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SEMICONDUCTOR DEVICES (2)

PUBLISHED 1972

1. INTRODUCTION.

1.1 Junction diodes, transistors and FET's, which are described in the paper 'Semiconductor Devices 1', are three of the many types of semiconductors components used in electronic circuits. Other types include the single-junction and three-junction units used in solid-state switching circuits, and components which respond electrically to the effects of heat, light voltage and magnetism. All of these components are used extensively in telecommunications equipment. For example, light-sensitive components are used in automatic mail handling equipment to detect and gauge the size of letters; solid-state switching components are used extensively in automatic control circuits for power plant.

1.2 This paper describes the principles of some of the semiconductor devices not covered in 'Semiconductor Devices 1' and gives simple examples of their application in telecommunications circuits. It also gives further applications of the junction diodes described in 'Semiconductor Devices 1'.

E.T.S. 12/0376

2. DIODE APPLICATIONS.

2.1 The semiconductor junction diodes introduced in 'Semiconductor Devices 1' h two main classes of application. These are:

- RECTIFICATION, which is the conversion of A.C. to D.C. Most mains ope D.C. power supplies use solid-state diodes as the rectifying elements.

- SOLID-STATE SWITCHING, which uses diodes in logic gates and other type switching circuits. For example, a diode connected in series with a r acts as an electronic switch. The application of one polarity makes the di 'switch on', and the relay operates. Reversal of the applied voltage switc the diode 'off' and releases the relay.

2.2 DIODES AS RECTIFIERS. Solid-state rectifiers used in telecommunications r from simple units which convert A.C. signals to D.C. in measuring instrumen to multi-kilowatt installations which provide D.C. to large automatic exchanges.

There are two types of rectifier. These are:

- HALF-WAVE RECTIFIERS, which produce D.C. from each alternate half-cycl of the A.C. (Fig. 1c). In effect, only half of the energy in the A.C. wave is supplied to the load.

- FULL-WAVE RECTIFIERS, which produce D.C. from all the half-cycles of t A.C. (Fig. 3c). In this case all the energy in the A.C. wave is avail as D.C.

2.3 HALF-WAVE RECTIFIER. The simplest rectifier circuit (Fig. 1) uses a sing diode to convert A.C. to D.C. This circuit, called a half-wave rectifier, consists of the A.C. supply, the diode, and the 'load'. For explanatory purpose the load is shown as a resistor; in practice it could be a relay, a meter, or a battery.

OPERATION OF HALF-WAVE RECTIFIER. During the half-cycles of A.C. shown shaded i Fig. 1a:

- The EMF induced into the transformer secondary winding is in such a direction as to forward-bias the diode and make it conduct.

- Current flows through the resistor and diode in series.

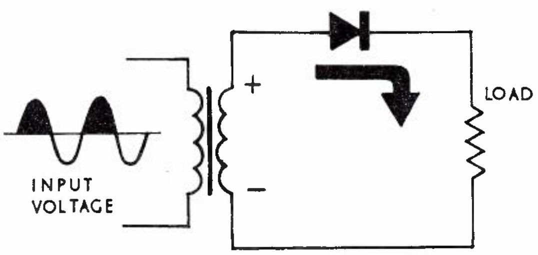
- The transformer secondary voltage appears across the load resistor. (very small voltage drop appears across the diode, but it can be ignore most practical purposes).

During the half-cycles shown shaded in Fig. 1b:

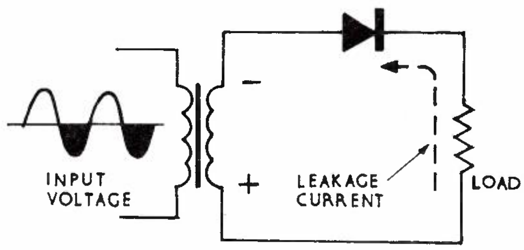
- The EMF induced into the secondary winding reverse-biasses the diode a causes it to block current flow. (The only current through the load consists of the very small diode leakage current which can be ignored for m practical purposes).

- The transformer secondary voltage appears across the anode and cathode the diode, as it is virtually an open circuit. No voltage appears acr the load.

The voltage applied to the load is a pulsating or 'half-wave' D.C. as shown in Fig. 1c.



(a) Conduction Half-Cycles.



(b) Non-Conduction Half-Cycles.

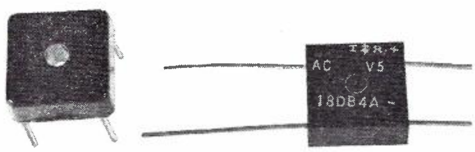
(c) Waveform of Output Voltage Across Load.

FIG. 1. HALF-WAVE RECTIFICATION.

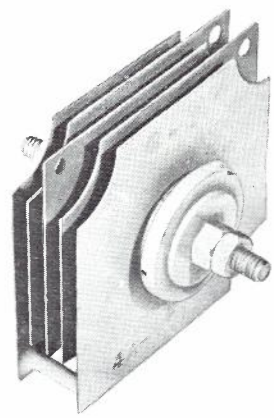
2.4 FULL-WAVE RECTIFICATION. The most commonly used rectifier circuits are those which provide a full-wave output. The output waveform is shown in Fig. 3c. A typical example of a full-wave rectifier circuit is the 'bridge' rectifier (Fig. 3).

Bridge rectifiers usually consist of a single physical unit containing four interconnected diodes. Fig. 2a shows two typical silicon bridge rectifiers. Each one consists of four silicon diodes sealed in a single plastic package. The hole in the centre of each unit facilitates bolting of the rectifier to a suitable heat sink.

Fig. 2b shows a typical selenium bridge rectifier unit. It consists of a row of selenium diode units, bolted into a single assembly together with large metal fins for dissipation of heat.



(a) Silicon Rectifiers.



(b) Selenium Rectifier.

FIG. 2. TYPICAL BRIDGE RECTIFIERS.

2.5 OPERATION OF BRIDGE RECTIFIER. During the half-cycles of A.C. shown sha
in Fig. 3a:

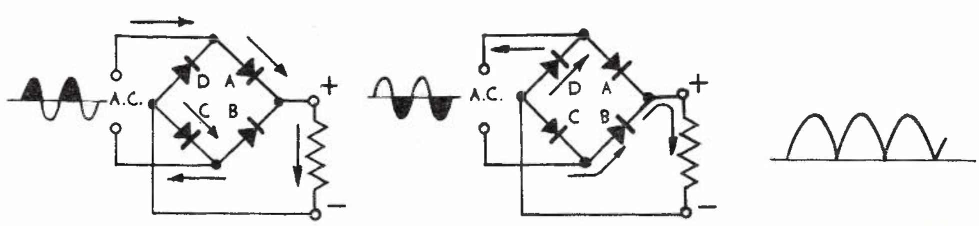
- Diodes A and C are forward-biassed. Diodes B and D are reverse-biasse
- Current flows through diode A, the load, and diode C in series with a polarity indicated by the arrows.
- The input voltage appears across the load resistor.

During the half-cycles shown shaded in Fig. 3b:

- Diodes B and D are forward-biassed, and diodes A and C are reverse-bia:
- Current flows through diode B, the load, and diode D in series, with th previous polarity maintained as indicated by the arrows.

Fig. 3c shows that the input voltage appears across the load as a pulsating D.C. consisting of all the half-cycles of rectified A.C.

Note that when one pair of diodes is forward-biassed, the reverse-biassed pair a effectively in parallel across the A.C. supply. This means that during each cyc both pairs of diodes are exposed in turn to the peak value of the A.C. supply. (must be taken, therefore, to use diodes of the correct voltage rating when a recti unit is being constructed or repaired.



(a) Diodes A and C conducting.

(b) Diodes B and D conducting.

(c) Output Waveform.

FIG. 3. FULL-WAVE BRIDGE RECTIFIER.

2.6 The bridge rectifier circuit can be drawn in a number of different ways, all which are electrically identical. Some of these alternative diagrams are sh in Fig. 4.

