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SEMICONDUCTOR SWITCHING PRINCIPLES

Page

1. INTRODUCTION

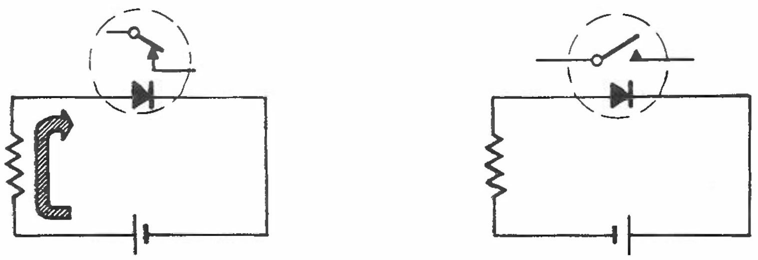
1.1 Solid-state switching circuits are used in every area of telecommunications. Typical applications range from simple one-diode or one-transistor switching circuits in relay sets, to complex integrated-circuit computer circuits in electronic switching centres. The functions provided by solid state switching circuits include timing, counting, computing, pulse generation, and the various types of logic.

1.2 Semiconductor switching circuits consist mainly of diodes, transistors, resistors, and capacitors. For many applications the circuits are available as integrated circuits (IC's) which contain all the necessary components sealed in the one package. When a switching circuit is made from discrete components, the semiconductor devices are usually high-speed 'switching' types, in contrast to those commonly used in audio amplifiers and other linear circuits. It is, therefore, important that care is taken to select the correct device when building or repairing discrete-component solid state switching circuits.

1.3 This paper introduces the principles of simple diode and transistor switching circuits. It also introduces the principles of some of the electronic logic circuits that are based on transistor switches.

2. DIODES AS SWITCHES

2.1 In the paper 'Semiconductor Devices 1' we saw that a semiconductor diode has a 'one-way' current flow characteristic. It has a low forward resistance, and a very high reverse resistance. Ideally, its forward characteristic would be a short circuit, and its reverse characteristic an open circuit. Therefore, an ideal diode would be equivalent to a closed switch when it is forward biassed (Fig. 1a) and an open switch when reverse biassed (Fig. 1b). Silicon diodes although not perfect, come very close to the ideal diode characteristics. For most practical purposes, they can be considered as equivalent to a short-circuit when 'on' and an open circuit when 'off'.



(a) Forward Biassed - Closed Switch

(b) Reverse Biassed - Open Switch

FIG. 1. DIODE SWITCHING PRINCIPLE

2.2 Fig. 2 shows a circuit which uses diodes as the switching elements. In this circuit the diodes switch current to either one of two lamps using one conductor and earth.

When switch S1 is in position 'A' (Fig. 2a), diode Y is switched on by a forward bias voltage from B1, and provides a current path to its associated lamp LP2. Diode X is reverse biassed by B1, and therefore prevents current flow to LP1.

When S1 is moved to position 'B', (Fig. 2b) diode X is switched on and diode Y is switched off by the applied voltage, causing lamp LP1 to glow and LP2 to extinguish.

It should be remembered that the switching on of diodes occurs only when the forward bias voltage reaches the 'threshold' value of 0.2 volts (germanium diodes) or 0.7 volts (silicon diodes).

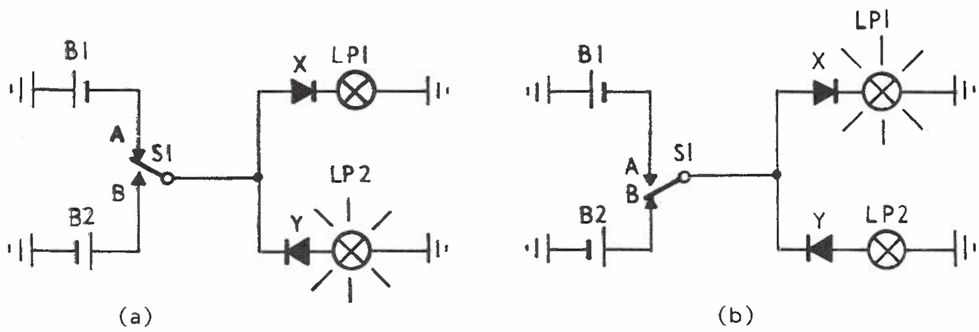


FIG. 2. SIMPLE DIODE SWITCHING CIRCUIT

2.3 The main applications for diodes as switches are in:

- SOLID STATE SWITCHING CIRCUITS, which are the semiconductor equivalents of relay switching circuits.
- A.C. SIGNAL SWITCHES, which switch low level A.C. voltages faster and more reliably than metal contact devices such as relays. Their main uses are in line transmission equipment.
- POLARITY-SENSITIVE SWITCHES, which control the operation of a relay or other device according to the polarity of the applied voltage.
- RECTIFIER CIRCUITS, where the diodes switch on and off under the control of the A.C. input to provide a D.C. output. These are described in the paper 'Semiconductor Devices 2'.

2.4 SOLID STATE SWITCHING CIRCUITS. The diode matrix is a common type of solid state switching circuit. Fig. 3 shows a simple example of a diode matrix circuit, in which earth on any one of the input leads lights a combination of coloured lamps. Each lead lights a different combination, as shown in the 'Results' column of Table 1. The combination of lamps lit when a particular input lead is earthed is controlled by the diode connections between the input leads (1, 2 and 3) and the lamp leads (A, B and C). The function of the diodes is to 'steer' the current to the lamps to be lit and block current to the other lamp. The state of each diode for each of the input conditions is shown in Table 1, where 'CON' represents conducting and 'NC' represents non-conducting.

For example, when input 2 is earthed,

- Diodes D3 and D4 conduct causing the red and yellow lamps to light.
- The earth on the A and B wires makes D1 and D5 non conducting and prevents earth being extended to the C lead to light the green lamp.

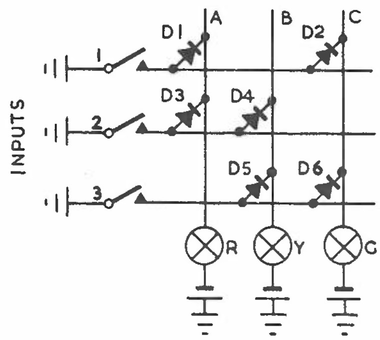


FIG. 3. DIODE MATRIX

Lead earthed	Conditions of diodes						Result (lamps lit)
	D1	D2	D3	D4	D5	D6	
1	CON.	CON.	NC	-	-	NC	Red and Green
2	NC	-	CON.	CON.	NC	-	Red and Yellow
3	-	NC	-	NC	CON.	CON.	Green, Yellow

2.5 Another common solid-state switching circuit is the 'logic gate'. A simple example of a solid-state logic gate is the 'AND' gate shown in Fig. 5. This circuit is the semi-conductor equivalent of the relay circuit shown in Fig. 4. The function of the relay circuit is to provide a positive potential of +5 volts at the output terminal only when contact units A AND B AND C are closed (Fig. 4b). If any contact unit is open the output potential is 0 volts, that is, earth potential (Fig. 4b).

