after oscillations in the pulse as is explained in the Shockley application referred to above.

The explanation of the invention has been given without any particular regard to quantitative effects. However, there is one effect which is significant with respect to the design of the system. This is that for the best operation the ratio of the total pulse period to the period during which the tube 19 is conducting should be greater than the number of windings on the linear inductor 30 (4 in the circuit of Fig. 2) by an amount depending upon circuit values. This relationship ensures that the stable periodic condition into which the system settles after the first few cycles is one for which the effective magnetization current in the non-linear coil passes from a value representing strong oversaturation in one direction to a value corresponding to saturation in the opposite direction during each cycle. In other words, that the full range of magnetization is traversed during each cycle. The exact relationship in any particular case can be determined experimentally by varying the length of the interval during which tube 19 is conducting.

What is claimed is:

1. In an impulse generator, a source of direct current, a capacitor, a first inductor having a readily saturable core, circuit connections for discharging said capacitor through said first inductor to the load, a second inductor, switching means for intermittently establishing a flow of current from said source through said inductors in series, the direction of flow through said first inductor being such that the core is polarized in the same sense as by the discharge of said capacitor therethrough, and connections for charging said capacitor by the surge developed upon the interruption of said flow of current.

2. In an impulse generator, a source of direct current, a capacitor, a first inductor having a readily saturable core and a plurality of windings thereon, circuit connections for discharging said capacitor through one of said windings of said first inductor to a load circuit, a second inductor, switching means for establishing an intermittent flow of direct current from said source through said second inductor and said windings of said first inductor in series in such a direction that said core is polarized in the same sense as by the discharge of said capacitor through said one of said windings, and circuit connections for charging said capacitor by the surge developed upon the interruption of said flow of current.

3. In an impulse generator, a source of direct current, a capacitor, a first inductor having a readily saturable core and a plurality of windings thereon, circuit connections opaque to direct current for providing a path for the surge discharge of said capacitor through one of said windings of said first inductor, a second inductor, switching means for intermittently closing a path for the flow of direct current from said source

through said second inductor and said windings of said first inductor in series whereby a surge voltage for charging said capacitor is developed upon the interruption of said path, and said core is polarized by the average flow of current through said windings in the same sense as by the surge discharge of said capacitor through said one of said windings.

4. In an impulse generator, a source of direct current, a first inductor having a core of magnetic material of high magnetic permeability at low flux densities and readily saturable at higher flux densities, a plurality of windings formed of conductors wound in parallel space relationship, a plurality of linear inductors, a series circuit including the windings of said first inductor and said linear inductors, each of said windings being connected between two of said linear inductors, a storage capacitor, switching means for intermittently supplying current from said source to said series circuit, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said supply current, and circuit connectors for discharging said storage capacitor to the load circuit through one of said windings of said first inductor.

5. In an impulse generator according to claim 4, blocking capacitors included in said circuit connection for discharging said storage capacitor so that said storage capacitor discharges through said one of said windings in the same direction as the current from said source flows therethrough.

6. In an impulse generator, a source of direct current, a first inductor having a core of magnetic material of high magnetic permeability at low flux densities and readily saturable at higher flux densities, a plurality of windings formed of conductors wound in parallel space relationship, a plurality of linear inductors comprising a core and a plurality of windings formed of conductors wound thereon in parallel space relation, a series circuit including the windings of said first inductor and said linear inductors, each of said windings being connected between two of said linear inductors, a storage capacitor, switching means for intermittently supplying current from said source to said series circuit, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said supply current, and circuit connections for discharging said storage capacitor to the load circuit through one of said windings of said first inductor.

7. In an impulse generator, a source of direct current, a first inductor having a core of magnetic material of high magnetic permeability at low flux densities and readily saturable at higher flux densities, a plurality of windings formed of conductors wound in parallel space relationship, a plurality of linear inductors comprising a core and a plurality of windings formed of conductors wound thereon in parallel space relation, a series circuit including the windings of said first inductor and said linear inductors, each of said windings being connected between two of said linear inductors, a storage capacitor, switching means for intermittently supplying current from said source to said series circuit, circuit connections for charging said storage capacitor by the surge developed upon the interruption of said supply current, and circuit connections for discharging said storage capacitor to the load circuit through one of said windings of said first inductor including blocking capacitors so connected that said storage capacitor discharges through said one of said windings in the same direction as the current from said source flows therethrough.

8. In an impulse generator, a source of direct current, a capacitor, a first inductor having a readily saturable core, circuit connections for discharging said capacitor through said first inductor to the load, a second inductor, switching means for intermittently establishing a flow of current from said source through both said inductors, the current to said first inductor being in such a sense that the core is polarized in the same sense as by the discharge of said capacitor, and connections for charging said capacitor by the surge developed upon the interruption of said flow of current.

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