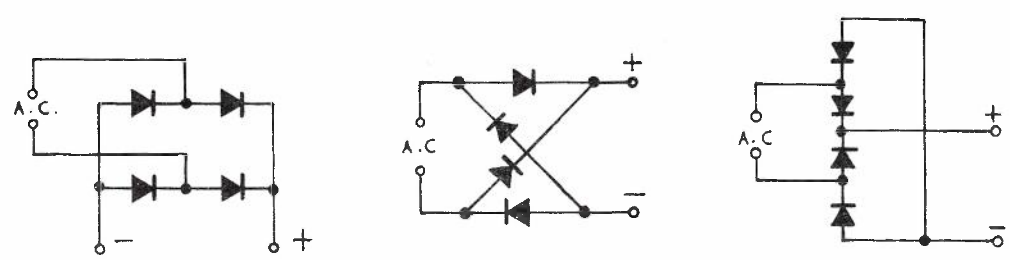


FIG. 4. BRIDGE RECTIFIER CIRCUITS.

2.7 TWO-DIODE FULL-WAVE RECTIFIER. Fig. 5 shows a type of full wave rectifier circuit that is used in the power supplies of many types of electronic equipment. It consists of a centre-tapped transformer, two diodes, and the load.

OPERATION. During the half cycles of A.C. shown shaded in Fig. 5a:

- Diode A is forward biassed by the voltage across points X and Y on the transformer secondary.

- Diode B is reversed biassed by the voltage across points X and Z on the transformer secondary. This is because diode A is switched on, allowing the potential present at X to be extended to the cathode of diode B.

- Current flows through diode A and the load in series as indicated by the arrows.

During the half-cycles shown shaded in Fig. 5b:

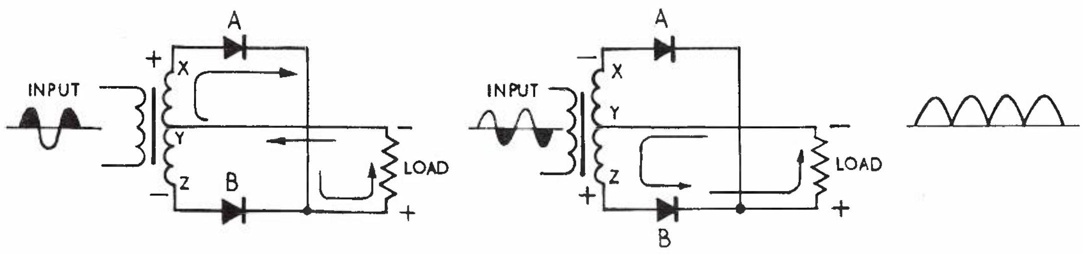
- Diode B is forward biassed by the voltage across points Y and Z on the transformer secondary.

- Diode A is reverse biassed by the voltage across points X and Z on the transformer secondary. This is because diode B is 'on', allowing the full secondary voltage to be impressed across diode A.

- Current flows through diode B and the load in series as indicated by the arrows.

Fig. 5c shows that the voltage across the load is a pulsating D.C. consisting of all the half cycles of rectified A.C.

Although this circuit uses only two diodes to provide a full-wave supply, each diode has to be able to withstand the peak voltage of the entire transformer secondary. It is, therefore, most important that diodes of the correct voltage rading be used when a rectifier unit is being constructed or repaired.



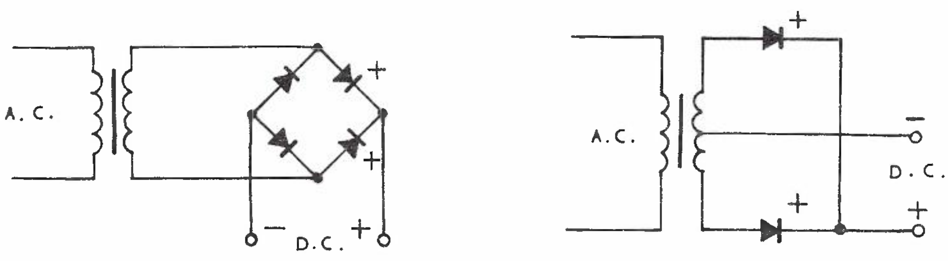
(a) Diode A conducting.　(b) Diode B Conducting　(c) Output Wave form.

FIG. 5. 2-DIODE FULL WAVE RECTIFIER.

2.8 Other types of full-wave rectifier include voltage multiplier circuits and three-phase rectifiers. Generally, the use of these circuits is restricted a few types of power supply; these are described in other papers.

2.9 OUTPUT POLARITY OF RECTIFIER CIRCUITS. The positive and negative out terminals of a rectifier circuit are usually clearly marked with + and - si or other suitable markings. If the output polarity is not shown, it can be iden by inspecting the diodes and connections which comprise the rectifier.

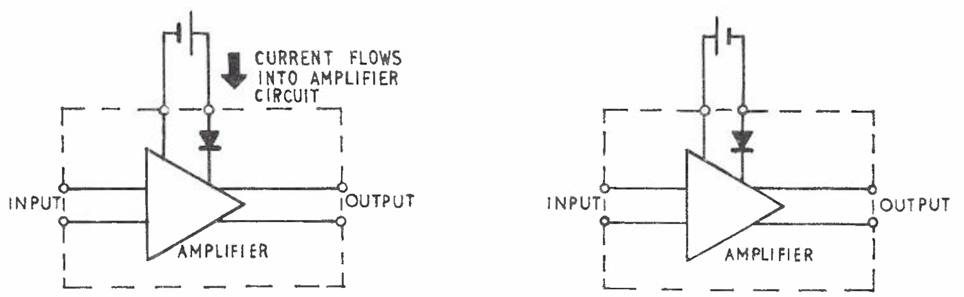
With respect to the output terminals, the positive terminal is the one that conn to the cathode of a diode(s) which has its anode connected to the AC supply (Fig. and 6b). Diode cathodes are usually identified by a dot, a bar, a diode symbo information given in manufacturer's data sheets.



(a) (b)

FIG. 6.

2.10 DIODES AS SWITCHES. Ideally, a switch is a device which has zero resist when 'on' and an infinitely high resistance when 'off'. For most practical purposes silicon diodes have characteristics which are very close to this ideal. When 'on', they have a low value of resistance; when 'off', their resistance is extremely high. Because of these characteristics, diodes are used extensively in solid-state switching circuits. Fig. 7 shows a simple example of a diode functioning as a switch. The diode is connected in series with one of the D.C. supply leads to a transistor amplifier. When the D.C. polarity to the amplifier correct (Fig. 7a), the diode is switched on by the forward biassing voltage, and provides a low resistance path for D.C. to the amplifier. Should the leads be accidentally transposed (Fig. 7b), the diode would be reverse-biassed and switched off. It would, therefore, block current to the amplifier, and protect the transistors and other polarity sensitive components against damage from reverse voltage.



(a) D.C. Supply Correctly Connected. (b) D.C. Supply Reversed.

FIG. 7. DIODE AS A SWITCH.

Further applications of diodes as switches are described in the papers on electronic switching circuits.

2.11 DIODE RATINGS. Semiconductor diodes have limits on the temperature, current, and voltage at which they may be safely and reliably operated. The safe maximum and minimum values for a given diode are termed its 'ratings,' and are listed in the form of tables of values in the manufacturer's handbook. Failure to observe these ratings frequently leads to the breakdown of equipment in service. Failure of a diode often causes damage to other components by subjecting them to excessive values of current (if diode goes short-circuit) or voltage (if the diode goes open circuit). It is important, therefore, that ratings and their significance are properly understood.

Terms applying to diode ratings, and their significance, are as follows:-

- PEAK INVERSE VOLTAGE (PIV): This is the highest value of reverse voltage which can be applied to a specific diode before it reaches the breakdown region. PIV ratings for silicon diodes, for example, range from 50 volts to over 1000 volts.

- MAXIMUM AVERAGE FORWARD CURRENT. This is the highest average value of current that the diode can carry continuously. It is usually specified at a certain temperature. For example, a diode may be rated to carry 5 amps continuously at 25°C. This means that it is able to carry an average current value of 5 amps indefinitely at that temperature.

- PEAK RECURRENT FORWARD CURRENT. This refers to the highest current that can flow intermittently, usually for a few seconds at a time. For example, a diode nominally rated at 0.5 amp maximum average forward current can usually withstand currents up to 6 amps intermittently, provided the temperature does not rise beyond 75°C.

