Bipolar Junction Transistors

A bipolar junction transistor (BJT) is an electronic device consisting of a sandwich of three pieces of semiconducting material with three terminals. The device when operated in what is known as the active region can amplify a weak electrical signal. When the bipolar junction transistor is operated in what is known as the saturation region mode it simply acts as an electrical switch to open and close a circuit. Bipolar junction transistors can be connected in a number of different ways to accomplish different tasks. This tech note will concentrate on one common connection mode that has wide applications. There will be a brief discussion of other connection modes for other applications. This tech note will show how an equivalent circuit diagram is used to analyze the expected performance of a bipolar junction transistor as well as explain how a current/voltage diagram is used. For a detailed discussion of semiconducting materials in electronic circuits refer to Tech Note 520.

Construction of a BJT: The bipolar junction transistor is constructed of three layers of semiconductor material where the top and bottom layers are the same and the middle layer is the opposite material. This is illustrated in Figure 525.1 where a thin layer of P-type semiconductor is sandwiched between layers of N-type semiconductor. This is referred to as an NPN bipolar juction transistor. It is important the center layer is thin compared to the top and bottom layers. The transistor can be constructed with P-type semiconductor as the top and bottom layers and N-type semiconductor in the middle. This is called a PNP bipolar junction transistor. This tech note will discuss bipolar junction transistor operation using an NPN transistor, but the PNP transistor works essentially the same but with the power supply polarity switched. The bipolar junction transistor has three terminals one connected to each of the three layers of semiconductor material.
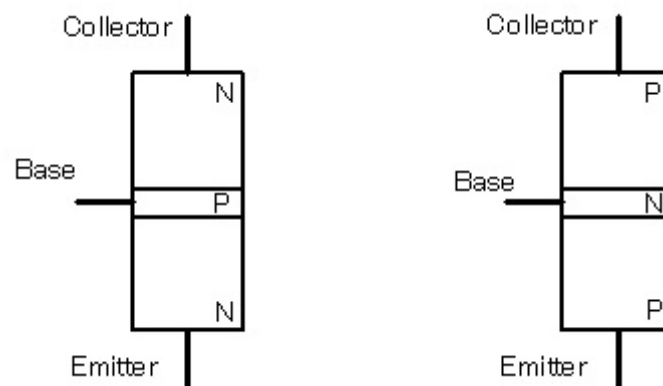

Figure 525.1 *The bipolar junction transistor consists of three layers of semiconductor material with a lead wire connected to each layer to form an NPN type or a PNP type.*

The bipolar junction transistor terminals are named base, emitter, and collector as shown in the previous diagram. Also note that the bipolar junction transistor has two PN junctions which actually act as diodes connected back-to-back. The following discussion is for an NPN bipolar

junction transistor with the emitter connected to the common negative chassis ground. In this connection mode the performance of the transistor is controlled by the level of current flow between the base terminal and the emitter terminal as shown in Figure 525.2.   The resistor connected to the base terminal limits the current flow to the base to a safe level for the transistor. Since the PN junction formed by the base and emitter semiconductors is forward biased, current will flow. By adding a varying voltage signal (V_X) to the forward bias voltage (V_S), the current flowing between the base and emitter will vary according to Ohm's law.
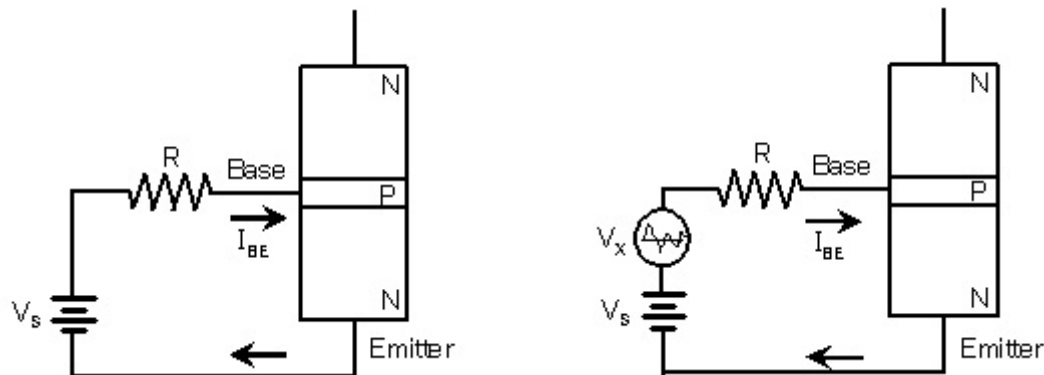
$$I_{BE} = \frac{V_S + V_X}{R}$$

