BJT Regions of Operation

To understand the three regions of operation of the transistor, consider the circuit below:
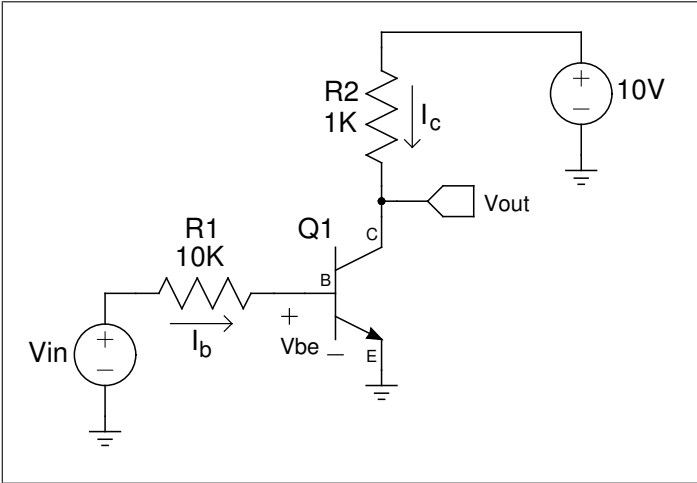

Figure 1: Typical BJT Circuit

The first region is called *cutoff*. This is the case where the transistor is essentially inactive. In cutoff, the following behavior is noted:

- $I_b = 0$ (no base current)
- $I_c = 0$ (no collector current)
- $V_{be} < 0.7V$ (emitter-base junction is not forward biased)

Whenever we observe the terminals of a BJT and see that the emitter-base junction is not at least 0.6-0.7 volts, the transistor is in the cutoff region. In cutoff, the transistor appears as an open circuit between the collector and emitter terminals. As is seen in 2, this implies V_{out} is equal to 10 volts.
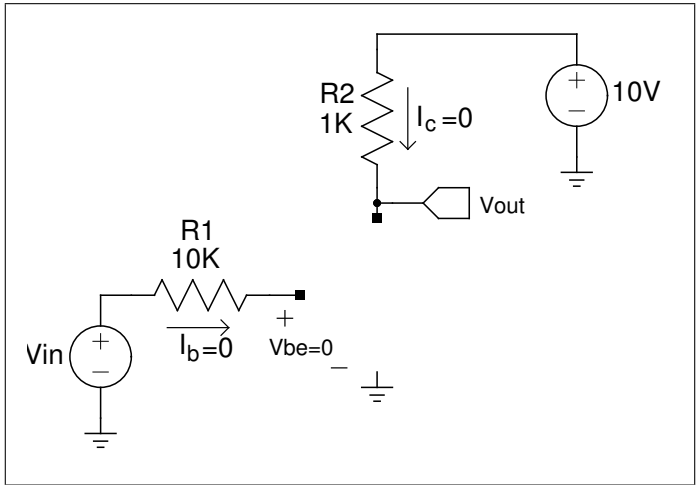

Figure 2: In Cutoff, the Transistor Essentially disappears

The second region is called *saturation*. In saturation, the following behavior is noted:

- $V_{ce} \leq 0.2V$; In this case, V_{ce} assumes the value $V_{ce(sat)}$
- $I_b > 0, and I_c > 0$
- $V_{be} \geq 0.7V$

Saturation, as the name might imply, is where the base current has increased well beyond the point that the emitter-base junction is forward biased. In fact, the base current has increased beyond the point where it can cause the collector current flow to increase. In saturation, the transistor appears as a near short circuit between the collector and emitter terminals. In figure 5, this implies V_{out} is almost 0 volts, but actually about 0.2 volts. Note also that the base-emitter junction is evident, acting like the diode that is actually is.
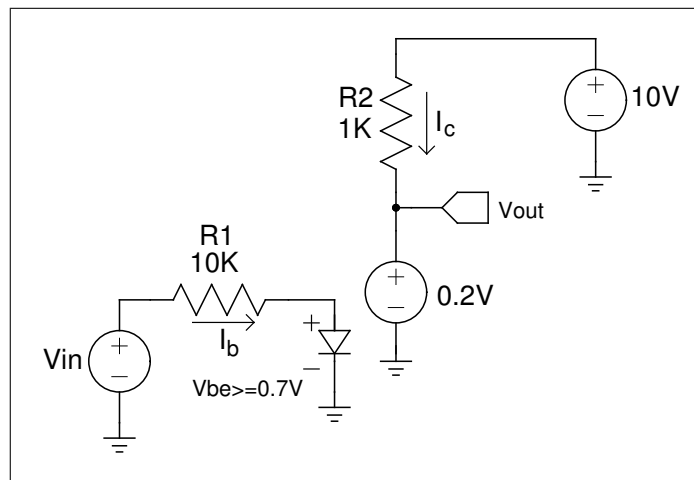

