Unit 30 Transistor structure and operation

- There are two types of transistors: npn and pnp.
- A transistor is correctly biased when:
  - The emitter-base junction is forward biased.
  - The base-collector junction is reverse biased.
- The current gain $\beta = h_{fe} = \frac{I_C}{I_B}$ and then $I_C = \beta \times I_B$
- The collector and emitter currents are approximately equal, $I_C \approx I_E$.
- Typical values for β lie in range 30 to 500.

A bipolar transistor is a three layer semiconductor device formed as either an npn or a pnp structure in a single semiconductor crystal. It is called bipolar because there are two types of semiconductor in the conduction path. The three layers are called emitter, base and collector. The fabrication methods will be discussed in more detail in Unit 36.

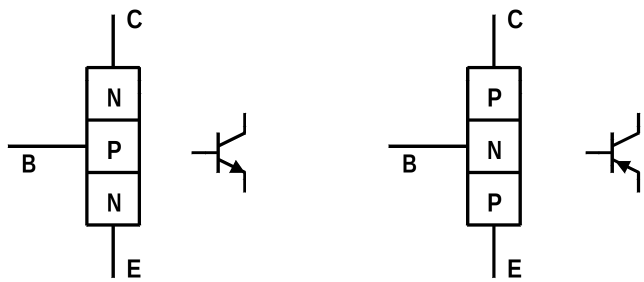

Figure 30.1: Bipolar transistor schematic structure.

The emitter region is usually more highly doped than the base or collector regions. Since there are three layers, there are two pn junctions and it is these junctions that determine the operation of the transistor. In order to bias the transistor correctly before it is used to form an amplifier, external voltages are applied so that one of these junctions, the emitter-base junction, is forward biased and the other, the base-collector junction, is reverse biased. This is shown in Figure 30.2, which is drawn for an npn transistor. For convenience, we will discuss the operation of a transistor in terms of an npn transistor but similar arguments apply to the pnp transistor, with voltages reversed and p-type and n-type materials interchanged.

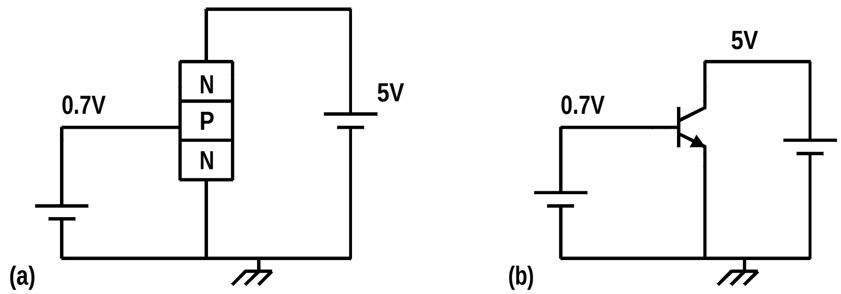

Figure 30.2: Correct biasing of npn transistor.

It is important to remember that a reverse biased pn junction is reverse biased for majority carriers only. The very small current which flows in a reverse biased pn junction diode is therefore due to the flow of minority carriers across the junction which is forward biased for minority carriers. The reverse current is so small because there are so few minority carriers present. In an npn transistor, the collector current should be very small since the base-collector junction is reverse biased and there are few electrons in the p-type base region. However, the collector current is dramatically affected by injection of electrons into the base region at the emitter-base junction.

In an npn transistor, positive bias voltage is applied between the emitter and the base to give a forward biased emitter-base diode. Since the n-type doping of the emitter region is heavier than the p-type doping of the base region, the current across the emitter-base junction will be mostly due to electrons flowing into the base region. Once within the base region, the electrons diffuse until they reach the base-collector junction. The thickness of the base region is made as small as possible to reduce the diffusion time and therefore improve the speed of the transistor. Typically the base region is 0.2 microns thick. Once the electrons, which are minority carriers in the base region, reach the base-collector junction they are swept across the junction to give a collector current.

Most of the current which enters the transistor through the emitter lead then leaves through the collector lead which gives $I_C \approx I_E$. A very small fraction, about 0.5%, of the electrons injected into the base from the emitter recombine with p-type holes in the base. This recombination would cause charging up of the base region to give an emitter-base junction which is no longer forward biased. However, a current is supplied to the base which

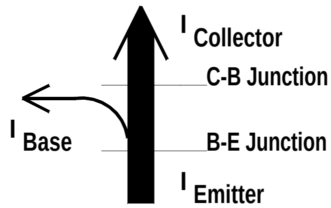

Figure 30.3: Current is proportional to line thickness.

compensates for this recombination, preventing the base charging up and maintaining the emitter-base forward bias. This base current is a nearly constant fraction of the emitter current and it is this small current into the base which controls the larger emitter current and gives the transistor its amplification properties. Figure 30.3 gives a diagrammatic representation of the various currents in the transistor.

