Characterization of an NPN Bipolar Junction Transistor (BJT)

Components:

<table>
<thead>
<tr>
<th>Kit Part #</th>
<th>Spice Part Name</th>
<th>Part Description</th>
<th>Symbol Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>2N3904</td>
<td>Q2N3904</td>
<td>NPN Bipolar Junction Transistor (BJT)</td>
<td>Q1</td>
</tr>
<tr>
<td>Resistor</td>
<td>R</td>
<td>100kΩ Resistor</td>
<td>RB</td>
</tr>
<tr>
<td>Resistor</td>
<td>R</td>
<td>1kΩ Resistor</td>
<td>RC</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Calculated Values</th>
<th>Simulated Values</th>
<th>Measured Values</th>
</tr>
</thead>
</table>

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: V_CE, I_C, and I_B from the curve markers in Table P.1, the values for 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: V_BE, from the curve markers in Table P.1
   j) Calculate the value of the DC current gain (beta = I_C / I_B) for each row of table P.1
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 $I_S = 6.734\text{fA}$, and the typical value for $V_T \approx 26\text{mA}$ (thermal voltage)
   c) Calculate the value of the DC current gain ($\beta = I_C / I_B$) for each row of table P.1

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

*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:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (with units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Collector-Emitter Voltage ($V_{CEO}$)</td>
<td></td>
</tr>
<tr>
<td>Maximum Emitter-Base Voltage ($V_{EBO}$)</td>
<td></td>
</tr>
<tr>
<td>Maximum Continuous Collector Current ($I_C$)</td>
<td></td>
</tr>
<tr>
<td>Maximum Collector-Base Voltage ($V_{CBO}$)</td>
<td></td>
</tr>
<tr>
<td>Maximum DC Current Gain ($\beta$ or $h_{FE}$)</td>
<td></td>
</tr>
<tr>
<td>Base-Emitter ON Voltage ($V_{BE}$) when $V_{CE}=5V$ and $I_C=10mA$ at room temperature (note: see graph section of spec)</td>
<td></td>
</tr>
</tbody>
</table>
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 10$\mu$A to 50$\mu$A in 20$\mu$A 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 ($I_C$ vs. $V_{BE}$) as you did in the prelab. $I_B$ will be the ‘parameter’ whose value will step from $I_B=10\mu A$ to $50\mu A$ in $20\mu A$ 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 $I_B$ in the range of 0 to $50\mu A$. In the lab, the power supply can behave as a current source, but it cannot produce a current as small as $50\mu A$. 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 $100k\Omega$ resistor at the base will behave as the 0 to $50\mu A$ 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 $I_B=10\mu A$ curve**

a. Build the circuit depicted in figure L.1 using the 2N3904 BJT
b. Measure the exact resistance of $R_B$ using the Ohm meter, record this value
c. Measure the exact resistance of $R_C$ using the Ohm meter, record this value
d. Use a DMM to measure the voltage at node $V_B$ in the circuit L.1, this is $V_{BE}$
e. Use a DMM to measure the voltage at node $V_C$ in the circuit L.1, this is $V_{CE}$
f. Adjust $V_{CC}$ until $V_{CE}$ equals 2V
g. Adjust $V_{BB}$ until $V_{BE}$ equals the value found in prelab when $I_B=10\mu A$ & $V_{CE}=2V$
h. Now, readjust $V_{CC}$ until $V_{CE}$ equals 0 V
i. Record $V_{CC}$, $V_{CE}$, $V_{BB}$, & $V_{BE}$ in table P.1
j. Calculate the voltage across $R_B$ to calculated and record current $I_B$ in table P.1
k. Calculate the voltage across $R_C$ to calculated and record current $I_C$ in table P.1
l. Adjust $V_{CE}$ from 0V to 2V in .2V steps, repeating steps (i)-(k) at each step
m. Adjust $V_{CE}$ from 2V to 10V in 1V steps, repeating steps (i)-(k) at each step.

**Measuring the $I_B=30\mu A$ curve**

a. Repeat steps (a)-(n) above, but in step (g) adjust $V_{BB}$ until $I_B=30\mu A$; you will need to calculate the current $I_B$ from the voltage across $R_B$.

**Measuring the $I_B=50\mu A$ curve**

a. Repeat steps (a)-(n) above, but in step (g) adjust $V_{BB}$ until $I_B=50\mu A$; you will need to calculate the current $I_B$ from the voltage across $R_B$. 

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**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.