Similarly, the function of the diode AND gate circuit is to provide an output voltage of +5V when input A AND input B AND input C all have +5 volts connected to them. If any input is at 0 volts, the output will be 0 volts (Fig. 5a). (This description assumes that the diodes have ideal characteristics).

Each input to the gate consists of a diode which is either forward or reverse biassed by the input voltage. There are only two inputs potentials that can be applied to each input; 0 volts (earth potential), or a positive potential of +5 volts.

When inputs A AND B AND C are all at +5 volts (Fig. 5b), all diodes are biassed 'off' and there is no P.D. across RB. Therefore, the +5V positive potential is extended to the output terminal.

2.6 The AND gate is only one of several types of semiconductor logic circuits. Most functions that can be performed by relay circuits can also be performed by solid state logic circuits. Detailed explanation of solid state logic principles is given in the paper 'Electronic Logic Principles 1'.

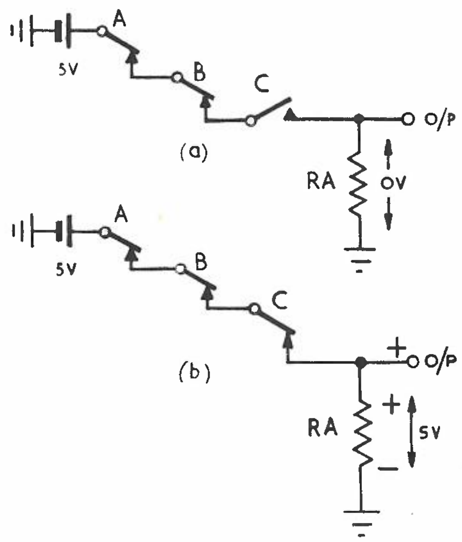


FIG. 4. RELAY EQUIVALENT OF 'AND' GATE

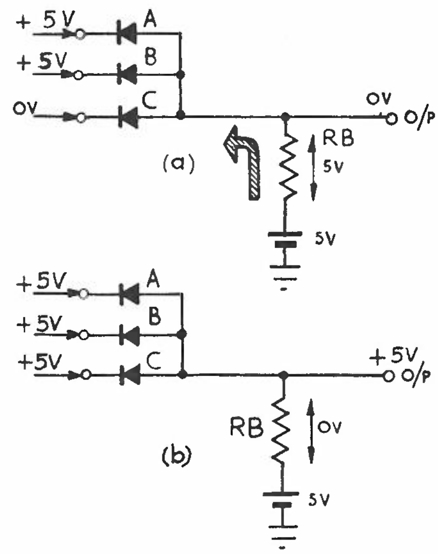


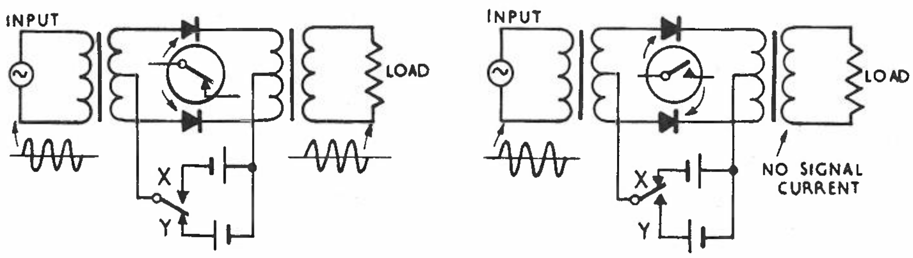
FIG. 5. 'AND' GATE

2.7 A.C. SIGNAL SWITCHES. In some items of transmission equipment, diode switches are used to open and close circuit paths carrying low-level A.C. signal currents. Fig. 6 shows a simple example of such a switch. The diodes open and close the circuit path for the A.C. signals between the input and the load.

When switch S1 is at position 'Y', (Fig. 6a) both diodes are forward biassed, causing them to switch on. This provides a low resistance path for the signal current to flow via the diodes from the input to the load.

When switch S1 is at position 'X' (Fig. 6b) both diodes are reversed biassed and are switched off. This open circuits the signal path between the input and the load and thus prevents signal current flowing through the load.

The D.C. voltages applied to the diodes are much greater than A.C. signal voltages. If this were not so, the A.C. voltages would interfere with the switching of the diodes by the D.C.

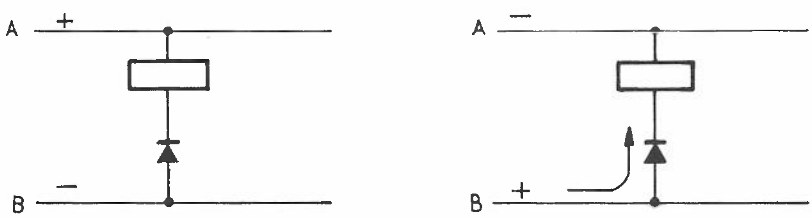


(a) Switched on (b) Switched off

FIG. 6. SIMPLE A.C. SIGNAL SWITCH

It might appear that relay contacts could switch low level A.C. currents as efficiently as diodes. However, it is found in practice that metal contacts are not as reliable as diodes for this type of switching. Further, diodes require far less power than relays, and switch much faster.

2.8 POLARITY-SENSITIVE SWITCHES. The 'one-way current flow characteristic of the diode is used to make a switching component, or circuit, respond to a reversal of applied voltage. Fig. 7 shows an example of such circuit. The relay in this circuit does not operate to the 'normal' condition of positive on wire 'A' and negative on wire 'B' (Fig. 7a), but operates when these potentials are reversed (Fig. 7b). The diode is said to 'polarise' the relay, because it makes the relay respond to only one polarity of applied voltage. This type of circuit is used widely in automatic telephone exchange equipment.

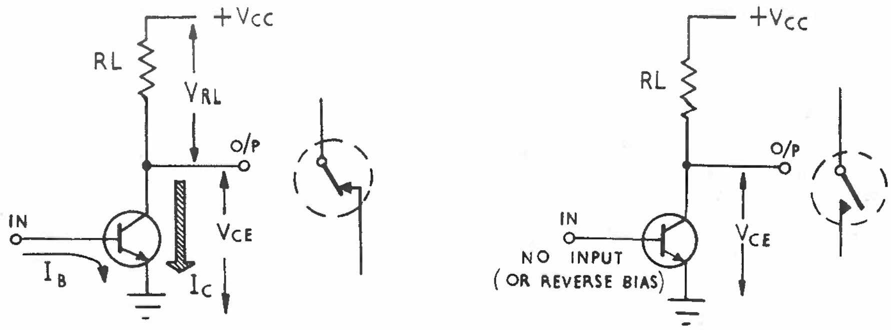


(a) Non-operated (b) Operated

FIG. 7. RELAY 'POLARISED' BY SERIES DIODE

3. BIPOLAR TRANSISTORS AS SWITCHES

3.1 The electrical characteristics of bipolar transistors make them particularly suitable for use as switching elements in many types of switching circuits. We saw in the paper 'Semiconductors Devices 1' that the collector-emitter impedance of a transistor is variable from values low enough to be considered a short circuit (Fig. 8a), to values high enough to be considered an open circuit (Fig. 8b). These two states correspond to the 'on' and 'off' conditions, respectively, as represented by the switch symbols in Fig. 8.



