The George Washington University
School of Engineering and Applied Science
Department of Electrical and Computer Engineering
ECE 20 - LAB
Experiment # 4

Characterization of an NPN Bipolar Junction Transistor (BJT)

Components:

Kit Part #	*Spice Part Name*	*Part Description*	*Symbol Name* (*used in schematics throughout this lab manual*)
2N3904	Q2N3904	NPN Bipolar Junction Transistor (BJT)	Q1
Resistor	R	100kΩ Resistor	RB
Resistor	R	1kΩ Resistor	RC

Table 1.1

Objectives:

- To characterize a BJT using the Tektronix Model 571 Curve Tracer
- To characterize the base-emitter pn-junction (BEJ) and base-collector pn-junction (BCJ) of a BJT using the Tektronix Model 571 Curve Tracer
- To characterize a BJT using a Power Supply & Keithley Model 175 DMM
- To compare measured characterization results to manufacturer specifications

Prelab: ***(Submit electronically prior to lab meeting,*** *also have a printed copy for yourself during lab)*

1. Read through lab, generate an equipment list.
2. Create a table called: Table P.1 with the following cell headings:

Calculated Values					Simulated Values					Measured Values						
I_B	V_{CE}	I_C	V_{BE}	βeta	I_B	V_{CE}	I_C	V_{BE}	βeta	I_B	V_{CC}	V_{CE}	I_C	V_{BB}	V_{BE}	βeta

3. Build & simulate the circuit in figure P.1 using SPICE
   a) Using the "Parametric Sweep Simulation of a BJT" SPICE tutorial on the lab website to generate an IV Curve (I_C vs V_{CE}) for the 2N3904 BJT transistor:
   b) Sweep V_{CE} from 0 to 10V, in .2V increments
   c) Set I_B to be the "parameter" and step it from 10μ to 50μA in 20μA steps
   d) Use a current probe to plot I_C vs. V_{CE} at each step of I_B to generate 3 curves
   e) Place markers at V_{CE}=2V on each curve
   f) Record the values for: $\mathbf{V_{CE}}$, $\mathbf{I_C}$, and $\mathbf{I_B}$ from the curve markers in Table P.1, the values for $\mathbf{V_{BE}}$ will be found in step i)
   g) Delete the I_C current probe & place a voltage probe at node V_B as shown in fig P.2
   h) Re-run the same simulation, place markers at V_{CE}=2V on each curve
   i) Record the values for: $\mathbf{V_{BE}}$, from the curve markers in Table P.1
   j) Calculate the value of the DC current gain (βeta = I_C / I_B) for each row of table P.1

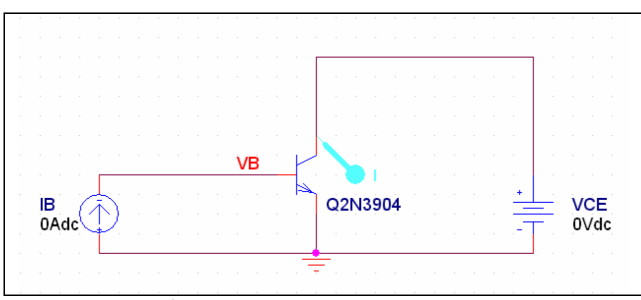

Figure P.1- Circuit to generate I_C vs. V_{CE} curve (*IB curves*)

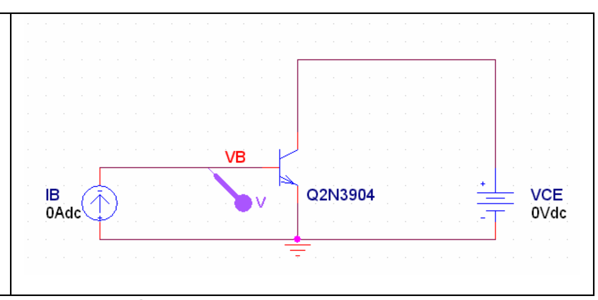

Figure P.2 Circuit to generate I_C vs. V_{CE} curve (*V_{BE} curves*)

4. Use equation P.1 to calculate I_C and record the values in the "calculated value" section of table P.1
    a) Calculate I_C for each value of V_{BE} collected in step 3
    b) Assume Is=6.734fA, and the typical value for $V_T \approx$ 26mA (thermal voltage)
    c) Calculate the value of the DC current gain (βeta = I_C / I_B) for each row of table P.1

$$I_C \cong I_S \left(e^{\frac{V_{BE}}{V_T}} \right)$$

Equation P.1 – Collector Current of NPN BJT in the active region of operation (Assumptions: $V_A >> V_{CE}$ and n=1)

5. In the simulation above, we have swept V_{CE} from 0 to 10V, and I_B from 10μ to 50μA. But the 2N3904 BJT can handle a significantly higher set of values. From the specification sheet for the 2N3904 BJT, gather the following specifications:

Parameter	**Value (with units)**
Maximum Collector-Emitter Voltage (V_{CEO})	
Maximum Emitter-Base Voltage (V_{EBO})	
Maximum Continuous Collector Current (I_C)	
Maximum Collector-Base Voltage (V_{CBO})	
Maximum DC Current Gain (βeta or h_{FE})	
Base-Emitter ON Voltage (V_{BE}) when V_{CE}=5V and I_C=10mA at room temperature (no*te: see graph section of spec)*	

