Washington State University

School of Electrical Engineering and Computer Science

EE 352 Electrical Engineering Laboratory

Lab # 9

BJT Characterization

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Lab Overview

The purpose of this lab was to generate a family of curves to plot the characteristic curves of a bipolar junction transistor (BJT). From the curves, the BJT parameters including the DC current, gain β, the small signal current gain β_{ac}, the reverse DC current gain β_r, the output resistance r_o, the early voltage V_A, and the input resistance, r_π. The outcome of the lab was that the gain exceeded the datasheet value, and the input resistance was close to the theoretical.

Experiment #1 BJT $i_C - v_{CE}$ Characteristic Curves

1.1 Purpose

The purpose of this lab was to use LTSPICE to plot the $i_C - v_{CE}$ characteristic curves for the 2N3904 npn transistor, then use the curves to find the BJT parameters stated in the lab overview outside of the input resistance.

1.2 Theoretical Background

The BJT is supplanted by CMOS as the dominant transistor technology in integrated circuits. It is also an important device for discrete-component printed circuit board designs, as well as have important design advantages for very high frequency and/or high-speed circuits.

This experiment had no prelab, though there are a few important things to note. The transistor used was the 2N3904 npn, shown in Fig. 1 below as well as the pinouts of the 2N3904 npn transistor from the parts kit.

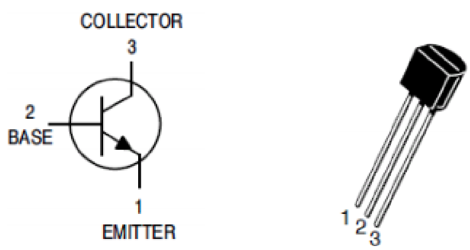

Figure 1: 2N3904 npn transistor. Maximum V_{CE} = 40 V. Maximum I_C = 200 mA

The circuits built in LTSPICE is Fig. 2 below which shows the circuit set-up to find parameters with I_C, and Fig. 3 below which shows Fig. 2 with the transistor reversed to find parameters with I_E.

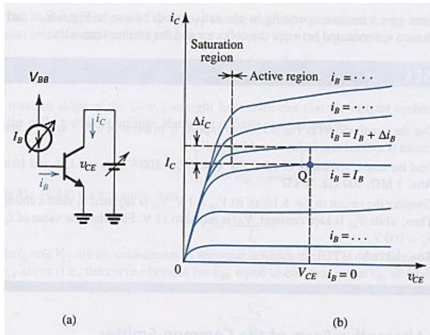

Figure 2: (from Sedra and Smith Fig. 6.20). (a) Schematic setup of $i_C - v_{CE}$ curve generation. (b) Example set of $i_C - v_{CE}$ curves, showing an operating point Q on one of the curves.

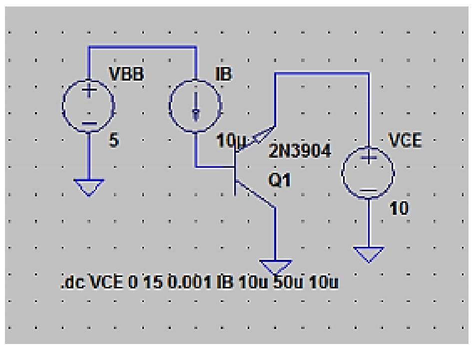

Figure 3: Fig.2 with transistor reversed.

Equations used were equation (1) which was to find β, equation (2) which was used to find β_{ac}, equation (3) which was used to find r_o, equation (4) which was used to find V_A, and equation (5) to find reverse beta β_r.

$$\beta = \frac{I_C}{I_B} \qquad (1)$$

$$\beta_{ac} = \frac{\Delta i_C}{\Delta i_B} \qquad (2)$$

$$r_o = \frac{1}{slope} \qquad (3)$$

$$V_A = r_o * I_C - V_{CE} \qquad (4)$$

$$\beta_r = \frac{I_C}{I_B} \qquad (5)$$

1.3 Procedure

1. Using LTSPICE, Fig. 2 was built to obtain the family of curves of the I_C Vs. V_{CE} like the ones shown in Fig. 2. This was built with V_{CE} = 10 V, I_B= 10 µA and V_{BB} = 5 V.

2. A DC sweep was applied with a linear sweep with 1st source set as V_{CE} having the start value=0, stop value = 15 V, and increment = 0.001.

