

Sept. 8, 1959

A. D. HASLEY

2,903,583

HARD TUBE MODULATOR PULSE TRANSFORMER

Filed Dec. 24, 1956

2 Sheets-Sheet 1

FIG. 1

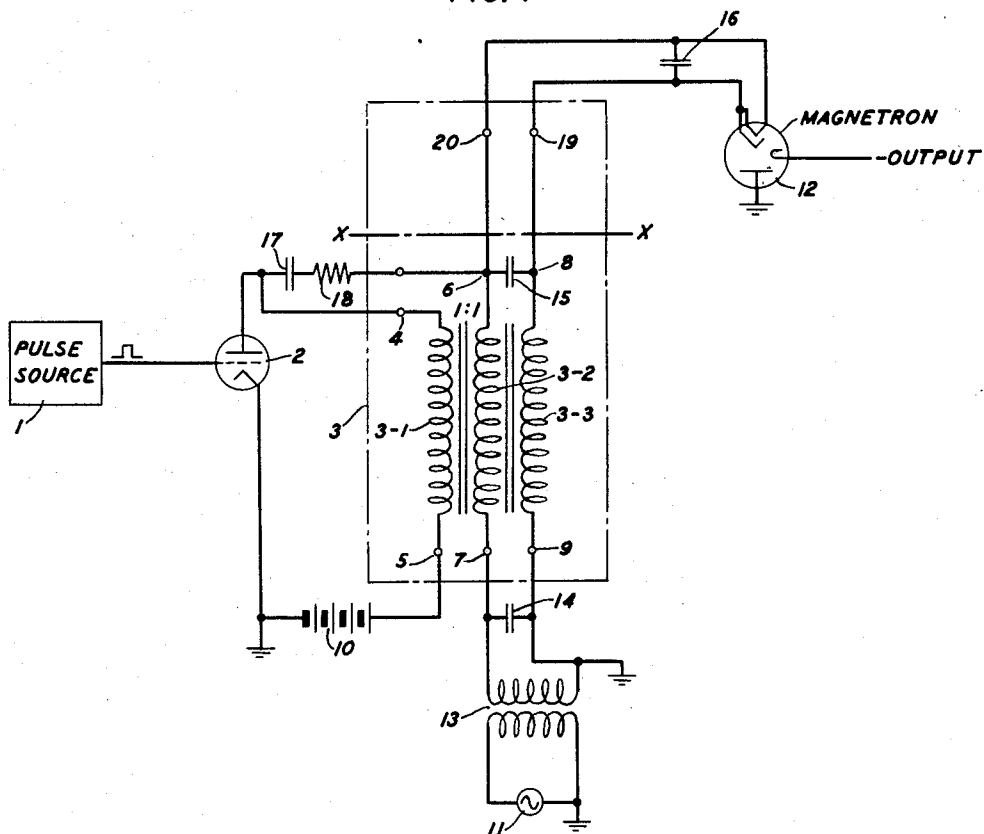
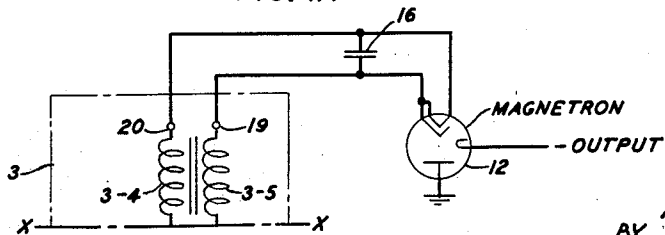


