WS No. 19 Mark III

# SEMI-CONDUCTOR DEVICES

## INTRODUCTION

1. This is the first of a series of three EMERs dealing with semi-conductor devices, division of the series is as follows:-

(a) Tels A 018 A series of brief descriptions, each one dealing with a distinct kind of semi-conductor device. No reference will be made to any individual type. This section will be kept up to date by the issue of additional sheets, as new kinds become available.

(b) Tels A 339 Description and examples of basic circuits involving the use of semi-conductor devices.

(c) Tels A 412 The elements of servicing, and techniques peculiar to circuits using semi-conductor devices.

2. Basic theory of semi-conductors will be found in

(a) The Services Text Book of Radio. vol. 1, and vol. 3.

(b) Basic electronics. Published by, The Technical Press.

## DIODES AND TRANSISTORS

3. Although a large number of different semi-conductor devices are in current use, many of them are only specialised forms of solid state diodes or transistors.

4. A semi-conductor diode has an electrical function similar to that of a conventional vacuum diode, exhibiting a characteristic curve of low forward resistance and high reverse resistance. (Fig 1).

5. A transistor is a three element device in which current flowing between emitter and collector is controlled by a proportionally small current in the base. The base current in the transistor may therefore be used to control the output current in the same way that the grid voltage in a conventional triode valve

controls the output current, and may be used as the active element in many electronic circuits, Fig 2 shows transistor symbols.

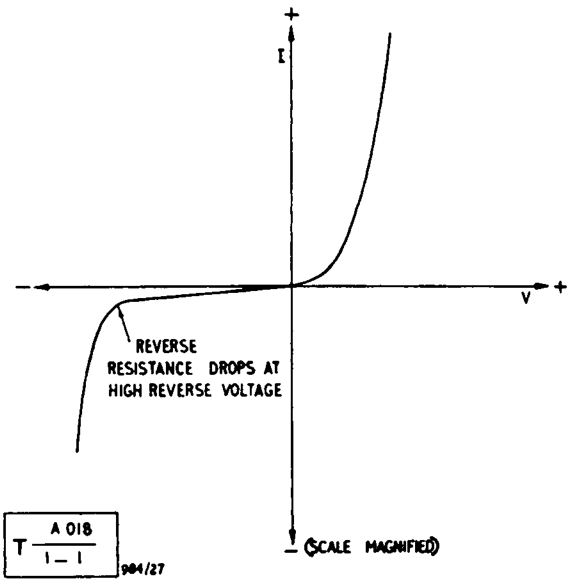


Fig 1 - Diode characteristic

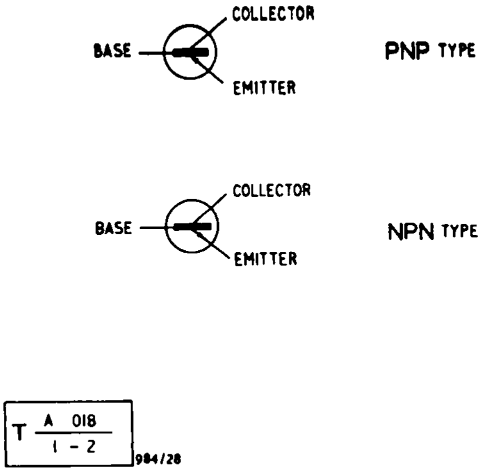


Fig 2 - Transistor symbols

THERMISTORS
(Fig 3)

6. The resistance of ordinary metal conductors increases slightly as a result of increase in temperature but thermistors (or thermal sensitive resistors) have a large temperature/resistance coefficient, (usually negative). This property has many applications in measurement and control circuits and is sometimes used to provide temperature compensation in transistor biasing arrangements.

7. The heat sensitive part of a thermistor is a two terminal non-polarised device and may be operated:-

(a) By ambient temperature changes.

(b) By change of current flow through the thermistor with consequent change of internally dissipated heat.