3. The I_B was set as the 2nd source in the linear DC sweep that started from 10 µA to 50 µA with steps of 10µA.

4. Four operating points Q were selected with two being at V_{CE} = 1 V with I_C≈3 mA and 12 mA and the other two at V_{CE} = 10 V also at I_C≈3 mA and 12 mA. These points were put in a table to then also calculate I_B and β at all four points using equation (1). The β at (1 V, 12 mA) was then compared to the h_{FE} values on the 2N3904 datasheet.

5. Then the small signal current gain βac was computed using equation (2) and the curve one up from the operating point (V_{CE} , I_C) = (10 V,3 mA) as well as this operating point. This was then compared to the value of h_{fe} in the 2N3904 data sheet.

6. Then the slope of the curve was measured at (V_{CE} , I_C) = (10V, ≈12 mA) operating point then use equation (3) to calculate r_o.

7. Then V_A was calculated with the values in step 6 and equation (4).

8. Then the circuit in Fig. 3 was built in LTSPICE with the same settings as in steps 1 and 2 and 3. The current gain was then investigated when the emitter and collector are reversed by selecting an operating point with $V_{CE} = 4\ V$ and any I_C to then measure and record the operating point (V_{CE} , I_C) and then find β_r using equation (5).

1.4 Results & Analysis

Fig. 4 below is the LTSPICE model of Fig. 2 with parameters specified in steps 1, 2, and 3 of the procedure. Figs. 5 and 6 are the plots showing the family of curves for I_C and I_B respectively.

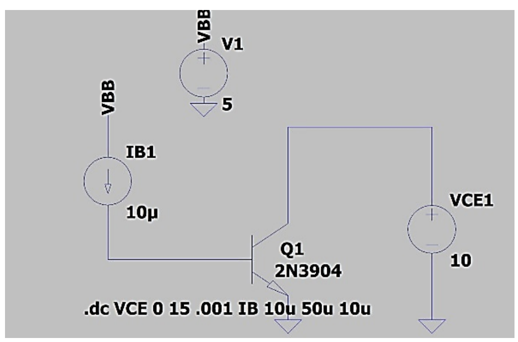

Figure 4: LTSPICE model of Fig. 2.

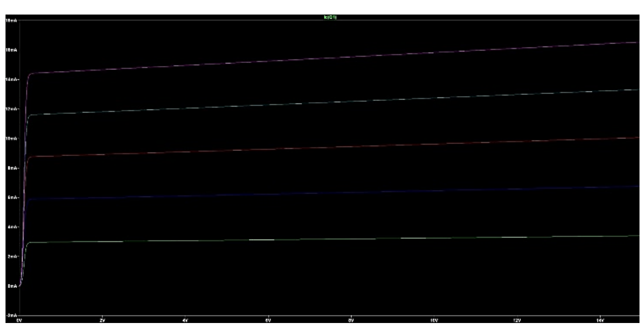

Figure 5: Plot of I_C Vs. V_{CE} for Fig. 4.

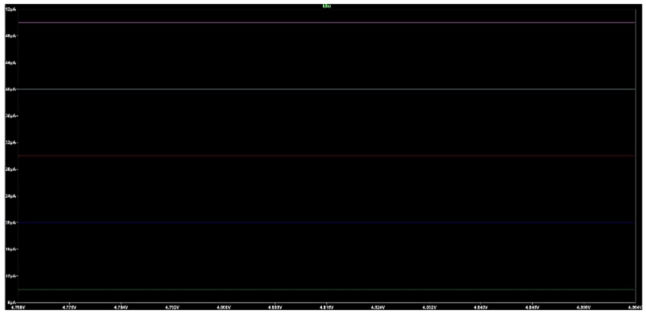

Figure 6: Plot of I_B Vs. V_{CE} for Fig. 4.

Table 1 below shows the four operating points selected on the plots shown in Fig. 5 and 6 and the calculated β using equation (1) as specified in step 4 of the procedure.

Table 1: Showing Color curve, V_{CE} that was picked on the plot in Fig. 5, I_C close to 3 mA and 12 mA for the chosen voltages, I_B of the corresponding curves, and β calculated.

