Aug. 31, 1948. A. G. GANZ ET AL 2,448,364

PULSE GENERATOR

Filed April 28, 1945

FIG. 1

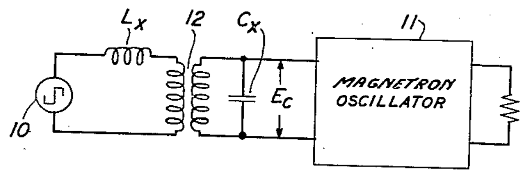


FIG. 2

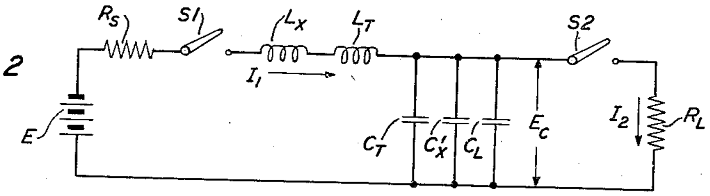


FIG. 5

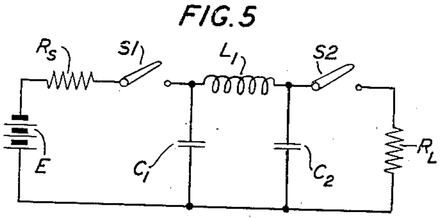


FIG. 4

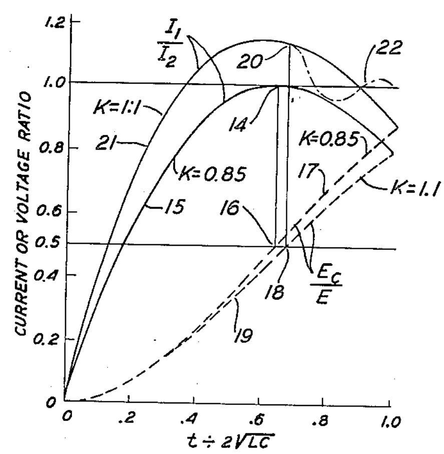


FIG. 3

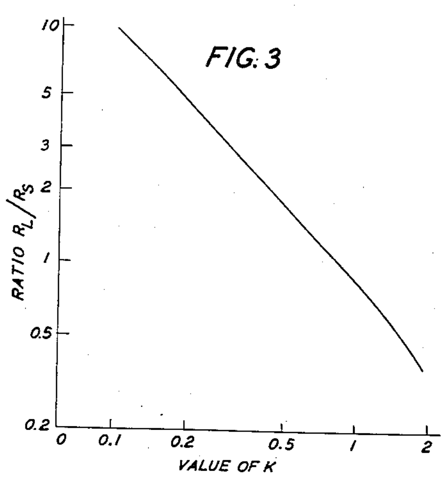
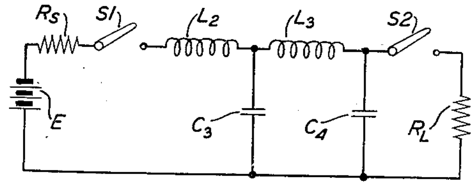


FIG. 6



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UNITED STATES PATENT OFFICE

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PULSE GENERATOR

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9 Claims. (Cl. 250—36)

1

This invention relates to pulse generating systems and more particularly to one in which an oscillator generates high frequency pulses corresponding to unidirectional rectangular pulses applied thereto.

The principal object of the invention is to reduce or prevent distortion of the envelope of the high frequency output pulse due to fluctuations in the input current to the oscillator.

In generating high frequency pulses a unidirectional pulse is applied to an oscillator, which may be of the magnetron type, through a coupling circuit which may include a transformer. When the impressed voltage reaches an assigned operating value the oscillator becomes conductive and starts to oscillate. However, associated with the coupling circuit there will be an inductance effectively in series with the load and a capacitance effectively in shunt with the load. These may produce a transient oscillation, upon the appearance of the unidirectional pulse, and delay the operation of the oscillator. Furthermore, unless this inductance and capacitance are properly related the input current to the oscillator will fluctuate in value and cause a distortion of the envelope of the output pulse.

