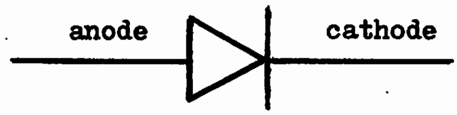
BBC ENGINEERING TRAINING information sheet (Preliminary)

SEMICONDUCTOR FUNDAMENTALS

1. PN JUNCTION DIODE

SYMBOL



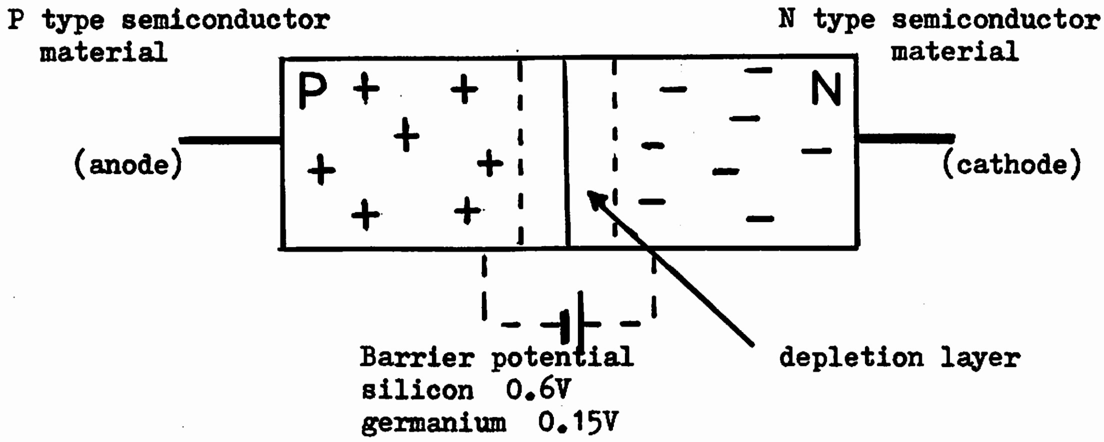


Figure 1(a) No External Bias

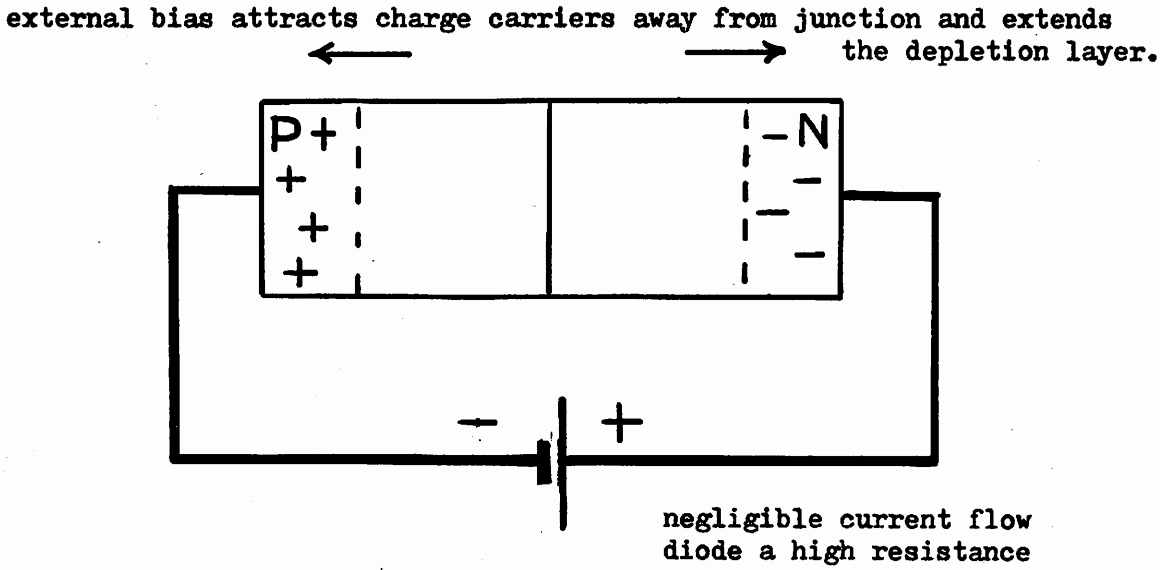


Figure 1(b) Reverse Bias

external bias opposes the barrier potential and charge carriers are forced across the junction .

