A Study on a High Frequency Application of Thyristor

Kazuo KUBOTA* and Sumio SHIRAKAWA**

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1. Synopsis

Static switches utilizing thyristor capable of switching at high frequency are described. A brief summary of the experimental operation of the device is included, followed by an analysis of the static switches. Design procedures and graphs are developed that make possible the design of such static switches based upon design criteria.

2. Introduction

Thyristor is a new semiconductor product developed in the field of solid state electronics, and owing to its many excellent features, nowadays being utilized so widely that it has got an important situation in the industrial field. However, at present the effort for utilization of the thyristor is directed mainly only to its power control function. Accordingly, present paper discusses the method of producing pulses by utilizing the thyristor, based on the consideration that the thyristor may be applicable to the field of electronic devices. In static switching applications, the bistable characteristics of the thyristor and its wide range of voltage and current capabilities make it particularly suitable among semiconductor device for this use.

3. General operation

The thyristor is a latching device and, once triggered into conduction, it will remain in its low impedance forward conducting stable as long as anode current is maintained above the holding current. So the normal design problems are: (1) Trigger circuit for thyristor
(2) Turn off circuit
(3) Flip-Flop type d-c switching circuit.

By a proper combination of these circuits proportioning control of the pulse output is possible, as well as on-off switching.

* Assistant of communication Engineering, Faculty of Engineering, Shinshu University, Nagano, Japan.
** Professor of Communication Engineering, Faculty of Engineering, Shinshu University, Nagano, Japan.

The block diagram shown in Fig. 1.

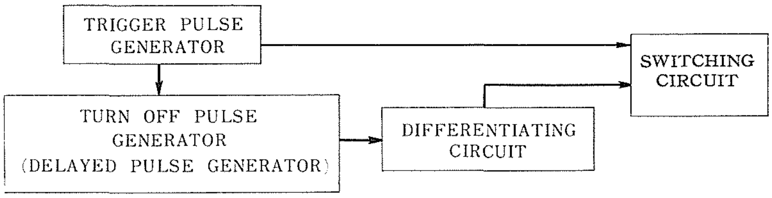

Fig. 1. Block diagram of static switching circuit.

Trigger circuit. Because of its unique combination of economy, simplicity and high effective power gain, the unijunction transistor (UJT) has been adapted for triggering applications. The UJT is functionally a unilateral voltage ratio activated device. The static emitter input characteristic of a typical UJT is shown in Fig. 2.

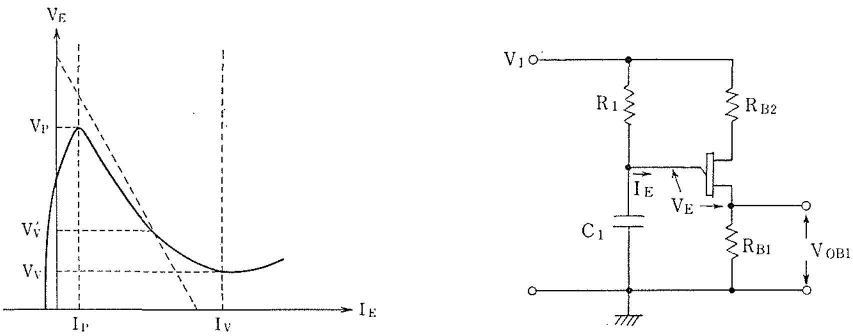

Fig. 2. (a) UJT static emitter characteristics.

(b) UJT relaxation oscillator thyristor trigger circuit.

To produce oscillation the value of R_1 must fall within bounds determined by the emitter peak point current I_p and valley point current I_v. Also the resistance of R_1 must be sufficiently low to permit a current flow which is greater than the peak point current I_p but the upper value of R_1 must be sufficiently high to ensure that the load line of this resistor drawn from the supply voltage V_1 to current axis I_E, intersects the emitter current curve in the negative resistance region between the peak and valley points. The circuit is regenerative by means of charging and discharging of capacitor C_1. The period T of the desired output pulse repetition rate can be determined from

$$T = 2.3\, R_1\, C_1\, log_{10}\left(\frac{1}{1-\eta}\right) \tag{1}$$

Turn-off pulse generator. Turn-off action for thyristor is effected by a certain amount of suitable reduction of anode current a sufficient period of time. For this reason, all practical thyristor circuit must incorporate provisions to effect anode turn-off by means of auxiliary circuit interruption, circuit reversal of current, reverse-biasing of the anode for a sufficient period of time or by diverting anode current. In practice to turn on TH_2 and to turn-off TH_1, a monostable diode multivibrator shows in Fig. 3 is used.