- SURGE CURRENT. This refers to the highest value of short-term current overload or 'surge' that the diode can withstand without detrimental effects. Such surges must not exceed a few milliseconds in duration. The diode quoted above would have a surge rating of about 35 amps. Provided such surges are of short duration, they do not heat the junction to destructive temperatures.

- MAXIMUM AND MINIMUM TEMPERATURES. These are quoted for the various conditions under which the diode may work. Excessive temperature, even without current flow, leads to a breakdown of the material forming the junction. High temperatures may also cause leakage current to increase, to a value that will overheat the diode.

  At very low temperatures, the P.D. across the diode during conduction is fairly high, causing higher power dissipation within the diode. Because of this effect, the diode must be operated above the rated minimum temperature.

- MAXIMUM FORWARD VOLTAGE DROP. This refers to the highest P.D. that is allowed to occur across a diode during conduction. An excessive value usually indicates that a diode is carrying too much current.

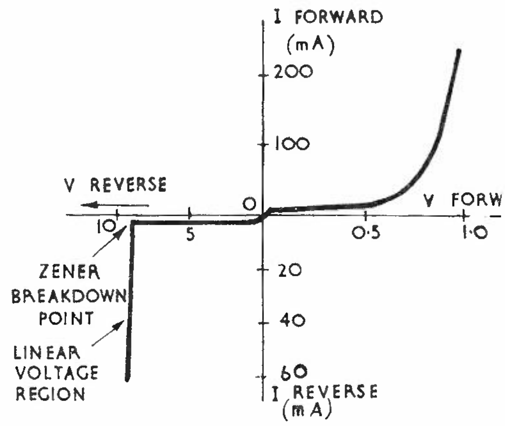
3. ZENER DIODES.

3.1 Zener diodes are junction diodes which have a linear 'constant-voltage' region in their reverse characteristic (Fig. 8b). The point in the reverse characteristic at which the constant voltage effect commences is called the 'Zener breakdown' voltage. (Fig. 8b). The Zener effect occurs to a certain extent in ordinary junction diodes, but in Zener diodes the effect is heightened by the use of different doping concentrations and construction.

The Zener breakdown point should not be confused with the point where the diode f
because of excessive power dissipation within the diode.

3.2 Figs. 8a and 8b show the Zener diode circuit symbol and a typical characteri
graph, respectively. Note that the reverse direction current axis is scaled
milliamps, rather than microamps as used for ordinary diode graphs. Because of t
construction, Zener diodes can safely carry higher reverse currents than ordinar
diodes.

(a) Circuit Symbol.



(b) Typical characteristic Graph.

FIG. 8. ZENER DIODE.

The values for the graph are derived from a test circuit such as that shown in Fi
In this circuit, the Zener diode is connected in the reverse direction, via a
resistor, to a variable D.C. supply. The series resistor limits the current to s
values over the range of test voltages. The values obtained from the test circui
for a low power 9-volt Zener diode are shown in Table 1. These figures show that
to the Zener point the reverse characteristic is similar to that of an ordinary
diode. Beyond this point, there is a constant voltage drop (VZD) across the Zene
diode. The rest of the supply voltage is dropped across the series resistor. In
practice, VZD increases slightly as the current flow increases. However, this
change in VZD is quite small, and for most applications the Zener diode is
considered as providing an acceptable constant voltage drop when operated in the
Zener region. It maintains the constant voltage drop up to the point where furthe
increase in current flow would overheat it.

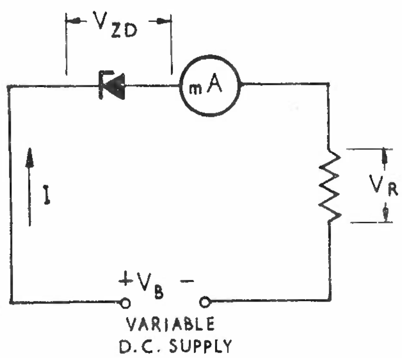


FIG. 9. SIMPLE ZENER DIODE TEST CIRCUIT.

V_B	I	V_{ZD}	V_R
5V	10μA	5V	0V
10V	10mA	9V	1V
11V	20mA	9V	2V
15V	60mA	9V	6V

TABLE 1.

3.3 TYPICAL APPLICATION. Zener diodes are commonly used in circuits that control or 'regulate' voltages within narrow limits. A simple voltage regulator circuit is shown in Fig. 10. The rectifier output voltage, which varies because of load current and mains voltage variations, is applied across the Zener diode and the resistor in series. The circuit is designed so that the Zener diode operates in the constant voltage region near the Zener point. The P.D. across the reverse-biassed Zener diode is constant over a wide range of current values. Since the load is connected across the Zener diode, the voltage applied to the load is constant. The Zener diode, therefore, regulates the voltage applied across the load to a constant value. This comparatively simple circuit can regulate voltages to within ±2% of the required value.

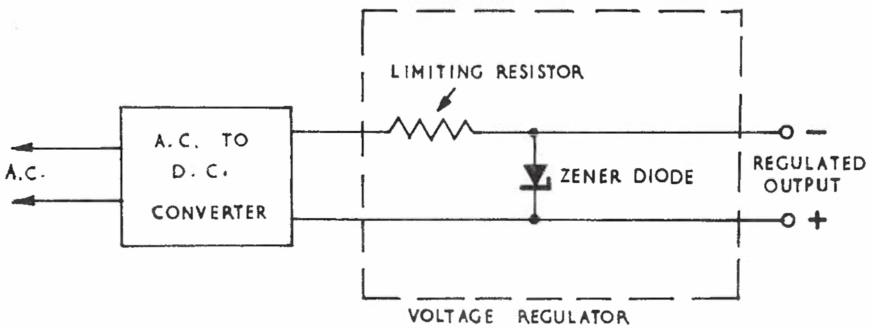
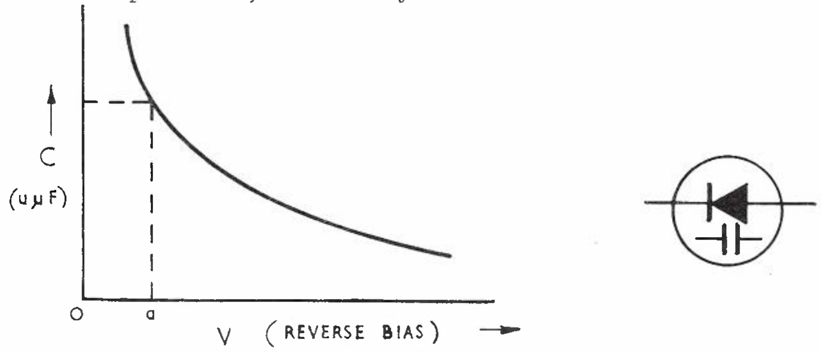


FIG. 10. REGULATED D.C. SUPPLY.

4. VARACTORS.

4.1 Varactors are junction diodes which, when reverse-biassed, have a capacitance which varies inversely with applied voltage. They are thus a form of Variable Reactance, which accounts for their name. The circuit symbol is shown in Fig. 11b. The dependency of junction capacitance on voltage for a typical varactor is shown in Fig. 11a. Point 'a' on the graph denotes a low value of reverse bias. The capacitance at this point is near the maximum. Succeedingly higher voltages causes the decrease in capacitance, as shown by the curve.



(a) Typical characteristic. (b) Circuit Symbol.

FIG. 11. VARACTOR.

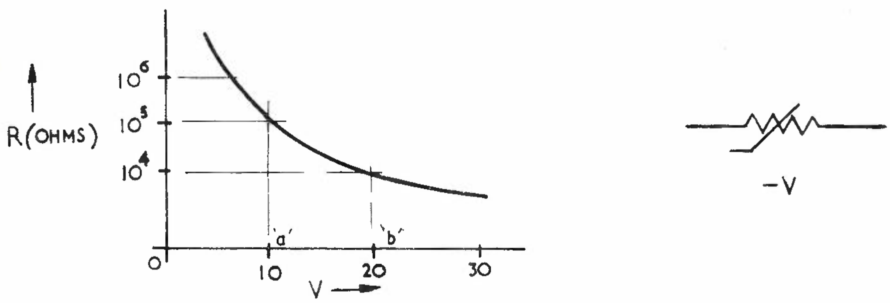
4.2 All diodes show the property of voltage controlled capacitance. However, varactors are made especially for operation at radio and microwave frequencies, having special doping concentration and distribution in the P-type and N-type materials. These special steps are taken in order to obtain the desired voltage/capacity characteristics and to minimise resistive losses at high frequencies.