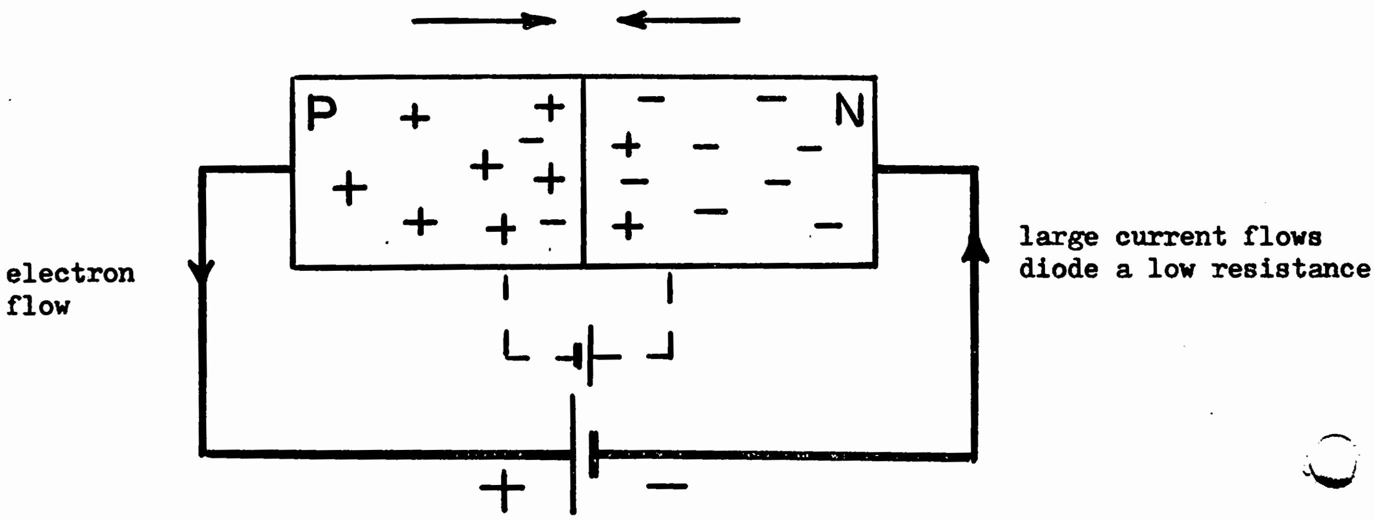


Figure 1(c) Forward Bias

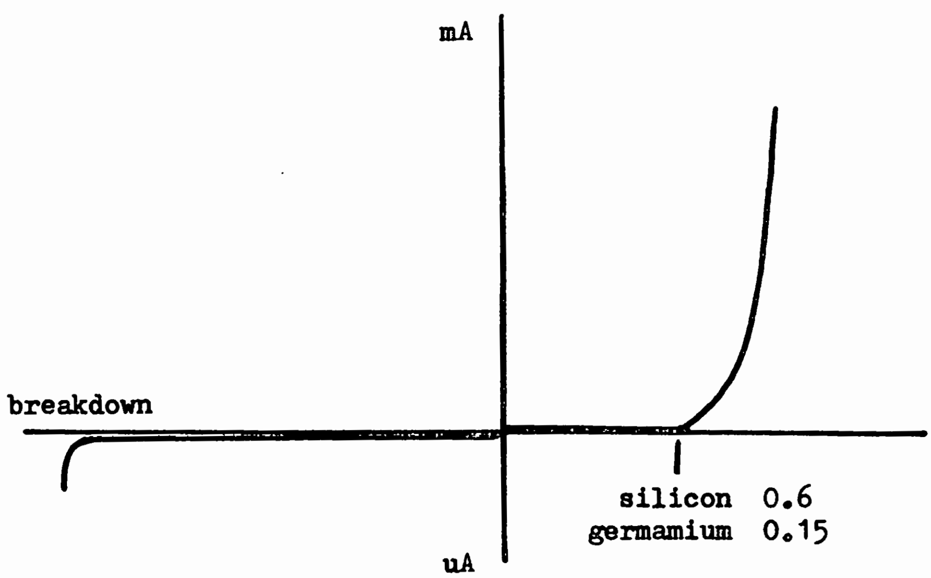
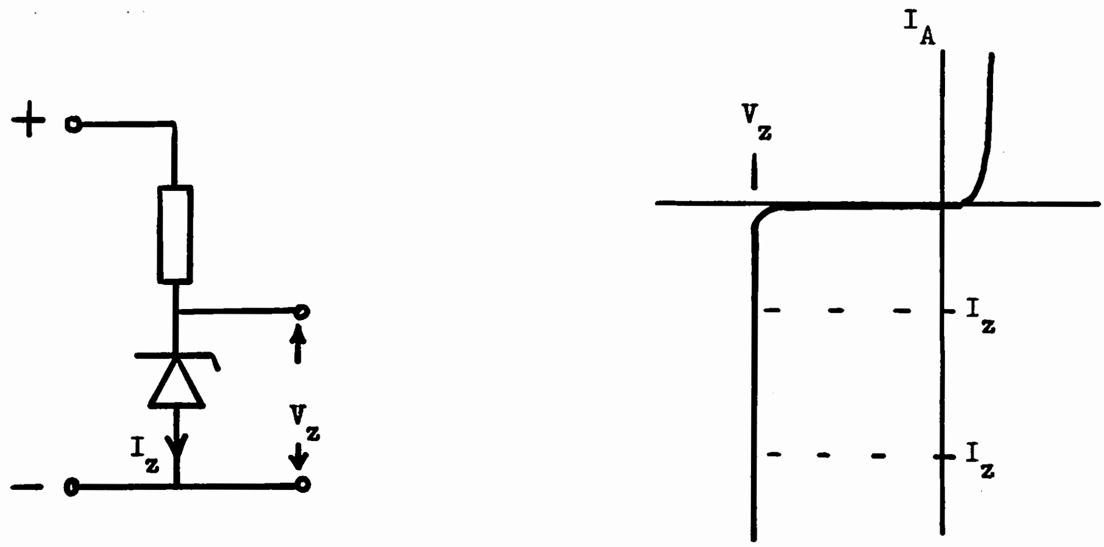