FIG. 1A



INVENTOR
A. D. HASLEY
BY *George C. Ford*
ATTORNEY

Sept. 8, 1959

A. D. HASLEY

2,903,583

HARD TUBE MODULATOR PULSE TRANSFORMER

Filed Dec. 24, 1956

2 Sheets-Sheet 2

FIG. 2

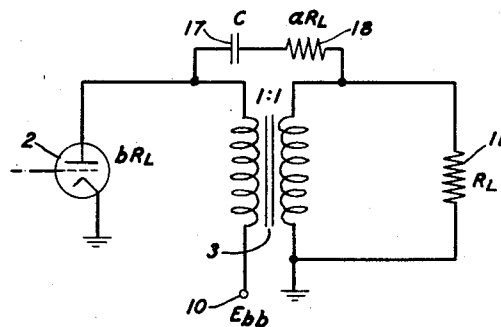
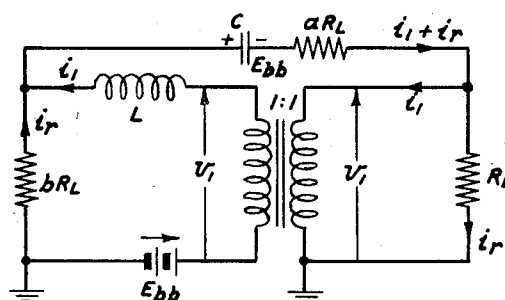


FIG. 3



INVENTOR
BY A. D. HASLEY

George C. Ford
ATTORNEY

1

2,903,583

HARD TUBE MODULATOR PULSE
TRANSFORMER

Andrew D. Hasley, Basking Ridge, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Application December 24, 1956, Serial No. 630,415

3 Claims. (Cl. 250—27)

This invention relates to pulse generators of the type employing pulse transformers and more particularly to pulsers of the hard tube type which modulate radar transmitters employing magnetrons.

There are several advantages to be gained by coupling the output of a pulser to the load through a pulse transformer. Some of these advantages are, for example, matching source and load impedances for maximum power transfer and inverting the polarity of a pulse. A pulse transformer, however, introduces parasitic effects of leakage inductance and distributed capacitance into the circuit of the pulser. These parasitic effects influence the pulse shape and particularly the leading edge of the pulse by causing the rise time of the pulse to be greater than it would be if the pulser were directly connected to the load. A detailed explanation of these parasitic effects on pulse shape is described in Radiation Laboratory Series, Pulse Generators, volume 5, chapter 14, section 1, pages 563 to 575.

Heretofore, the parasitic effects of the pulse transformer were principally eliminated by employing special windings which were closely coupled and utilized relatively few turns. A thorough treatment of the pertinent design procedures is also given in Radiation Laboratory Series, Pulse Generators, volume 5, chapter 13. It is readily apparent, however, that as the load voltage requirements increase considerable care and ingenuity are required in using the present design techniques to prevent insulation breakdown from occurring due to the close coupling of the transformer windings. In short, at high load voltages the protection measures against insulation breakdown of the pulse transformer windings are inherently opposed to the design requirements for minimization of the pulse transformer's parasitic effects. Thus, the versatility of such a pulser is limited.

It is an object of the present invention to provide a pulse generator employing a pulse transformer which produces an output pulse rectangular in shape regardless of load voltage requirements.

It is a more particular object of the invention to eliminate or compensate for the parasitic effects of the pulse transformer included in the circuit of a hard tube pulser.

In accordance with a feature of the invention, a series resistor-capacitor circuit, each circuit element having a predetermined value, is properly connected in the circuit of the pulser so as to store and properly discharge energy over the pulse period to compensate for the parasitic effects of the transformer thereby enabling the pulser to produce an output pulse rectangular in shape.

In an illustrative embodiment of the invention a pulse transformer is intermittently connected across a source of direct current by a high-vacuum tube responsive to a source of unidirectional control pulses. A series resistor-capacitor circuit of predetermined values is connected between the primary and secondary windings so as to be charged to the source potential during the nonconducting state of the switching tube. The stored charge is uniquely supplied to the secondary of the transformer

2

when the high-vacuum tube switch is made conducting to compensate for the energy removed from the source by the parasitic effects of the transformer. Accordingly, the output pulse of the circuit appearing across the transformer secondary is rectangular in shape.

The invention will be more fully apprehended from the following detailed description taken in conjunction with the appended drawings in which:

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

Fig. 1A is a schematic circuit diagram of a second embodiment of the invention;

Fig. 2 is a simplified circuit diagram of the embodiment of Fig. 1; and

Fig. 3 shows an equivalent circuit giving an indication of the loop currents in the circuit of Fig. 2.

Referring to Fig. 1, a hard tube pulser including a pulse transformer is shown employing the principles of the invention. A source of unidirectional control pulses 1 is connected to the grid of a high-vacuum tube 2. The combination of source 1 and tube 2 operates as a switch in that the presence of a pulse causes the tube to be conductive and the absence of a pulse results in the tube being nonconductive.