(a) Transistor switched on (b) Transistor switched off

FIG. 8. BIPOLAR TRANSISTOR AS A SWITCH

3.2 OPERATION OF SIMPLE TRANSISTOR SWITCH. In simple circuits, such as that shown in Fig. 8, the transistor is made to 'switch' or change state, by the application of an input signal to the base-emitter junction.

When a positive voltage of sufficiently high amplitude is applied to the base (Fig. 8a).

- Base current (I_B) flows, causing collector current to flow.
- The collector current (I_C) rises to a value determined by the supply voltage V_{CC} and the load resistance RL.
- Further increase in I_B causes no further increase in I_C, and the transistor is said to be in a state of saturation.
- The collector-emitter circuit of the transistor is now switched 'on', causing current to flow in the load. The collector-emitter resistance is usually less than 10 ohms, so the collector voltage almost equals the emitter voltage, which is 0 volts.

When the input voltage is removed or a reverse bias applied, (Fig. 8b),

- I_B ceases.
- I_C drops to the leakage value.
- The collector-emitter circuit of the transistor is now equivalent to an open switch, because current has virtually ceased in the load. The transistor is said to be 'cut off'.
- The collector voltage in the 'off' state equals the supply voltage V_{CC}.

3.3 SATURATION MODE SWITCHING. In the example described in para 3.2, the transistor is said to be operating in the 'saturation mode'. In the 'off' state the collector current is cut off, and in the 'on' state the collector circuit is saturated. 'Saturation' means that the transistor is switched on in such a way that further increases in the base current cause no increase in collector current. (Fig. 9). When a transistor is in this state, its collector-emitter voltage (V_{CE}) is less than the base-emitter voltage (V_{BE}). Also, once in saturation, it is comparatively slow to switch back to the 'off' state when the input voltage is removed.

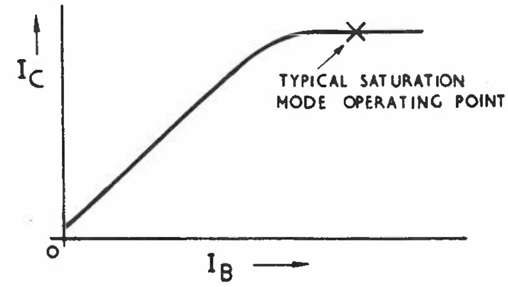


FIG. 9. SATURATION MODE OPERATING POINT.

3.4 SWITCHING SPEED. All switching devices take a certain amount of time to change their state. For example, an ordinary relay takes about 20 milliseconds to operate, a reed relay takes about 1 millisecond, and a typical saturation mode transistor switch changes state within about 100 nanoseconds. The time taken to change state is usually referred to as 'switching delay'.

The main effect of switching delay is to limit the rate at which a switch can be 'cycled' (repeatedly opened and closed). For example, if a reed relay takes 2 milliseconds to operate and then release, then the fastest rate at which it can be cycled is 500 times per second. If a transistor switch can be turned on and then off again in 100 nanoseconds, its highest cycling rate is 10^7 times per second. Short switching delays, therefore, lead to higher switching speeds.

3.5 The effects of switching delay are shown in Fig. 10. These graphs show the shape of a input pulse applied to a transistor switch, and the shape of the resultant output pulse. The input pulse to the switch starts at time 'a' and finishes at time 'b'.

The graph of the output pulse shows that its shape is different to that of the input pulse. These changes in shape are caused mainly by switching delays introduced by the transistor itself, and to a lesser extent by capacitance and inductance in the circuit wiring and components.

There are three main switching delays. These are:

- The switch-on delay, indicated by 'x'. This is the delay between application of the input pulse and the actual switching on of collector current.

- The part of the switch-off delay indicated by 'y'. This is the time that elapses between the end of the input pulse and the commencement of the switching off of the transistor.

- The part of switch-off delay indicated by 'z'. This is the time taken for the output voltage to decrease from the 'on' value to the 'off' value.

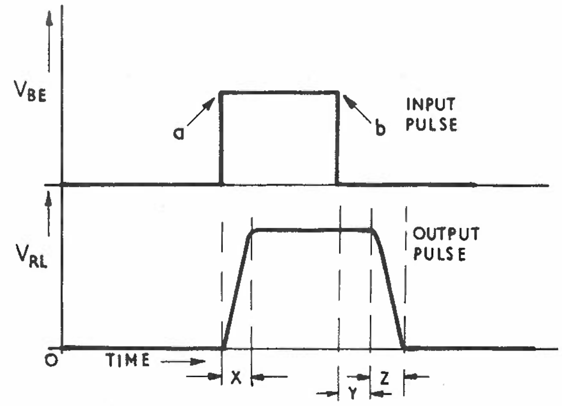


FIG. 10. SWITCHING TIME DELAY

3.6 Switching delays occur mainly because of the effects within the transistor. The worst delays occur when the transistor is saturated in the 'on' state. For this reason, saturated switches are amongst the slowest solid state switches and because of their limited speed of operation, they are used mainly where the switching speed is not critical. The speed of operation of saturated switches can, however, be improved by certain types of circuit modification, and also by the use of high input voltages. For applications requiring still higher switching speeds, non-saturating circuits are used. In these circuits, the transistor is said to be operating in the 'current' mode.

3.7 NON-SATURATION MODE (CURRENT MODE) SWITCHES are those in which the transistor does not saturate when switched on. Instead, the collector current value rises to a point below saturation, (point 'a' on Fig. 11) and is held or 'clamped' at that point in order to prevent saturation.

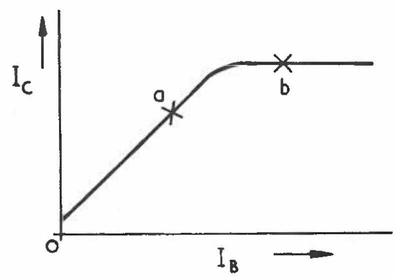


FIG. 11. CURRENT MODE OPERATING POINT

A simple non-saturating or current mode circuit is shown in Fig. 12. It consists of a basic transistor switch to which has been added components R1, R2, and D1.

3.8 OPERATION OF CURRENT-MODE SWITCH. When a positive voltage of suitable amplitude is applied to the input (Fig. 12a).

- Base current flows.
- The collector current increases, causing a rise in V_{RL} and an accompanying drop in V_{CE}.
- When V_{CE} has decreased to a value which is less positive than the input pulse, diode D1 is forward biassed and switches on.

- D1 now provides a shunt path to earth for input current. This path consists of R1, D1 and the transistor. The current through R2 and the base-emitter junction is thus prevented from rising to a value that would lead to saturation of the transistor.

- The limitation of base current automatically limits the maximum value of collector current (I_C is dependent on I_B), and prevents saturation. The collector current value is said to be 'clamped' at this level.

