Two-threshold ON/OFF thyristors, switchable by the input signal level

M.A. SHUSTOV
Tomsk polytechnical university, RUSSIA, shustov@tpu.ru
https://www.famous-scientists.ru/14268/

Abstract: - A description is given of a new class of bistable elements - two-threshold thyristors, switching On/Off from one state to another occurs when control voltages of two levels ("High" or "Low") other than zero are applied to the input of the thyristor.

Key-Words: - Thyristor, bistable element, switching threshold, High (H) and Low (L) switching levels, LH-thyristor, HL-thyristor.

1 Introduction

In 1955, American scientists in the field of solid-state physics from Bell Telephone Laboratories Morris Tanenbaum (1928–), James/Jim M. Goldey (1926-2017) and Nick Holonyak (1928–) published an article describing the design of a four-layer p-n-p-n semiconductor device - thyristor, Silicon Controlled Rectifier (SCR).

In 1956, the silicon semiconductor structure p-n-p-n (SCR) was created at Bell Telephone Laboratories, on the basis of which Robert Noel Hall (1919-2016) and Frank William (Bill) Gutzwiller (1926-2011), researchers at the General Electric electrotechnical concern, developed the first controlled silicon rectifiers in 1957.

In 1981-1984, a team of German scientists from Munich (Leipold Ludwig; Jens P. Stengl; Jenii Tihanyi) solved the problem of low input resistance of thyristors (a thyristor was created, which is a combination of a MOSFET or field-effect transistor and a thyristor).

In 1984, American engineer Victor A. K. Temple from Harris Corporation proposed a variant of a powerful integrated MOS (MOSFET) thyristor - a combination of a MOSFET and a thyristor [1].

2 Problem Formulation

Conventional thyristors have a single unmanaged switching threshold. When this threshold is exceeded, the thyristors switch to the conducting state. The return of thyristors to the original ("Off") state is possible only by disconnecting the supply voltage or closing the electrodes anode-cathode of the thyristor [2-9].

In addition to the above, thyristors of early releases had a low input impedance, a high voltage drop on an open thyristor, low speed and a number of other disadvantages.

To increase the input resistance of the thyristor (see above [1]), it was proposed to combine the properties of a MOSFET and a thyristor.

To enable the thyristor to be switched on/off by applying an external control signal to its control electrode, a thyristor design was developed that has a pair of MOS-N and MOS-P transistors in the input circuits (MOS-controlled thyristor (MCT) - a voltage-controlled thyristor) [1]. Switching of such a thyristor occurs when a pulse of positive or negative polarity is applied to its input.

Obviously, the use of control signals of different polarities is not acceptable in practice.

3 Problem Solution

In order to realize the function of a two-threshold switching of a thyristor, it must have electronic elements having two different switching thresholds that are not equal to zero.

Below (Fig. 1-5) are the variants of the schemes of new On-Off two-threshold thyristors, switched from one state to another when voltage levels are applied to their inputs: Low and High (LH), or High and Low (HL).

Fig.1 shows an example of the practical implementation of a two-threshold bistable element (LH-thyristor) made on Q1–Q3 field-effect transistors and VS1 thyristor.

At the initial time (when the supply voltage is applied and there is no control voltage at the input), the thyristor VS1 is in a non-conducting state. Transistors Q1 and Q2 are closed, transistor Q3 is open. If you supply a control voltage to the input of the LH-thyristor, gradually increasing it (low-level voltage), then first the transistor Q1 opens, providing a voltage supply to the control electrode of the thyristor VS1. The thyristor opens, thereby connecting the load resistance to the power supply circuit.

When the voltage at the CE input increases further (high-level voltage) (Fig.1) transistor Q2 opens, shunting the control circuits of transistors Q1 and Q3. Both of these transistors are closed. Accordingly, the current in the VS1 thyristor circuit is interrupted, disabling this thyristor and the load resistance.

The threshold for switching on the LH-thyristor (Fig.1) is in the range from 3.9 to 4.8 V. The threshold for switching off exceeds 4.9 V.

The switching thresholds of the two-threshold thyristor can be adjusted by selecting the resistor ratings R4 and R5.