If the current into the base of a transistor is kept constant and the collector current is measured as a function of the collector voltage we then obtain what is called the transistor output characteristic. Figure 30.4 shows the output characteristic for a typical npn small signal transistor, the BC109.

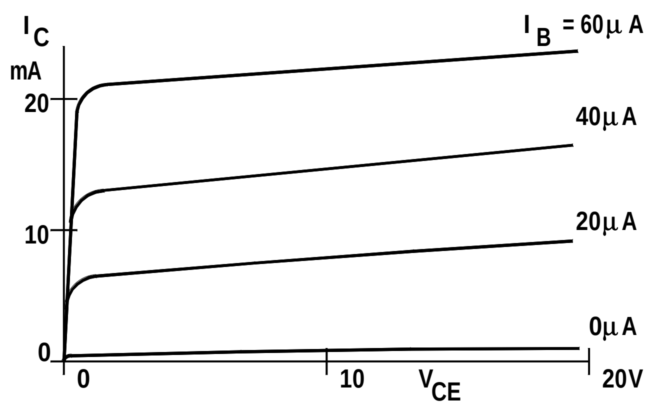

Figure 30.4: BC109 transistor output characteristic.

These characteristics would be measured using a circuit similar to that shown in Figure 30.5. The variable resistor, R_V, is varied to set the base current at the required value and the variable voltage supply is varied to sweep the V_{CE} over the range from 0 V to about 20 V.

Two very important results can be abstracted from these characteristics.

- The collector current is relatively independent of the collector voltage.

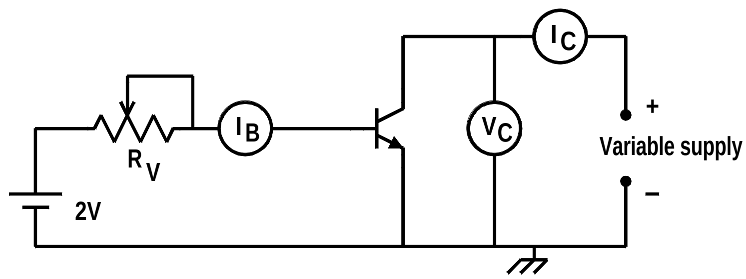

Figure 30.5: Circuit for measuring output characteristic.

- The collector current is $\beta \times I_B$ where β is the current gain for the transistor. In some data sheets you may find h_{fe} used instead of β. The symbol h_{fe} is used in the h parameter matrix method of transistor specification.

30.1 Example

30.1 Calculate the current gain at $V_{CE} = 5\,\text{V}$ for the BC109 transistor whose characteristics are shown in Figure 30.6 (a).

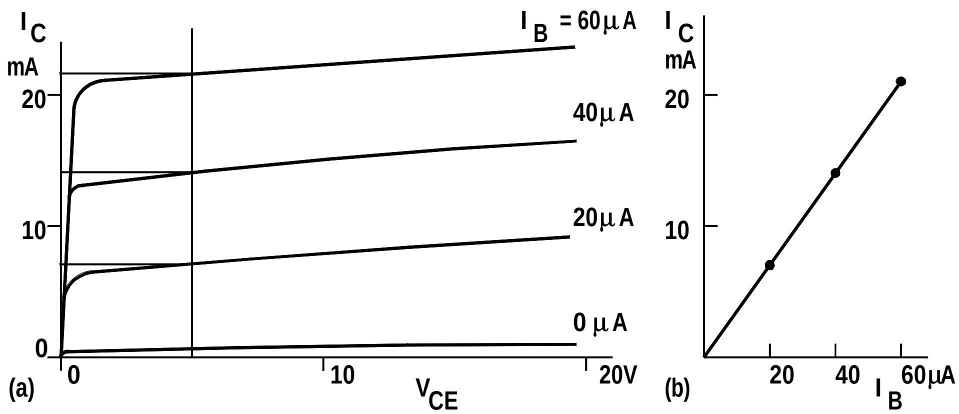

Figure 30.6: Example 30.1.