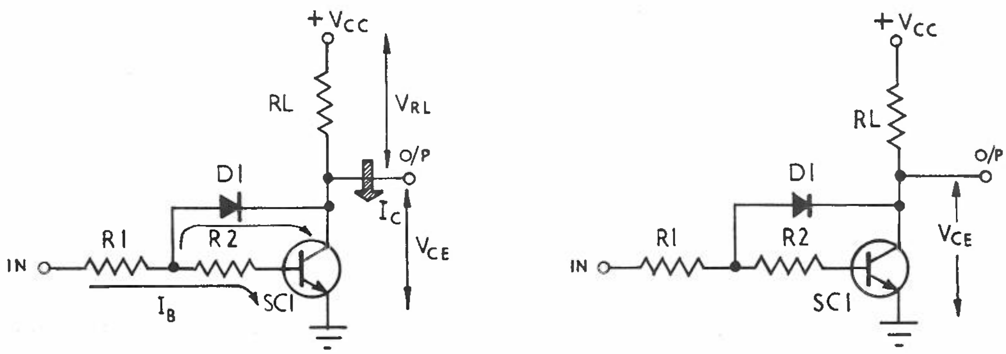
- The transistor switch is now 'on' (Fig. 12a) and remains in this state until the positive input voltage is removed (Fig. 12b).

When the input voltage is removed:

- The base current ceases.

- Collector current ceases, and the transistor is switched off.

- The voltage across the diode changes back to a reverse bias, switching the diode off.



(a) Switch in 'on' state (b) Switch in 'off' state

FIG. 12. SIMPLE 'CURRENT MODE' TRANSISTOR SWITCH

3.9 SWITCHING CIRCUITS WITH HIGH POWER LOADS. Solid state switching circuits are sometimes used to control the operation of comparatively high power loads, such as solenoids, motors, and lamps. As most solid-state switching circuits operate at low power levels, it is usually necessary to provide a 'power stage' between the switching circuit and the load. The power stage can be a relay, a thyristor, or a power transistor. Circuits or devices of this type are often called 'interfaces'. The function of this stage is to energise a high-power load in response to a low power input signal from the switching circuit. For example, Fig. 13 shows a transistor switch controlling the operation of a relay which is used to switch an electric motor on and off. When the transistor is switched on, it operates the relay, which in turn energises the motor. When the transistor is switched off, the relay releases and disconnects the motor. The back EMF from the relay is limited to a safe value (one which will not harm the transistor) by the diode.

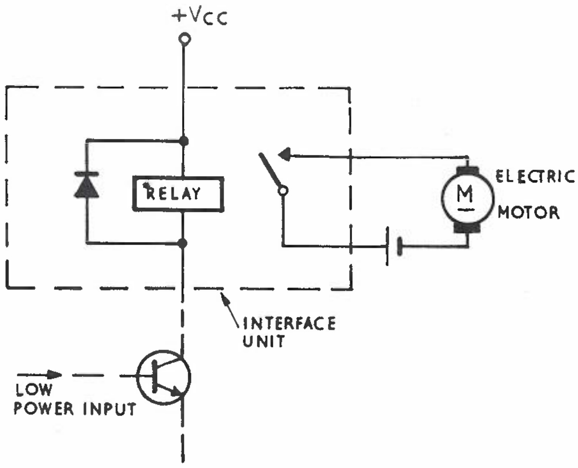


FIG. 13. EXAMPLE OF INTERFACE CIRCUIT

4. MULTIVIBRATORS

4.1 A common application of transistor switches is in 'multivibrator' circuits. A multivibrator consists of a pair of transistor switches coupled together by a network of resistors or capacitors. The components used in this coupling network determine whether the multivibrator functions as an oscillator (usually called a 'relaxation oscillator'), or as a switching circuit.

Multivibrator circuits use either saturated-mode or current-mode transistor switches, depending on the required switching speed. For simplicity, the circuit descriptions in this paper are based on basic discrete-component circuits having saturation- mode switching. Also, it is assumed that the transistors act as ideal switches, and change between the short-circuit 'on' and the open-circuit 'off' states in zero time.

The output waveforms of all multivibrators are non-sinusoidal, and are therefore rich in harmonic frequencies. Typical waveforms are shown in Fig. 14. The name 'multivibrator' is derived from the characteristics of the output wave, which contains 'multi' (many) - 'vibrations' (frequencies).

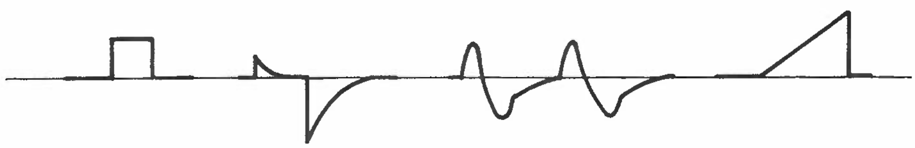


FIG. 14. TYPICAL MULTIVIBRATOR WAVEFORMS

4.2 There are three main types of multivibrator. These are:-

- Bistable multivibrators.
- Monostable multivibrators.
- Astable multivibrators.

4.3 BISTABLE MULTIVIBRATORS. A 'bistable' circuit is one which always takes up either one of two possible stable states, and remains in that state until an external signal makes it change to the other state. For example, an electric light switch is a bistable device. It has two stable states: the 'on' and 'off' positions. It requires a manual 'signal' to make it change from one state to the other.

The bistable multivibrator consists of two transistor switches connected so that when one switch is on, the other is off, and vice versa. When a suitable input pulse is applied to the circuit, both switches change state. The circuit is stable in either state; that is, it remains indefinitely in the last state to which it was switched.

4.4 The symbol for a basic bistable multivibrator is shown in Fig. 15, together with the common names for the input and output leads. The letters 'FF' stand for 'flip-flop', which is the common alternative name for a bistable multivibrator. The two stable states of the multivibrator are indicated by the voltages on the output leads. Fore example, if the D.C. supply voltages were OV and +5V, the two states are:

- The state where the 'set' output is at (or near) +5 volts, and the 'reset' output is at O volts.
- The state where the 'set' output is at O volts, and the 'reset' output is at (or near) +5 volts.

In logic applications the two possible states of a multivibrator are usually called "set" and "reset".

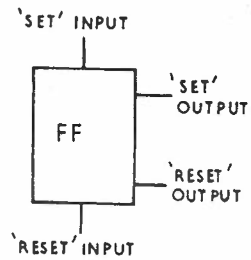


FIG. 15. BISTABLE MULTIVIBRATOR SYMBOL

4.5 A basic bistable multivibrator circuit is shown in Fig. 16. The circuit consists of two transistor switches, SC1 and SC2, with their associated load resistors (RL1 and RL2) and bias resistors (R1 and R2). The two switches are coupled together via coupling resistors R3 and R4. The function of these resistors is to make the switches dependent on each other so that when SC1 is on, SC2 is off, and when SC1 is off, SC2 is on.

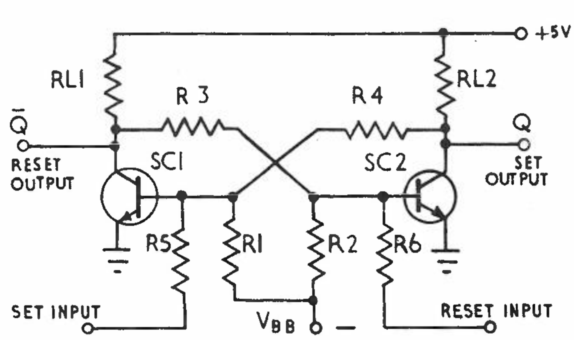


FIG. 16. BASIC BISTABLE MULTIVIBRATOR CIRCUIT

4.6 OPERATION OF BISTABLE MULTIVIBRATOR. (Refer to Fig. 17 and the timing diagram in Fig. 18). Assume that the circuit is in the state shown in Fig. 17a. In this condition SC1 is on so its collector potential is at O volts, and SC2 is off so its collector potential is at +5 volts. The +5 volts collector potential from SC2 is applied across R4 and the base-emitter junction of SC1 in series, causing sufficient base current through SC1 to hold it in saturation. Since there is no forward bias available from the collector of SC1, SC2 is held off by the negative potential applied to its base from V_{BB} terminal. Therefore, the set output is at +5 volts and the reset output is at O volts, as shown at time 'a' in Fig. 18.

