EE3302, Section 306
Laboratory Fundamentals II

Lab Topic: BJT AC Analysis
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Abstract

In this lab, the AC characteristics and small signal model of the BJT is analyzed, quantified, and measured. First, a common emitter amplifier is designed, constructed and analyzed. The frequency response is measured and its transient characteristics are recorded. Afterwards, A differential long-tailed pair amplifier was designed and constructed. The characteristics of this system were measured and compared to the theoretical values.

Introduction

The design of the common emitter amplifier was performed under the guidance of the lab manual and introduction. By using rules of thumbs and performing simulations, the circuit with the desired gain and frequency response was specified and constructed. The differential amplifier was made with a similar guise. Using the BJT equivalent model with equations listed in the manual, a differential long tailed pair amplifier was exhibited was the desired characteristics. The important characteristics of the differential amplifier includes the differential gain as well as the input and output impedances.

Procedure

The procedure consisted of constructing 2 circuits: a common emitter amplifier, a differential amplifier

1. **Common Emitter Amplifier**

   The common emitter amplifier designed and simulated in the prelab was constructed with on hand components. With the amplifier constructed, the network analyzer features of the ADALM2000 was utilized to characterize the frequency response of the amplifier. The measured frequency response allowed one to calculate the gain of the amplifier. This measured gain was compared to the theoretical expected value of the gain which was determined by the simulations and circuit analysis.

2. **Differential Amplifier**

   The differential amplifier designed and simulated in the prelab was constructed with on hand components. The transient response of the amplifier was measured by applying 2 sinusoids that were out of phase by 180 degrees to the amp inputs and by measured the voltage across the collectors. The input impedance was measured by applying a differential voltage across the inputs of the amplifier and measured the current through the inputs.

Prelab Simulations and Results

Problem 1

Repeat example 1, but assume an amplifier with a gain of -8 which has identical 3 dB corner frequencies of 10 kHz for high pass coupling at the input and output. Use a power supply of 5 volts.

$$\begin{aligned} G &= -8 \\ f_i &= f_o = 10^4\text{Hz} \\ V_{CC} &= 5\text{V} \end{aligned}$$

Two Arbitrary Initial Conditions

$$R_C = 800\Omega$$
$$R_2 = 1000\Omega$$

Now,

$$R_E = \frac{R_C}{|G|}$$
$$R_E = 100$$

Using a load line to determine R1

$$I_C = -\frac{1}{R_E + R_C}(V_{CE} - V_{CC})$$
$$y_{\text{int}} = \frac{V_{CC}}{R_E + R_C}$$
$$y_{\text{int}} = \frac{5}{900} = 5.55\,10^{-3}$$

Arbitrary Decision on load line

$$V_{CE} = 1.5\text{V}$$
$$I_B = 20 \times 10^{-6}$$

Now,

$$I_C = 3 \times 10^{-3}\text{A}$$
$$\beta = \frac{3 \times 10^{-3}}{20 \times 10^{-6}}$$
$$\beta = 150$$
$$\beta \gg 1$$
$$I_E = I_C + I_B$$
$$I_E = 3 \times 10^{-3} + 20 \times 10^{-6}$$
$$I_E = 3.02 \times 10^{-3}$$
$$V_B = 0.7 + R_E I_E$$
$$V_B = 0.7 + (100)3.02 \times 10^{-3}$$
$$V_B = 1.002$$
$$\frac{V_{CC} - V_B}{R_1} = I_B + \frac{V_B}{R_2}$$
$$\frac{5 - 1.002}{R_1} = 20 \times 10^{-6} + \frac{1.002}{1000}$$
$$\frac{3.998}{R_1} = 1.022 \times 10^{-3}$$
$$R_1 = 3911.94\Omega$$