Figure 525.2 *With a forward biased voltage applied between the base and emitter of a bipolar transistor, a current will flow.*

A dc voltage source (V_{CC}) is connected between the bipolar transistor collector and emitter through a load resistor (R_L) as shown in Figure 525.3. Current will not flow from the collector to the emitter because there are two PN junctions between those two terminals and one is reverse biased.
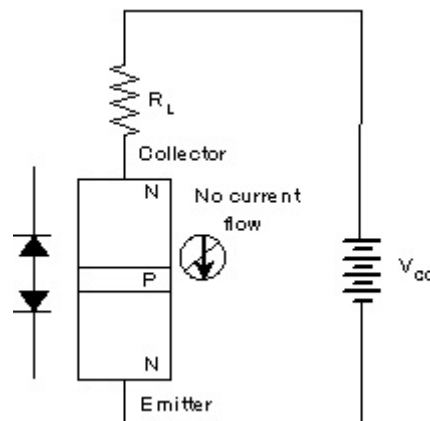

Figure 525.3 *When a dc voltage source is connected between the collector and the emitter of an NPN bipolar transistor current will not flow because the path through the transistor acts like two diodes back-to-back with one reverse biased.*

Now consider the circuits of Figure 525.2 and Figure 525.3 together connected to the bipolar junction transistor. The unique aspect of this sandwich of semiconductor materials is that when current flows from the base to the emitter (I_{BE}), current will also flow from the collector to the emitter (I_{CE}). Within a certain range, the level of current flowing from the collector to the emitter is proportional to the level of current flowing from the base to the emitter. The ratio of the base - emitter current (I_{BE}) to the collector - emitter current (I_{CE}) is called the gain of the bipolar junction transistor and is designated by the symbol β or h_{fe}. Figure 525.4 shows the base to emitter circuit and the collector to emitter circuit for an NPN bipolar junction transistor. Base current controls the flow of collector current for an NPN bipolar junction transistor.
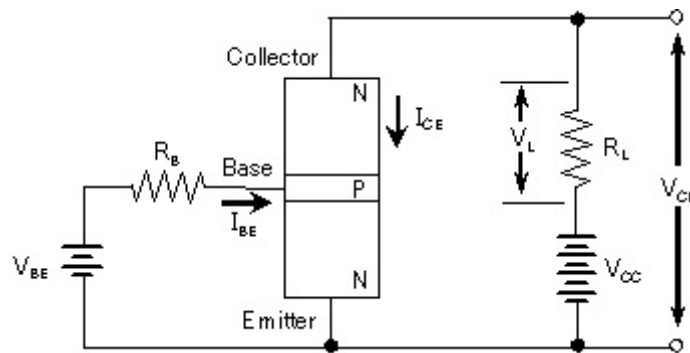
$$\beta = \frac{I_{CE}}{I_{BE}}$$

Figure 525.4 *When current flows from base to emitter for an NPN bipolar transistor, current will also flow from collector to the emitter.*

The symbols for bipolar junction transistors are shown in Figure 525.5. The emitter terminal is designated with an arrow. If the arrow is pointing out of the circle the transistor is an NPN type. If the arrow is pointing in towards the center the transistor is a PNP type. The terminals on the symbol are generally not labeled so it is important to memorize which is the base, collector, and emitter.
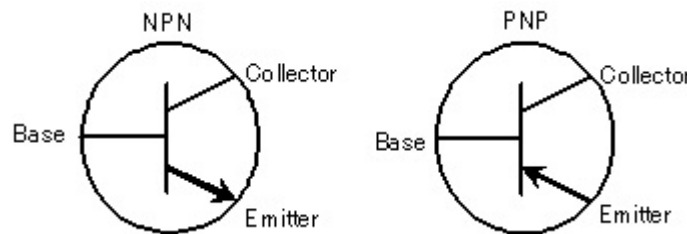

Figure 525.5 *The symbol for a bipolar transistor is shown with the emitter designated with an arrow pointing out for NPN and pointing in for PNP. In many diagrams a circle is not included.*

BJT Characteristic Voltage/Current Curves: The previous discussion of the operation of a bipolar junction transistor is typically quantified by the manufacturer in the form of a graph with the voltage between the collector and emitter terminals (V_{CE}) along the x-axis and the current at the collector terminal (I_{CE}) on the y-axis as shown in Figure 525.6. The actual operating circuit is shown in Figure 525.4. Note that the collector to emitter circuit is powered with the voltage source V_{CC}.