(c) By a resistive heating element placed close to the thermistor, but electrically isolated from it.

8. Thermistors are available in a variety of shapes and sizes ranging from spherical beads one eighth of an inch in diameter, to rods an inch or more in length. When a heating element is used the complete assembly is usually enclosed in a glass or metal envelope and provided with four lead out wires.

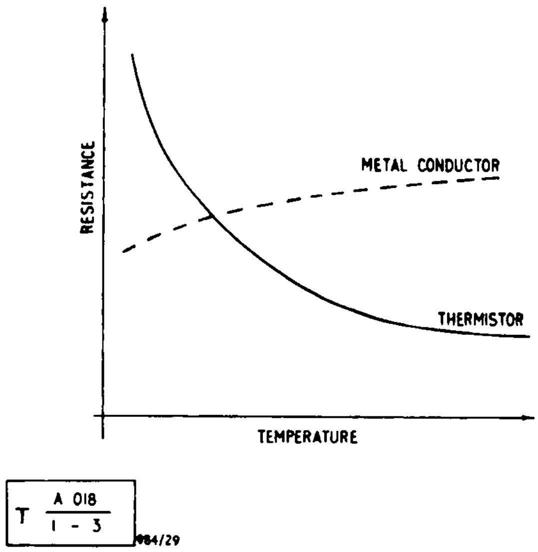


Fig 3 - Thermistor characteristic

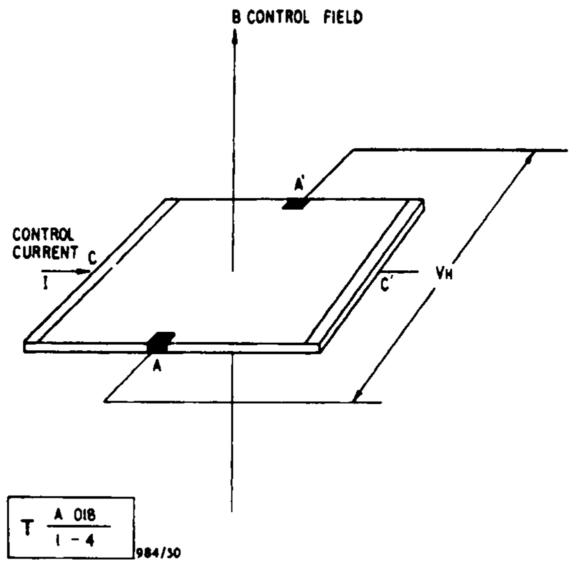


Fig 4 - Hall generator

HALL GENERATORS

(Fig 4)

9. Electrical devices utilising the 'Hall effect' are known as Hall Generators. The 'Hall effect' in semi-conductors is the development of a potential difference VH, between the edges A and A1 of a thin strip of material and occurs only when two conditions are fulfilled:-

(a) Current from an external source is allowed to flow between edges C and C1.

(b) An external magnetic field is set up in the direction of B.

10. It will be seen that the three axes are mutually at right angles. The voltage thus set up, is proportional to control current I, and control field B, so that three basic modes of operation are possible.

(a) Fixed control current and variable field intensity, causing similar variation of VH.

(b) Fixed field intensity and variable, control current, causing similar variation of VH.

(c) Both field and control current variable, so that VH is proportional to the product of the instantaneous values of I and B.

11. It will be seen that configuration (c) has some application as a modulator whilst (a) is suitable for direct measurement of magnetic field intensity. Hall generators are often in the form of thin wafers, the size of a postage stamp or smaller, typically one sixteenth of an inch thick.

TUNNEL DIODES

12. Tunnel diodes, although outwardly similar to other miniature semi-conductor diodes, have different electrical characteristics. Fig 5 shows a typical voltage/current characteristic exhibited by a tunnel diode, and it will be observed that there is a negative resistance region between X and X1. Tunnel diodes operating in this negative resistance region, can function as, amplifiers, oscillators and switches, usually in low power applications. These devices have fast rise times, good high frequency performance and when exposed to radiation or large temperature changes, show much greater stability than junction transistors of comparable power handling capacity.