To determine cutoff frequency for input coupling cap

$$R_{ei} = R_1 \parallel R_2 \parallel \beta R_e$$

$$f_i = \frac{1}{2\pi R_{ei} C_i}$$

$$C_i = \frac{1}{2\pi R_{ei} f_i}$$

$$R_{ei} = \left(\frac{1}{3900} + \frac{1}{1000} + \frac{1}{15000}\right)^{-1}$$

$$R_{ei} = 755.814$$

$$C_i = \frac{1}{2\pi(755.814)\left(10^4\right)}$$

$$C_i = 2.1 \times 10^{-8}\text{F}$$

Now the output cap

$$f_o = \frac{1}{2\pi(R_C + R_L)C_0}$$

$$C_0 = \frac{1}{2\pi(R_C + R_L)f_0}$$

$$C_0 = \frac{1}{2\pi(850)10^4}$$

$$C_0 = 1.87241 \times 10^{-8}\text{F}$$

In summary,

$$R_1 = 3911.94$$
$$R_2 = 1000\Omega$$
$$R_C = 800\Omega$$
$$R_E = 100\Omega$$
$$C_i = 2.1 \times 10^{-8}\text{F}$$
$$C_o = 1.87241 \times 10^{-8}\text{F}$$

Problem 2

Use PSpice to model the amplifier in part 1. Do an AC sweep of the circuit for a frequency range 1 kHz-40 kHz. Show the gain of the circuit over this frequency band. Comment on your observation (make sure that you use a small enough input signal that does not result in a nonlinear behavior for the amplifier).