When a positive pulse of sufficient amplitude to overcome the effect of V_{BB} is applied to the reset input (the base of SC2):

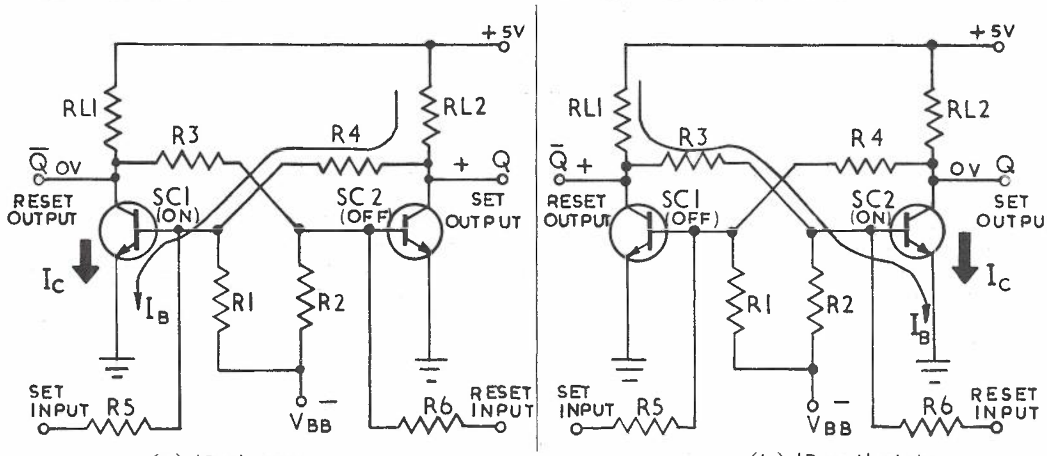
. SC2 switches on causing its collector voltage to drop to O volts. (Shown at time 'b' on Fig. 18).

. The drop in SC2 collector potential causes a corresponding drop in the base current of SC1.

. SC1 switches off and its collector voltage increases to +5 volts.

. With SC1 off and SC2 on, the circuit is in the 'reset' state. The electrical state of the circuit is shown in Fig. 17b, and the corresponding output levels are shown graphically at point 'c' on Fig. 18.

To set the multivibrator again (point 'd' in Fig. 18) a positive pulse is applied to the set input, and a similar circuit action occurs to switch SC1 on and SC2 off.



(a) 'Set' state (b) 'Reset' state

FIG. 17. BISTABLE MULTIVIBRATOR STATES

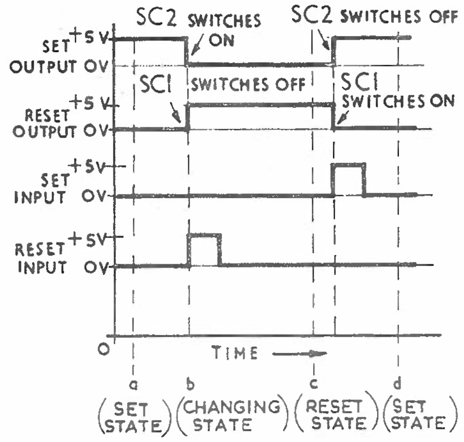


FIG. 18. TIMING DIAGRAM

4.7 The behaviour of the bistable switch shown in Fig. 17 cannot be predicted at the instant of connecting the power supply. Either SC1 or SC2 will turn on first, depending mainly on small differences in the transistor characteristics and resistor values. When it is required that the bistable circuit always takes up the same state each time it is switched on, it is modified to include extra circuitry and connections.

4.8 APPLICATIONS OF THE BISTABLE MULTIVIBRATOR. Bistable multivibrators or 'flip-flops' are used in electronic control equipment, electronic exchanges, computers and measuring instruments. In most of these applications they perform 'logic' and 'memory' functions, which are described in detail in the paper 'Electronic Switching Principles 2".

4.9 MONOSTABLE MUTLIVIBRATORS. A monostable multivibrator has only one ('mono') stable electrical state. In this state, one of its transistor switches is on and the other is off. When an input pulse is applied, it causes the 'normally off' transistor to switch on, and the 'normally on' transistor to switch off. This action commences the output pulse. The circuit remains in this state for a short period of time, and then reverts to its normal stable state, causing the output pulse to cease. Each input pulse to a monostable circuit produces an output pulse of fixed duration.

The symbol for a basic monostable circuit is shown in Fig. 19. The letters 'SS' stand for 'single-shot', which is a common alternative name for monostable circuits. The time figure in the symbol denotes the length of the pulse generated by the multivibrator.

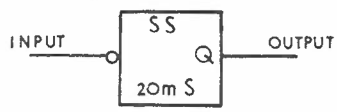


FIG. 19. SYMBOL FOR MONOSTABLE MULTIVIBRATOR

4.10 Fig. 20 shows a simple monostable multivibrator circuit, consisting of two transistor switches SC1 and SC2, with their associated load and bias resistors. The two switches are coupled by the resistor R3 and the capacitor C1. These two components make the transistor switches dependent on each other in such a way as to provide the monostable function. Normally, SC1 is off and SC2 is on, and the output is at 0 volts. This is the stable state of the circuit. The application of a suitable input signal causes SC1 to turn on and SC2 to turn off, resulting in a +5 volt potential at the output. The circuit remains in this state for a time determined by the R-C time constant circuit, and then returns to its normal state.

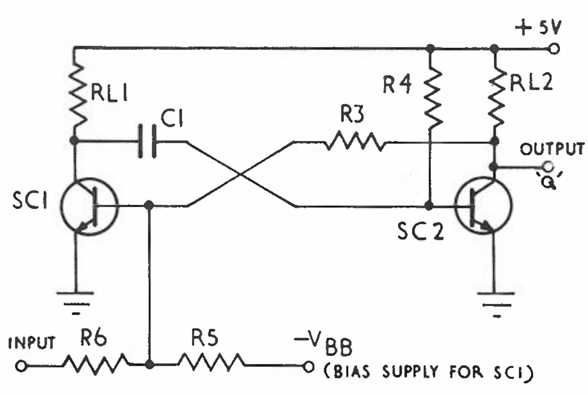


FIG. 20. BASIC MONOSTABLE MULTIVIBRATOR CIRCUIT

4.11 OPERATION OF MONOSTABLE MUTIVIBRATOR. In the stable state (Fig. 21a) SC 2 is biassed on by current through R4 and its base-emitter junction. SC1 is kept in the off state by the negative potential from the VBB terminal. The output terminal ('Q') is held at 0 volts by the earth extended to the collector of SC2 via the low resistance collector-emitter circuit.