In accordance with the invention this distortion of the envelope is greatly reduced or entirely prevented by so proportioning the ratio of the inductance to the capacitance with respect to the impedance of the source that the transient current substantially reaches a maximum, and approximately the value drawn by the magnetron in the steady state condition, at the instant the impressed voltage reaches the assigned operating value. The required proportion may be obtained by properly designing the transformer or by adding an inductance or capacitance, if necessary.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a schematic circuit of a high frequency pulse generating system in accordance with the invention;

Fig. 2 is an equivalent circuit of the system;

Figs. 3 and 4 show curves used in explaining the invention; and

Figs. 5 and 6 are equivalent circuits of other pulse generating systems embodying the invention.

The high frequency pulse generating system shown in Fig. 1 comprises a unidirectional rectangular pulse generator 10, a load device 11 including an oscillator which may be of the magnetron type, and a coupling circuit which includes a transformer 12. The series inductance L_X and the shunt capacitances C_X are elements which may be added, if required. When a unidirectional pulse reaches the assigned operating value E_0, the magnetron will start to oscillate or "fire." However, since the transformer 12 inevitably has leakage inductance, the voltage E_C impressed upon the load 11 will not rise to its full value immediately upon the appearance of the unidirectional pulse but will be somewhat delayed. Furthermore, since the load 11 and the coupling circuit will have considerable capacitance, the voltage rise will tend to be oscillatory in character. Consequently, after the application of the pulse, there will be a brief period during which the magnetron is non-conductive and during which a transient oscillation will take place in the coupling circuit. Unless this circuit is designed to control the transient properly, the energy stored in the transformer inductances and in the parasitic capacitances at the moment the magnetron fires may discharge through the magnetron and produce a serious distortion of the output pulse envelope.

2

For analytical purposes the system of Fig. 1 may be represented by the circuit shown in Fig. 2. The transformer 12 is represented by its leakage inductance L_T and its output shunt capacitance C_T, both referred to the transformer primary. The generator 10 is represented by a unidirectional electromotive force E in series with a resistive impedance R_S, connected to the transformer through a switch S1. The load 11 is represented by its effective shunt capacitance C_L and its operating resistive impedance R_L, both referred to the primary side of the transformer. The impedance R_L is connected to the circuit through a secondary switch S2. The element C_X' represents the value of C_X, also referred to the transformer primary. It is assumed that the switch S1 is closed at the instant the voltage pulse E is applied to the transformer 12 and that the switch S2 is closed the instant the voltage E_C impressed upon the magnetron reaches the operating value E_0. For analytical purposes the two series inductance L_T and L_X may be combined into a single inductance L, that is,

$$L=L_T+L_X \quad (1)$$

and the three shunt capacitances into a single capacitance C having the value

$$C=C_L+C_T+C_X' \quad (2)$$

When the rectangular pulse E is applied but before the magnetron fires, that is, with S1 closed and S2 open, the circuit of Fig. 2 behaves simply as a damped series resonant circuit. The input current I_1 is oscillatory and rises toward a maximum determined by the circuit constants R_S, L and C. The voltage E_C across the capacitance C also rises toward a final steady voltage E which it approaches in an oscillatory fashion. When the voltage E_C reaches the operating voltage E_0 of the magnetron, the latter fires, that is, S2 is closed and the magnetron draws a steady state load current I_2 given by

$$I_2=\frac{E_0}{R_L} \qquad (3)$$

If at the instant the magnetron fires the current I_1 is not the same as I_2, the excess or deficit has to be balanced by a change in the current through the capacitance C, which will be accompanied by a change in the voltage across the capacitance and a distortion of the output pulse envelope. However, if at the instant the voltage E_C reaches the operating value E_0 the current I_1 has reached its maximum value and is equal to the load current I_2, then the sudden closing of the magnetron path will produce no disturbing transient. Furthermore, for the duration of the pulse, the voltage E_C will remain fixed at the value E_0, that is,

$$E_C=E_0=\frac{ER_L}{R_S+R_L} \qquad (4)$$

At any time t after S1 has been closed but before S2 is closed the current I_1 and the voltage E_C are given by the expressions