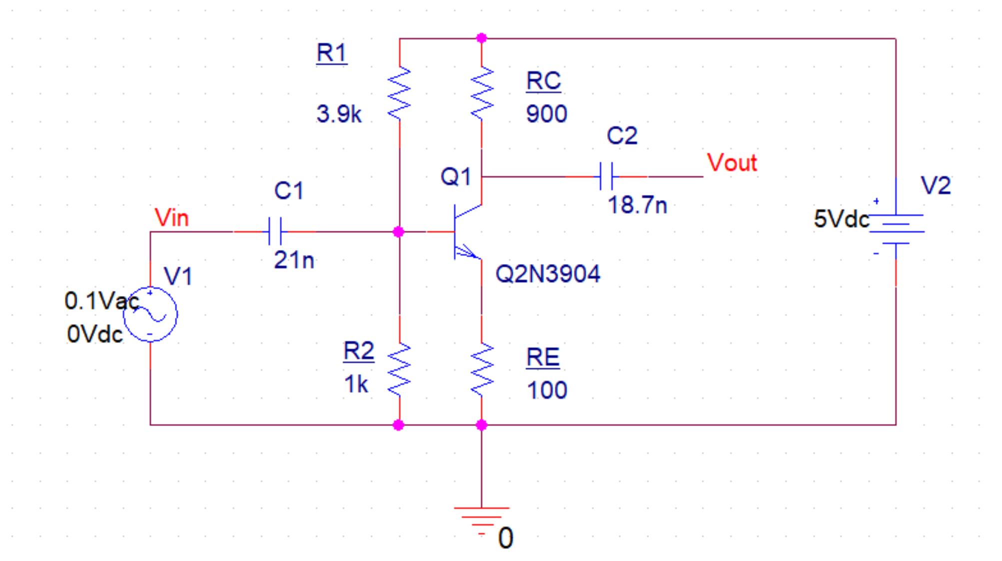

Figure 1: BJT Amplifier Circuit Schematic

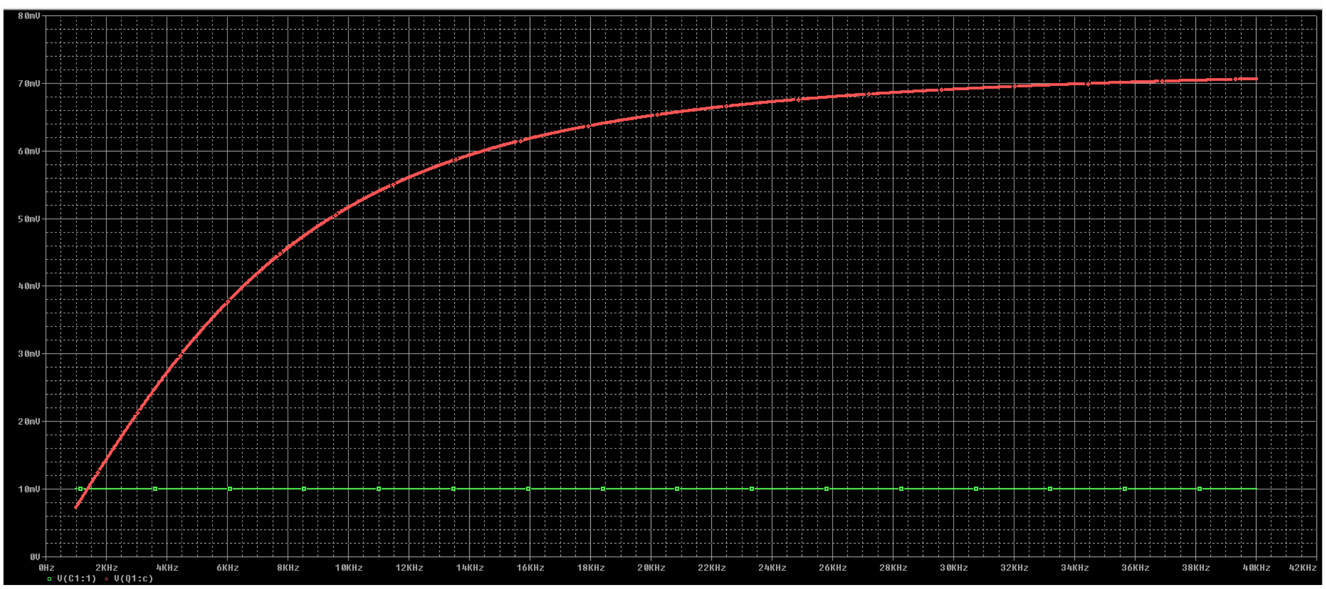

Figure 2: Input and Output Voltages of AC sweep (1kHz to 40kHz) of BJT amp with no load

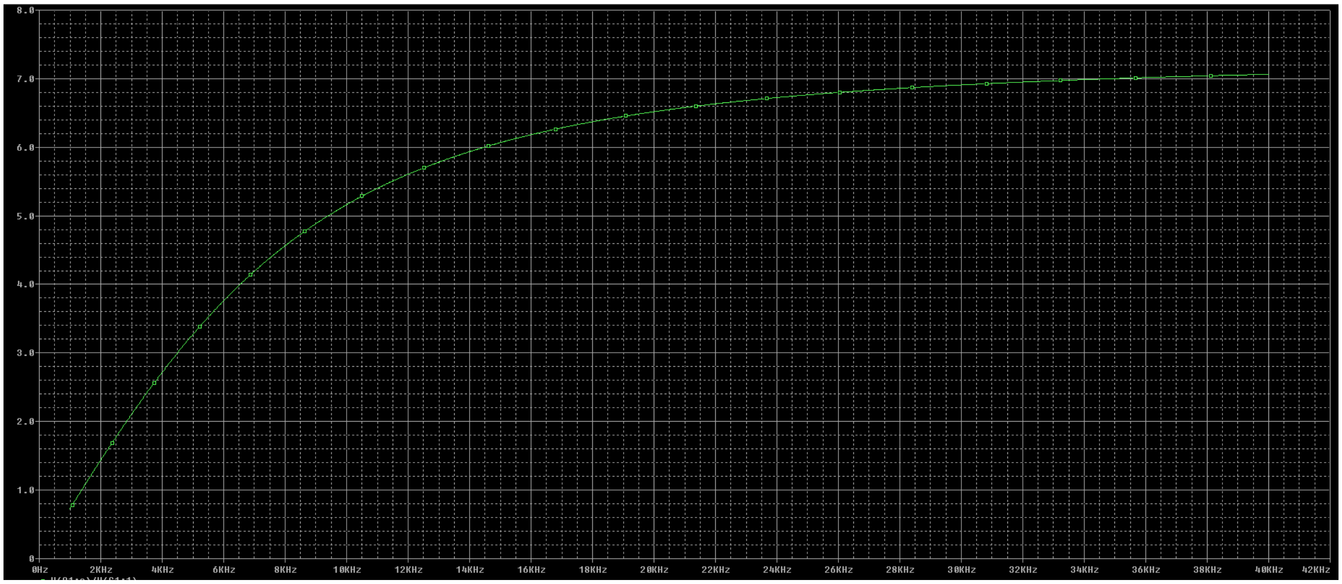

Figure 3: Gain of BJT Amp no load : AC sweep (1kHz to 40kHz)