When a positive pulse of sufficient amplitude is applied to the input:-

- SC1 switches on (Fig. 21b) causing its collector-emitter resistance to drop to a negligible value. The resulting current flow causes the potential at the collector of SC1 to change from +5 volts to 0 volts.

- C1 commences discharging via SC1, R4 and the power supply. The rosultant P.D. across R4 drives the base of SC2 negative with respect to the emitter.

- SC2 switches off, and its collector voltage rises to +5 volts. This is the commencement of the output pulse. (point 'a' on Fig. 22).

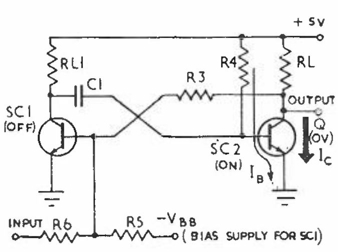
- The SC2 collector voltage is applied via R3, to the base of SC1. This voltage produces base current I_B to hold SC1 on while SC2 is off.

- SC2 remains cut-off by the discharge current of C1 via R4 and SC1. When C1 is fully discharged it commences to recharge to the power supply polarity thus the voltage on C1 is reversed momentarily driving the base of SC2 positive with respect to the emitter.

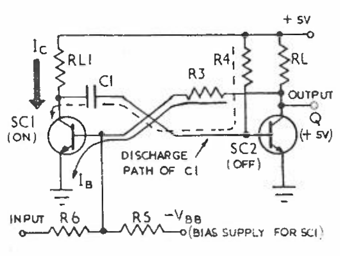
- SC2 switches on. The resulting decrease in its collector voltage decreases the forward bias applied to the base of SC1, which is driven negative by - Vbb thus SC1 is switched off.

- With the switching-off of SC1 and the switching-on of SC2, the output pulse ends (Fig. 22), and the circuit returns to its normal state.

The length of the output pulse is the time that elapses between SC2 switching-off and switching-on again. This time is determined by the values of C1 and R4.



(a) Stable state



(b) State for duration of output pulse

FIG. 21. MONOSTABLE MULTIVIBRATOR STATES

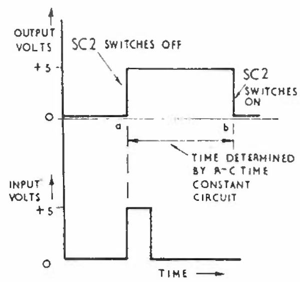


FIG. 22. TIMING DIAGRAM

4.12 APPLICATIONS OF MONOSTABLE MULTIVIBRATORS. Monostable multivibrators are used mainly in electronic circuits to provide time delays. The amount of delay is easily changed by varying the value of C1.

4.13 ASTABLE MULTIVIBRATORS. An astable multivibrator has no stable electrical state. Its two transistor switches are so connected that they continually switch between the two states where one transistor is on while the other transistor is off and vice versa. The circuit remains for a short time in one state and then switches to the other state. The output from each collector is, therefore, a series of non-sinusoidal pulses. The circuit is often called a 'free-running' multivibrator, because it generates a continuous oscillatory output. Another common name is 'relaxation oscillator'.

Fig. 23 shows the symbol for the astable multivibrator. The term 'clock' in the symbol is a name often used for astable circuits that supply timing pulses to electronic logic circuits.

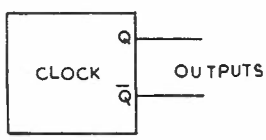


FIG. 23. SYMBOL FOR ASTABLE MULTIVIBRATOR

4.14 The circuit of a simple astable multivibrator is shown in Fig. 24. It consists of two transistor switches, SC1 and SC2, coupled together by capacitors C1 and C2. The rate at which the circuit oscillates from one state to the other is determined by the value of the capacitors and the values of R3 and R4.

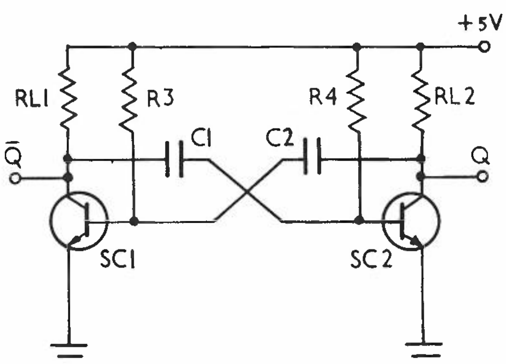


FIG. 24. BASIC ASTABLE MULTIVIBRATOR CIRCUIT

4.15 OPERATION OF ASTABLE MULTIVIBRATOR. It will be assumed for the purposes of this description that the circuit is in operation, and that it has just switched to the state where SC1 is on and SC2 off, as shown in Fig. 25a. The circuit operation from this state is as follows:

- The collector of SC1 is at 0 volts potential, so C1 is charging via R4 and SC1. The voltage at the base of SC2 is insufficient to switch it on.
- The charge stored in C2 (which was charged via R3 and SC2, in the previous cycle) is causing current flow via RL2 and the base-emitter junction of SC1. This current holds SC1 on.
- As C1 becomes charged to P.D. across R4 decreases and the voltage applied to the base of SC2 becomes high enough to switch it on (Point 'a' in Fig. 26).
- The SC2 collector voltage decreases to 0 volts, providing a charging path for C2 via R3.
- The charging current of C2 increases the P.D. across R3 and thus reduces the voltage across the base-emitter junction of SC1. SC1 turns off.

The circuit is now in the state where SC2 is on and SC1 is off as shown in Fig. 25b. After a short time in this state, it will revert to the original state (Point 'b' in Fig. 26), by a similar process to that described.

4.16 OUTPUT FREQUENCY AND PULSE WIDTH. Astable multivibrators can be made to run at almost any desired frequency. The time that SC2 output is high (Fig. 26) is determined by the value of the components C1 and R4. The time that the output is low is determined by the value of the components C2 and R3. The output pulse duration and pulse repetition frequency are therefore variable. When C1 = C2 and R3 = R4 the pulse high time is equal to the pulse low time and the output waveform is symetrical. Reducing the value of C1 or R4 reduces the pulse duration and increases the pulse repetition frequency.