A pulse transformer 3 having a 1:1 turns ratio is shown within the blocked out portion of Fig. 1. (Pulsers having transformers with turns ratios other than 1:1 are discussed hereinafter.) The transformer comprises windings 3-1, 3-2, and 3-3. The winding 3-1 is the transformer primary and is connected between terminals 4 and 5. Windings 3-2 and 3-3 form a bifilar secondary winding for use with magnetron devices as is well understood in the art. The ends of windings 3-2 and 3-3 are connected between terminals 6 and 7 and terminals 8 and 9, respectively.

The source of energy for the pulser is direct voltage source 10. The pulsing circuit is formed by connecting the negative side of source 10 to the cathode of tube 2, and grounding the connection; connecting the anode of tube 2 to terminal 4; and connecting the positive side of source 10 to terminal 5.

A source of alternating current 11 furnishes the heater current for a magnetron 12. Source 11 is connected to heater current for a magnetron 12 by way of windings 3-2 and 3-3. This is accomplished by connecting source 11 to terminals 7 and 9 through transformer 13; and, connecting the heater of magnetron 12 across terminals 6 and 8. Capacitors 14, 15 and 16 are placed across the heater circuit to enable pulse current appearing in windings 3-2 and 3-3 to divide without affecting the heater current. The anode of magnetron 12 is grounded to complete the secondary circuit of the pulser.

As shown in Fig. 1, a capacitor 17 and a resistor 18 are connected in series between the terminal 4 and the terminal 6. During each period between pulses there is stored in the capacitor energy which is delivered to the transformer on the initiation of the pulse period. The resistor causes this energy to be delivered in proper phase to compensate for the effects of the transformer leakage reactance. The values of the capacitor and resistor are most important to the proper performance of the pulser, as will be evident hereinafter. Accordingly, it appears logical at this point to explain the choice of values for these passive circuit elements.

We begin the explanation by indicating the simplified circuit shown in Fig. 2. An exact analysis of the circuit shown in Fig. 1 leads to impractically complicated results. The circuit of Fig. 2, however, represents a satisfactory approximation of the invention's circuit as evidenced by empirical results obtained therefrom.

Referring to Fig. 2, transformer 3 is indicated and is assumed to be ideal except for leakage inductance L.

3

Further, no energy is stored in the leakage inductance L prior to switching the battery into the primary circuit. The resistance of magnetron 11 or other load device is shown as R_L . The space path resistance of tube 2 is shown as bR_L , where b is a constant to be later determined. The tube resistance is assumed constant during the conducting period. Voltage source 10 is shown on Fig. 2 as E_{bb} . Capacitor 17, whose value is to be determined, is shown as C . The capacitor is assumed to be fully charged before switching. Resistor 18 is shown as aR_L , where a is a constant representing the ratio of R_L to the resistance of resistor 18.

The circuit of Fig. 2 appears as Fig. 3 after tube 2 is switched into the conducting state. The loop equations of the circuit written in differential form are:

$$v_1 - L \frac{di_1}{dt} + bR_L i_r = -E_{bb} \quad (1)$$

$$v_1 + aR_L i_1 + \frac{1}{C} \int_0^t i_1 dt + (a+b)R_L i_r + \frac{1}{C} \int_0^t i_r dt = -E_{bb} \quad (2)$$

subject to conditions:

$$\begin{aligned} (a) \quad & t > 0 \\ (b) \quad & i_1(0) = 0 \\ (c) \quad & i_r = \frac{v_1}{R_L} \end{aligned} \quad (3)$$

Substituting condition (c) into Equations 1 and 2 and rewriting produces the following:

$$(1+b)v_1 - L \frac{di_1}{dt} = -E_{bb} \quad (4)$$

$$(1+a+b)v_1 + \frac{1}{R_L C} \int_0^t v_1 dt + aR_L i_1 + \frac{1}{C} \int_0^t i_1 dt = -E_{bb} \quad (5)$$