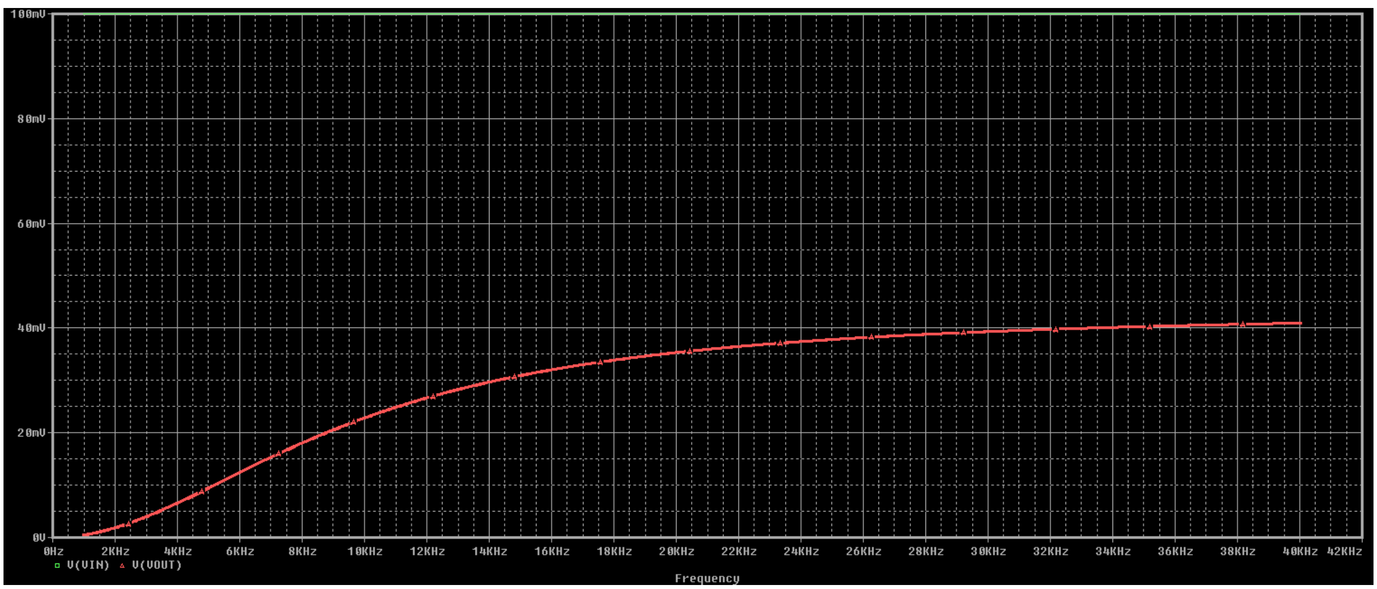

Figure 4: Input and Output Voltages of AC sweep (1kHz to 40kHz) of BJT amp with load