Color Curve	V_{CE} (V)	I_C (mA)	I_B (μA)	β
Green	1	2.987	9.999999	298.7
Teal	1	11.69	39.999999	292.25
Green	10	3.255	9.999999	325.5
Teal	10	12.742	39.999999	318.55

One curve up from the point closest to (10 V,3 mA) is the blue curve which gave the point (10 V, 6.462 mA) for I_C and (10 V, 19.9999 μA) for I_B. Using these points to find change in current from (10 V, 3.255 mA) and (10 V, 9.999999 μA) respectively, and equation (2), β_{ac} was found to be 320.7. When comparing this to the h_{FE} value from the datasheet, it was found that 320.7 is 20.7 above the maximum which is a 6.9% error. This is since this experiment is simulated based rather than being done with actual equipment. The slope around the point (10 V, 12.742 mA) was determined by using LTSPICE cursors to find the slope between when the voltage was 9.9 V and 10.1 V. This was found to be .000116597. Using equation (3) to find r_o, and this slope, it was found to be 8576.55 Ω. Then using the same point to which the slope was based, the r_o value, and equation (4), V_A was found to be 99.28 V.

Fig. 7 below shows the LTSPICE model shown in Fig. 3, with the set-up indicated in step 8 of the procedure. Figs. 8 and 9 are the plots of Fig. 7 used to find the desired (V_{CE}, I_C) point to find β_r.

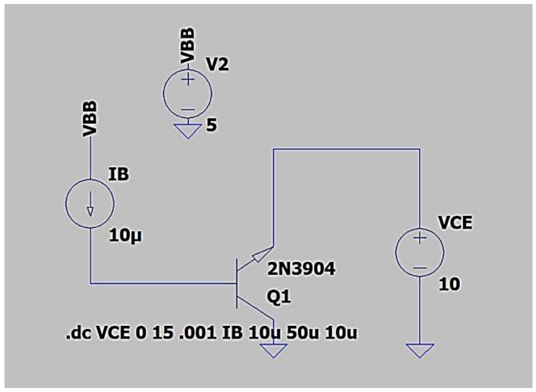

Figure 7: LTSPICE model of Fig. 3.

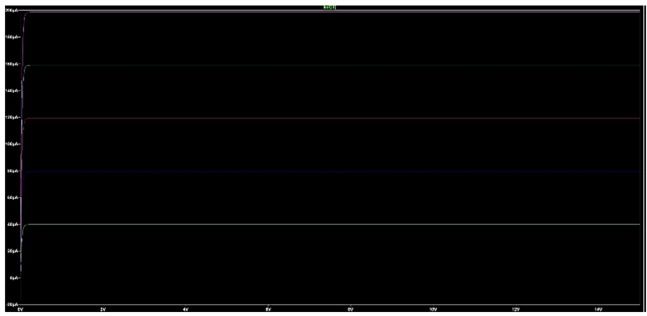

Figure 8: Plot of I_E Vs. V_{CE} for Fig. 7.

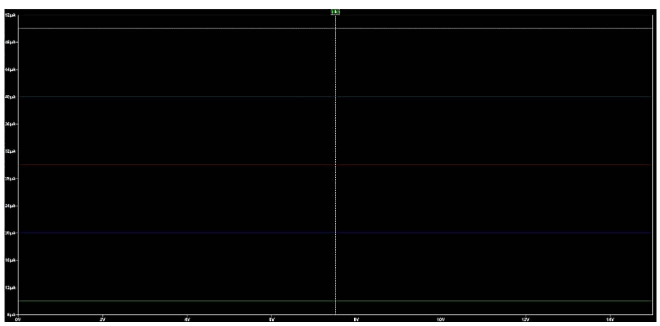

Figure 9: Plot of I_B Vs. V_{CE} for Fig. 7.

The point picked was on the top curve, which showed the point (4 V,198.773 µA). The top curve of I_B Vs. V_{CE} then showed the I_B value of 49.99999 µA. Using equation (5) and these values, β_r was found to be 3.975. Compared to the theoretical value of 4, this means there was only a .625% error between the experimental and theoretical.

1.5 Conclusion

To conclude this experiment, the β_{ac} revealed a 6.7% error between the datasheet value and the experiment value due to this experiment being simulation based. The β_r revealed only a .625% error between the experimental and theoretical and the r_o was shown to be 8576.55 Ω with a V_A of 99.28 V.

Experiment #2 BJT $i_B - v_{BE}$ Characteristic Curves

2.1 Purpose

The purpose of this experiment was to use LTSPICE to plot the $i_B - v_{BE}$ characteristic curve for the 2N3904 npn transistor and use the curve to find the input resistance r_π.