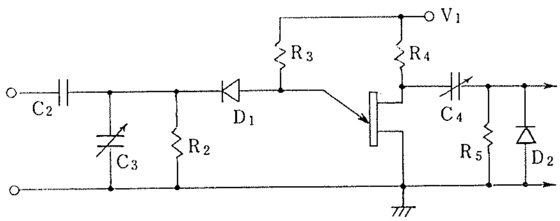

Fig. 3. Monostable diode multivibrator

This is a very simple monostable circuit which is made possible by the use of UJT. A useful application of this monostable circuit is in the production of delayed pulses. If the output of a monostable circuit is applied to an R-C differentiating circuit the output of the differentiator consists of a short pulse initiated by the leading edge of the pulse generated by the monostable circuit and a second short pulse of opposite polarity initiated by the falling edge. The delay between the second pulse and the triggering pulse applied to the monostable circuit can be adjusted by changing the length of the pulse generated by the monostable circuit. The pulse length varies linearly with the capacitance C_3.

Switching circuit. To switch off a direct current it is necessary to reduce the thyristor current to a value below its holding value so that it can assume its blocking state.

Various methods have been devised to do this, most of them involving charging or discharging a capacitor, since it may be regarded as a load or source of practically zero resistance at the time of switching. One simple circuit is shown in Fig. 4.

Suppose TH_1 is conducting at time t as shown in Fig. 4 (b). The polarity of the potential across the capacitor is shown in Fig. 4 (a); if TH_2 is switched on a little later, the positive terminal of the capacitor is connected to earth, making the anode of TH_1 instantaneously $-V$ volts relattive to earth.

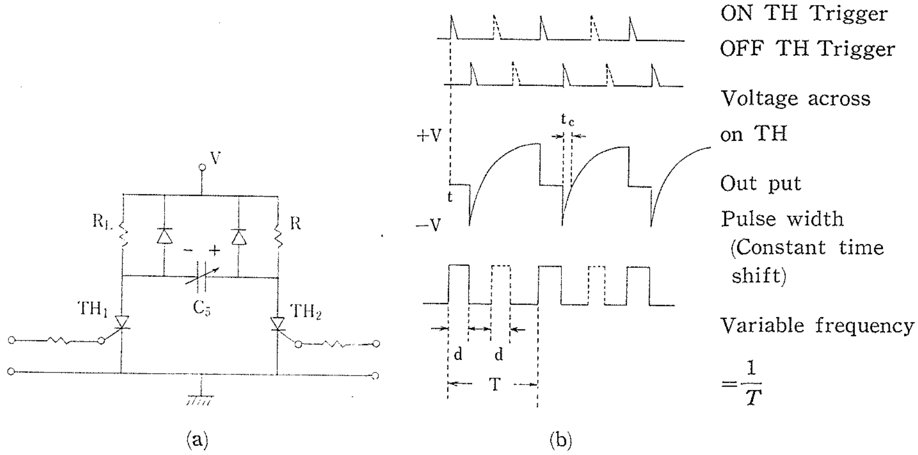

Fig. 4. Thyristor (TH) turn-off and turn-on intervals (a) general circuit, (b) output waveform.

This thyristor is now reverse bissed, and provided forward current does not flow for a time equal to the turn-off time of the device, the thyristor will assume its forward blocking condition. To switch the load current on, a trigger is applied to the gate of TH_1 which turns TH_2 off by the process outlined above. Thus a train of positive pulses applied simultaneously to the gates of the thyristors causes them to switch on and off alternately.

4. Design procedure and experimental results.

UJT relaxation oscillator thyristor trigger circuit : Necessary condition required for oscillation

$$\frac{V_1-V_P}{R_1}>I_P \tag{2}$$

$$\frac{V_1-V_V}{R_1}<I_V \tag{3}$$

$$R_{B2}\simeq\frac{0.7\ R_{BB}}{\eta\cdot V_1}+\frac{(1-\eta)\,R_{B1}}{\eta} \tag{4}$$

The trigger pulse of amplitude may be directly, capacitively, or transformer coupled to the thyristor gate.

