A New Pulse Generator Using a Saturable-Core Transformer and a Switching Transistor

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The performance of a large portion of electric equipment, such as logit, counting and relay equipment, relies on dependable pulse generators. Many counting systems require fast-responding, compact and economic pulse generators along with the demand for reliability. The saturable magnetic circuit combined with transistor promises good solutions for these control requirements.[1]

Small, efficient convertors and invertors without no moving parts can be constructed using transistors to switch the d.c. to a saturable-core transformer.[2,3,4] This paper describes a magnetic-transistor pulse generator that

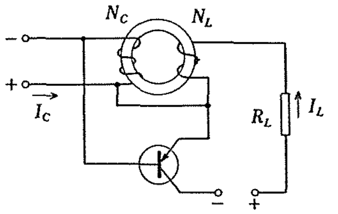

Fig. 1. Circuit of magnetic-transistor pulse generator using saturable current transformer and switching transistor.

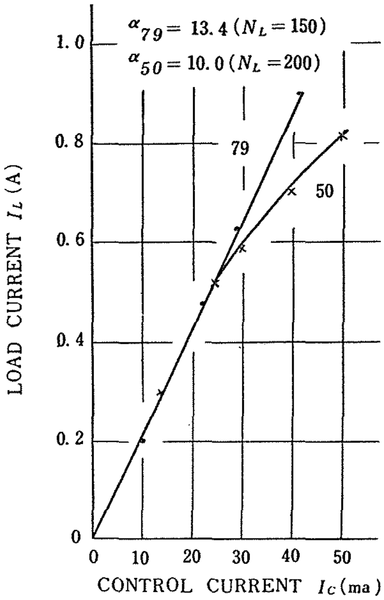

Fig. 2. Transfer characteristics of circuit of Fig. 1. α is the winding ratio of the saturable core.

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uses a saturable current transformer and a switching transistor, see Fig. 1. The saturable transformer transistor circuit is an oscillator, which is similar to that described in refernce 5, except that a saturable crrent transformer is replaced by the saturable voltage transformer. The characteristic frequency of the oscillator of Fig. 1 is controlled by a direct current in a winding of the saturable transformer, and the load current I_L is controlled, as shown in the transfer characteristics of Fig. 2. This paper describes methods of controlling the magnetic-transistor pulse generator by a direct current and a variable resistor such as thermistor.

Principle of Operation

Basically, the magnetic-transistor pulse generator operates as a chopper similar to the operation of the switch chopper. In the circuit of the switch chopper, the length of time while the switch is closed remains approximately constant, while the length of time it is open is varied. The shorter the time it is open, the greater the load power becomes, while the longer the time it is open, the smaller the load power becomes. The circuit of Fig. 3 oscillates and opens and closes the load similar to the switch chopper. The load current I_L wave shapes provided by the magnetic-transistor pulse generator are shown in Fig. 4 (A), (B) and (C).

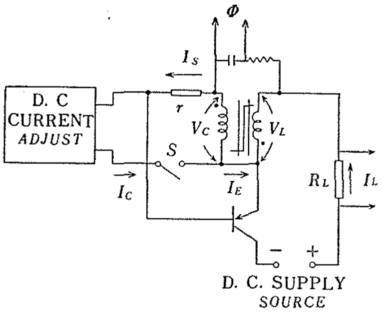


Fig. 3. Measurement circuit of magnetic-transistor pulse generator.

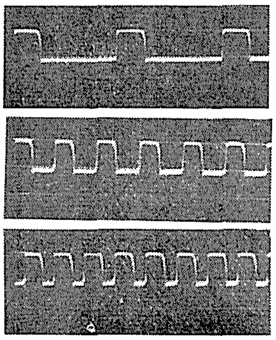
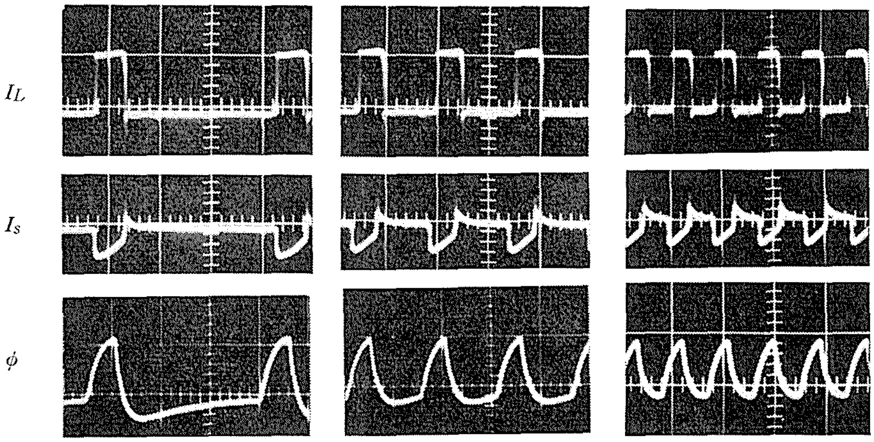


Fig. 4. Load current wave shapes of circuit of Fig. 3. (A) I_L at minimum output. (B) I_L at one-half maximum output. (C) I_L at maximum output.

