Mutual Characteristic

Fig. 34 is a graph of I_C against V_{BE} for a constant value of V_{CE} (5 volts) which is called the 'mutual' characteristic. It may be plotted by drawing a constant voltage line (i.e. one parallel to the I_C axis) on the output characteristic (fig. 33) at V_{CE} =5 volts.
The I_C values at the intersection points of this line and the V_{BE} lines are, approximately:

I_C	(mA)	5.0	3.8	2.8	2.0	1.3	1.0	0.5	0.2
V_{BE}	(mV)	650	640	630	620	610	600	585	560

When these values are plotted the solid line in fig. 34 is obtained. The dotted lines on each side indicate the deviations or 'spreads' within which limits all devices in the BC107 series can be expected to fall. It will be noticed that the I_C axis is drawn logarithmically to give an enlarged impression for very low values of I_C. However, the relationship between V_{BE} and I_C is not a linear one as can be seen by plotting the above values with both axes linear. This is due to the non-linear relationship between V_{BE} and I_B. We have seen in Section 2 that the current-voltage relationship for a p-n junction is exponential. In effect this means that the base-emitter resistance varies considerably with I_B.

Transfer Characteristic

The graph of I_C against I_B, called the 'transfer' characteristic (fig. 35), is linear. (Both axes are logarithmic.) This is because the number of electron-hole combinations per second in the base, which causes the base current, is proportional to the collector current (see Section 3). For linear amplification, a transistor in a common emitter circuit should be driven from a high resistance source, that is a source whose current output is not significantly affected by the variation in base-emitter resistance.

Transistor Ratings

Apart from detailed specification data sheets, manufacturers also publish 'quick-reference' data which gives the essential parameters and maximum permissible ratings for all their semiconductor devices. In this book we shall consider briefly these ratings for transistors only. For other definitions, symbols, etc. the reader is referred to British Standards, 3363, 3939 and 3494.

Typical 'quick-reference' ratings are as follows:

V_{CBO} max — The maximum collector to base voltage which should be applied to the device when the emitter is open circuited. For the BC107 this is 50 volts.

V_{CEO} max — The maximum collector to emitter voltage which should be applied when the base is open circuited. For the BC107 this is 45 volts.

I_{CM} max — The maximum peak value of collector current which should be permitted. For the BC107 this is 200mA.

$I_{C(AV)}$ max — The maximum average value of collector current. For the BC107 this is 100mA.

T_j max — The maximum junction temperature. For the BC107 this is 175°C.

P_{tot} max — The maximum total power which should be dissipated in the device itself. For the BC107 this is 300mW at an ambient temperature of 25°C.

h_{FE} — The static value of the forward current transfer ratio for the common emitter configuration. The ratio of the continuous collector current to the continuous base current, the collector voltage being held constant. For the BC107 this is 110 (min) to 450 (max), at I =2mA.

NOTE: h_{FB} and h_{FC} are the ratios for the common base and common collector configurations.

h_{fe} — The small signal forward current transfer ratio for the common emitter configuration. The ratio of the alternating collector current to the small sinusoidal base current producing it under small-signal conditions, the collector being short circuited to a.c. For the BC107 this is 125 (min) to 500 (max) at 1kHz for I_C=2mA and V_{CE}=5V.

NOTE: h_{FB} and h_{FC} are the ratios for the common base and common collector configurations.

$V_{CE(sat)}$ typ. — The typical value of the residual value of voltage between collector and emitter under specified saturation conditions of I_B and I_C (e.g. I_C=10mA, I_B=0.5mA). For the BC107 under these conditions the value is 0.09 volt.

f_T — The transition frequency which is related to (but not equal to) the maximum useful working frequency of the device. It is defined as the product of the frequency at which h_{fe} falls off at the rate of 6db per octave and the value of h_{fe} at that frequency.

SECTION 6 — SOME OTHER SEMICONDUCTOR DEVICES

Photoelectric Devices

When light falls on a semiconductor material current carriers are liberated. This effect is exploited in PHOTODIODES and PHOTOTRANSISTORS. Fig. 36 shows a simple linear lightmeter which uses the BPX25 silicon planar phototransistor. Variations in the intensity of light falling near the base-collector junction cause variations in the emitter-collector current which are indicated on the meter.

The PHOTOCONDUCTIVE CELL, fig. 37, is a light sensitive resistor. The resistance between the metal electrodes decreases as the intensity of light falling on the substrate increases. Common semiconductor materials used for photoconductive cells are cadmium sulphide, lead sulphide, indium antimonide and copper doped germanium. The material used determines the range of frequencies to which the cell is sensitive. Cadmium sulphide is mainly suitable for visible light whereas lead sulphide has its peak response in the infra-red region and is therefore used in infra-red detectors.

