Lab 4 Report: BJT Modeling

Cory Lanker

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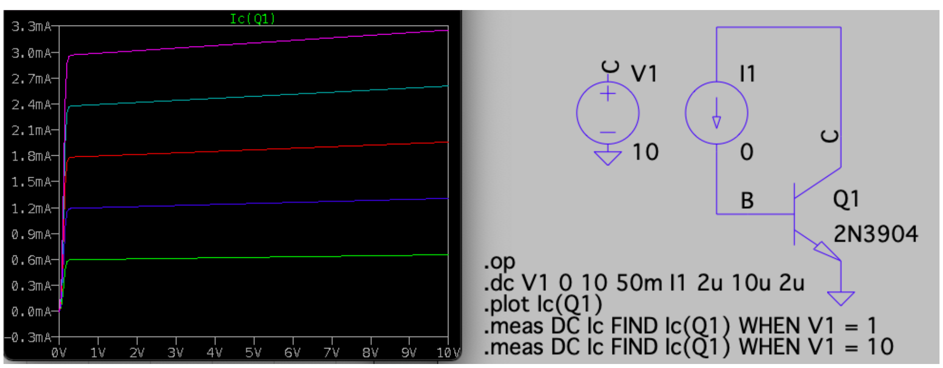
Introduction

This lab introduces the BJT. Tasks in this lab are:

1. Simulate I_C vs. V_{CE} in LTspice using different base currents
2. Build a BJT circuit to plot observed I_C vs. V_{CE} for different base currents
3. Show the current gain at $V_{CE} = 5V$ vs. I_C
4. Estimate the Early voltage for each base current observation
5. Estimate the empirical emission coefficient n_F
6. Estimate the reverse saturation current I_S
7. Compare the calculations for Parts 3-6 with the manufacturer's specifications
8. Discuss the pros and cons of assuming $V_{BE} = 0.7V$ for the forward active BJT in circuit analysis.

1. LTspice Simulation

Here are the plots for I_C vs. V_{CE} in LTspice:



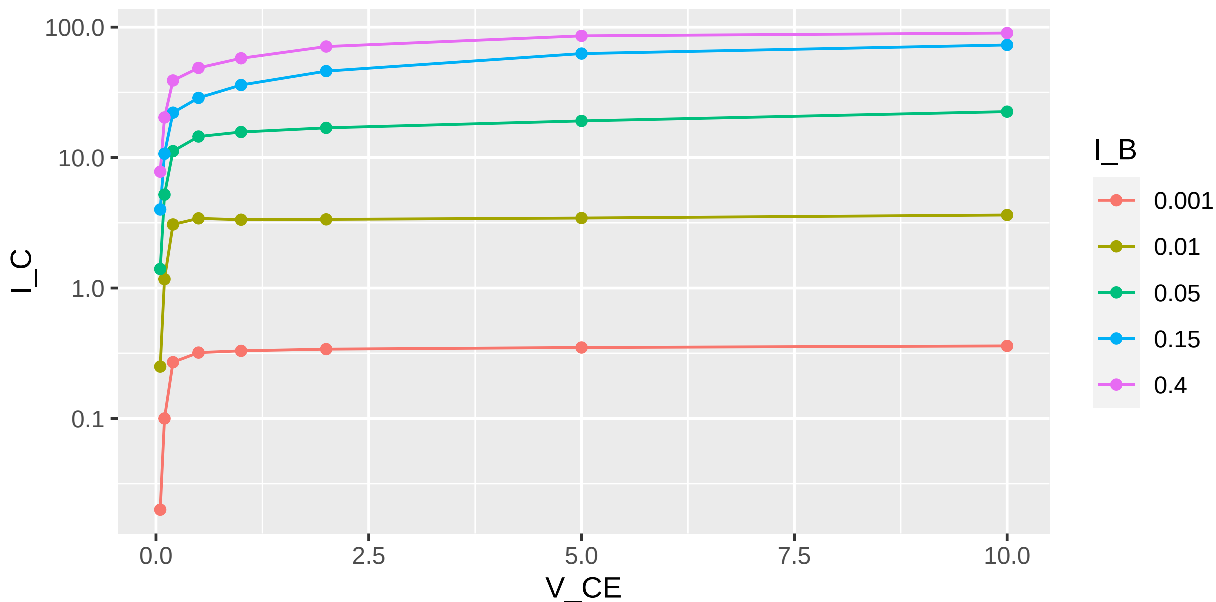
The Early voltage is calculated by saving the curves at V_{CE} at 1V and 10V:

I_B (μA)	$I_C(V_{CE} = 1V)$ (mA)	$I_C(V_{CE} = 1V)$ (mA)	V_A
2	0.6012	0.6552	99.35
4	1.200	1.308	99.34
6	1.798	1.959	99.33
8	2.393	2.608	99.32
10	2.987	3.255	99.32

The calculated gain using ΔI_B for the I_C simulated values at $V_{CE} = 5V$:

I_B (μA)	ΔI_B (μA)	$\Delta I_C(V_{CE} = 5V)$ (mA)	β
4	2	0.6231	1.308
6	2	0.6212	1.959
8	2	0.6193	2.608
10	2	0.6175	3.255

2. Measured I_C for I_B and V_{CE}



3. Current gain estimate

Using $\beta = \Delta I_C / \Delta I_B$ given the measured data at $V_{CE} = 5V$ (for $I_B \leq 50\mu A$ to avoid large current effects):

ΔI_B (μA)	ΔI_C (mA)	$\widehat{\beta}$
$10 - 1$	$3.44 - 0.35$	343
$50 - 10$	$19.1 - 3.44$	391

4. Early voltage calculation

Using the range V_{CE} from 1V to 10V, I have these two estimates for the Early voltage:

I_B (μA)	$\widehat{V_A}$
10	$1V - 9V\frac{0.33}{0.03} = -98.0$
50	$1V - 9V\frac{3.34}{0.29} = -102.7$

5. Empirical emission coefficient

The empirical emission coefficient is between 1 and 2, there values closer to 1 appear on ICs and to 2 for discrete diodes.

I_B (μA)	I_C (mA)	V_{BE} when $V_{CE} = 5V$
2	0.70	0.601
4	1.41	0.626

The calculation for n_F proceeds in the following:

$$\frac{1.41}{0.70} = \frac{I_S \; \exp(0.626/(n_F \, V_T))}{I_S \; \exp(0.601/(n_F \, V_T))}$$

$$\ln(2.0143) = exp(0.025/(n_F \, V_T))$$

yielding $n_F = 1.37$.

6. Reverse saturation current I_S

Using $n_F = 1.37$ in the previous formulae gives $I_S = 32.9pA$ which is a very large value for I_S.

7. Listed values on 2N3904 LTspice model

.model 2N3904 NPN(IS=1E-14 VAF=100 + Bf=300 IKF=0.4 XTB=1.5 BR=4 CJC=4E-12 CJE=8E-12 RB=20 RC=0.1 RE=0.1 + TR=250E-9 TF=350E-12 ITF=1 VTF=2 XTF=3 Vceo=40 Icrating=200m mfg=NXP)

My estimate for β is 367, close to the LTspice value of 300. Even more impressive is the estimate for V_A of 100.4, minorly off from the LTspice value of 100. My I_S estimate is off by three orders of magnitude though.

8. Using a constant value for V_{BE}

The biggest pro for this simplification is that the schematic analyses greatly simplify. Another pro is that the simplification is justified in that every $36mV$ (using $n_F = 1.37$) the collector current multiplies by 2.718, so keeping I_C in a given range that doesn't vary broadly will constrain the base-emitter voltage to a limited range. A con for this simplification is that a $83mV$ change in base-emitter voltage ($n_F = 1.37$) yields a 10x change in collector current, so unless the current range is known, the base-emitter voltage could be incorrect by over 100mV, and that magnitude could throw off the analysis accuracy.