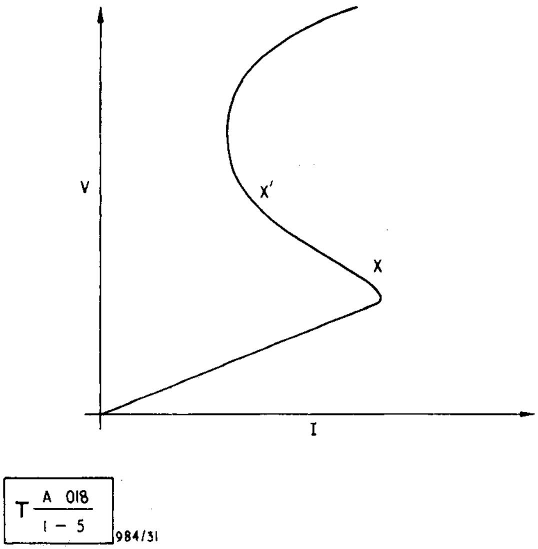


Fig 5 - Tunnel diode characteristic

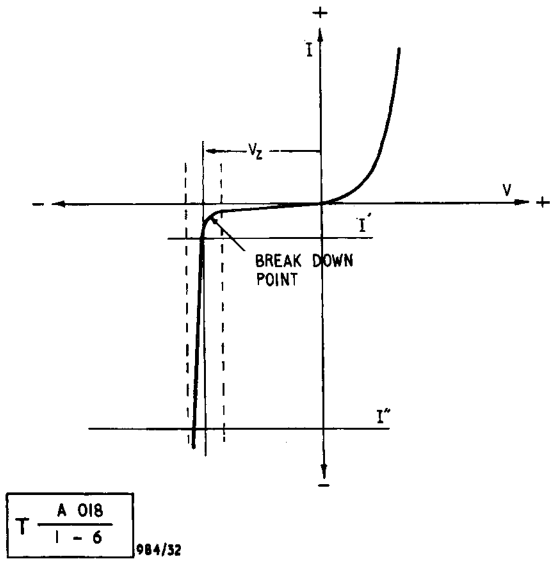


Fig 6 - Zener diode characteristic

ZENER DIODES

13. Zener diodes are junction diodes having a well defined reverse breakdown point and low slope resistance beyond this point. In Fig 6 the device is biased to the voltage VZ, and large current changes within the range I' to I" will produce only small changes in VZ, as shown by the dotted lines. The breakdown point is temperature dependent and may exhibit a positive or negative change depending on applied voltage, and current. The slope resistance and reverse leakage current, both increase proportionally with junction temperature. Because of the improbability of two diodes having identical breakdown points and thermal drift characteristics, it is not usual for two or more to be connected directly in parallel, since unequal current sharing would result, with consequent damage to the diode. Zener diodes are available in a variety of voltage and power ratings and some can dissipate up to 30 watts. Main applications are; voltage surge limiters, shunt stabilisers and voltage references under conditions of varying load or supply currents.

## DOUBLE BASE DIODES

14. The construction of a double base diode is similar to that of a semi-conductor junction diode except that two connections are made to different points on the base electrode. These points are shown as 1 and 2 in Fig 7. For normal operation, points 1 and 2 are connected across a bias voltage causing a small current to flow in the base. The operating circuit is then established between e and base. When a voltage is applied to the diode, a high impedance is exhibited until a value X (Fig 8) is reached, at which point, the characteristic shows a negative resistance region finally passing into a high conduction, low voltage state. Reducing the current reverses these conditions, returning the device to a high impedance state. The voltage level X, at which switching takes place, is accurately predictable, but the negative resistance region is small, so that the double base diode is almost exclusively used as a two state switch, in which role it has some application as a stable sawtooth voltage generator.