Other semiconductor photoelectric devices are PHOTOVOLTAIC or SOLAR CELLS which generate a voltage dependent on the intensity of incident light, and ELECTROLUMINESCENT DIODES which emit infra-red or visible radiation when a current is passed through them. Semiconductor radiation detectors for α-particles, β-particles, X-rays and γ-rays are also available.

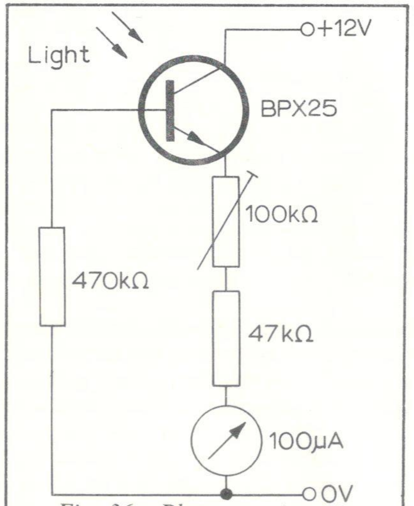

Fig. 36 Phototransistor in Lightmeter Circuit

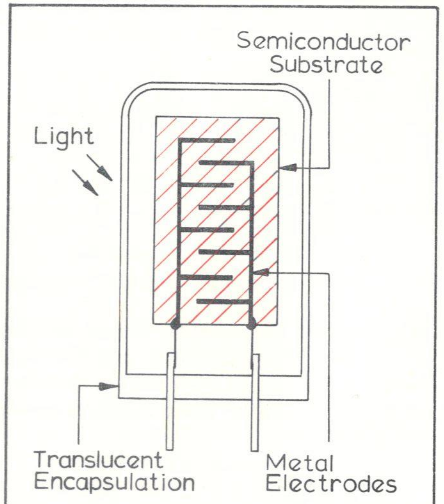

Fig. 37 Photoconductive Cell

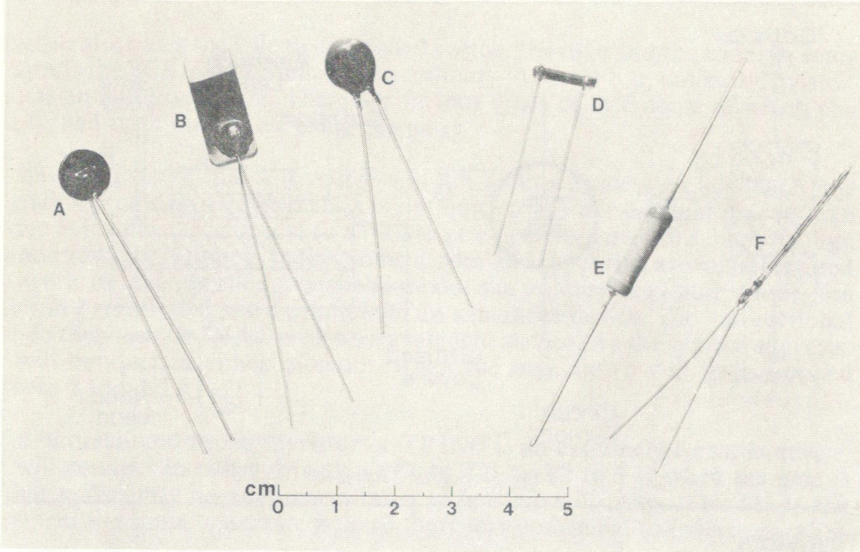

Fig. 38 Thermistors — *A. Disc NTC Type*, *B. Plate NTC Type*, *C. PTC Type*, *D. Rod NTC Type*, *E. Rod VDR*, *F. Bead-in-Glass*

Thermistors

THERMISTORS are temperature sensitive resistors made from semiconductor materials. The temperature change may be brought about by the direct application of heat or by changing the current through the device. Thermistors have a wide range of applications including the control and measurement of temperature and the limiting of current or voltage. Materials commonly used in the production of thermistors are the oxides of nickel, zinc, copper and manganese. Most thermistors are of the NEGATIVE TEMPERATURE COEFFICIENT (NTC) type—their resistance decreases with increases in temperature. POSITIVE TEMPERATURE COEFFICIENT (PTC) devices are also available. A similar type of device is the VOLTAGE DEPENDENT RESISTOR (VDR) whose resistance varies according to the applied voltage but is almost independent of temperature. The common types are illustrated in fig. 38.