Figure 2 PN Junction Characteristic

1.1 The 'lift-off' potential depends on temperature. It falls approximately 2.5 mV per °C rise in temperature.

2. THE ZENER DIODE



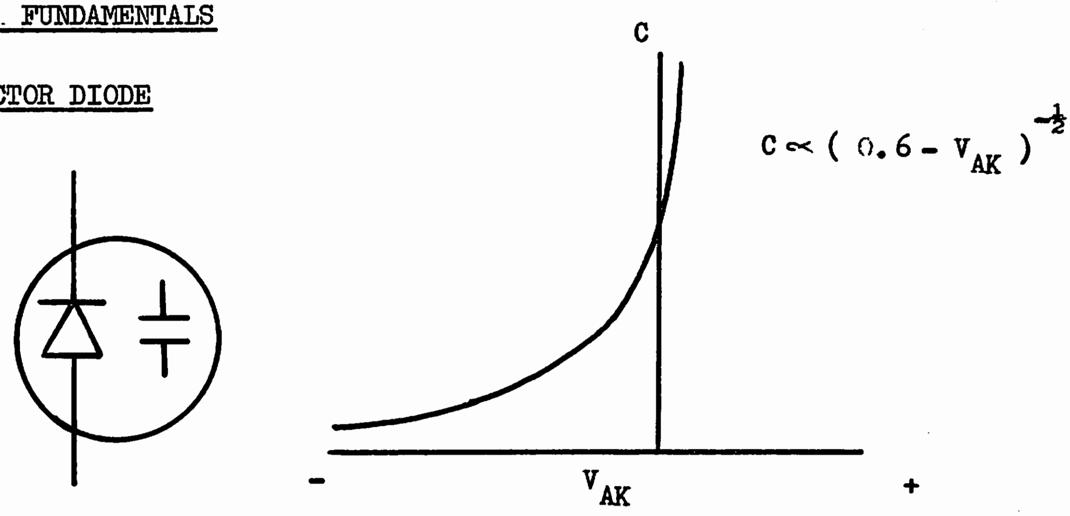
V_z remains substantioally constant over a wide range of anode current

Figure 3 Zenor diode characteristic

2.1 The 'zener effect' is responsible for voltage breakdown occuring in diodes where V_Z is approximately 5V or less. Heavy doping of the semi-conductor materials is responsible for a very narrow depletion layer at the PN junction. This results in a very high electric field strength across the junction under reverse bias conditions. A field strong enough to pull electrons from their parent atoms and allow conduction to occur.

2.2 In diodes with V_Z greater than 5V avalanche breakdown is responsible for conduction under reverse bias conditions. Thermally generated electrons are accelerated by the reverse bias. These electrons collide with semiconductor atoms releasing further electrons, the effect avalanches and the resistance of the diode falls sharply.

