ELE339, Electronics I Laboratory

LAB 5 - Bipolar Junction Transistor (BJT) Modeling

Introduction

Objective:
This lab introduces a new circuit element, the BJT. This versatile device is used in many applications such as in sensors, amplifiers (including operational amplifiers), oscillators and digital logic gates.
In this lab, we will determine important SPICE model parameters for the 2N3904 NPN BJT.

BJT Fundamentals:
Figure 1 shows a common implementation of an NPN transistor.

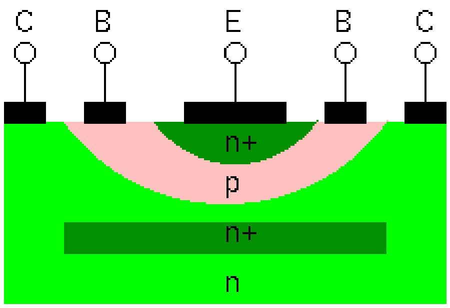

Figure 1: Cross section of an NPN Transistor

The BJT consists of two very closely spaced pn junctions, the *base-emitter* junction and the *base-collector* junction. Under typical operating conditions (forward active mode), the *base-emitter* junction is forward biased while the *base-collector* junction is reverse biased.
The positive base-emitter voltage attracts electrons from the emitter. These electrons accumulate in the base, where they create a non-uniform distribution. Random thermal motion causes the electrons to disperse across the base. Since the highest concentration of electrons is found at the base-emitter interface, more electrons move away from the junction than approach it, thus forming a net flow of electrons (from areas of high concentration to areas of low concentration). This transport process is called diffusion. Note that the high concentration of electrons at the base-emitter interface is maintained by the current through the forward biased pn junction. If the reverse biased base-collector junction is located close enough to the base-emitter junction, a sufficient number of diffused electrons reach the base-collector interface, where they are swept into the collector by the strong (reverse) electric field. Since the current in the base is caused by carrier diffusion (in contrast to carrier drift), the electric field in the base region is negligibly small.
The collector current is proportional to the density of electrons in the base at the base-emitter interface. This density varies exponentially with V_{be}. The collector current can therefore be written as

$$I_C = I_S \exp(\frac{V_{be}}{n_F V_T}) \qquad (1)$$

where V_T=kT/q is the thermal voltage (approximately 26mV at T=300K), I_S the reverse saturation current (which strongly depends on the physical properties of the junction), n_F the empirical (forward) emission coefficient ($1<n_F<2$), q the charge of an electron (1.6×10^{-19}As) and k Boltzmann's constant (1.38×10^{-23}J/K=8.62×10^{-5}eV/K).
If the forward biased BJT is replaced by a (simplified) linear model, the collector current I_c is typically described as a multiple of the base current I_b, i.e.

$$I_c = \beta I_b \qquad (2)$$

where β is the forward current gain (Note: β does slightly vary with the operating point). The SPICE model parameter for β is BF. As pointed out by this simplified equation, a BJT in the *forward active* mode can be thought of as a *current controlled current source*.

Pre-Lab

Tasks:

1. Simulate the output characteristics (I_C versus V_{CE}) of an NPN BJT (2N3904) using PSpice. In so doing, apply a fixed base current I_B, i.e., a current source, and sweep the collector voltage from 0 to 10V while the emitter remains grounded. Use the following 5 values for the base current I_B: 2μA, 4μA, 6μA, 8μA and 10μA.
2. Use the 5 simulated curves to evaluate the actual current gain $\beta_{ac}=\Delta I_C/\Delta I_B$ at a constant collector-emitter voltage of 5V for each value of I_C.
3. Plot the simulation output characteristics using *Matlab* or *Excel* and find a numerical value for the slope *($\Delta I/\Delta V$)* in the linear region, where V_{CE}>0.5V. At what point would this linear approximation intersect the V_{CE} axis? The magnitude of this intersection is called *Early Voltage* (or VA in the Spice model parameter set).
4. Use Pspice to find the base-emitter voltage V_{BE} for the two lowest base currents of 2μA and 4μA, respectively, while the collector voltage is held constant at 5V. Use these two measurements to find a value for the emission coefficient n_F (assume T=300K).
5. Based on your findings in task 4, what is the approximate value of the reverse saturation current I_s of your transistor?
6. Compare your values for β(BF), n_F(NF) and I_S(IS) with the manufacturer's (Spice) model parameters for the 2N3904 and comment on the potential differences.
7. To simplify matters, we frequently assume a constant value (how much) for the forward biased base-emitter voltage of a BJT. Is this good engineering practice? Provide at least one pro and one con argument.

Experimental

9. Build the circuit you simulated in task 1 of the pre-lab . Realize the current source at the base by using a variable source voltage V_S which connects to the base via a 1MΩ resistor and perform the activities described in that task.
10. Repeat the activities of task 2 of the pre-lab using the measured values of task 9 and compare your experimental results to the simulated results.
11. Repeat the activities of tasks 3 and 4 using your experimental results. Compare to the simulated.
13. Based on your findings in task 12, what is the approximate value of the reverse saturation current I_s of your transistor?
14. Compare your experimental values for β(BF), n_F(NF) and I_S(IS) with the manufacturer's (Spice) model parameters for the 2N3904 and comment on the potential differences.