Fig 7 - Double base diode symbol

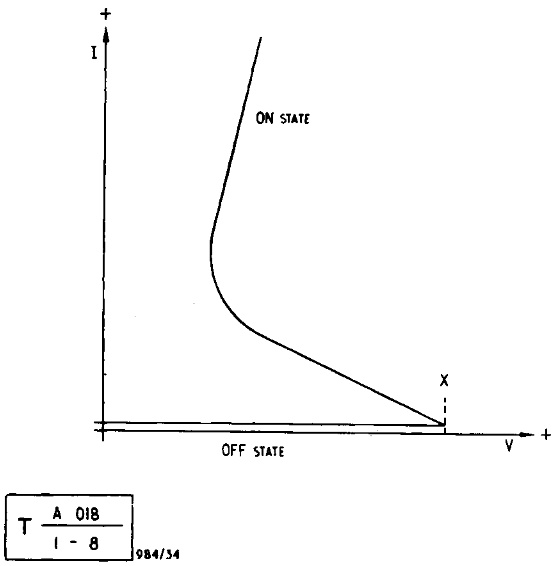


Fig 8 - Double base diode characteristic

## FOUR LAYER (SHOCKLEY) DIODES

15. Four layer or Shockley diodes are two terminal devices, which exhibit a switching action between low and high conductance states. Basically, these devices have a normal diode characteristic but with switching action in the 'reverse' condition only (Fig 9), or switching action in both 'forward' and 'reverse' directions (Fig 10). In some cases, one switching state may operate above the thermal breakdown (overload) point and would therefore not be used. Because of this, the usual operational mode is as a two state (ON-OFF) switch, biased in the forward direction. Four layer diodes have high switching speeds and are sometimes used as the active element in sawtooth waveform generators.

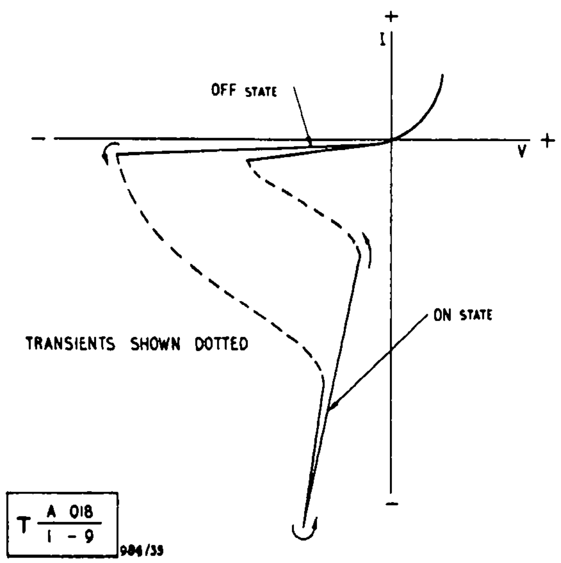


Fig 9 - Four layer diode
- 'reverse' switching

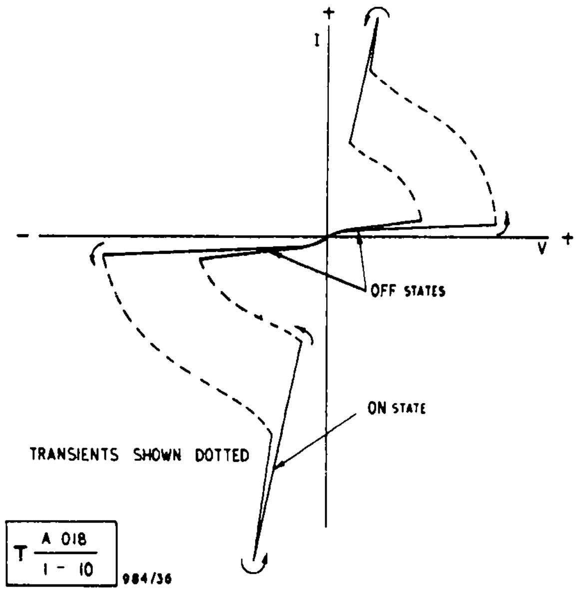


Fig 10 - Four layer diode
- 'forward' and 'reverse' switching

SEMI-CONDUCTOR VARIABLE CAPACITORS

16. A semi-conductor diode, when reverse biased, exhibits a value of capacitance which depends upon the reverse voltage:-