5. VARISTORS (VOLTAGE DEPENDENT RESISTORS)

5.1. The resistivity of some semiconductor compounds varies according to the valu voltage to which they are subjected. When the applied voltage is increased, their resistance decreases; when the voltage is reduced, their resistance increa Semiconductor devices which utilise this effect are termed 'varistors' (or VDR's) The circuit symbol for a varistor is shown in Fig. 12a.

Most types of varistor are formed from a single bead, disc, or rod of the appropr semiconductor material and have, at a given voltage, the same resistance to curre flow in either direction.

5.2 The voltage-resistance characteristic of a typical varistor is shown in Fig. When the applied voltage is increased from 10 volts (point 'a') to 20 volts (point 'b'), the resistance decreases from 100K ohms to 12.5K ohms. Further incr in voltage cause further reduction in resistance. The resistance change in a vari is, therefore, inversely related to the voltage change.



(a) Typical VDR Characteristic. (b) Circuit Symbol.

FIG. 12. VARISTOR CHARACTERISTIC AND SYMBOL.

5.3 APPLICATIONS. Varistors are used in 800 type telephone circuits to control speech levels. Fig. 13 shows the connection of the 'line' VDR in an 800 ser telephone. It is connected across the line pair and its resistance depends on th D.C. voltage at the telephone terminals. On a long line the D.C. voltage at the telephone terminals would be lower than for a short line. For this reason, the shunting effect of the VDR on speech currents is less on long lines than on short lines. The speech levels therefore tend to remain constant regardless of the len of line to which the telephone is connected.

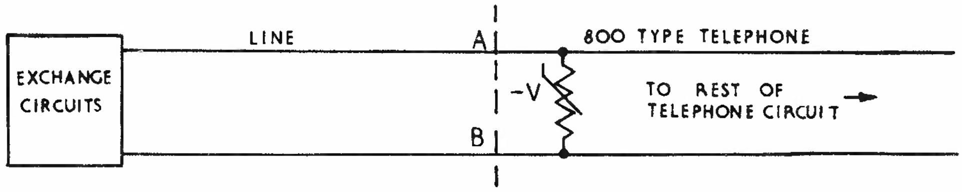


FIG. 13. VARISTOR USED FOR SPEECH LEVEL CONTROL.

VDR's are also used as 'surge suppressors' across the coils of relays and other types of electromagnet (Fig. 14). When the contacts open the self-induced e.m.f. from the coil is applied directly across the varistor, causing its resistance to drop to a low value. The varistor, therefore provides a shunt path for inducer current that would otherwise produced an arc across the contacts. When the surge dies away the varistor resistance returns to the normal high value. The varistor is said to be acting as a 'spark quench'.

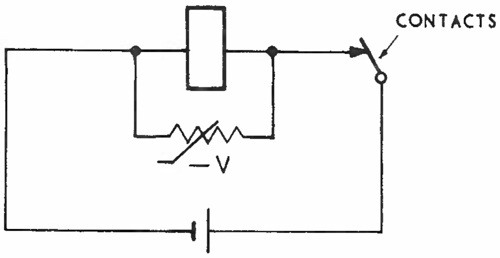


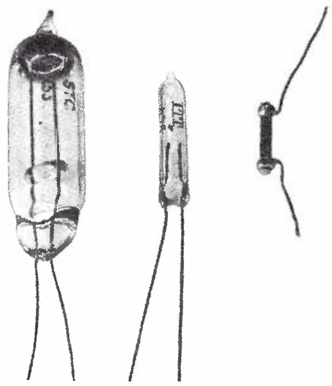
FIG. 14. VARISTOR AS A SURGE SUPPRESSOR.

A further application of varistors is for lightning protection. They are wired directly across the equipment to the protected, and bypass surge currents that would otherwise destroy the protected equipment.

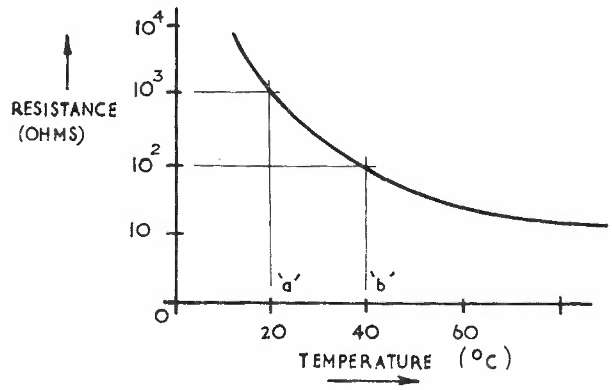
6. THERMISTORS.

6.1 Most semiconductor materials have a 'negative temperature coefficient of resistance'; that is, their resistivity decreases with increase in temperature. In certain semiconductor compounds, such as metal oxide mixtures, this temperature dependence is quite marked; small pieces or 'beads' of these materials have a resistance which changes from several hundred thousand ohms at $0^{\circ}C$, down to a few hundred ohms at $100^{\circ}C$. The high degree of temperature sensitivity of these compounds is utilised in semiconductor 'thermistors' (from Thermal Resistor).

The temperature-resistance characteristic of a typical semiconductor thermistor is shown in Fig. 15b. The graph shows that when the thermistor temperature is increased from 20°C to 40°C (point 'a' to point 'b'), the resistance decreases from 1000 ohms to 100 ohms. Further increase in temperature causes further reduction in resistance. The resistance change in a thermistore is, inversely (or 'negatively') related to temperature change. Thermistors therefore are said to have a 'negative temperature coefficient' (NTC) of resistance. The alternative semiconductor thermistor name of NTC Resistor stems from this characteristic.



(a) Typical Thermistors.



(b) Typical thermistor characteristic.

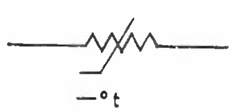
FIG. 15. THERMISTORS.

6.2 Thermistors are used in circuits where current flow has to be controlled by temperature. The effect of temperature changes on the current in an NTC thermistor is as follows:

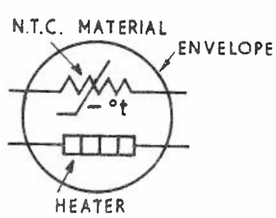
- When the temperature of a thermistor increases, the resistance decreases, causing the current to increase.
- When the temperature of a thermistor decreases, the resistance increases, causing the current to decrease.

6.3 TYPES OF NTC THERMISTOR. There are two main classifications of thermistor, the 'directly heated' and the 'indirectly heated' types.

- DIRECTLY HEATED THERMISTORS consist of a single piece of NTC material with two leads. They are heated either by current flow through the NTC material, or by their surroundings. The circuit symbol is shown in Fig. 16a.
- INDIRECTLY HEATED THERMISTORS consist of an assembly containing a thermistor and a heating element inside a sealed glass tube. The temperature of the NTC material is controlled by the current flow in the heater. The circuit symbol is shown in Fig. 16b.



(a) Directly heated.



(b) Indirectly heated.

FIG. 16. THERMISTOR CIRCUIT SYMBOLS.

6.4 APPLICATIONS. The three main methods of using thermistors in telecommunications equipment are as follows:

- TEMPERATURE SENSING CIRCUITS: This involves positioning a directly heated thermistor on a circuit board, or other suitable location, so that its temperature follows that of its immediate surroundings. The resistance change resulting from temperature changes is used to control the operation of an appropriate circuit. For example, thermistors are fitted to some types of equipment where excessive temperature would damage components. The thermistor acts as a heat sensor, and governs the operation of ventilation fans.

- TIME DELAY CIRCUITS: Directly heated thermistors are commonly used to provide time delays in relay circuits. The directly heated thermistor is connected in series with the relay that is to have the delay action (Fig. 17). When the circuit is energised, the current flow heats the thermistor. The thermistor resistance decreases, allowing more current flow. This process continues until the current approaches its maximum value and the relay operates. Circuits such as this give much longer time delays than relay slugs.