3. THE VARACTOR DIODE



SYMBOL CHARACTERISTIC

Figure 4 The Varactor Diode

3.1 The depletion layer at the junction of a PN diode acts in similar manner to the dielectric in a two plate capacitor. Increasing the reverse bias across the diode increases the thickness of the depletion layer and reduces the capacitance between the anode and cathode of the diode.

3.2 Varactors up to 500pF are available with a 15:1 tuning range for a 9V variation in reverse bias.

4. LIGHT EMITTING DIODE (LED)

4.1 When a PN junction diode is forward biased electrons and holes cross the junction and recombination takes place. Before an electron and hole can recombine the electron must give up energy and in semi-condutor materials such as gallium-arsenide the energy is in the form of EM radiation in the visible spectrum, i.e. red light.

5. THE BIPOLAR TRANSISTOR

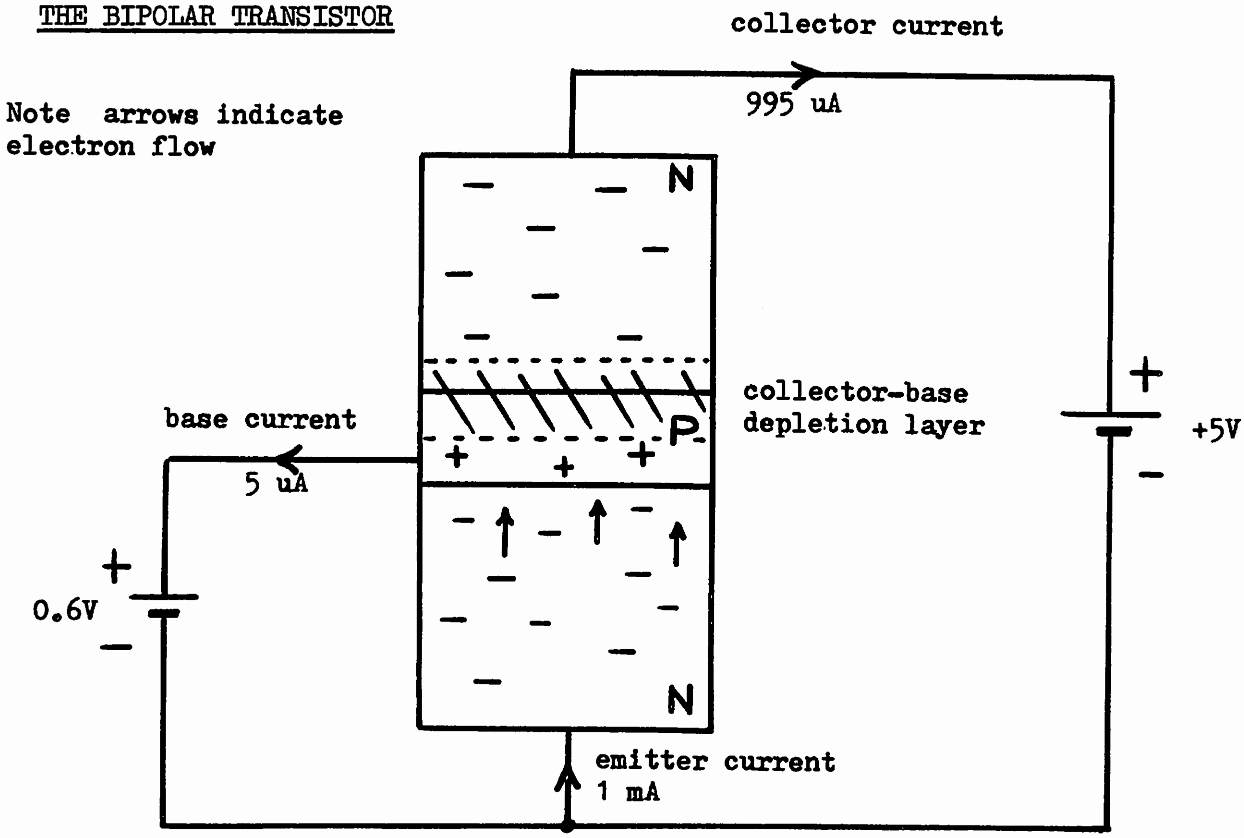


Figure 5 Bipolar Transistor Action

5.1 The collector-base junction is reverse biased and the depletion layer extends well into the base region. The direction of the electric field across the depletion layer is such as to accelerate any free electrons in the base towards the collector. With no base-emitter bias the only free electrons in the base will be those generated thermally. In silicon at room temperature there are very few such electrons and the leakage current is negligible.