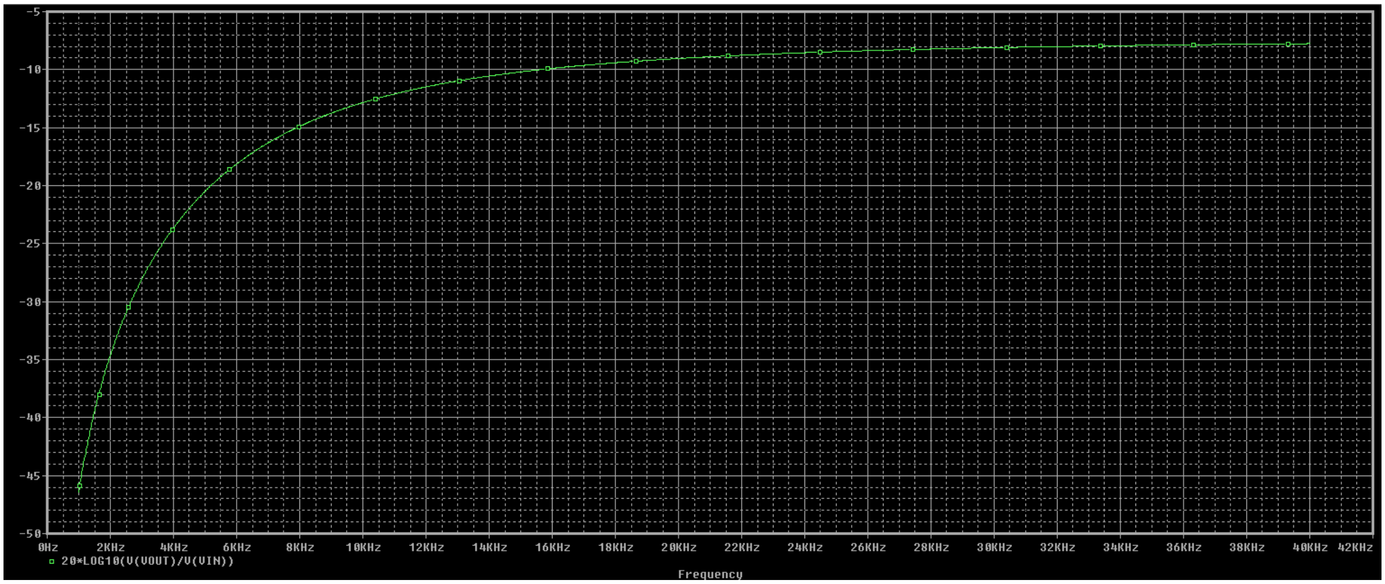

Figure 5: Gain of BJT Amp with load : AC sweep (1kHz to 40kHz)

At around 40kHz the gain seems to be around -8. Not evident on these graphs, is the 180 degree phase difference. This would make the +8 apparent gain to a -8 gain.With the load, the gain seems to max out at around -6dB. The high pass effects are as desired.

Equivalent BJT

Find an equivalent model for your BJT by examining the datasheet for 2N3904. You should be able to fund Cu and Cpi from the datasheet. They are named differently in the datasheet. Use the operating point (iC) obtained in steps 1 and 2. For VA use the IV characteristics of the BJT which you had found in the previous experiment

On the ST datasheet for the 2N3904 the collector base capacitance is 4pF and the emitter base capacitance is 18pF. The collector base capacitance is the same as C_μ and the emitter base capacitance is the same as C_π.

$$
\begin{aligned}
C_\pi &= 18 \times 10^{-12}\text{F} \\
C_\mu &= 4 \times 10^{-12}\text{F} \\
g_m &= \frac{I_C}{V_T} \\
g_m &= \frac{3 \times 10^{-3}}{0.026} \\
g_m &= 0.115385 \\
r_e &= g_m^{-1} \\
r_e &= 8.66664 \\
r_\pi &= \frac{\beta}{g_m} \\
r_\pi &= \frac{150}{0.115385} \\
r_\pi &= 1300
\end{aligned}
$$

Points from the Measured I_C vs. V_{CE}

$$
\begin{aligned}
(V_{CE}, I_C) &= (0.788, 0.009759) \\
(V_{CE}, I_C) &= (3.403, 0.009997) \\
m &= \frac{0.009997 - 0.009759}{3.403 - 0.788} \\
m &= 9.101 \times 10^{-5} \\
y &= m(x - V_a) + y_0 \\
y &= mx - mV_a + y_0 \\
y - mx &= -mV_a + y_0 \\
(0.009759) - \left(9.101 \times 10^{-5}\right)(0.788) &= -9.101 \times 10^{-5} V_a + y_0 \\
(0.009997) - \left(9.101 \times 10^{-5}\right)(3.403) &= -9.101 \times 10^{-5} V_a + y_0 \\
9.68728 \times 10^{-3} &= -9.101 \times 10^{-5} V_a + y_0 \\
9.68729 \times 10^{-3} &= -9.101 \times 10^{-5} V_a + y_0 \\
V_a &= 106.438 \\
y_0 &= 9.68728 \times 10^{-3} \\
r_0 &= \frac{V_A}{I_C} \\
r_0 &= \frac{106.438}{3 \times 10^{-3}} \\
r_0 &= 35.479\text{k}\Omega
\end{aligned}
$$