Letting the Laplace transforms $\mathcal{L}(V_1) = V_1(s)$ and $\mathcal{L}(i_1) = I_1(s)$, then:

$$(1+b)V_1(s) - LsI_1(s) = -\frac{E_{bb}}{s} \quad (6)$$

$$\left(1+a+b+\frac{1}{R_L C s}\right)V_1(s) + \left(aR_L + \frac{1}{C s}\right)I_1(s) = -\frac{E_{bb}}{s} \quad (7)$$

Solving for $V_1(s)$

$$V_1(s) = -\frac{E_{bb}}{(1+a+b)} \frac{\left[s^2 + \frac{aR_L}{L}s + \frac{1}{LC}\right]}{s \left[s^2 + \frac{L}{R_L} + (1+b)aR_L C\right] - s + \frac{(1+b)}{(1+a+b)LC}} \quad (8)$$

For the output voltage v_1 to be constant the coefficients of like powers of s in the quadratics appearing in the numerator and denominator of Equation 8 must be equal. It may be readily shown that this condition cannot be met exactly. If it is assumed that $b=a$ and that $b \ll 1$ and $(a+b) \ll 1$, it may be met approximately. Thus,

$$\frac{1+b}{(1+a+b)LC} \approx \frac{1}{LC} \quad (9)$$

and

$$\frac{aR_L}{L} = \frac{L}{(1+2a)LC} \quad (10)$$

where

$$C = \frac{L}{(aR_L)^2} \quad (11)$$

Since $a=b$, then

$$C = \frac{L}{(bR_L)^2} \quad (12)$$

4

In designing the pulser the first step is the selection of high-vacuum tube 2. It will be remembered that the tube resistance is bR_L where $b \ll 1$. Accordingly, a tube is selected having a resistance much less than the load resistance. As an example, a high-vacuum tube having a space path resistance of 50 ohms should be employed with a magnetron having an effective load resistance of 1200 ohms. The value of resistor 18 should also be 50 ohms since, as indicated above, $aR_L = bR_L$. The value of capacitor 17 is obtained by estimating or measuring the leakage inductance of transformer 3 and substituting this value and the tube resistance value into Equation 12. These chosen values of resistor 18 and capacitor 17 enable the output pulses of the circuit shown in Fig. 1 to be rectangular in shape in accordance with the mathematical proof outlined above.

Returning to Fig. 1, the operation of the invention will be described in detail. In one condition of the pulser, tube 2 is nonconducting due to the absence of a pulse from source 1. During this period capacitor 17 is in series with source 10 and charges to the potential of the source. The heater of magnetron 11 is energized from source 11, but no pulse energy is received from transformer 3 since winding 3-1 is disconnected from source 10.

In the next condition of the pulser, tube 2 is made conductive by the appearance of a pulse from source 1. As a consequence, source 10 is connected across winding 3-1 and current flow commences in the primary circuit of the pulser. Since magnetron 11 is a biased diode type of device, there is no load current flowing until the voltage across the primary and secondary of transformer 3 exceeds the equivalent bias voltage of the magnetron. Ordinarily, the buildup of the source voltage across magnetron 12 is less than the buildup of the voltage across winding 3-1 due to the fact that a portion of the source current reflected into windings 3-2 and 3-3 is diverted by the leakage inductance and distributed capacitance of transformer 3. However, the present invention enables the voltage across the magnetron to rise as fast as the voltage across winding 3-1 as explained hereinbelow.

The conduction on the part of tube 2 connects capacitor 17 and resistor 18, to ground (through space path of tube) and therefore in parallel with windings 3-2 and 3-3. Hence, the voltage across capacitor 17, which is the same as that of source 10, is applied across windings 3-2 and 3-3, and, in contrast to conventional pulser, the equivalent bias of magnetron 12 is overcome without delay when tube 2 is made conducting. Load current commences to flow in the secondary of transformer and capacitor 17 supplies the current difference between primary and secondary windings temporarily lost to the parasitic effects of the transformer. It is obvious that the values of capacitor 17 and resistor 18 are most important to the proper performance of the pulser since energy delivered by capacitor 17 which is more or less than the requirements of the leakage inductance, etc. will alter the desired pulse shape. However, as the result of the design considerations outlined above, the relative values of the capacitor and resistor are chosen to control the flow of energy from capacitor 17 in such phase as to compensate for the energy diverted to the transformer's parasitic elements.