5.2 Applying approximately 0.6V forward bias to the base-emitter junction will cause electrons to cross from the emitter into the base region. The majority of these electrons are subsequently swept into the collector by the electric field across the collector-base depletion layer. Approximately 0.5% recombine with holes in the base region, this causes base current to flow to compensate for the 'loss' of holes within the base.

5.3 Hence if 1mA emitter current flows then 99.5%, 995μA, reaches the collector and the base current will be 5μA.

5.4 A small increase in the base-emitter bias of approximately 20 mV will double the emitter current to 2mA. This will cause the base current to double to 10μA and the collector current to increase to 1.99mA.

5.5 It follows therefore that if this relationship holds true the ratio of the base and collector current will be a constant and is called the forward d.c. current gain h_{FE}

$$h_{FE} = \frac{I_C}{I_B}$$

Note: The use of capital letters is used to indicate d.c. current or voltage.

5.6 For collector currents between approximately 1mA and 50mA silicon small signal transistors have an h_{FE} of 100 - 400. This figure is reduced if the collector current is very small or very large when the probability of recombination occurring within the base region is much higher. Power transistors usually have an h_{FE} between 10 and 70.

5.7 The circuit action in a PNP transistor is similar to that of an NPN if holes are switched for electrons as majority current carriers and bias potentials are made negative.

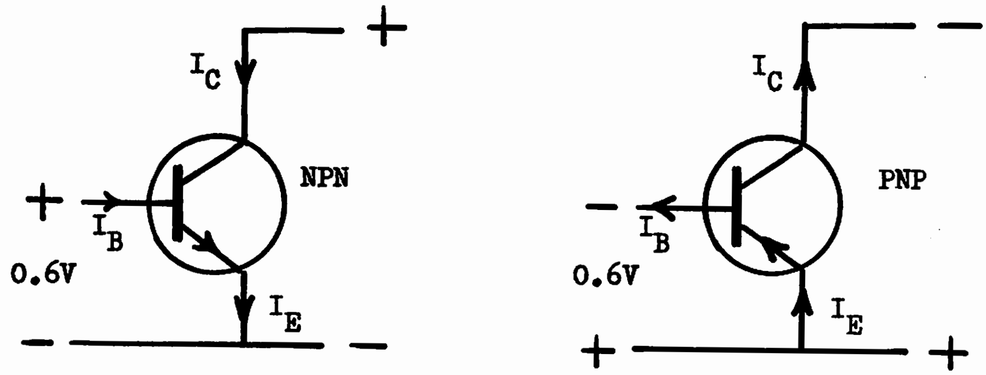


Figure 6 NPN and PNP Transistors

5.8 Note that $I_E = I_C + I_B$ as I_C is very much greater than I_B it can be assumed that in small signal transistors

$$I_E = I_C$$

6. BIPOLAR TRANSISTOR CHARACTERISTICS

6.1 There are three main graphs or characteristics which are used to show the relationship between the various voltages and currents in a transistor.

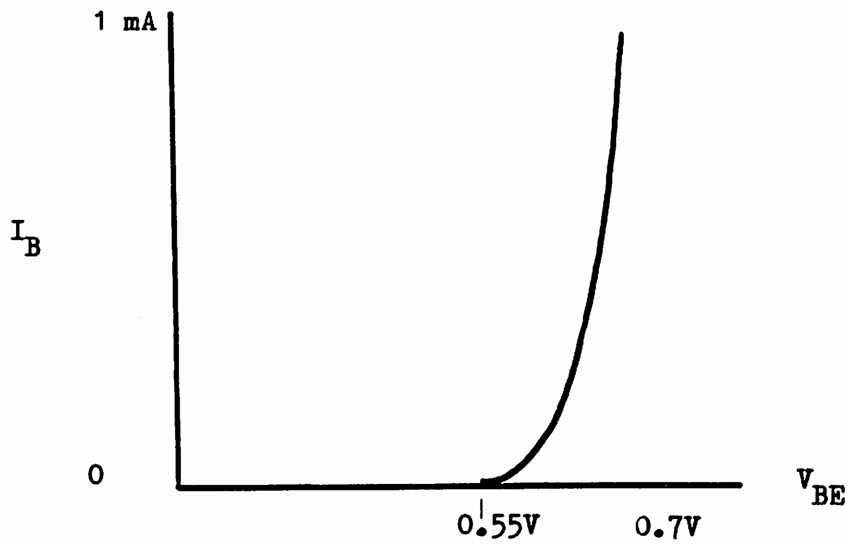


Figure 7 Input Characteristic

6.2 The input characteristic shows the relationship between the input voltage V_{BE} (base-emitter voltage) and the input current I_B (base current). It is that of a forward biased PN junction diode.