In the latter case, the primary of a pulse transformer may be substituted for R_{B1}. Making $R_{B1}=0$ and placing the pulse transformer primary in series with capacitor C_1 eliminates the small d-c component of current in its primary. This component is otherwise given by

$$I_{d\text{-}c} \approx \frac{V}{R_{B2}+R_{BB}+R_X} \tag{5}$$

where R_{BB} = minimum specified interbase resistance of UJT.

R_X = equivalent d-c resistance of transformer.

When V_{0B1} is directly coupled to the TH gate, care must be taken that $I_{d\text{-}c}$ does not prebias the TH gate to turn on. This can be avoided if R_{B1} is selected on the bias of voltage dividing action so that

$$R_{B1} < \frac{R_{BB_{min}} + R_{B2}}{\dfrac{V_1}{V_{GT_{max}}} - 1} \tag{6}$$

where $V_{GT_{max}}$ = maximum gate voltage at specified temperature at which TH will not trigger.

V_1 = UJT supply voltage

The trigger circuit oscillation characteristics shown in Fig. 5.

Delay circuit. UJT diode multivibrator may be made monostable if

$$\frac{R_2 V_1}{R_2 + R_3} < V_P \tag{7}$$

and

$$\frac{V_1}{R_3} < I_V \tag{8}$$

Eq. (7) fixes the stable operating point of the UJT in the cut-off region and (8) insures that this is the only stable operating point. If (7) and (8) are satisfied, a positive pulse will trigger the UJT from the OFF state to the ON state. The UJT will then remain conductive until the capacitor discharges through R_2. when the diode reverses at the end of the capacitor discharge cycle, the UJT becomes nonconductive. But since it is stable in cut-off state, the circuit remains stable until the next positive trigger pulse is applied. Thus, the regenerated output waveform duration is

$$t_d = -R_2 C_3 \ 1n \frac{V'_V}{V_P} \tag{9}$$

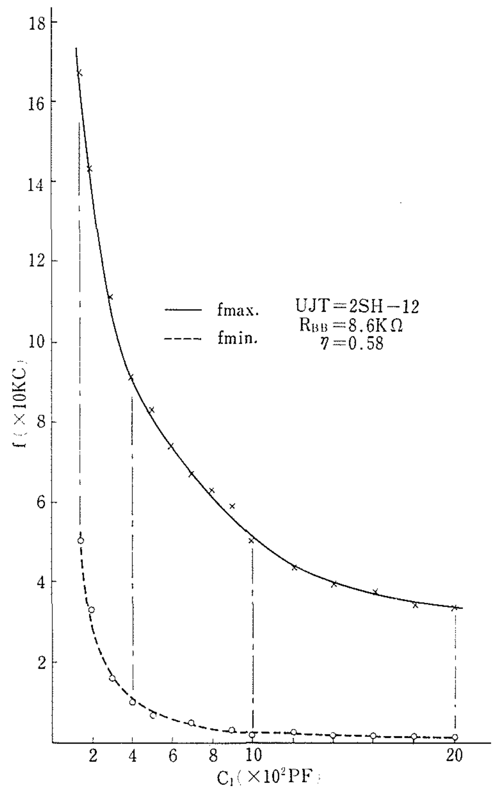

Fig. 5. Trigger pulse generator characteristics.

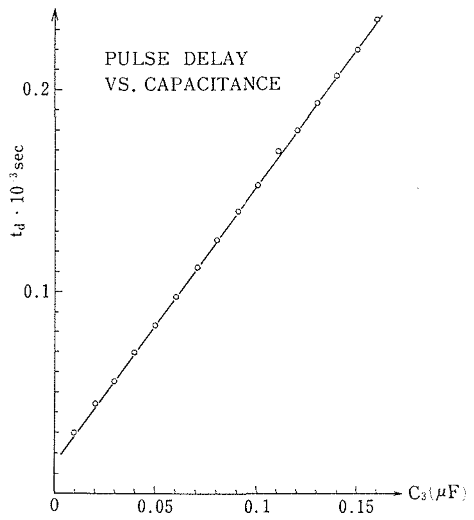

Fig. 6. Experimental delayed pulse generator characteristics

And minimum spacing of the trigger pulses is limited by the circuit's time constants. In Fig. 3, R_5 and C_4 are used as a simple differentiating network and diode D_2 filters out the pulses of unwanted polarity. Experimental delayed pulse generator characteristics shown in Fig. 6, has been built with components $UJT = 2SH-13$, $R_2 = 1.8K\Omega$, $R_3 = 6K\Omega$ $R_4 = 8K\Omega$ and $D_1 = SD34$.