$$I_1=\frac{E}{\omega L}\theta^{-\alpha t}\sin \omega t \qquad (5)$$

$$E_C=E\left[1-\frac{\omega_0}{\omega}\theta^{-\alpha t}\sin(\omega t+\Phi)\right] \qquad (6)$$

where

$$\alpha=\frac{R_S}{2L} \qquad (7)$$

$$\omega_0=\frac{1}{\sqrt{LC}} \qquad (8)$$

$$\omega\sqrt{\omega_0^2-\alpha^2} \qquad (9)$$

and

$$\Phi=\tan^{-1}\frac{\omega}{\alpha} \qquad (10)$$

Now if we introduce a factor K defined as

$$K=R_S\sqrt{\frac{C}{L}} \qquad (11)$$

it may be shown analytically, starting with Equations 5 and 6, that if K has the value given by

$$\frac{R_L}{R_S}=\frac{e^x}{K}-1 \qquad (12)$$

where

$$x=\frac{\tan^{-1}\sqrt{\frac{4}{K^2}-1}}{\sqrt{\frac{4}{K^2}-1}} \qquad (12a)$$

then the current I_1 will have risen to its maximum value and will be equal to I_2 at the instant the voltage E_C has reached the operating value E_0. As pointed out above, these are the desired conditions for an undistorted output pulse. The curve of Fig. 3 is a plot of the value of K for the range of ratios

$$\frac{R_L}{R_S}$$

from 0.4 to 10, the range most likely to be encountered in practice. A logarithmic scale is used for both the ordinates and the abscissas. To determine a point on the curve, a value of K is assumed and the corresponding value of

$$\frac{R_L}{R_S}$$

is found from Equation 12.

For the particular case where R_L is equal to R_S, that is, when the load resistance as seen from the transformer primary terminals matches the resistance of the pulse source, the proper value of K, as given by Fig. 3, is 0.85. In Fig. 4 the dash line curves give the ratio of E_C to E and the solid line curves give the ratio of I_1 to I_2, plotted against abscissas which are proportional to the time t and are equal to t divided by $2\sqrt{LC}$. If K is equal to 0.85, the current I_1 will reach its maximum value and be equal to the steady state load current I_2 at the point 14 on the curve 15 at the instant the voltage E_C has reached the operating value 0.5E at the point 16 on the curve 17. If the switch S2 is now closed, the current will remain at the value I_2 given by

$$I_2=\frac{E}{R_S+R_L}=\frac{E}{2R_S} \qquad (13)$$

and the voltage E_C at the operating value E_0 given by

$$E_C=E_0=0.5E \qquad (14)$$

for the duration of the pulse without being disturbed by undesired transients.

However, if K has any other value, transients will occur. For example, if K has the value 1.1, at the instant the voltage E_C reaches the value 0.5E at the point 18 on the curve 19, the current I_1 has progressed beyond its maximum and is larger than the desired value I_2, as shown by the point 20 on the curve 21. Now, upon the closing of S2, the current I_1 will approach the operating value I_2 in an oscillatory manner as indicated by the dot and dash curve 22, thus introducing a disturbing transient.

In designing a particular pulse generating system the values of the source resistance R_S and the load resistance R_L will usually be known in advance. The proper value of K can be found from Fig. 3. The required ratio of C to L may then be found from Equation 11. However, C is made up of C_L, C_T and C_X' and L is made up of L_T and L_X. The value of C_L, the capacitance associated with the load, is ascertainable, and L_X and C_X' are building out elements which are only included when necessary. Therefore, the required ratio of the output shunt capacitance C_T of the transformer to its leakage inductance L_T can be determined. If it is found to be difficult to design the transformer 12 to have the required ratio of C_T to L_T, then either a capacitance C_X' or an inductance L_X of proper value is added to the circuit of Fig. 2. The required value of C_X in Fig. 1 may now be found by dividing C_X' by the impedance transformation ratio of the transformer. Also, the addition of either C_X or L_X may be found useful in adjusting a transformer to compensate for manufacturing variations.

