TRANSISTOR CIRCUITS

Transistor Behavior

The Ebers-Moll equation describes the relationship between the collector current I_C and the voltage drop from base to emitter V_{BE} by

$$I_C = I_o(e^{\frac{eV_{BE}}{kT}} - 1) \qquad (3)$$

where I_o is the reverse leakage current from the emitter to the base, $e = 1.6 \times 10^{-19}$ C is the elementary unit of charge, $k = 1.38 \times 10^{-23}$ J/K is the Boltzmann constant, and T is the absolute temperature (in Kelvin). With typical doping levels, the leakage current arising from the ``intrinsic'' behavior of the pure semiconductor is very small, and the second term (-I_o) is negligible, giving a simple exponential dependence of I_C on V_{BE}.

Transistor Switch

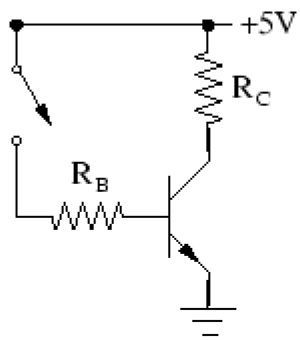

Figure 14: Transistor switch circuit.

The circuit shown in Figure 14 implements a transistor as a switch controlling power delivered to the ``load" R_C. With a proper choice of R_B, closing the mechanical switch drives a large enough base current that the current flowing through the collector resistor forces the voltage of the collector below that of the base. That is, the collector current produces a voltage drop across R_C of about 5 V. The collector voltage is very close to the emitter (ground in this case), and the right branch of the circuit behaves as if the collector is grounded. In this state, called **saturation**, increasing the base current can produce no further increase in the collector current, because R_C, not the transistor, is limiting the current. The Ebers-Moll equation and the rough rule $I_C = \beta I_B$ do not apply here. Opening the switch brings V_{BE} below 0.6 V, and the transistor shuts off power to the load.

In designing the circuit, let us assume that $R_C = 1$ k Ω. (Perhaps we know that this is the resistance of the load we would like to switch, or perhaps we want to limit the collector current to $5\mathrm{V}/1\mathrm{k}\Omega = 5$ mA.) Within these constraints, we need to choose an appropriate value of R_B to produce the behavior outlined above. Assuming $\beta = 100$ for the transistor, we need a base current of at least 0.05 mA to saturate the transistor and drive maximal current through R_C. The maximal value of R_B is then $5\mathrm{V}/0.05\mathrm{mA} = 100$ k Ω. However, it is important to be conservative, because we cannot depend on a particular β value. A transistor operating in saturation is not sensitive to excess base current, so we can safely use a base resistor much smaller than our upper limit.

Logical NOT Gate

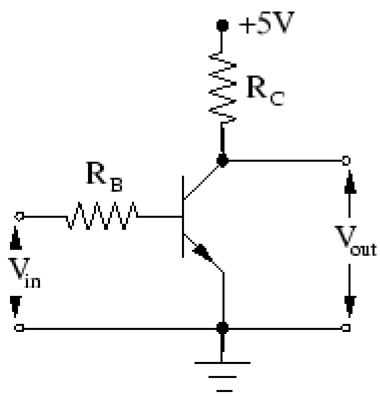

Figure 15: Logical inverter (NOT gate) circuit.

The circuit of Figure 15 is identical in form to the switch circuit of Section 3.2, except that we consider the behavior of the circuit as a logic gate with input and output terminals labelled with V_{in} and V_{out} in the figure. When V_{in} is above about 0.6 V, the base current turns on, significant current flows through R_C, and V_{out} drops. Conversely, when V_{in} drops below 0.6 V, the base and collector currents are zero, the voltage drop across R_C is zero, and V_{out} is 5 V. Hence, this circuit inverts its input, at least in the crude sense that when V_{in} is high, V_{out} is low and vice versa.

Source: http://webpages.ursinus.edu/lriley/ref/circuits/node4.html