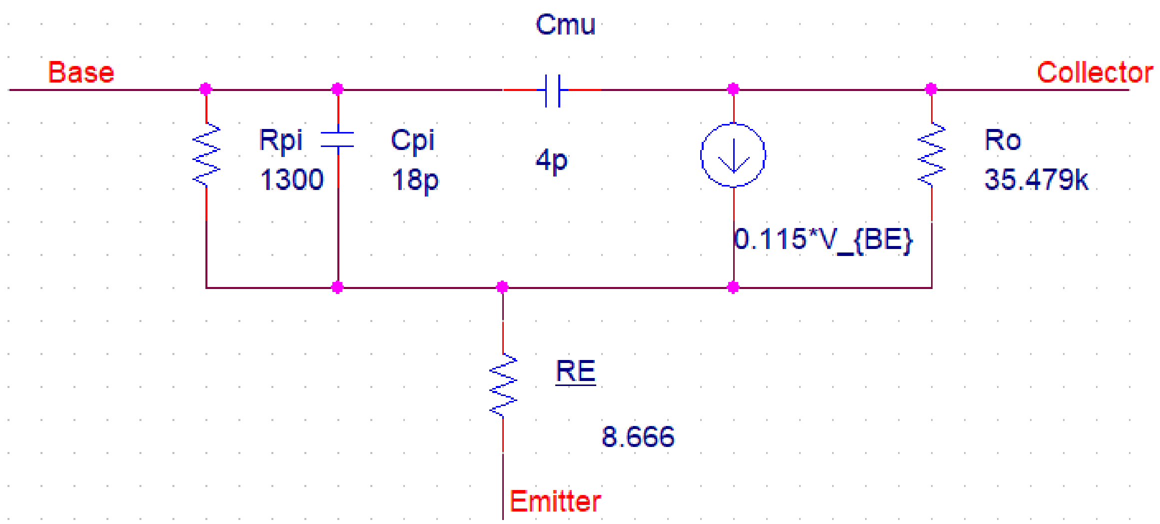

Figure 6: Equivalent BJT circuit schematic

DIBO Differential Amp

Use PSpice to model the differential amplifier circuit shown in Fig. 4 in DIBO mode. Use 2N3904 BJTs and use appropriate values for resistors (you can choose the values that will not lead to excessive gain and saturation) to demonstrate that the circuit provides differential amplification. Use Vcc = 5 and Vee = 5. Use a pair of sinusoids with opposing polarity (180 degree phase shift) as the inputs to the differential amplifier. Recall from the theory Ic is needed to compute re . Make sure that the conditions set in the analysis of DIBO circuit are satisfied. Assume RS1 = RS2 = 50 Ohm.

$$
\begin{aligned}
&\text{Conditions} \\
R_1 &= R_2 = R_L \\
r_{e1} &= r_{e2} = r_e \\
\frac{R_{s1}}{\beta}, \frac{R_{s2}}{\beta} &\ll R_3, r_e \\
&\text{Design} \\
i_C &= \frac{V_{ee} - V_{BE}}{2R_3} \\
R_3 &= \frac{V_{ee} - V_{BE}}{2i_C} \\
i_C &\to 2 \times 10^{-3} \\
R_3 &\to \frac{5 - 0.7}{2\left(2 \times 10^{-3}\right)} = 1075 \\
g_m &= \frac{I_C}{V_T} = \frac{2 \times 10^{-3}}{0.026} \\
g_m &= 7.692 \times 10^{-2} \\
r_e &= \frac{1}{g_m} = \frac{1}{7.692 \times 10^{-2}} = 13 \\
\text{Gain} &= 4 \\
R_L &= R_1 = R_2 = 13 \cdot 4 = 52
\end{aligned}
$$