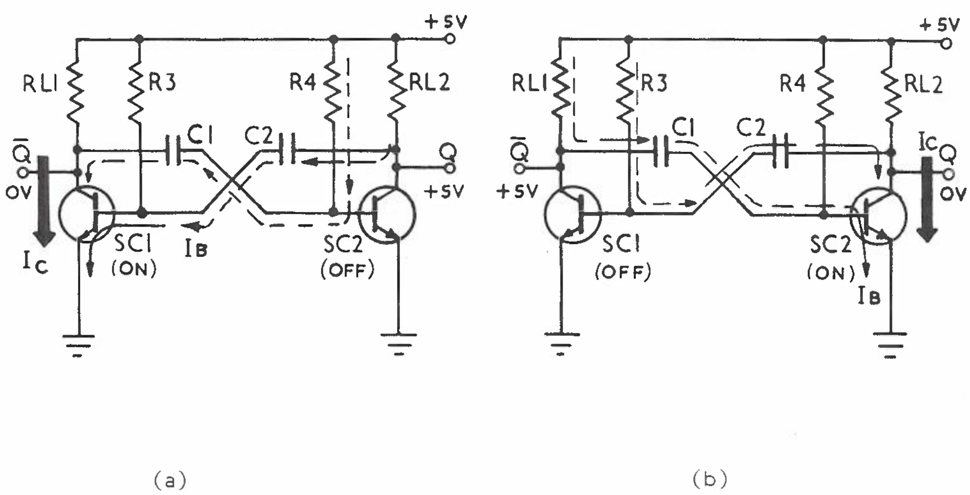


FIG. 25. CIRCUIT STATES OF ASTABLE MULTIVIBRATOR

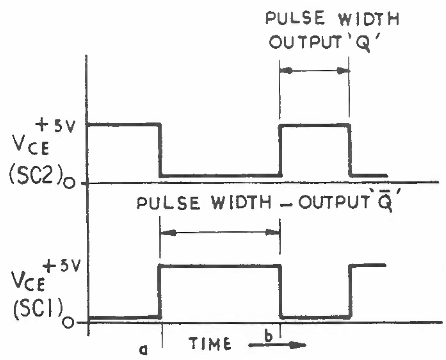


FIG. 26. TIMING DIAGRAM

4.17 APPLICATIONS OF ASTABLE MULTIVIBRATORS. Normally, the output frequency of an astable circuit varies slightly about an average figure. However, the output frequency is easily synchronised to that of a precision oscillator (such as a crystal type). In this 'synchronised' form, astable multivibrators are used in electronic logic circuits for timing of switching processes and for pulse supply.

Astable multivibrators are also used as test oscillators in applications requiring square, triangular, and other non-sinusoidal waveforms.

5. SCHMITT TRIGGER

5.1 A 'schmitt trigger' circuit is a modified form of bistable multivibrator. It consists of two transistor switches directly coupled by a network of resistors (Fig. 28). The circuit has two states. These are:

- The normal or 'rest' state. The circuit remains in this state while the input voltage is less than a particular value called the 'turn-on threshold voltage'.
- The 'on' state, to which the circuit switches after the turn-on threshold is exceeded. The circuit remains in this state until the input voltage drops below a value called the 'turn-off threshold voltage'.

The function of the Schmitt trigger is to provide an output pulse which starts when the input voltage exceeds the turn-on threshold, and finishes when the input voltage drops below the turn-off threshold.

5.2 The symbol for a typical Schmitt trigger circuit is shown in Fig. 27. The letters 'ST' in the symbol stand for Schmitt trigger. The voltage values are those of the turn-on and the turn-off threshold, respectively.

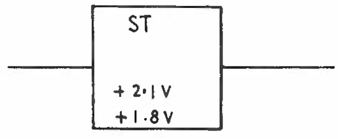


FIG. 27. SYMBOL FOR SCHMITT TRIGGER

5.3 A basic Schmitt trigger circuit is shown in Fig. 28. It consists of two transistor switches, SC1 and SC2, which are made dependent on each other by the coupling resistor R3 and the shared emitter resistor RE. In the normal or 'rest' state, SC1 is off and SC2 is on. The application of a suitable value of input pulse switches SC1 on and SC2 off, for as long as the input exceeds the turn-off threshold.

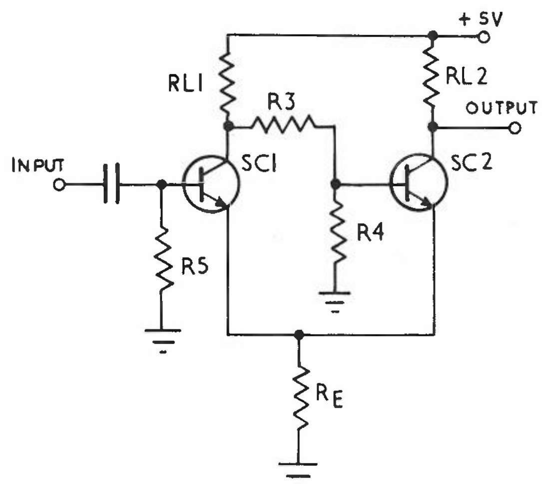


FIG. 28. BASIC SCHMITT TRIGGER CIRCUIT

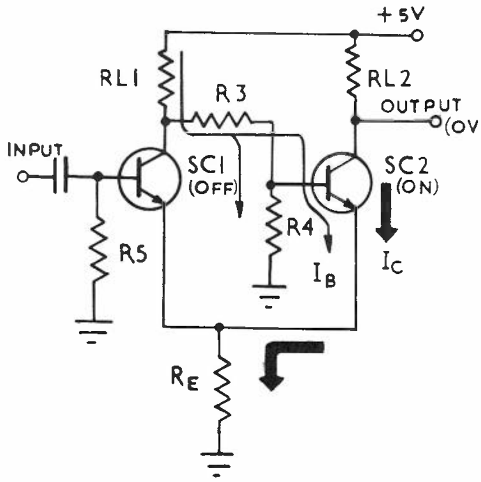
5.4 OPERATION OF SCHMITT TRIGGER. In the normal state, (Fig. 29a) SC2 is held on by current through RL1, R3, and its base-emitter junction. The flow of collector current via SC2 and RE causes a P.D. across RE. This P.D. causes the emitter of SC1 to be at a higher potential than its base. This reverse bias holds SC1 switched off.

When the input voltage exceeds the turn-on threshold value, (Fig. 29b)

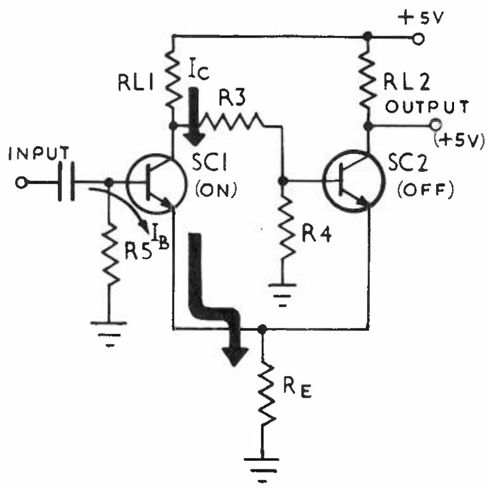
- SC1 switches on because the input voltage has overcome the effect of the reverse bias on RE.
- The switch-on of SC1 causes its collector voltage to drop to 0 volts. There is now no bias supply via RL2 to the base of SC2.
- SC2 switches off, and its collector voltage rises to +5 volts. (Point 'a' on Fig. 30). This is the start of the output pulse.

The circuit is now in the on state, and remains in this state until the input voltage decreases below the turn-off threshold value. When this occurs:

- SC1 switches off, terminating the output pulse (Point 'b' on Fig. 30). The SC1 collector voltage rises to +5 volts, causing the flow of bias current to SC2 via R3.
- SC2 switches on. The circuit is now back in the normal state.