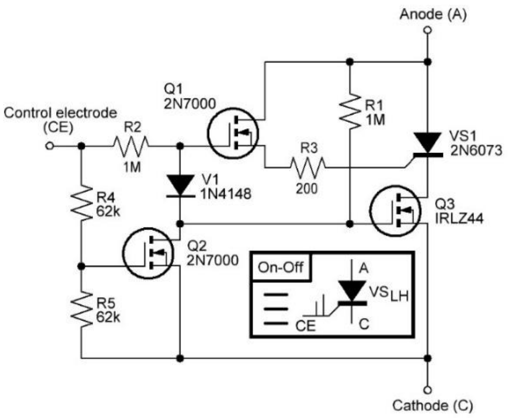

Fig.1: Electrical diagram of a two-threshold Low-High thyristor (LH-thyristor).

The HL-thyristor (Fig.2) also has two control thresholds. It contains an additional transistor cascade-inverter (transistor Q4 and resistor R5). The HL-thyristor goes into a conducting state if a high-level voltage is applied to the CE control electrode, and turns off if a low-level voltage is applied to this electrode.

The threshold value of the input voltage for switching on the HL-thyristor exceeds 3.9 V (Fig.2). The threshold of the shutdown voltage is in the range from 3.2 to 3.8 V.

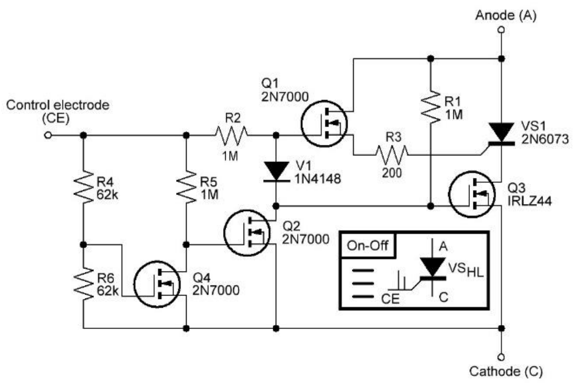

Fig.2: Electrical diagram of a two-threshold High-Low thyristor (HL-thyristor).

A two-threshold bistable switching element (LH-thyristor) made entirely on transistors - (Fig.3) combines the possibility of operation in a wide range of supply voltages (from 8 to 20 V) with a high load capacity provided by the Q1 2N7075 field-effect transistor or its analog.

The operating voltages range of the device can be set by selecting the nominal value of the resistor R1, as well as the type of transistors used.

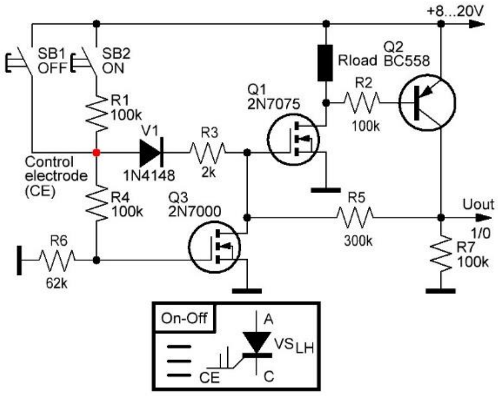

Fig.3: Electrical diagram of a two-threshold LH-thyristor, completely made on transistors, and the method of its control on a two-wire line.

The device works as follows. A control panel containing a power supply, two control buttons SB1 and SB2, as well as a resistor R1 is connected to a two-threshold bistable element by a communication line. When the SB2 (ON) button is briefly pressed, the voltage of the power supply of the control panel is applied to the input of the device through the resistor R1. The voltage supplied to the input of the device is divided by a resistive divider R1, R4, R6, so the voltage applied to the gate of the field-effect transistor Q3 is not enough to open it. Therefore, for this case, the field-effect transistor Q3 can be excluded from consideration.

At the same time, the voltage removed from the resistive divider (low voltage level) is sufficient to open transistors Q1 and Q2. The high-level voltage removed from the resistor R7 through the resistor R5 enters the gate of the transistor Q1. This transistor "blocks itself". The two-threshold bistable element remains in the "On" state.