2.2 Theoretical Background

The theoretical background of this experiment is the same as the one for experiment 1, only this time the $i_B - v_{BE}$ characteristic curve is being analyzed in a transistor diode connection as shown in Fig. 10. Equation (6) below was used to find the input resistance r_π using the slope around I_B= 20 µA.

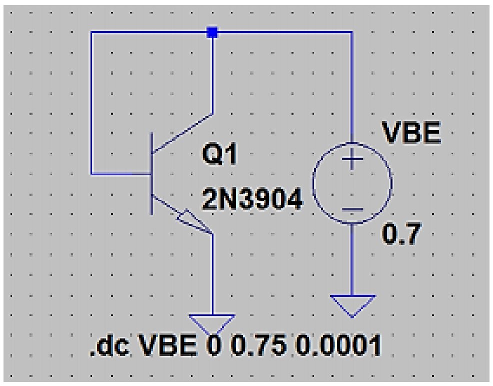

Figure 10: Transistor Diode Connection.

$$r_\pi = \frac{1}{slope} = \frac{V_T}{I_B} \qquad (6)$$

2.3 Procedure

1. Fig. 10 was created in LTSPICE to investigate the relationship between I_B and V_{BE}.

2. Using linear DC sweep on the DC voltage source V_{BE}, the parameters applied with start value 0 V stop value 0.75 V and increment of 100 u to then plot I_B Vs. V_{BE}.

3. The slope at the operating point of I_B= 20 µA was measured to compute the base input resistance r_π using equation (6).

2.4 Results & Analysis

Fig. 11 is the LTSPICE built circuit of Fig. 10 with parameters declared in steps 2 and 3 of the procedure. Fig. 12 is the I_B Vs. V_{BE} for Fig. 11 to find the slope at the operating point of I_B= 20 µA to compute the base input resistance r_π using equation (6).

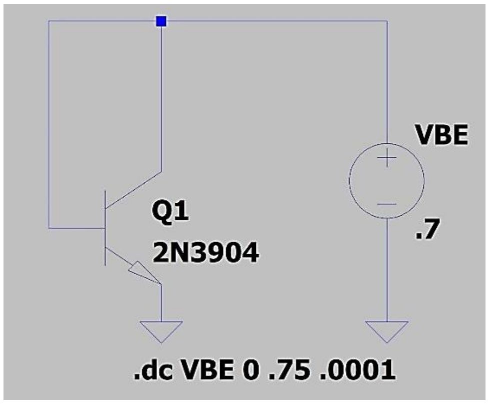

Figure 11: LTSPICE model of Fig. 10.

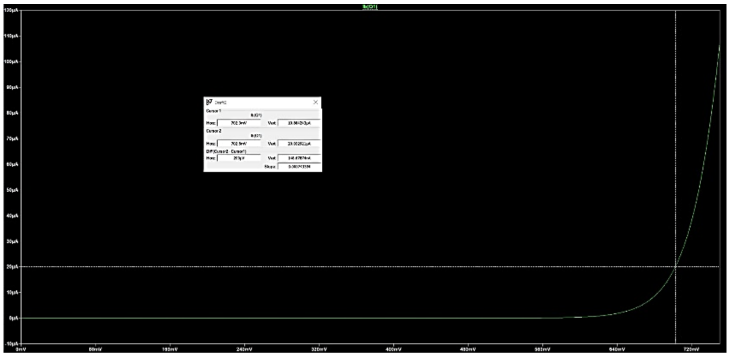

Figure 12: Plot of I_B Vs. V_{BE} for Fig. 11.

The points used to measure the slope was when the V_{BE} was 702.3 mV and 702.5 mV, since the associated V_{BE} value at I_B= 20 µA was 702.4 mV. The slope was found using the cursor tracers in LTSPICE on the Fig. 12 plot which showed the slope to be .000743394 A/V. Then using equation (6) and the slope, the r_π was found to be 1345 Ω. This was only 45 Ω away from the theoretical value of 1.3 kΩ which is determined using a V_T of 26 mV and a I_B of 20 µA. This yields a 3.46% error between the experimental and theoretical.

2.5 Conclusion

To conclude this experiment, the input resistance showed a 3.46% error between the experimental and theoretical which is due to potential measurement errors, as well as the LTSPICE settings.

Appendix

Appendix A

(no checklist provided)