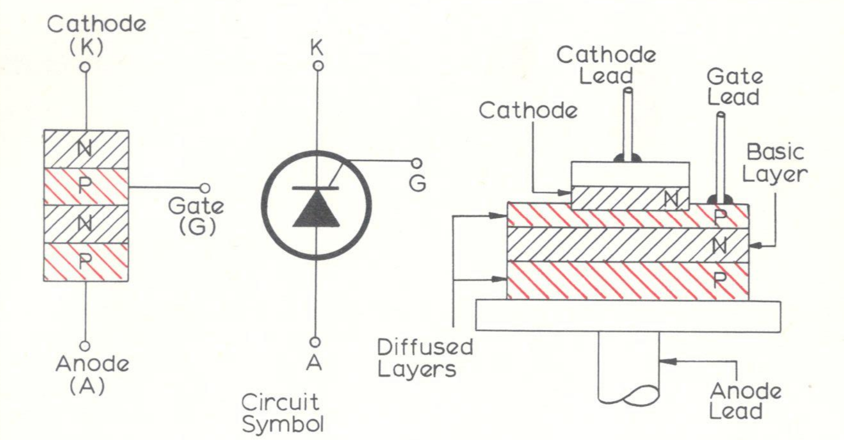

Fig. 39 The Thyristor

Thyristors

The thyristor family includes reverse blocking triode thyristors often called 'silicon controlled rectifiers' or just simply 'thyristors', diacs and triacs. Fig. 39 illustrates the construction and symbol for a (reverse blocking triode) THYRISTOR. It is a four layer device with three electrodes—the gate, the anode and the cathode. As the symbol suggests, the thyristor behaves like an ordinary diode but conduction between anode and cathode can take place only when the gate-cathode junction is adequately forward biased. Thus when the anode is positive with respect to the cathode, and sufficient gate current is flowing, conduction between anode and cathode is initiated. Once conduction has commenced the gate loses control and cannot be used to switch the device off. To switch off, the anode current must be reduced below its maintenance level. In practice the anode-cathode supply is often the a.c. mains and the thyristor is turned on periodically by short gate pulses and turned off by the reversal of the mains supply. Thyristors are used in apparatus such as motor speed controllers, lamp dimmers, temperature controllers, choppers, power supplies and inverters.

The most commonly employed manufacturing methods are the planar and the alloy-diffusion techniques. Fig. 39 illustrates the alloy-diffused type. A basic n-type silicon wafer is diffused on both sides with trivalent material to obtain a p-n-p structure, then the cathode pellet of pentavalent material is alloyed to the control p region. The gate terminal is also bonded on to the control layer as shown.

Other Thyristors

Fig. 40 illustrates the silicon controlled switch, the diac and the triac. In some respects the SCS is very similar to an ordinary thyristor but, unlike a thyristor, it has an additional gate. There are various types of SCS some of which can be turned both on *and* off using the gates.

It has been stated that a thyristor will not conduct unless an adequate gate signal is provided. However, this is not quite true since conduction can take place by avalanche action even with the gate open circuited if a high enough anode voltage is applied. In fact some diodes and thyristors are manufactured to work in a controlled avalanche mode; the voltage regulator diode (see section 2) is a well-known example of an avalanche device. The 'bidirectional diode thyristor' or DIAC is also an avalanche device. As the symbol suggests, it will conduct in either direction when the breakdown voltage is applied across T1 and T2.

The bidirectional triode thyristor or TRIAC is an extremely versatile device. It will conduct in either direction (T1 to T2, or T2 to T1) when the gate is either sufficiently negative or sufficiently positive with respect to T1. It can perform the same tasks as a pair of thyristors connected in inverse parallel.

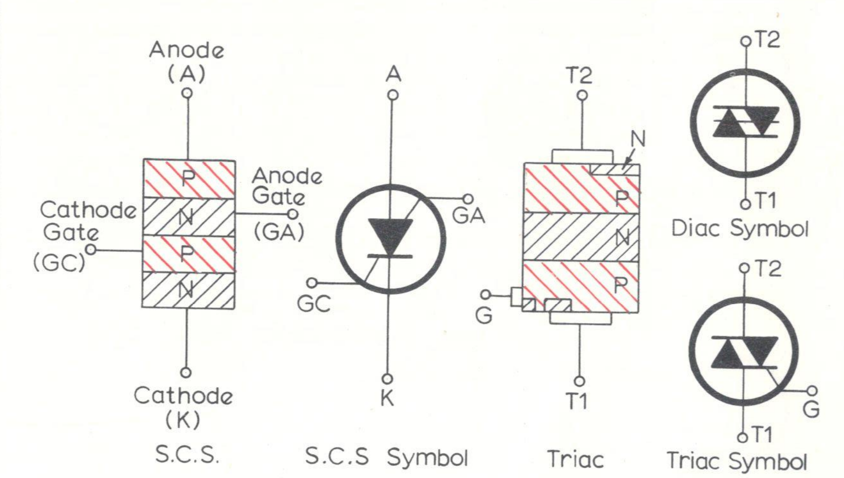

Fig. 40 The Silicon Controlled Switch, the Diac and Triac

Field Effect Transistors

A disadvantage of conventional transistors (referred to as 'bipolar' transistors) is their low input resistance. Even when connected in common collector mode their input resistance is too low for many applications. Field effect devices on the other hand have input resistances of the order of hundreds of megohms. Field effect devices are a type of 'unipolar' device so called because their operation depends only on the flow of majority carriers as opposed to both majority and minority in bipolar devices.