The supply voltage is $20V$ which shows that the theoretical and practi cal results agree reasonably well.

Switching circuit. To turn the thyristor off by static means in a *d-c* system requires an external commutating means, as described formerly. The required size of commutating capacitor C_5 for resistive loads can be determined by analyzing the switching interval just after TH_2 is triggered. Just before TH_2 is triggered, capacitor C_5 is charged to V. If TH_2 is triggered at time $t=0$, and we then consider the discharge current i through C_5 and load R_L,

$$V = \frac{1}{C_5}\int_0^t i\,dt + iR_L$$

Solving for i, we have

$$i = \frac{2V}{R_L} exp - t/R_L C_5 \tag{10}$$

The voltage V_C across capacitor C_5, which is also the voltage across TH_1 when TH_2 is conducting, is

$$V_C = -V + \frac{1}{C_5}\int_0^t i\,dt$$

so

$$V_C = V[1 - 2exp(-t/R^L C_5) \tag{11}$$

Turn-off time t_C is the interval between $t=0$ and the instant when $V_C=0$ or

$$0 = V[1 - 2exp(-t_C/R_L C_5)]$$

solving for t_C, we get

$$t_C = 0.69 R_L C_5$$

Since $R_L = V/I$ (the maximum load current), the minimum required commutating capacitor C_5 is

$$C_5 \geq \frac{1.45tI}{V}(\mu F) \tag{12}$$

Conversely, the turn-off time is

$$t = \frac{C_5 V}{1.45 I} \tag{13}$$

A circuit giving a frequency range between 5.0 KC and 12.8 KC shown in Fig. 4 has been built with components $R_L = 20\ K\Omega$, $R = 10\ K\Omega + 50\ K\Omega$ variable, $C_4 = 0.005\ \mu F$ and $TH = 2SF - 101$. The supply voltage is 12 V and a plot of variation of frequency with C_5 is shown in Fig. 7.

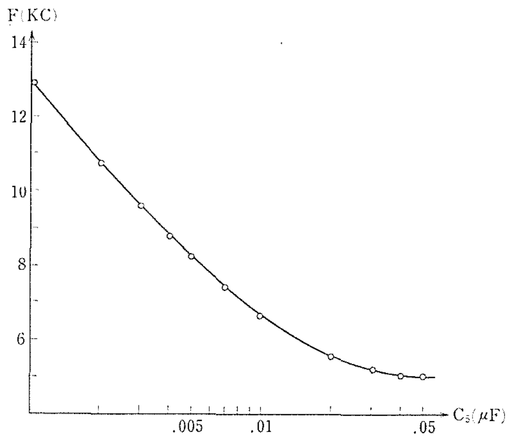

Fig. 7. Variation of output frequency with capacitor C

5. Conclusion

The basic principle and its experimental results of SWITCHING utilizing the thyristor are described here.

For the current inversion through the thyristor, it requires a certain restoration time, owing to which the switching frequency will be limited. From equations (13) it is evident that the circuit turn-off time is a direct function of the load current.

The commutating capacitor C_5 must be selected for the heaviest load that will ever be commutated consistent with the turn-off time requirements of the thyristor. Also, the larger the commutating capacitor the better the output waveforms, but the capacitance of it should preferably be chosen as well as possible within the extent of possible current inversion.

REFERENCES

1) I. A. Lesk and V. P. Mathis, The Double Base Diode A New Semiconductor Device, Convention Record of the I. R. E., Part 6, March, pp. 28 (1953).
2) S. R. Brown, T. P. Sylvan: The Silicon Unijunction Transistor, Electronic Design, pp. 56 59 (Jan. 8, 1958).
3) V. Joyce and Clarke. Transistor Circuit Analysis. Addison Wesley, (1961).
4) Semiconductor Hand Book. Toshiba, 1962.