$$C \propto \frac{1}{\sqrt{V}} \quad \text{approx (see Fig 11)}$$

Semi-conductor variable capacitors are similar to miniature semi-conductor diodes but are designed to have a much greater range of capacitance. In the reverse biased condition the leakage current may be very small, so that the effective Q may be high, typically 1,000 at 1Mc/s. Operation up to 5,000Mc/s can be achieved in applications where a high Q value is unimportant. The minimum capacitance is limited by the highest reverse voltage that the device can withstand, which is about 24 volts in the case of the small types operating in the range 0.2pf to 2pf. The larger types with a typical range of 150pf to 400pf have a maximum reverse voltage of about 6 volts. Applications for semi-conductor variable capacitors are; automatic and remote tuning, automatic frequency control and frequency modulation.

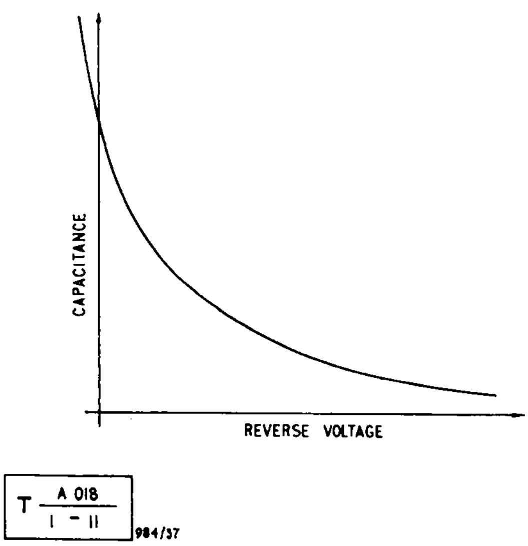


Fig 11 - Semi-conductor variable capacitor
- typical characteristic

PHOTOSENSITIVE DEVICES

17. The photosensitive diode is a semi-conductor junction diode encapsulated in a transparentenvelope, or a container with a 'window' at one end. In total darkness the photo-diode has a normal characteristic with low reverse conductance, so that only small reverse or "dark current" can flow. Light falling on the device causes an increase in conductance, the increase being approximately proportional to the intensity of the light (see Fig 12). The conductance is also affected by the wavelength of the incident light, normal germanium junction photodiodes being capable of operation with visible light, but most sensitive to the infra-red part of the spectrum. In common with all other semi-conductor devices, the conductance of a photodiode is temperature dependent; so that circuits using photodiodes, are sometimes temperature compensated.

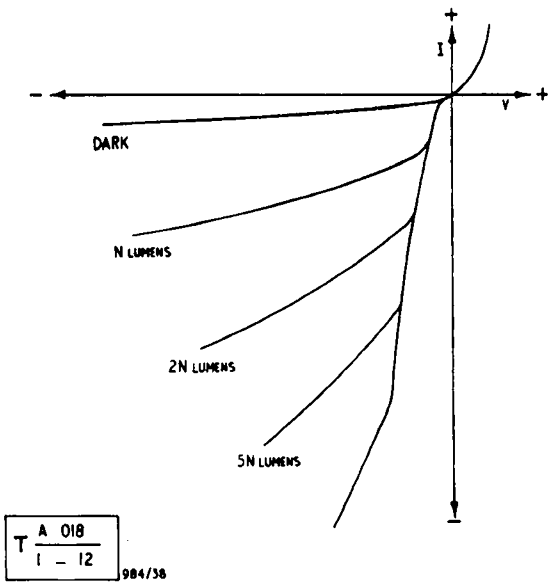


Fig 12 - Semi-conductor photosensitive device - typical characteristic

18. Photodiodes operated by light of very high intensity, can operate as switches, and are capable of working small relays. When light of low intensity is used, thermal drift and random current changes may be as large as the signal to be detected. In this case, it is usual to modulate the light source at low frequency. (eg. tungsten lamp on a.c. mains supply, is a 100 c/s source), so that the resultant alternating "light current" may easily be amplified.