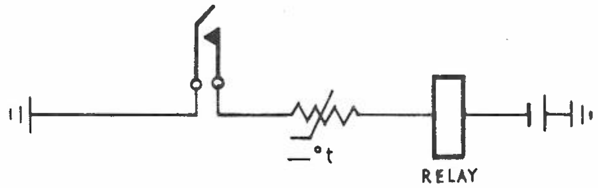


FIG. 17. SIMPLE TIME DELAY CIRCUIT.

- INDIRECTLY CONTROLLED CIRCUITS: Some items of automatically controlled line transmission equipment require the operation of one circuit to be under the control of current flow in an entirely separate circuit. One method of achieving this is by using an indirectly heated thermistor (Fig. 18). The controlling current flows through the heater and the resultant changes in thermistor temperature determine the current flow in the controlled circuit. This method is usually preferred to mechanically operated devices, as it is more reliable under extreme climatic conditions.

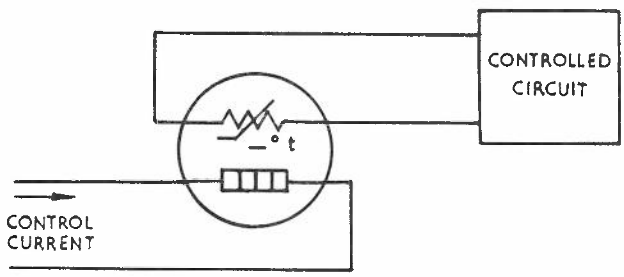


FIG. 18. "INDIRECT" CONTROL WITH A THERMISTOR.

6.5 POSITIVE TEMPERATURE CO-EFFICIENT (PTC) THERMISTORS are those which increase their resistance when heated. They are made from metals rather than from semiconductor materials. An ordinary incandescent lamp is a form of PTC resistor.

7. HALL-EFFECT DEVICES.

7.1 When a magnetic field acts perpendicular to a thin film of metal or semiconduc material (Fig. 19) the D.C. resistance of the film increases in proportion to strength of the field. This is caused by the magnetic field deflecting the current paths at an angle to their normal direction. This behaviour is named 'Hall-effect' after E.L. Hall who discovered the effect in 1879.

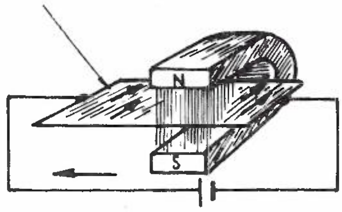
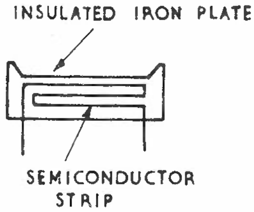
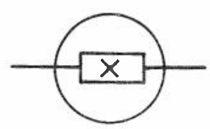


FIG. 19. HALL EFFECT.

7.2 Two-terminal components utilising the Hall-effect (such as that illustrated in Fig. 19) are usually termed 'magneto-resistors'. The construction of a typica magneto resistor is shown in Fig. 20a. In this device, a semiconductor film which about 2×10^{-3} millimetres thick is laid on a flat piece of insulation-coated iron plate. Iron is used because it causes concentration of magnetic flux close to the semiconductor material.



(a) Construction



(b) Circuit Symbol.

FIG. 20. MAGNETO-RESISTOR.

7.3 APPLICATIONS. The contactless push-button switch (Fig. 21) is a typical examp of the use of Hall-effect devices. The switch consists of case containing a magneto-resistor, an integrated circuit (IC), and the plunger mechanism. A permaner magnet is fixed to the plunger so that it passes close to the magneto-resistor when the plunger is depressed. The resulting change of resistance changes the value of a current flow in the magneto-resistor. The comparatively weak voltage thus generated is amplified to the required level by the IC. Although such switches are more cost than mechanical types, they are free from the undesirable effects of contact bounce and contact contamination.

Hall-effect devices are also used for measurement of magnetic field strength, and for contactless commutation in small D.C. motors.

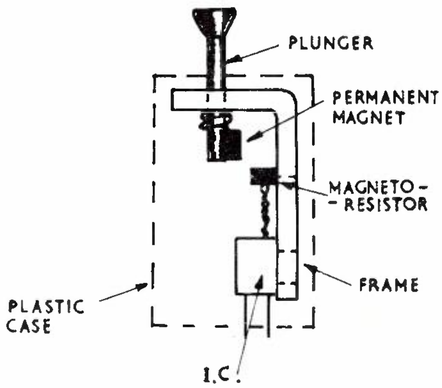


FIG. 21. PRINCIPLE OF CONTACTLESS PUSH-BUTTON SWITCH.

PHOTO-ELECTRIC AND PHOTO-EMISSIVE DEVICES.

GENERAL. Photo-electric semiconductor devices or 'photo-cells' changed their electrical behaviour when subjected to light waves. Conversely, photo-emissive iconductor devices emit light waves when current flows through them. Photo-ssive semiconductor devices are described in para. 8.10.

? The two main types of photo-electric semiconductor device are:

- PHOTOCONDUCTIVE DEVICES, which change their resistance in proportion to light intensity. The three main types of photoconductive devices are the light dependent resistor or LDR, the photo-diode, and the photo-resistor.

- PHOTOVOLTAIC DEVICES, which develop an e.m.f. when exposed to light.

3 Photoconductive devices all respond in the same general way to changes in light intensity, in that their resistance decreases when the light intensity is creased. This effect is shown in Fig. 22, where a low light level (point 'x') is companied by a high value of resistance. A change to a high light level (point ') causes the resistance to decrease appreciably. These devices, therefore, come more conductive when the light intensity is increased.

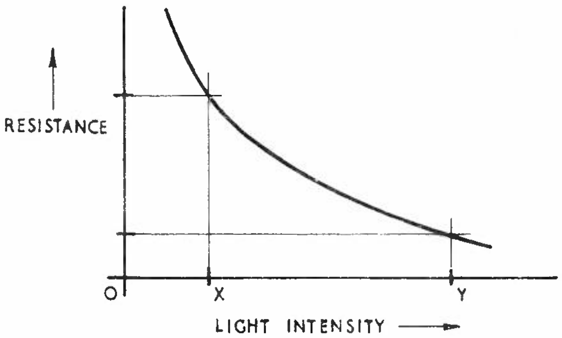


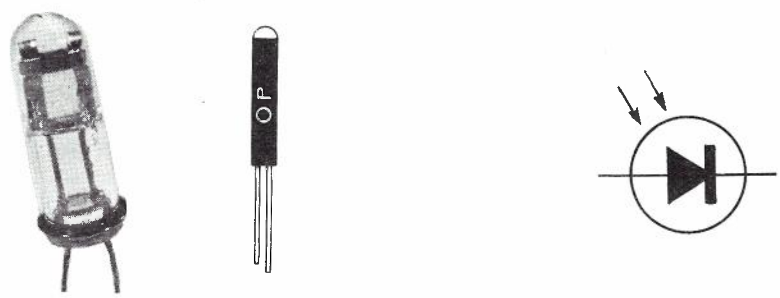
FIG. 22. PHOTOCONDUCTIVE EFFECT.

8.4 LIGHT DEPENDENT RESISTORS are the simplest type of photo-conductive device. They consist of a single piece or crystal of light-dependent semiconductor material such as selenium or cadmium sulphide, to which electrodes are attached. The semiconductor material is sealed inside a protective jacket of clear plastic (Fig. 23a). Normal daylight causes resistance values of the order of one hundred to one thousand ohms, and the non-illuminated resistance value is of the order of one to one hundred megohms. Typical LDR circuit symbols are shown in Fig. 23b. In these symbols, the arrows represent light rays.

(a) Typical LDR (b) Circuit Symbols

FIG. 23. LIGHT DEPENDENT RESISTOR.

8.5 PHOTO-DIODES consist of either a P-N semiconductor junction or a metal-to-semiconductor junction, sealed in a transparent protective jacket (Fig. 24a). When connected into a circuit which reverse-biasses the junction, the resistance of the device becomes subject to the amount of light falling on the junction. An increase in the light intensity causes the resistance to decrease, allowing more reverse current through the junction. Conversely, reducing the light intensity increases the junction resistance, and thereby reduces the reverse current. The conductivity, therefore, is proportional to light intensity, similar to the characteristic shown in Fig. 22. The circuit symbol is shown in Fig. 24b..