After the parasitic effects of the transformer have been compensated, capacitor 17 is recharged by source 10 so that when tube 2 is made nonconducting the capacitor is essentially fully charged and ready for the next switching operation. During this charging period capacitor 17 acts to maintain the top of the pulse essentially flat by absorbing energy in excess of the pulse requirements or supplying energy when the pulse energy is insufficient.

Fig. 1A shows another embodiment of the invention where the turns ratio of transformer 3 is other than 1:1. However, as shown in Fig. 1, the resistor-capacitor circuit is connected to the secondary of transformer 3 so that the lower portion of the secondary winding has the same

number of turns as the primary of transformer 3. In the event that the resistor-capacitor circuit was connected to some other point on the secondary winding, it would produce more complicated formulae for determining the values of the elements of the resistor-capacitor circuit. Hence, the 1:1 tap on the secondary is arbitrarily selected for reasons of convenience.

In Fig. 1A the arrangement of the secondary windings produces autotransformer action with windings 3-2 and 3-3 forming the primary and windings 3-4 and 3-5 forming the secondaries of the autotransformer, respectively. The voltage buildup across the autotransformers will be degraded from the ideal condition due to the parasitic effects of the autotransformer. However, it is evident that there is better coupling between the sections of the autotransformer windings than between the primary and the whole secondary winding of transformer 3. Thus the circuit of Fig. 1A operates the same as Fig. 1 except that it produces voltage step-up of the pulse with some parasitic effects. Coupling the autotransformer winding as closely as possible substantially eliminates these parasitic effects.

It will be evident from the foregoing that the series resistor-capacitor circuit is relatively simple to select and install on a transformer included in the circuit of a pulser. The improvement in pulse shape obtained therefrom also enables the pulser to be operated at faster pulse repetition rate than for pulser without the modification since the voltage buildup across the load device is faster than that for prior art devices.

The series resistor-capacitor circuit is also applicable to low voltage transformers as well as in the case of the described high voltage applications. Thus, the invention in its broad application offers convenient means for effecting a number of desirable improvements in the characteristics of all pulsing circuits employing transformers.

It is to be understood that the above-described arrangements are merely illustrative of the principles of the invention, and applicant does not intend to limit the invention of the particular embodiments shown herein. Numerous other embodiments may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A pulse generator comprising a pulse transformer having primary and secondary windings, said primary having first and second terminals, a circuit including a capacitor and a resistor connected between the first ter-

minal and the secondary, an output circuit connected across said secondary, a source of direct current, and switching means operable intermittently for simultaneously connecting said capacitor and resistor circuit across the secondary and said source between the first and second terminals, the resistance of the switching means in its closed condition being bR_L , where R_L is the resistance of a load connected across the output circuit and b is a constant subsequently less than one, the capacitor having a value of the transformer's leakage inductance divided by the square of bR_L and the resistor having a value of bR_L .

2. A pulse generator comprising a pulse transformer having primary and secondary windings, said primary having first and second terminals, said secondary being tapped at a point corresponding to the number of turns on the primary, an output circuit having one side at ground potential being connected across the secondary, a source of direct current connected between ground and the second terminal, a circuit including a capacitor and resistor connected between the first terminal and the secondary tap, and switching means operable intermittently connected between ground and the first terminal.

3. A pulse generator comprising a pulse transformer having primary and secondary windings with a leakage inductance L , a load circuit of resistance R_L connected to said secondary winding, a source of direct current having one terminal connected to a first terminal of said primary winding and a second terminal connected to a point of voltage common to one terminal of said secondary winding, a vacuum tube switching device having a space path resistance in the conducting condition of bR_L , where b is a constant substantially less than unity, and connected between said second terminal of said source of direct current and a second terminal of said primary winding, means for intermittently rendering said switching device conductive to produce pulses in said secondary winding and in said load circuit during the conductive periods, and a capacitor of capacitance C divided by the square of bR_L and a resistor of resistance bR_L connected in series between said second terminals of said primary and secondary windings.

References Cited in the file of this patent

UNITED STATES PATENTS

2,412,345	Lindenblad	Dec. 10, 1946
2,579,542	Bostik	Dec. 25, 1951