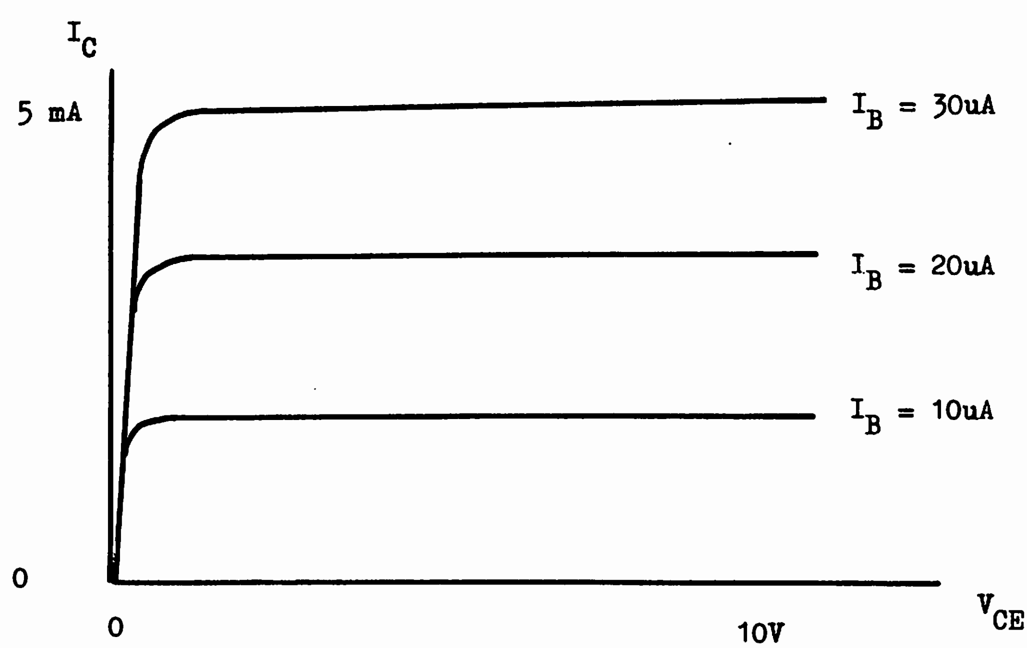


Figure 8 Output Characteristic

6.3 The output characteristic shows the effect of the output voltage V_{CE} (collector-emitter voltage) on the output current I_C (collector current). As I_C also depends on I_B, a family of curves are plotted, each for a particular value of I_B.

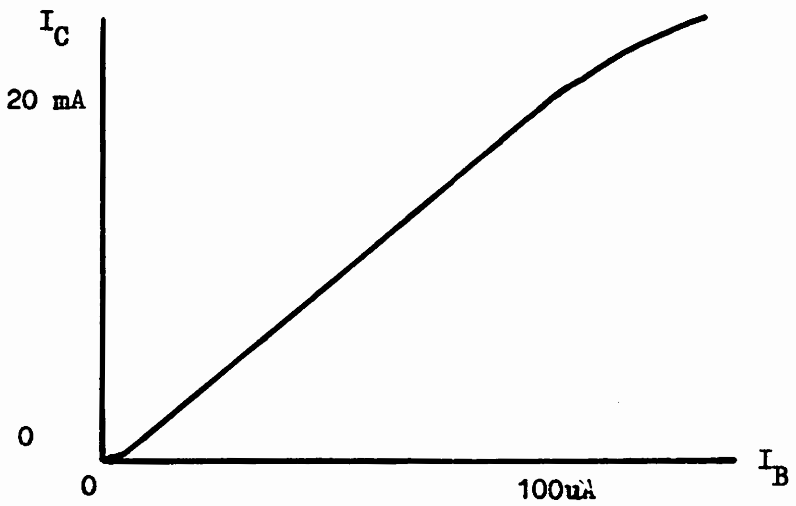


Figure 9 Current Transfer Characteristic

6.4 The current transfer characteristic shows the effect of the input current I_B on the output current I_C for a particular value of V_{CE}. Over the normal range of currents in a small signal transistor it can be considered a straight line.

i.e. h_{FE} is constant.