19. Phototransistors are junction transistors which make use of the photodiode effect, and utilise transistor action to amplify the current changes due to light. The phototransistor characteristics are therefore similar to those of the photodiode, but the difference between dark and light currents may be greater. It is common practice for stability reasons, to connect the base to a bias chain, one element of which may be a thermistor to provide temperature compensation.

20. Applications for photosensitive devices are, process control, high speed tape readers, smoke detection, and in the case of phototransistors, intensity measurements.

SILICON CONTROLLED RECTIFIERS

21. A silicon controlled rectifier is a semi-conductor device which exhibits a high impedance to a voltage applied in either direction, between anode and cathode. Fig 13 shows the symbol. These high impedance regions are shown in Fig 14 as AB and BC, non-reversible breakdown sometimes taking place when voltages exceeds the value of A or C (typically 400V). A small current pulse applied to the 'gate' electrode of a forward biased controlled rectifier operating in the high impedance mode (BC in Fig 14) will cause it to switch to a high conductance mode (BD in Fig 14). The 'gate' pulse used to switch the device on, will not switch it off, and the only method of changing back to the high impedance mode is to interrupt the load current. Controlled rectifiers two or three inches long may handle up to 50 amps continuously, with less than two volts drop in potential. Typical values for the 'gate' pulse are 100mA at 3 volts, reverse leakage current being about 5mA or less. Since silicon controlled rectifiers are capable of switching large currents in very short time intervals, they are particularly suitable for power control purposes.

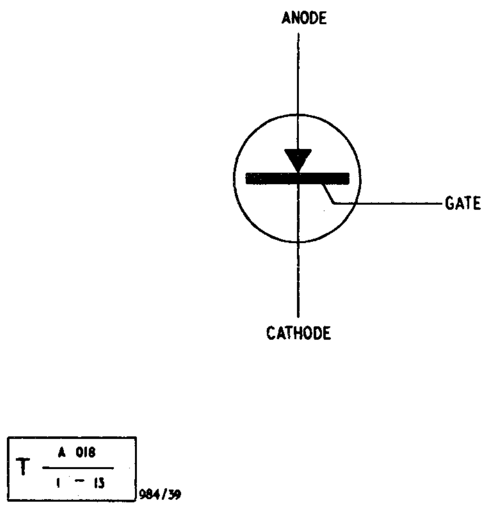


Fig 13 - Silicon controlled rectifier - symbol

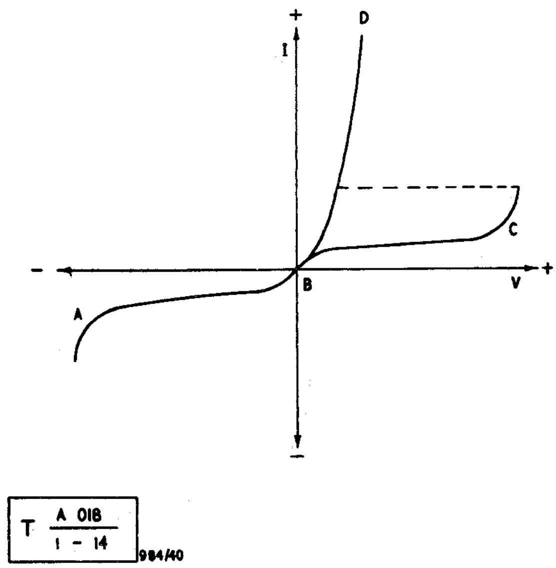


Fig 14 - Silicon controlled rectifier - typical characteristic

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