(a) Typical Photo-Diodes (b) Symbol

FIG. 24. PHOTO-DIODE.

8.6 PHOTO-TRANSISTORS are transistors constructed with a transparent 'window' adjacent to the base-emitter junction. Illumination of the base region has a similar effect to that of illuminating the junction of a photo-diode, in that the resistance of the transistor decreases with an increase in light intensity. However, photo-transistors are much more sensitive than photo-diodes, because of the amplification effect of transistors. This results in a much greater change in resistance, for a given change in light intensity, than for a photo-diode. Fig. 25 shows typical photo-transistors and the circuit symbol for a NPN photo-transistor.

(a) Typical Photo-Transistors.

(b) Circuit Symbol for NPN Photo-Transistor.

FIG. 25. PHOTO-TRANSISTOR.

8.7 APPLICATIONS OF PHOTO-CONDUCTIVE CELLS. One of the most common applications of photo-conductive cells is in light actuated switching circuits. Fig. 26 shows a simple example of such a circuit used in automatic mail handling equipment for detecting the presence of letters. The photo-cell is normally illuminated by a light beam and its resistance therefore is low. When the light beam is interrupted by a letter, the resistance of the photo-cell increases, causing the current to decrease. This change in current value causes a change in P.D. across the photo-cell, providing the signal to the input of the amplifier. The amplifier output is used to operate a relay, which in turn operates the required part of the equipment. In other applications, the load could consist of an indicator or some type of logic circuitry.

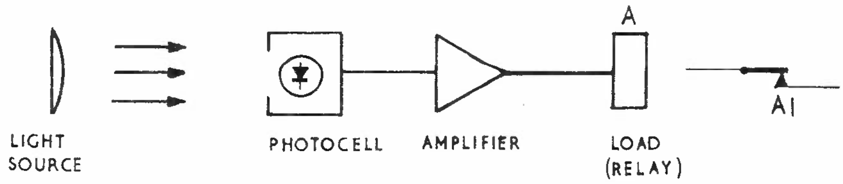
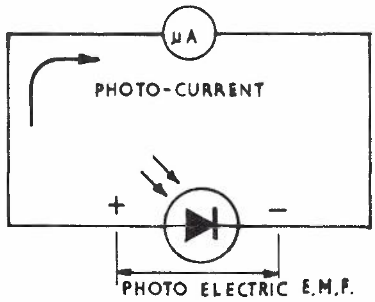
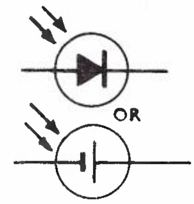


FIG. 26. PRINCIPLE OF LIGHT ACTUATED SWITCHING CIRCUIT.

8.8 LIGHT SENSITIVITY OF SEMICONDUCTOR JUNCTIONS. All semiconductor junctions are sensitive to light waves. This accounts for the opaque jacket on normal diodes and transistors. If the jacket is damaged or removed, allowing exposure of a junction to light waves, the performance of the device is seriously affected.

8.9 PHOTO-VOLTAIC DEVICES are semiconductor junction components which generate an e.m.f. when exposed to light waves. When they are connected into a circuit without an external power supply (Fig. 27a), the illumination of the junction area causes generation of a voltage, and the resultant current flow. The amount of current flow depends on the type of junction and the intensity of the light.



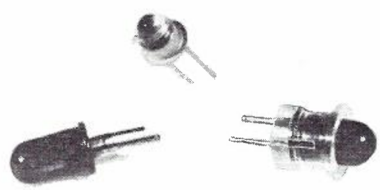


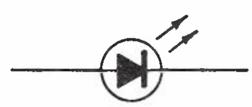
(a) Generation of Photo-Current. (b) Circuit Symbols.

FIG. 27. PHOTO-VOLTAIC EFFECT.

Photo-voltaic cells are used as 'solar cells' for the generation of electricity from sunlight. They are grouped together in a solar battery, and when used in conjunction with a storage battery, provide enough energy to power transistorised transmission equipment. The two commonly used circuit symbols for photo-voltaic devices are shown in Fig. 27b.

8.10 PHOTO-EMISSIVE SEMICONDUCTOR DEVICES are P-N junction components which emit light when a current flows through them. Most light-emitting semiconductor devices consist of diodes formed from elements such as gallium and arsenic. The emission of light is not caused by heat, as in incandescent lamps, but by the effect of the current flow on the internal structure of the semiconductor material. They operate on low values of current, 20mA being a typical value, and have a brightness comparable to a similarly sized incandescent lamp. Fig. 28a shows a typical light-emitting diode (LED). The symbol for the LED is shown in Fig. 28b.





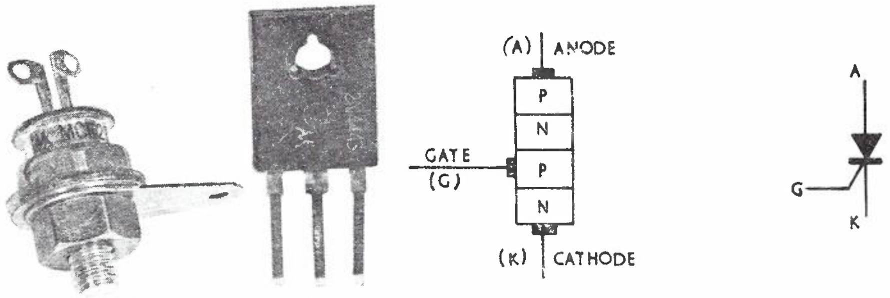
(a) Single Unit. (b) Symbol. (c) Digital Display Unit.

FIG. 28. LIGHT-EMITTING DIODE.

Light-emitting diodes are used individually as panel lamps on telecommunications equipment, or are grouped together into 'digital display' blocks (Fig. 28c) for use on digital read-out instruments.

9.1 'Thyristor' is the family name for solid-state switching devices that have only two electrical states, the 'off' state and the 'on' state. Unlike transistors and diodes, they cannot take up an intermediate resistance value between these states. There are many types of thyristor, including three electrode devices known as controlled rectifiers, and two electrode devices known as diacs. The most common type of thyristor is the silicon controlled rectifier (SCR).

9.2 SILICON CONTROLLED RECTIFIERS are a four layer P-N-P-N device having three electrodes termed the anode, cathode, and gate (Fig. 29b). These electrodes are designated on the circuit symbol (Fig. 29c) which is a modification of a rectifier or diode symbol. The anode and cathode have similar functions to those of an ordinary diode, and the gate is used to control the switching on of the SCR.



(a) Typical SCR's (b) Structure (c) Circuit Symbol

FIG. 29. SILICON CONTROLLED RECTIFIERS.

9.3 The action of an SCR is explained as follows:-

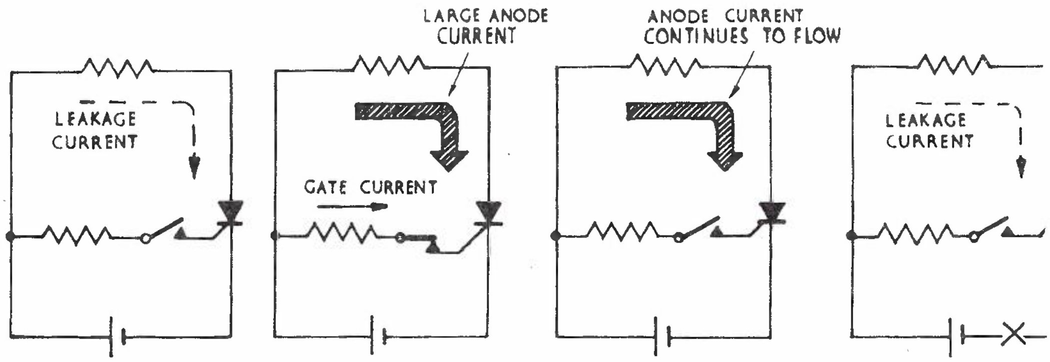
- In the off state the SCR is non conducting. (Fig. 30a). It has a very high resistance between the cathode and anode, and only a very small leakage current flow.