7. THYRISTOR DIODE

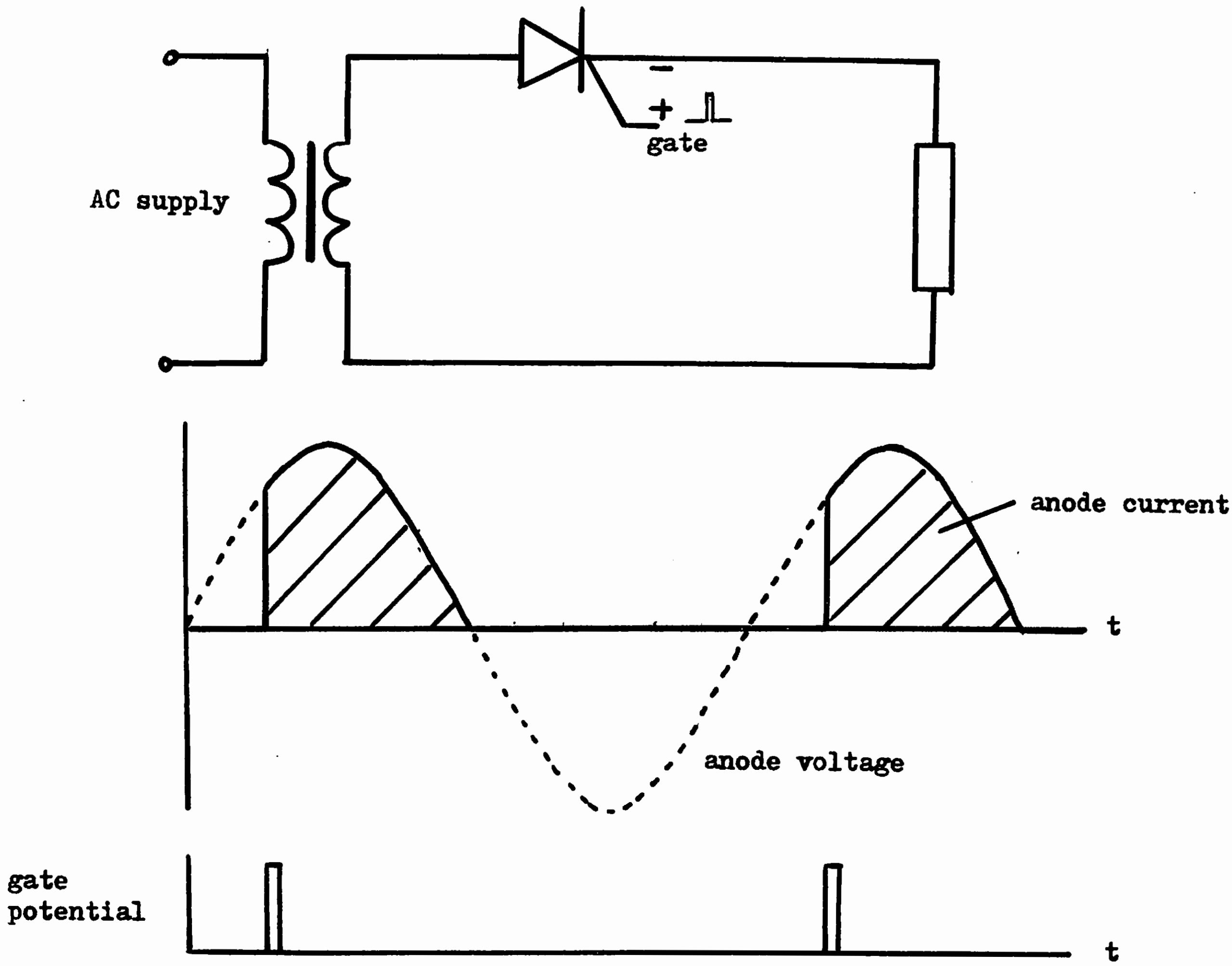


Figure 10 Thyristor Diode Rectifier

7.1 The thyristor diode will conduct as long as the anode of the diode remains positive with respect to its cathode and the diode has been triggered on by a positive pulse applied to the gate.

7.2 The thyristor is a four layer device which can be considered as forming two complementary transistors. Refer to figure 11.