To turn off the load, need to briefly press the SB1 (OFF) button. In this case, the voltage at the gate of the transistor Q3 exceeds its switching threshold (about 2.1 V). Transistor Q3 opens and shunts the gate of transistor Q1, in connection with which transistor Q1 unlocks and goes to the initial closed state. The Rload is disconnected from the power supply.

Fig.4 shows the scheme and method of controlling the operation of a two-threshold HL-thyristor.

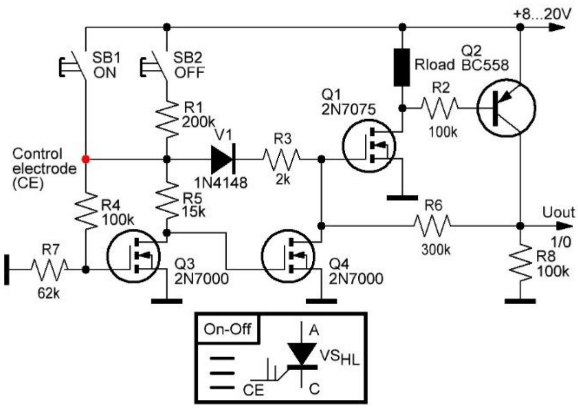

Fig.4: The electrical circuit of a two-threshold HL-thyristor, completely made on transistors.

Based on the devices discussed earlier, a two-anode MOSFET LH- or HL-thyristor with two-threshold control can be created (Fig.5). Such a thyristor has four pin outputs: A1, A2, CE and GND [8]. A two-anode LH- or HL-thyristor with two-threshold control is capable of operating on two loads, switching them in turn. If there is no need for a second load, a high-resistance resistor can be used instead.

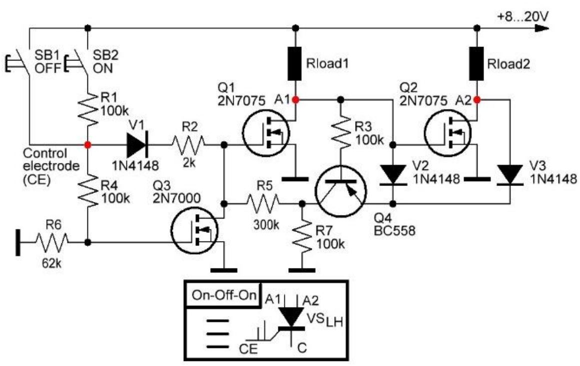

Fig.5: A two-anode MOSFET LH-thyristor with dual-threshold control.

Practical schemes for using two-threshold thyristors are shown in Fig.6-8. For Fig.6 shows load control schemes, such as the EL1 incandescent lamp, using the "On" and "Off" buttons. a unique feature of these schemes is that the load can be switched on and off over a two-wire line from several identical spaced control panels.

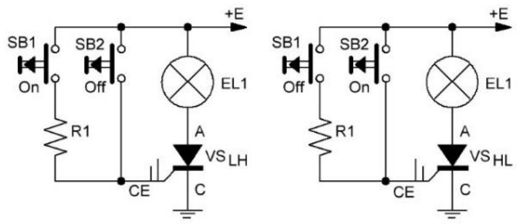

Fig.6: Examples of controlling the operation of two-threshold LH-thyristor (left) and HL-thyristor (right).

Fig.7 shows the possibility of using two-threshold LH- and HL-thyristors as conventional, single-threshold ones. In addition, parallel to the control electrode and the cathode of a two-threshold ristor a Zener diode can be connected in, to which a control voltage is applied through a resistor and a control button.

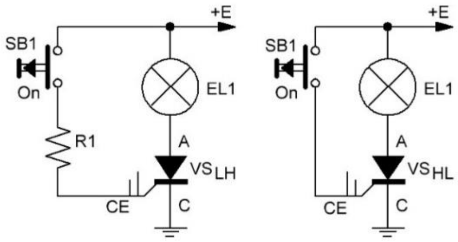

Fig.7: Using a two-threshold LH-thyristor as a classic single-threshold thyristor.

On the basis of two-threshold LH-thyristor, timers can be assembled (Fig.8). A unique feature of such a timer is that after closure the control key SB1, the load is connected after a certain time, determined by the charging speed of the capacitor C1 up the voltage of the first switching threshold. The load is switched off after the voltage on the capacitor C1 reaches the second switching threshold.