Figure 3: In Saturation, Collector and Emitter are Nearly Shorted Together

Using the two states of cutoff and saturation, the transistor may be used as a switch. The collector and emitter form the switch terminals and the base is the switch handle. In other words, the small base current can be made to control a much larger current between the collector and emitter. For example, our circuit can be modified to control an electric motor. The motor would replace the collector resistor and transistor would act as a switch. The switch only needs to handle the small base current due to the current amplification provided by the transistor.
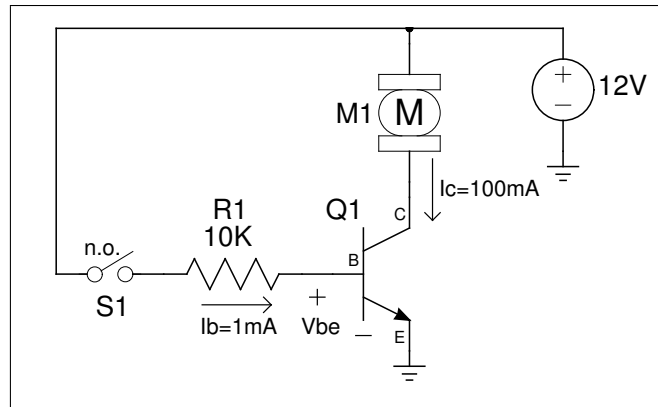
Figure 4: Transistor Acting as a Switch for the Motor

If high current motors are directly switched on and off, mechanical switch contacts will eventually wear out from switching the high current, causing the switch to fail. However, the BJT can operate nearly indefinitely as the switch as it has no mechanism that causes it wear out. When it is saturated, the bottom terminal of the motor is essentially connected to ground. When cutoff, the bottom end of the motor is seemingly not connected to anything. Used in this manner, the switch only has to handle $\frac{1}{100}$ of the motor current, greatly increasing its life.

When the transistor is either in saturation or cutoff modes, it dissipates little power. When in cutoff, there is no current flow between collector and emitter thus $P = V_{ce} * I_c = 0$. When in saturation, the current may be high, but V_{ce} is very small, keeping the power dissipated by the transistor very low. Most of the power that must be dissipated by the transistor when used as a switch comes from the short time periods between between being fully saturated an fully cutoff.

The final region of operation of the BJT is the forward active region. It is in this region that the transistor can act as a fairly linear amplifier. In this region, we see that:

- $0.2 < V_{ce} < V_{cc}$; where V_{cc} is the supply voltage

- $I_b > 0$, and $I_c > 0$

- $V_{be} \geq 0.7V$

Thus, the transistor is on and the collector to emitter voltage is somewhere between the cutoff and saturated states. In this state, the transistor is able to amplify small variations in the voltage present on the base. The output is extracted at the collector. In the forward active state, the collector current is proportional to the base current by a constant multiplier called *beta*, denoted by the symbol β. Thus, in the forward active region we will also observe that:

- $I_c = \beta * I_b$

Another way to think about the different regions of operation is to consider the how collector and base currents are related. In the graph below, we see that at cutoff, I_b and I_c are equal and are zero. In the linear region, $I_c = \beta * I_b$. In the saturated region I_b and I_c are not zero but further increases in I_b barely increase I_c at all.
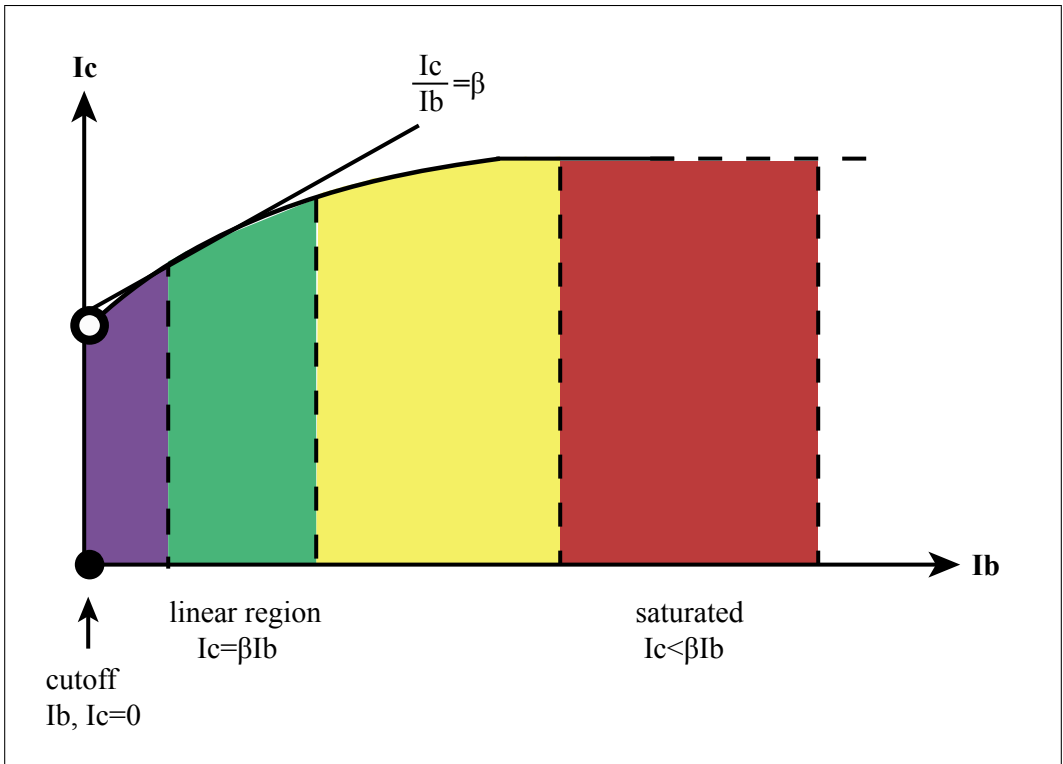
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Figure 5: Ic and Ib for the Different Operating Modes of a BJT