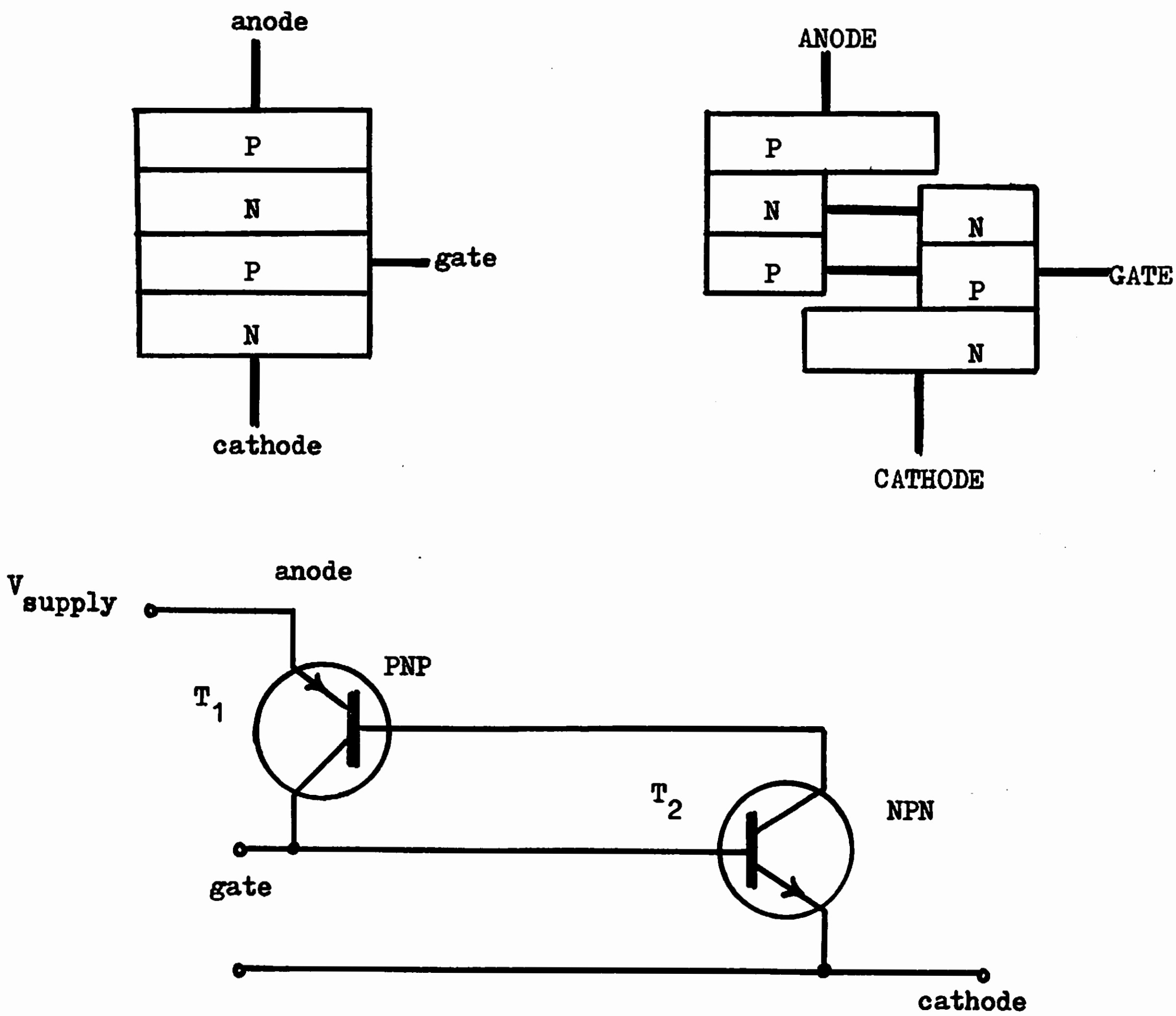


Figure 11 Thyristor Action

7.3 With transistor T_2's V_{BE} equal to zero volts the transistor will be cut-off, hence its collector potential will be at V_{supply}. It therefore follows that the base and emitter of T_1 will be at the same potential, i.e. $V_{BE} = 0$, and T_1 will also be cut-off. The resistance of the thyristor diode under such conditions will be several megohms even though the anode is positive with respect to the cathode.

7.4 A positive trigger to the base of T_2 will cut it on and its collector potential will fall. Transistor T_1 will conduct and maintain the positive potential on the base of T_2. Only when the supply voltage falls to zero will both transistors cut-off and the diode become a high resistance.

7.5 The switching time between conducting states can be of the order of 1μs and the potential drop across the diode may only be 1V with an anode current of 10^3A flowing.

7.6 A Triac's action is similar to two complementary thyristors. This gives bidirectional conduction, controlled by a trigger pulse on the positive and negative half cycles of the input waveform.

7.7 A Diac has no gate terminal and switches on at a particular anode-cathode potential owing to avalanche breakdown.

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20th November 1980