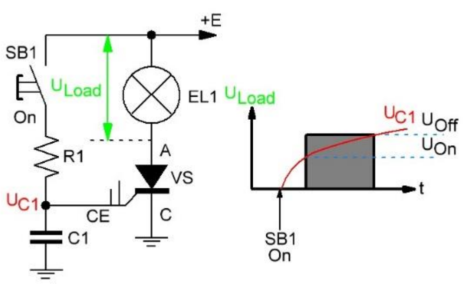

Fig.8: A Timer based on the LH-thyristor and the dynamics of electrical processes, illustrating its operation.

Fig.9 shows the dynamics of electrical processes at the inputs and outputs of the two-threshold LH-thyristor (left) and HL-thyristor (right) when a linearly increasing voltage is applied to the CE inputs.

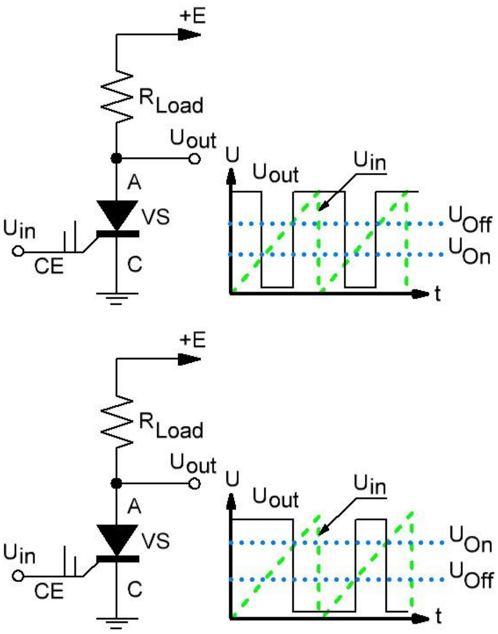

Fig.9: Dynamics of electrical processes when the input of two-threshold LH-thyristor (left) and HL-thyristor (right) is linearly increasing voltage Uin.

4 Conclusions

Let's list the main advantages of two-threshold LH- and HL-thyristors:

1. High input impedance (tens and hundreds of Ohms).
2. Increased operating frequency (tens of kHz).
3. Minimum open state resistance (tenths-hundredths of an Ohm).
4. Controlled switching on and off of the thyristor.
5. The ability to control (load on/ off) via a two-wire line.
6. The possibility of creating a two-anode thyristor with two-threshold control.
7. Extended possibility of synthesis of new electronic devices for various purposes.

Two-threshold LH- and HL-thyristor can be used in power electronics circuits, voltage control and auto-regulation, relay and switching circuits, electrical switches, pulse generators, frequency doublers, etc.

References:

[1] M.A. Shustov, *The history of electricity*, Moscow; Berlin: Direct-Media, 2019, 567 p.

[2] F. Mazda, *Power Electronics Handbook*, Third edition, Newnes, 1997, 448 p.

[3] M.S. Berde, *Thyristor Engineering (Power Electronics)*, Ninth Edition, New Delhi: Khanna Publishers, 2005, 739 p.

[4] M.H. Rashid, *Power Electronics Handbook*, 4th edition, Butterworth-Heinemann, 2017, 1510 p.

[5] M.A. Shustov, *Analogs of trinistors with field-effect transistors*, Radio (RU), 2016, No.12, P. 27.

[6] M.A. Shustov, *Push-button thyristor operation*, Electronics World, Vol.107, No.4(1780), 2001, P. 299.

[7] M.A. Shustov, A.M. Shustov, *Electronic Circuits for All*, London: Elektor International Media BV, 2017, 397 p. (England); *Elektronika za sve: Priručnik praktične elektronike*, Niš: Agencija EHO, 2017; 2018, 392 St. (Serbia).

[8] M.A. Shustov, A.M. Shustov, T. Giesberts, *Dual-Anode MOSFET Thyristor*, ElektorLabs, Vol.45, No.3(495), 2019, pp.15-19.

[9] M.A. Shustov. *Pseudo-thyristor*, Elektor, Vol.46, No.6(504), 2020, P. 32.