(a) Normal or 'rest' state



(b) 'On' state

FIG. 29. STATES OF SCHMITT TRIGGER CIRCUIT

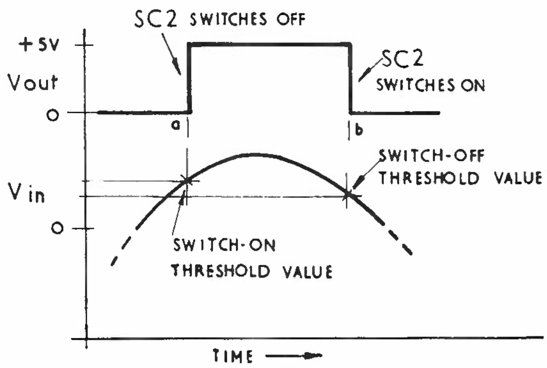


FIG. 30. TIMING DIAGRAM

5.5 APPLICATIONS. One of the most common applications of Schmitt triggers is in 'squaring circuits'. they are used to convert sine waves to square waves in some types of signal generator, and to re-form telegraph and data pulses which have been distorted during transmission. For example, Fig. 31 shows how such pulses appear before and after processing through the squaring circuit.

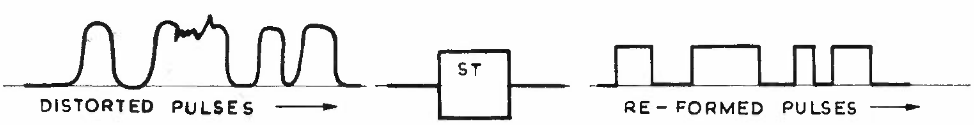


FIG. 31. APPLICATION OF A SQUARING CIRCUIT

6. BLOCKING OSCILLATORS

6.1 A blocking oscillator is one which uses a transformer and an R-C (or L-C) time-constant circuit to generate narrow-width pulses. Depending on the type of application, it can be made single-shot (monostable) or free-running (astable) in its operation. The circuit symbols for each mode are shown in Figs. 19 and 23 respectively. In this paper, the operation of a monostable circuit is described. Astable circuits are different only in the bias circuit used for the transistor.

A simple monostable blocking oscillator circuit is shown in Fig. 32. The circuit consists of a transistor switch, a transformer, and a time-constant circuit consisting of R1 and C1 in series. The application of a pulse to the input causes SC1 to switch on for a short interval of time. At the end of this time interval, SC1 reverts to the 'off' condition, causing the generation of an inductive pulse by T1. The length of this pulse is determined by R1 and C1.

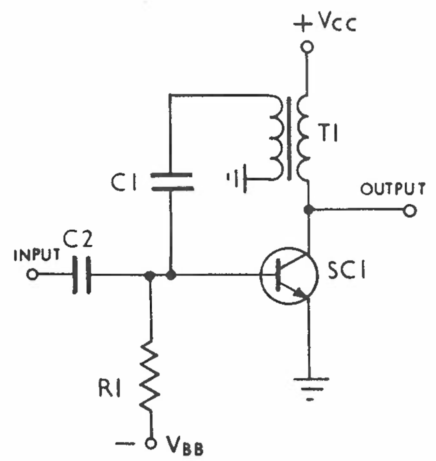
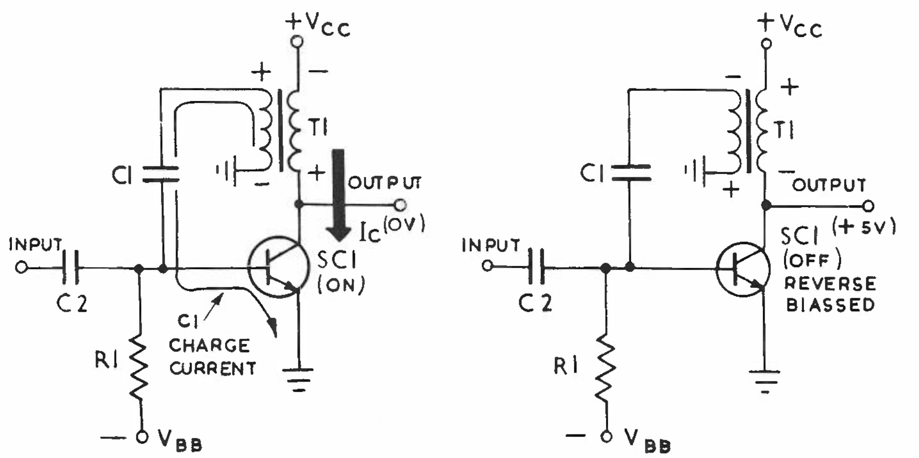


FIG. 32. MONOSTABLE BLOCKING OSCILLATOR CIRCUIT

6.2 CIRCUIT OPERATION. In the stable state, SC1 is biassed off by the negative potential from the VBB terminal. The output voltage, therefore, equals the collector supply voltage (VCC) as shown in Fig. 34. When an input pulse of sufficient amplitude is applied:

- SC1 switches on (Fig. 33a), and the current and associated magnetic field in the primary of T1 increases rapidly.
- The rising field induces a voltage in the secondary of T1. The windings are so connected that this voltage forward biasses SC1 while C1 charges.
- When I_C reaches saturation point, the flux in T1 reaches a steady value, and the secondary voltage ceases. For a brief interval of time, (caused by effects within the transistor) SC1 remains on. The output voltage during this interval is 0 volts (points a to b in Fig. 34b).
- Without forward bias, SC1 switches off. The resultant collapse of the T1 field induces voltages in both its windings. The secondary voltage aids V_{BB} in keeping SC1 switched off (Fig. 33b). The induced primary voltage in conjunction with the discharge of C1 causes the positive-going pulse 'P' on the output wave (Fig. 34). The length of this positive-going pulse is determined by the values of R1 and C1.

When T1 flux drops to zero, the output voltage decreases back to the V_{CC} value. The ripple or 'ringing' effect at the end of the pulse is caused by a resonance effect between C1 and T1.



(a) SC1 on (b) SC2 off. Flux collapsing around T1

FIG. 33. STATES OF BLOCKING OSCILLATOR

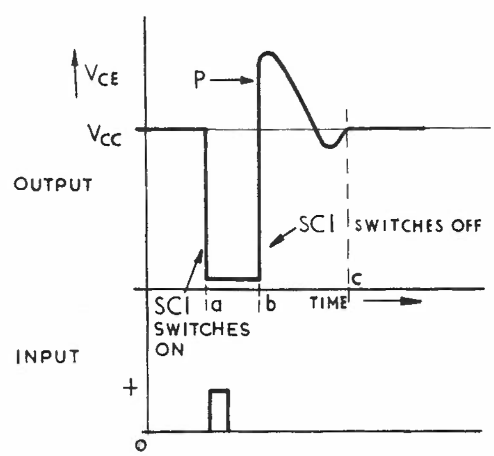


FIG. 34. OUTPUT WAVEFORM

6.3 The output waveform (Fig. 34) contains both a negative-going pulse (points a to b) and a positive-going pulse (points b to c). In many applications, only one of these is required. The required pulse is selected by means of a suitable circuit, such as a rectifier, and the other pulse suppressed.

6.4 APPLICATIONS Monostable blocking oscillators are commonly used in logic and switching circuits. The output pulse from a blocking oscillator is typically narrow with nearly vertical sides, and is ideal for logic circuit applications such as pulse supply or the re-shaping of rounded pulses.

END