As current flows in the collector to emitter circuit (I_{CE}), a voltage drop will occur across the load resistor (R_L). With no current flow the voltage across the collector to emitter terminals (V_{CE}) will be equal to the supply voltage (V_{CC}). This is because there is no voltage drop across the load resistor (R_L). As collector to emitter current increases the voltage drop across the load resistor (V_L) will also increase. Note that the supply voltage (V_{CC}) is equal to the voltage across the collector to emitter terminals (V_{CE}) plus the voltage drop across the load resistor (V_L). For a particular value of load resistor, collector to emitter current will increase as base to emitter current increases until a maximum level is achieved. The load resistance must be chosen to prevent collector to emitter current from exceeding the limits of the bipolar junction transistor. Note in Figure 525.6 the series of curves for different values of base to emitter current (I_{BE}). The diagonal line on the graph is known as the load line. The load line will intersect to x-axis at the value of the collector circuit supply voltage (V_{CC}). Since there is no collector to emitter current, this point is known as the cut-off point. The slope of the line will depend upon the value of load resistance. Note as base to emitter current increases (I_{BE}), collector to emitter current will also increase (I_{CE}). Due to the voltage drop across the load resistance the collector to emitter voltage (V_{CE}) will decrease until a point is reached at which an increase in base to emitter current will not cause an increase in collector to emitter current. At this point the voltage across the collector to emitter terminals reaches a minimum value and the bipolar junction transistor is said to have achieved saturation. Beyond this point the transistor is no longer useful as an amplifier. If, however, the transistor is being used as a switch, the goal is to saturate the transistor and operate it with a base to emitter current above the saturation point, but less than a value that will damage the transistor.
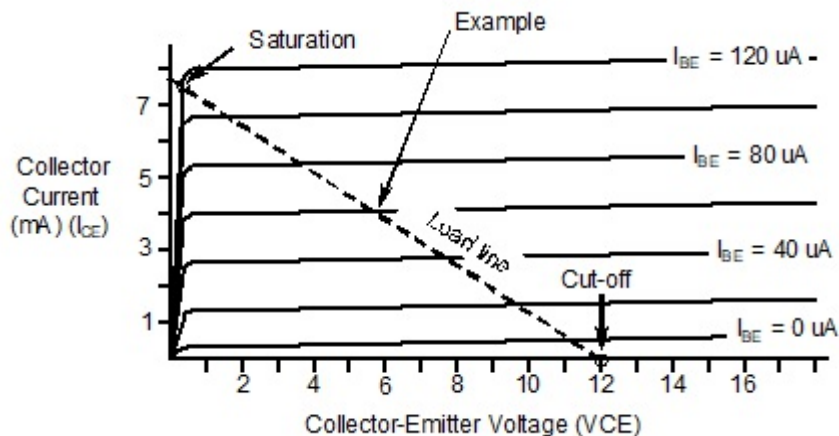

Figure 525.6 *Characteristic curves for collector current (I_{CE}) and collector to emitter voltage (V_{CE}) for different levels of base to emitter current (I_{BE}) for an NPN bipolar junction transistor connected common emitter.*

Note in Figure 525.6 that the collector to emitter current has a much greater value than the base to emitter current. This can be determined by finding the collector to emitter current for the point where the load line cross a curve for base to emitter current. The gain (β) or (h_{fe}) for that point is determined by dividing the collector to emitter current (I_{CE}) by the base to emitter current (I_{BE}). Look at the point marked as example in Figure 525.6. The curve is for a base to emitter current of 60 micro-amperes (60 x 10^{-6} A). At the point where the curve intersects the load line determine the value of collector to emitter current which in this case is approximately 4 mA (4 x 10^{-3} A). In this case divide the collector to emitter current by the base to emitter current to obtain a gain of 67.