There are two main classes of field effect transistors (FETs). These are the junction f.e.t. (sometimes abbreviated JFET) and the insulated gate metal oxide semiconductor transistor (sometimes abbreviated IGFET or MOST). Both types are illustrated in the simplified sketches in fig. 41. In the JUNCTION FET shown on the left-hand side, a channel of n-type material is surrounded by an area of p-type. The p-n junction so formed causes a depletion region near the junction. In the common source configuration the gate (g) is made negative with respect to the source (s) and the drain (d) is made positive with respect to the source. Thus the p-n junction is reverse biased and the input resistance (g to s) is very high. The current flowing between source and drain is controlled by changes in the reverse bias of the gate-source diode. These changes in reverse bias vary the width of the depletion region near the junction. If sufficient reverse bias is applied the flow of drain current can be arrested completely.

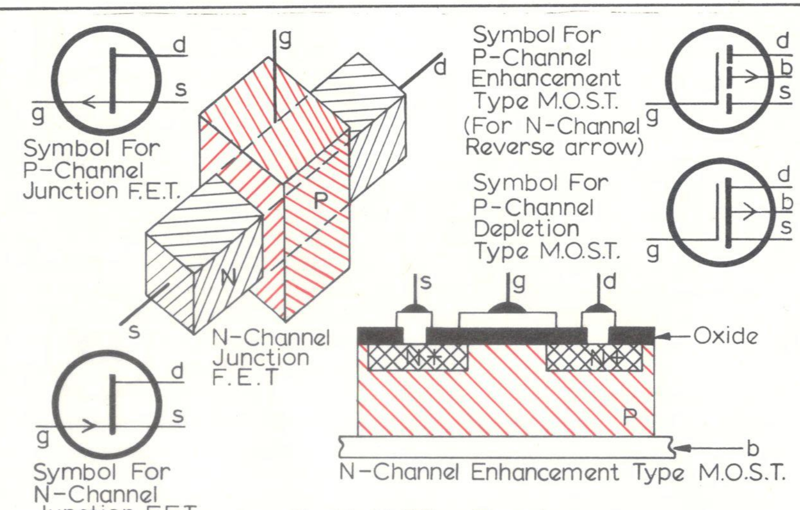

Fig. 41 Field Effect Transistors

The MOST has an even higher input resistance than the junction FET because the gate is insulated from the underlying channel by a layer of silicon oxide. When the device illustrated is connected in common source mode, the gate is made positive with respect to the source. The drain is also made positive with respect to the source. The positive gate potential attracts electrons into the p region between the two n^+ layers and increases the conduction between source and drain. This type is called the ENHANCEMENT N-CHANNEL MOST because increasing the positive gate potential enhances the conduction (reversal of the n- and p-type regions would produce a p-channel enhancement type transistor). In a DEPLETION type MOST the channel between source and drain exists as the result of the impurity concentration. Application of the gate voltage reduces the conductivity of the channel i.e. depletes it.

NOTE: The words 'emitter' and 'collector' may be used as alternatives to 'source' and 'drain'.

High Frequency Diodes

In recent years several new semiconductor diodes have been invented which are mainly intended for use at very high or microwave frequencies. Among these are gallium arsenide high speed diodes, varactor diodes, Gunn effect devices and tunnel diodes.

The GUNN 'DIODE' is a truly remarkable device and yet, in construction, it is quite simple. It is not a diode in the normal sense of the word since it is little more than a tiny piece of n-type gallium arsenide. When a low voltage d.c. power supply is connected across the crystal it emits microwaves (frequencies well above 10GHz are possible). Devices of this type, which do not have a p-n junction, are called 'bulk effect' devices. Some other diodes also use gallium arsenide, 'high speed' diodes for example, but these are fairly conventional p-n junction devices which use the material for its high speed properties.

VARACTOR DIODES are also often made from gallium arsenide. All diodes have a finite capacitance but in varactor diodes this capacitance is deliberately exploited. The capacitance of a diode is due to the depletion region. This region is the dielectric of the capacitance and it is bounded by the two non-depleted n- and p-type regions which are the plates of the capacitor. The capacitance is varied by changing the width of the depletion region i.e. by changing the applied bias. Not all varactor diodes are made from gallium arsenide—those which are for use below about 100MHz are made from silicon. The STEP RECOVERY DIODE is a special type of varactor diode.

TUNNEL DIODES are similar in construction to ordinary germanium p-n junction devices but the impurity levels are very high. The forward character-