Consider the operation of the circuit of Fig. 3. When the switch S in the control circuit is closed, the control current I_c is divided into bias current I_e and secondary current I_S. Starting with the transformer core at negative saturation, the application of transistor bias supplied by I_e permits a small amount of load current I_L to flow through the primary of the current transformer, producing voltage V_L.

The control volage V_c is applied to the transistor bias voltage in a regenerative manner and forces the transistor to "snap full on". The transistor remains full on during the flux density excursion from negative saturation to positive saturation. At the point of positive saturation, the saturable current transformer saturates. The contorl voltage now drops to $V_c=0$, and the transistor turns almost off, decreasing the load current I_L in the primary winding. As current I_L decreases, voltage V_c is induced negative forcing the transistor to snap off ($I_L=0$). With the transistor turned off, the load current I_L and the transistor base current are negligible. The control current I_c forces the transistor to be held off by negative voltage V_c until the saturable current transformer core reaches negative saturation. After negative saturation, the secondary voltage drops to $V_c=0$ and the transistor bias partially turns on the transistor sufficiently for the regenerative action of the current transformer to force the transistor to snap on the oscillation continuing. The distributed capacitance in the current transformer winding helps the circuit to snap on and snap off in the manner of the saturable voltage transformer.[5]

The wave shapes of the load current I_L, secondary current I_s and magnetic flux ϕ in the magnetic-transistor pulse generator are shown in Fig. 5.



I_c = 10ma I_c = 20 ma I_c = 40 ma

Fig. 5. The Wave shapes of load current I_L, secondary current I_c and magnetic flux ϕ of the magnetic-transistor pulse generator in Fig. 3.
〔Time scale=1 (ms/cm).〕

The time the transistor is turned on remains constant as long as the saturable current transformer core maintains the full excursion from negative to positive saturation. During the transistor is turned on, the saturable transformer by the primary current (I_L) and the secondary voltage is set by the secondary current and the secondary circuit resistance. The time the transistor is turned on is determined by

$$\tau = N_c \frac{\Delta\phi}{V_c}, \tag{1}$$

where N_c is the number of turns on the secondary of the saturable transformer and $\Delta\phi$ the flux excursion of the transformer core.

The turns N_c and flux excursion $\Delta\phi$ are design parameters of the saturable transformer. The secondary voltage V_c is a function of design parameters of the saturable transformer, the secondary circuit components, the power source voltage and load resistance.

$$V_c = \frac{N_c}{N_L} V_L = \alpha(E_L - V_{tr} - R_L I_L). \tag{2}$$

The flux excursion $\Delta\phi$ is

$$\Delta\phi = \frac{s\mu}{l}\left[\Delta N_L I_L - \Delta N_c I_c\right]. \tag{3}$$

Substituting eqs. (2) and (3) into eq. (1), we obtain

$$\tau = N_L \frac{s\mu}{l}\left[\frac{\Delta N_L I_L - \Delta N_c I_c}{E_L - V_{tr} - R_L I_L}\right], \tag{4}$$

where s, l and μ are the core cross-section, the magnetic path length and the permeability of the saturable transformer corerespectively. V_{tr} is the voltage drop in the switching transistor.

Load Characteristics

The use of a high permeability material with a rectangular loop characteristics such as 79 permalloy is recommended to promote rapid switching. Fig. 6 (A) shows typical load current I_L depending on load resistance (R_L), and presents a comparison of the load characteristics of 79 and 50 permalloys. Since the output can be connected in series with load resistance, the current I_L of magnetic-trnasistor pulse genetator decreases exponentially, and advantage is claimed for the current transformer core with high permeability. The effect of winding ratio $\alpha = (N_c/N_L)$ is shown in Fig. 6 (B). The poorer the winding ratio of saturable core is, the greater the distortion of the load current wave shape becomes. Designs are largely based on the core material and winding machines available.

The load current I_L and repeating period T of the magnetic-transistor pulse generator vary by the applied voltage E_L of load circuit (see Fig. 7). The transistor, however, has the rating and the specified heating dissipation, so that the most favourable applied voltage E_L is obtained by experiments. Fig. 8 shows the characteristics of the frequency ($f = 1/T$) dependence the control current I_c.

The characteristic frequency, dependence load resistance R_L, has the linearity by controlling current, then exceeding any limit and each curve decreases.