- An SCR will not conduct unless it is switched on by a suitable forward bias voltage between the gate and the cathode. Application of this forward bias voltage switches the SCR from its normal high resistance off state to the low resistance on stage (Fig. 30b).

- Once the SCR is switched on it remains 'on' independent of the gate voltage (Fig. 30c). In other words, the gate voltage can be removed and the SCR will continue to conduct.

- The SCR is switched off either by reducing the anode current below a critical value called the holding current, or by reversing the anode voltage. Fig. 30d shows the SCR being switched off by opening the circuit, thus reducing the anode current to zero.

The SCR can only be switched on for current flow in the one direction, that is, with the anode positive and the cathode negative. If the potentials across the cathode and anode are reversed, the SCR will be non-conducting, preventing the flow of anode current regardless of the voltage applied to the gate. This one-way conducting characteristic when switched on is usually called 'controlled rectifier' action.



(a) SCR in off state

(b) SCR switched on by momentary gate signal

(c) SCR remains on after gate signal removed

(d) Anode current interrupted - SCR switches off

FIG. 30. OPERATION OF AN SCR.

The SCR can also be switched on by means of high forward voltage across anode and cathode. Once switched on in this fashion, it behaves the same way as an SCR switched on by a gate signal. However, this method is rarely used in practice.

9.4 D.C. APPLICATIONS. Fig. 31 shows a simple switching circuit using an SCR t switch the current to a 'contactor', which is a heavy-duty form of relay used in power plant. In this circuit, an SCR is used because it can be switched on by comparatively low power pulse applied to the gate. Also, although the contactor requires several amps to operate, there is little power dissipation in the SCR because of its low anode resistance when switched on.

The input circuit to the SCR consists of a D.C. supply, a switch S1, and a limitin resistor which prevents excessive current through the gate-cathode junction. When the switch is closed, current flows through the gate-cathode junction, causing the SCR to turn on and operate the contactor. When S1 is opened, the input current ceases, but the SCR remains on. The SCR is turned off by some other circuit actio in this type of circuit, the turning-off is usually done by a switch (or springset that either opens the anode circuit as shown, or short-circuits the anode to the cathode.

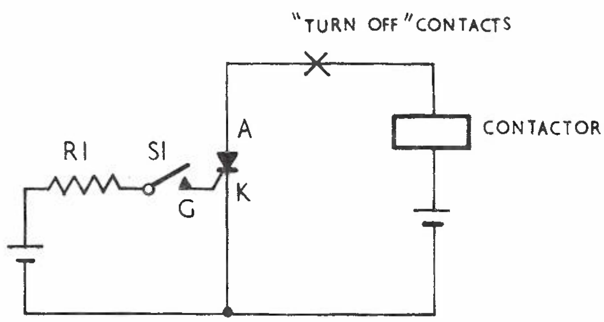


FIG. 31. SCR AS A SWITCH.

9.5 A.C. APPLICATIONS. In most A.C. applications, SCR's function as controlled rectifiers. They have low input power requirements, and low power dissipation when turned on. They therefore provide an efficient and reliable means of controlling high levels of output voltage and current from telecommunication power plant, where it is essential that the output voltage remains constant regardless of the current drawn by the load. Fig. 32 shows a typical D.C. power supply that provides a constant output voltage. The rectifier is a full-wave bridge, consisting of two ordinary rectifier diodes and two SCR's functioning as controlled rectifiers. the SCR gate circuits are controlled or 'triggered' by pulses, supplied at the appropriate instant in each half-cycle, from a trigger pulse circuit. By this means, the SCR's control the length of the half-cycles of energy supplied to the load. The average amount of energy available to the load, therefore, is controlled by the amount of time the SCR's are turned on in each cycle.

When A.C. is applied to the rectifier bridge,

- On the half-cycle that makes terminal 'A' positive, D2 and SCR2 are forward biassed. At the appropriate instant, SCR2 is triggered on, and current flows in the load for the rest of the half cycle.

- On the next half-cycle D2 and SCR2 are turned off, and D1 and SCR1 are forward biassed. At the appropriate instant, SCR1 is triggered on, and current flows in the load for the rest of the cycle.

- When the output voltage changes because of changes in load current, the trigger pulse circuit changes the timing of the pulses, in order to correct the value of the output voltage. For example, if the output voltage starts to rise, the trigger circuit will delay the application of trigger pulses until later in each half-cycle, reducing the average value of output voltage.

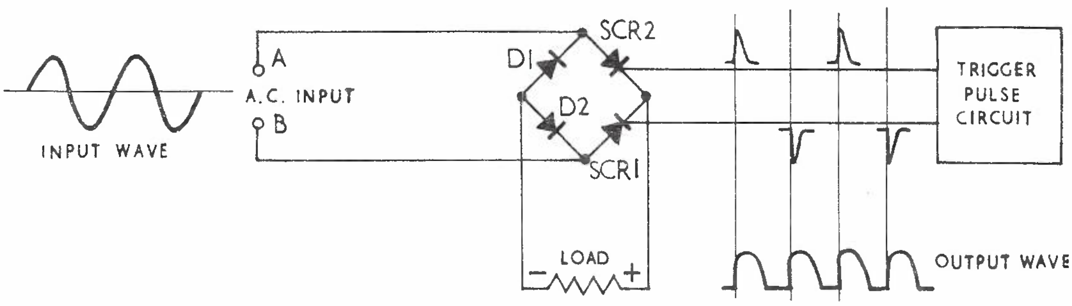


FIG. 32. SCR'S USED FOR POWER CONTROL.

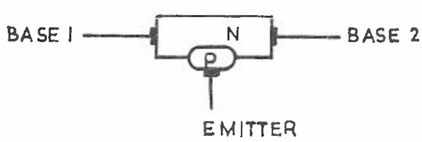
Circuits of this type are also used extensively for applications such as motor speed control and lamp dimming. The control of the time of switching of SCR's in such circuits can be achieved either manually or automatically.

9.6 OTHER TYPES OF THYRISTOR. There are several other types of thyristor bes: the SCR. Some of these types are:

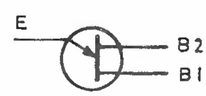
- TRIACS, which conduct current in either direction when turned on by a g signal. They are mainly used in A.C. power control circuits.
- SILICON CONTROLLED SWITCHES (SCS's), which have a similar structure to SCR (see Fig. 29), but have a second gate called the 'anode gate'. The provision of the anode gate adds electrical characteristics that make the SC more suitable than SCR's for some switching applications. Silicon controlle switches are used in SCR trigger circuits and other switching applications.
- DIACS, which have only two electrodes. When a sufficiently high voltag either polarity is applied across the leads, the diac 'breaks over' and conducts readily. When the voltage is removed, the resistance returns to it normal high value. Diacs are used in SCR and triac triggering circuits.
- PROGRAMMABLE UNIJUNCTION TRANSISTORS, or 'complementary SCR's', which a low-power SCR's having an anode gate instead of a cathode gate. They a commonly used in SCR trigger circuits.

10. UNIJUNCTION TRANSISTORS. (U.J.T's.)

10.1 The unijunction transistor or 'double-base diode' consists basically of a junction diode having two connections to its base. Most unijunction transis consist of a base of N-type material with a P-type region fused on to one side. P-type region is termed the emitter. (Fig. 33a). The circuit symbol is shown in Fig. 33b.



(a) Typical Construction



(b) Circuit Symbol

FIG. 33. UNIJUNCTION TRANSISTOR.

10.2 CHARACTERISTICS. A typical unijunction transistor has a resistance of 4 t 12 KΩ between B1 to B2. From either B1 or B2 to E, it displays junction dio characteristics. These characteristics are represented by the circuit arrangemen shown in Fig. 34. The resistors RB1 and RB2 in series represent the D.C. resista between the base 1 and base 2 electrodes. The diode characteristic between the emitter and either base is represented by the diode symbol.