LAB:

Part I – Transistor Characterization using a Curve Tracer:

Generating an I_C vs. V_{CE} IV-Curve for the BJT:

a. Allow the GTA to demonstrate using the Tektronix Model 571 Curve Tracer for an NPN device.

b. Set the Tektronix Model 571 Curve Tracer to generate 3 IV-curves for the 2N3904 Transistor with the following limits:
   - Limit I_C to be no greater than 10mA
   - Set V_{CE} to be swept from 0 to 10V
   - Step I_B from 10μ to 50μA in 20μA steps to generate the 3 curves
   - Print the resulting family of curves, annotate I_B on each curve (by hand), and indicate the limits of your setup in the lab write-up. Be sure to scan the printout into your lab write-up.

Generating the IV-Curve for BEJ and CEJ for the BJT pn-junctions:

c. Set the Tektronix Model 571 Curve Tracer to generate the forward IV characteristic curve for the Base-Emitter Junction of the 2N3904 Transistor.
   - Determine the limits for the B-E junction using the manufacturer specification sheet as done in lab 1
   - Print the resulting curve, indicate the voltage & current limits and scan the printout into your lab write-up

d. Set the Tektronix Model 571 Curve Tracer to generate the forward IV characteristic curve for the Base-Collector Junction of the 2N3904 Transistor.
   - Determine the limits for the B-E junction using the manufacturer specification sheet as done in lab 1
   - Print the resulting curve, indicate the voltage & current limits and scan the printout into your lab write-up

Part II – Transistor Characterization Using a Test Circuit -
Generating the I_C vs. V_{CE} family of IV-Curves for a BJT:

In this lab, you will generate only 3 IV-Curves (IC vs. VBE) as you did in the prelab. IB will be the 'parameter' whose value will step from IB=10uA to 50uA in 20uA steps.

In the prelab you generated an IV-Curve for the 2N3904 using the schematic in figure P.1. You were able to generate base current IB in the range of 0 to 50uA. In the lab, the power supply can behave as a current source, but it cannot produce a current as small as 50uA. To create the same family of IV-Curve in the lab, we must use the circuit in figure L.1. The voltage source combined with the 100kΩ resistor at the base will behave as the 0 to 50uA current source from figure P.1.

The data collected during this section of lab is to be recorded under the "Measured Values" section of Table P.1

Measuring the IB=10uA curve

a. Build the circuit depicted in figure L.1 using the 2N3904 BJT
b. Measure the exact resistance of RB using the Ohm meter, record this value
c. Measure the exact resistance of RC using the Ohm meter, record this value
d. Use a DMM to measure the voltage at node VB in the circuit L.1, this is VBE
e. Use a DMM to measure the voltage at node VC in the circuit L.1, this is VCE
f. Adjust VCC until VCE equals 2V
g. Adjust VBB until VBE equals the value found in prelab when IB=10uA & VCE=2V
h. Now, readjust VCC until VCE equals 0 V
i. Record VCC, VCE, VBB, & VBE in table P.1
j. Calculate the voltage across RB to calculated and record current IB in table P.1
k. Calculate the voltage across RC to calculated and record current IC in table P.1
l. Adjust VCE from 0V to 2V in .2V steps, repeating steps (i)-(k) at each step
m. Adjust VCE from 2V to 10V in 1V steps, repeating steps (i)-(k) at each step.
n. Calculate βeta for each recorded value of IC and IB

Measuring the IB=30uA curve

a. Repeat steps (a)-(n) above, but in step (g) adjust VBB until IB=30uA; you will need to calculate the current IB from the voltage across RB.

Measuring the IB=50uA curve

a. Repeat steps (a)-(n) above, but in step (g) adjust VBB until IB=50uA; you will need to calculate the current IB from the voltage across RB.

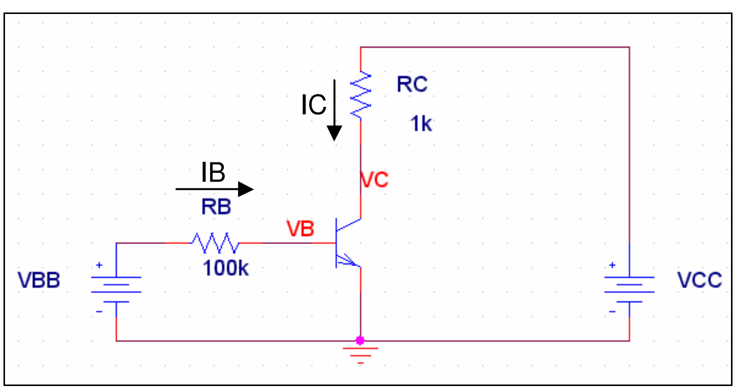

Figure L.1 – Test circuit to generate family of IV-curves for an NPN BJT

Part III – Data Analysis

1. Plot a family of IV-Curves for the data collected for *Calculated Values* & *Measured Values*, in table P.1
2. Extract a few values for IB, VCE, IC, and VBE from the curve-tracer plots, place these in another set of columns in table P.1
3. Compare the Calculated, Simulated, Measured (curve-tracer & keithley measured values) via graphs (overlaying them where possible) and percentage error in all cases.