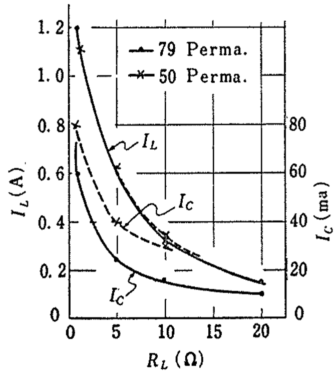


Fig. 6 (**A**). Load characteristics.

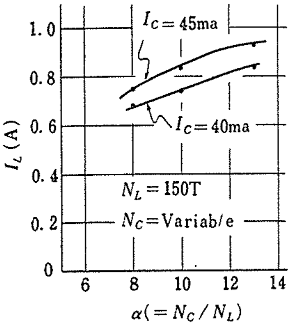


Fig. 6 (**B**). Load current I_L dependence the winding ratio α.

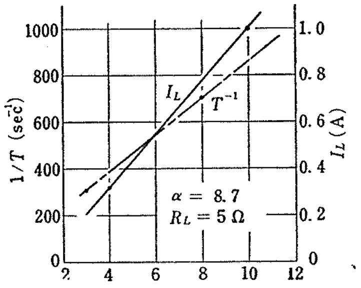


Fig. 7. Characteristic frequency $1/T$ and load current (I_L) depenence applied primary voltage (E_L).

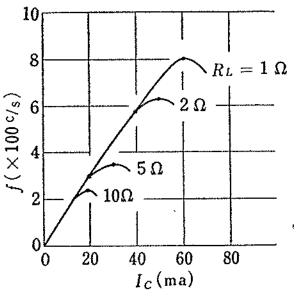


Fig. 8. The curves of characteristic frequency (f) controlled by the current (I_C).

Thermistor Control

The magnetic-transistor pulse generator can be controlled by temperature. The pulse generator circuit for thermistor control is shown in Fig. 9 (A). Fig. 9 (A) is the same as Fig. 3 except that an arm of the control bridge circuit is replaced by a thermistor. Fig. 9 (B) shows the characteristics of the resistance of thermistor, the load current I_L and control current I_c of the magnetic-transistor pulse generator depend on temperature. It has been shown in Fig. 9 (B) that the thermistor has the resistance $R_t = 100$ ohms at the temperature of 20°C, since the control bridge circuit maintains the balance in during this time, the magnetic-transistor pulse generator does not oscillate. Therefore, the primary circuit does not permit the load current to flow through. As the temperature of the thermistor increases and the resistance of thermistor decreases, control current I_c increases. The magnetic-transistor pulse generator begins to operate at 30°C ($R_t = 77$ ohms) and the thermistor resistance becomes $R_t =$ 15 ohms at 120°C. According to the change in the thermistor resistance, load current I_L increases from initial value 0 to 550 ma. The frequency characteristics of the magnetic-tansistor pulse generator are shown in Fig. 9 (C).

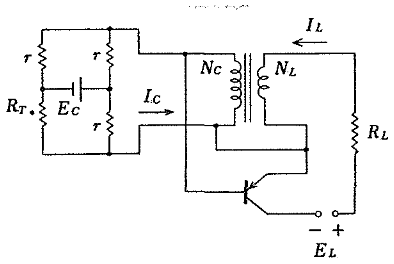


Fig. 9 (**A**). Circuit of thermistor control.

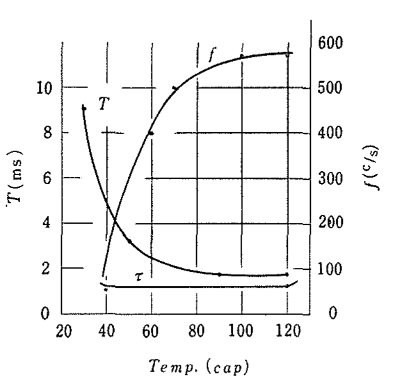


Fig. 9 (**B**). Temperature control of magnetic-transistor pulse generator.

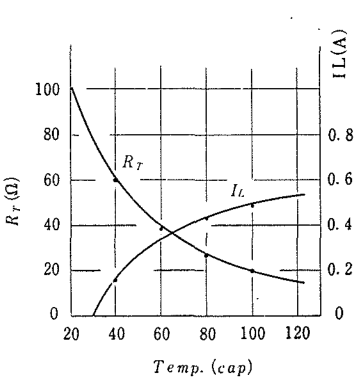


Fig. 9 (**C**). Frequency characteristics of the pulse generator.

Conclusions

The principle of using a combination oscillator and amplifier provides reliable, compact, fast-responding and economical pulse generators. Operating at characteristic frequncies between 0.1 and 2 kc permits the use of compact economical components for controlling power. The power dissipated in the saturable current transformer and the transistor used in the magnetic-transistor pulse generator are exceedingly small proving a high efficient economical amplifier.

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