In most applications, the diode action of the P-N junction is controlled by the potential across B1 and E. When a forward bias is applied between E and B1, the junction switches on, causing the E to B1 resistance to drop sharply This chan in resistance is indicated by representing RB1 as a variable resistor.
The reduction in the E to B1 resistance results in a drop in the total resistance between B1 and B2. For example, if the respective values of RB1 and RB2 (before the E-B1 junction is switched on) were 4 KΩ and 5 KΩ, the total B1 to B2 resistan would be 9 KΩ. After the E to B1 junction is switched on, assuming RB1 drops to negligible value, the total B1 to B2 resistance would be little more than 5 KΩ.

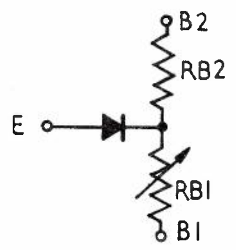


FIG. 34. D.C. CHARACTERISTICS OF A UJT.

10.3 Unijunction transistors are most commonly used in pulse generating circuits and timing circuits. Fig. 35 shows a typical UJT 'relaxation oscillator' or pulse generator. This circuit forms the basis of the explanation of the operation of a unijunction transistor in a simple typical application.

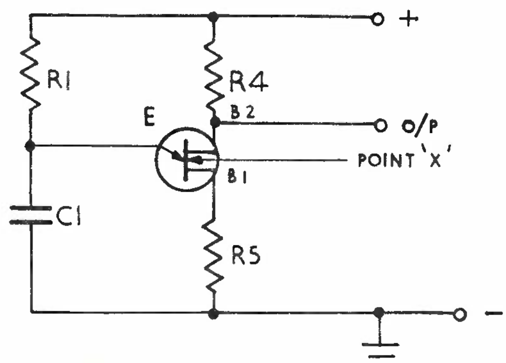


FIG. 35. UNIJUNCTION OSCILLATOR.

10.4 OPERATION. When the supply voltage is connected:

- C1 commences to charge via R1.
- Current flows through R4, the base material, and R5 in series. This current causes P.D's across RB2 (between points B2 and X), and across (RB1 X and B1).
- The P.D. between X and B1 reverse biasses the E to B1 junction, preventing current flow from C1.

When C1 has charged to the point where its voltage exceeds the reverse bias voltage across E and B1,

- The emitter-base 1 junction switches on, allowing rapid discharge of the capacitor.
- The increased current flow through R5 is accompanied by a drop in the P.D., due to the drop in resistance of the E to B1 junction.
- The drop in resistance of the E to B1 region allows more current to flow through R4, causing its P.D. to rise.

When the fast discharge of C1 causes its P.D. to drop below that required to maintain the forward bias voltage on the E and B1 junction.

The junction reverts to the blocking condition.

- The P.D's revert to their former values.
- C1 commences to charge again.

In this circuit, therefore, the unijunction transistor functions as a switch that 'fires' each time the capacitor voltage reaches the appropriate value. The charge and discharge of C1 cause the generation of a sawtooth waveform (Fig. 36) across i hence the common name 'sawtooth generator' for this circuit.

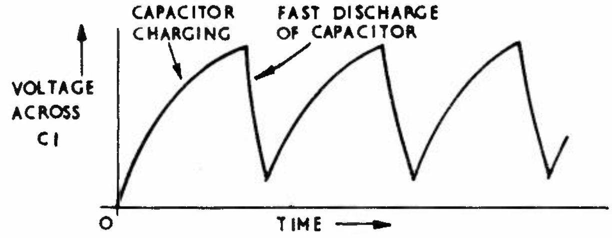


FIG. 36. WAVEFORM ACROSS C1.

11. TEST QUESTIONS.

1. *Fig. 37 shows a half-wave rectifier circuit.*

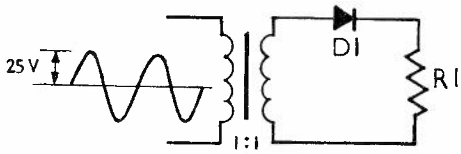


Fig. 37.

(a) What is the peak P.D. across D1 during 'blocking' half cycles?

(b) Assuming D1 to have a forward P.D. of 0.5V during conduction, what is the peak P.D. across R1 during conduction?

2. *Complete this circuit of a bridge rectifier, and label the polarity of the output terminals.*

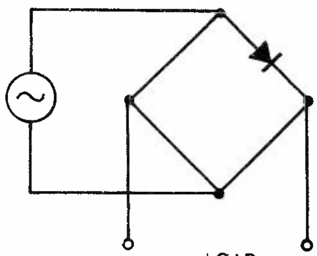


Fig. 38.

3. *Fig.39 shows a rectifier supplying full-wave D.C. to a relay. At instant 'x' on the input wave, the input polarities are as shown. Which 2 diodes are conducting at this instant?*

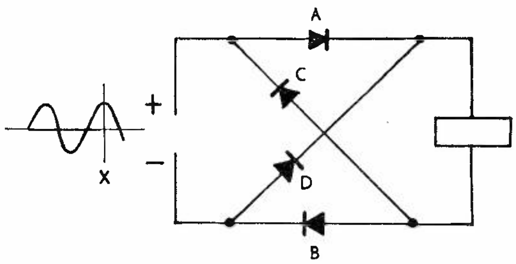


Fig. 39.

4. *Write in your own words the meanings of the expressions*

   (i) Peak Inverse Voltage

   (ii) Surge Current

   as applied to diodes.

5. *(a) Sketch the circuit symbol for a Zener diode.*

   (b) Sketch the E/I graph for a Zener diode. Show the characteristic for a 9.1 volt diode (current values not necessary).

TEST QUESTIONS (CONTD.)

6. *Complete this circuit of a simple voltage regulator.*

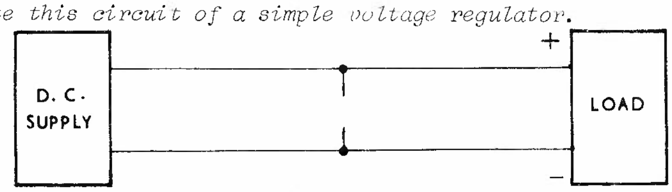


Fig. 40.

7. *Draw a graph that illustrates the resistance/temperature characteristic of a thermistor.*

8. *Sketch the circuit symbol for an indirectly heated thermistor.*

9. *Briefly list the steps that lead to a decrease in current through a directly heated thermistor.*

10. (a) *Sketch the circuit symbol of a varistor.*

    (b) *Briefly list the steps that lead to an increase of current flow through a varistor.*

11. *From this group of circuits symbols, identify the correct symbols for*

    (a) *A photo-transistor*

    (b) *A photo-voltaic device.*

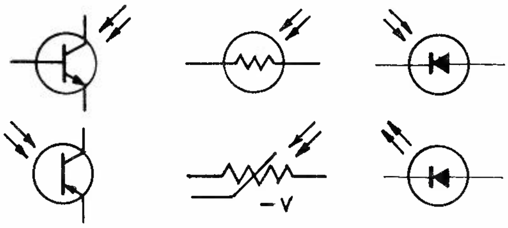


Fig. 41.

12. *Draw a graph that shows the resistance vs. light intensity characteristic of a photo-conductive device.*

13. (a) *Sketch the circuit symbol for a light emitting diode.*

    (b) *What is the main difference between the operation of an incandescent lamp and an L.E.D.?*

14. *Draw a simple circuit showing the generation of photo-current by a photo-voltaic cell. Show the output polarity of the cell.*

15. (a) *Label the electrodes of this SCR symbol.*

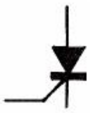


Fig. 42.

(b) *Name the two ways of making an SCR switch on.*

TEST QUESTIONS (CONTD.)

16. *What is the result of applying a reverse potential of 200V to the A and K terminals of a 300V SCR?*

17. *Name two ways of turning off the anode current of an SCR.*

18. *Sketch and label the circuit symbol for a unijunction transistor.*

19. *If you were testing a unijunction transistor with a multimeter,*

    (a) *what characteristic would you expect between the two 'B' leads?*

    (b) *what characteristic would you expect between each base and the emitter?*

20. *In what way does the resistance of a Hall effect device depend on an applied magnetic field? (Answer in terms of both field direction and intensity).*

21. (a) *Sketch a graph that illustrates the dependence of capacitance upon voltage in a varactor.*

    (b) *Draw the circuit symbol for a varactor.*

END OF PAPER.