The above description shows how the necessary conditions for constant current into and voltage across the load can be satisfied for the simple case of a series inductance L and shunt capacitance C. These considerations apply similarly to pulse generating systems for which the equivalent circuits are more complex such, for example, as those shown in Figs. 5 and 6. The circuit of Fig. 5 comprises a series inductance L_1 with a shunt capacitance C_1 on the input side and a second shunt capacitance C_2 on the output side. The circuit of Fig. 6 comprises two series inductances L_2 and L_3, an interposed shunt capacitance C_3, and a second shunt capacitance C_4 on the output side. The proper values for the elements L_1, C_1 and C_2 of Fig. 5 or the elements L_2, L_3, C_3 and C_4 of Fig. 6 to meet the necessary conditions may be obtained by trial and error or by the solution of a perfectly determinate set of simultaneous equations.

The equivalent circuit of Fig. 6 may, for example, represent the pulse generating system shown in Fig. 1 when the impedance transformation ratio of the transformer 12 is so low that the shunt capacitance C_3 on the primary side cannot be neglected. In this case the inductance L_2 is the series inductance L_X, the inductance L_3 is the leakage inductance L_T of the transformer 12, and the capacitance C_4 is the capacitance C as given by Equation 2.

If the inductance L_X in Fig. 1 is zero the equivalent circuit of Fig. 5 is obtained. In this case the capacitance C_1 represents the sum of the input shunt capacitance of the transformer 12 and the shunt capacitance associated with the source 10. The inductance L_1 and the capacitance C_2 represent the same quantities, respectively, as the elements L_3 and C_4 shown in Fig. 6.

What is claimed is:

1. A high frequency pulse generating system comprising a source of unidirectional pulses, a load device which becomes conductive and draws a predetermined current when the voltage impressed thereon reaches an assigned value, and a circuit coupling said source and said load device, said circuit including an inductance L effectively in series with said load device and a capacitance C effectively in shunt with said load device, said inductance and capacitance producing a transient oscillation on the appearance of a pulse and delaying the operation of said load device, and the ratio of L to C being so proportioned with respect to the resistance impedance R_S of said source that the transient current approximately reaches a maximum and approximately the steady state value of the load device current at the instant the voltage impressed upon said load device reaches said assigned value.

2. A system in accordance with claim 1 in which said coupling circuit includes a transformer.

3. A system in accordance with claim 1 in which said coupling circuit includes a transformer having an impedance transformation ratio chosen to match R_S to the resistive impedance of said load device.

4. A system in accordance with claim 1 in which said coupling circuit includes a transformer and an added series inductance.

5. A system in accordance with claim 1 in which said coupling circuit includes a transformer and an added shunt capacitance.

6. A system in accordance with claim 1 in which the resistive impedance looking into the input terminals of said coupling circuit is approximately equal to R_S.

7. A system in accordance with claim 1 in which R_S, L and C have the relationship

$$R_S=K\sqrt{\frac{L}{C}}$$

where K is a constant having approximately the value given by the equation

$$\frac{R_L}{R_S}=\frac{e^x}{K}-1$$

where

$$x=\frac{\tan^{-1}\sqrt{\frac{4}{K^2}-1}}{\sqrt{\frac{4}{K^2}-1}}$$

8. A system in accordance with claim 1 in which the resistive impedance R_L looking into the input terminals of said coupling circuit, R_S, L and C have the relationship

$$R_L=R_S=K\sqrt{\frac{L}{C}}$$

where K is a constant having a value approximately equal to 0.85.

9. A high frequency pulse generating system comprising a source of unidirectional pulses, a load device comprising a magnetron oscillator which becomes conductive when the voltage impressed thereon reaches an assigned value, and a circuit coupling said source and said load device, said circuit including an inductance L effectively in series with said load device and a capacitance C effectively in shunt with said load device, said inductance and capacitance producing a transient oscillation on the appearance of a pulse and delaying the operation of said load device, and the ratio of L to C being so proportioned with respect to the resistive impedance R_S of said source that the transient current approximately reaches a maximum and approximately the steady state value of the load device current at the instant the voltage impressed upon said magnetron oscillator reaches said assigned value.

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