Draw a vertical line at 5 V. Note the collector current, I_C, for each crossing of the curves for $I_B = 0\,\mu\text{A},\ 20\,\mu\text{A},\ 40\,\mu\text{A},$ and $60\,\mu\text{A}$. Plot these values for I_C as a function of I_B as shown in Figure 30.6 (b). The slope of this curve then gives the current gain:

$$\beta = \frac{dI_C}{dI_B} \approx \frac{20\,\text{mA}}{55\,\mu\text{A}} = 363$$

It can be seen that this curve is very nearly a straight line corresponding to a constant value of β. The fact that β is nearly constant is used in the transistor parameter measuring feature, h_{fe} or β, which you will find on many digital multimeters. A fixed current of say $10\,\mu$A is injected into the base of a transistor and the value of the collector current, I_C, is indicated on the meter but scaled as a multiple of the I_B of $10\,\mu$A. This is then numerically equal to the current gain, β, for the transistor.

30.2 Problems

30.1 Calculate the current gains for the transistor in the characteristics in Figure 30.6 (a) for collector voltages of 2 V and 10 V.

30.2 Draw the circuit which you would use to measure the characteristics of a pnp transistor such as the BC179 (pnp version or complement of the npn BC109).

30.3 The characteristics for a 2N3055 power transistor are shown in Figure 30.7. Estimate the current gain for collector voltages of 5 V and 10 V.

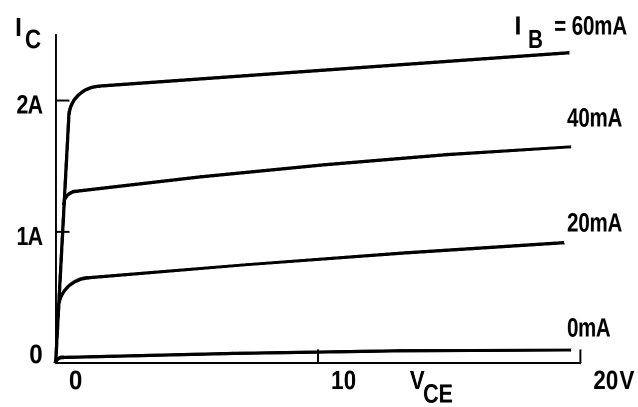

Figure 30.7: 2N3055 power transistor output characteristics.

30.4 A power transistor in a particular circuit is operated with a V_{CE} of 25 V and passes peak currents of 4.5 A. If the transistor is mounted on a heat sink which is rated at 0.9 °CW^{-1}, calculate the maximum temperature reached by the transistor, if the ambient temperature is 27°C.

30.5 In the event of a fault in a circuit, it is necessary to test an npn transistor to verify that it is functioning. This is normally done by testing for diode action across the emitter-base and the base-collector junctions.

Use a digital multimeter in diode test mode to measure the resistance in forward and reverse directions across the junctions.

Fill in the following table with H for high resistance and L for low resistance when the + and − terminals of the multimeter on diode test setting are connected to the indicated transistor terminals. If possible you should verify your results in the laboratory.

Would you expect a different result if a pnp transistor is tested?

+ Terminal	− Terminal	Resistance H/L
base	collector	
collector	base	
base	emitter	
emitter	base	
collector	emitter	
emitter	collector	

30.6 Figure 30.8 shows a range of transistor package types. Refer to an electronic components catalog and identify the different package type code numbers and also identify the emitter, base and collector leads or connections for each transistor package type.

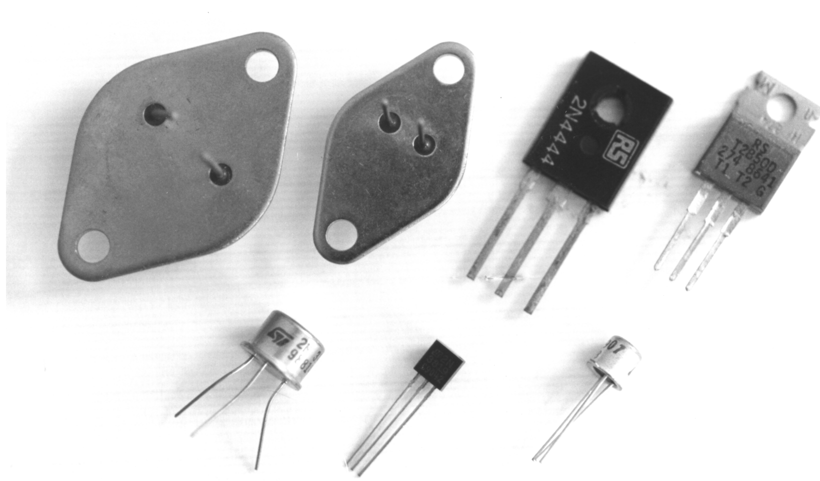

Figure 30.8: Typical transistor packages.