Experimental Results

Common Emitter Amplifier

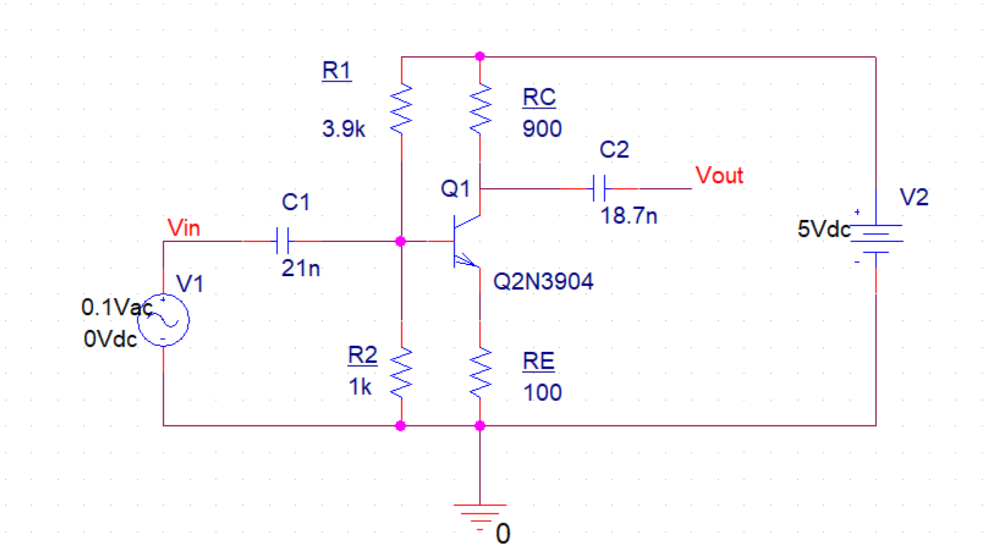

Figure 7: BJT Common Emitter Amplifier Schematic

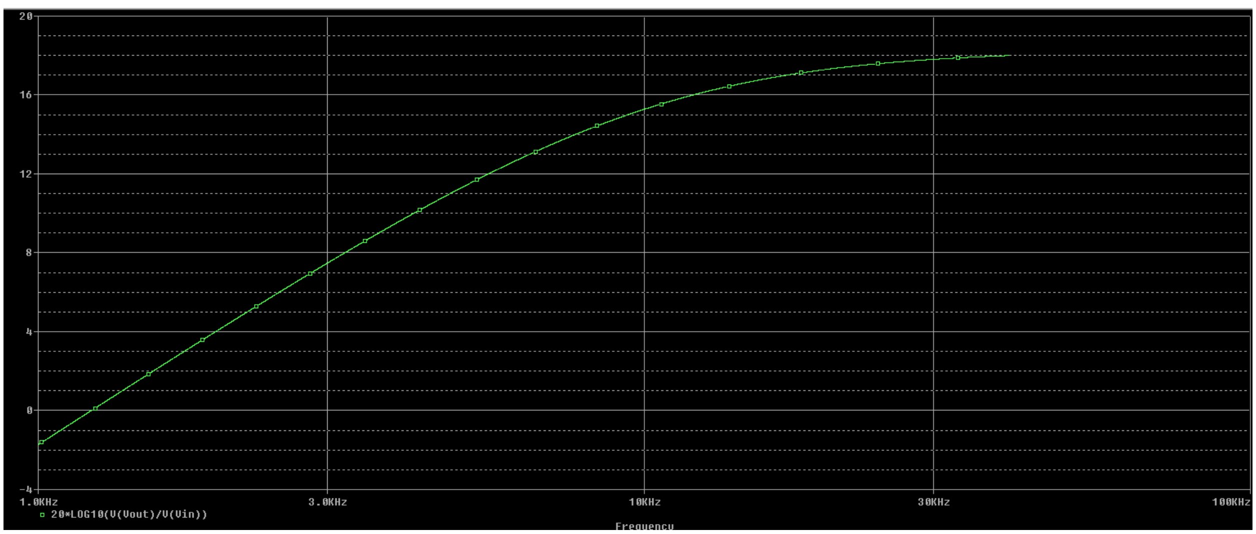

Figure 8: Simulation of BJT Common Emitter Amplifier Frequency Response

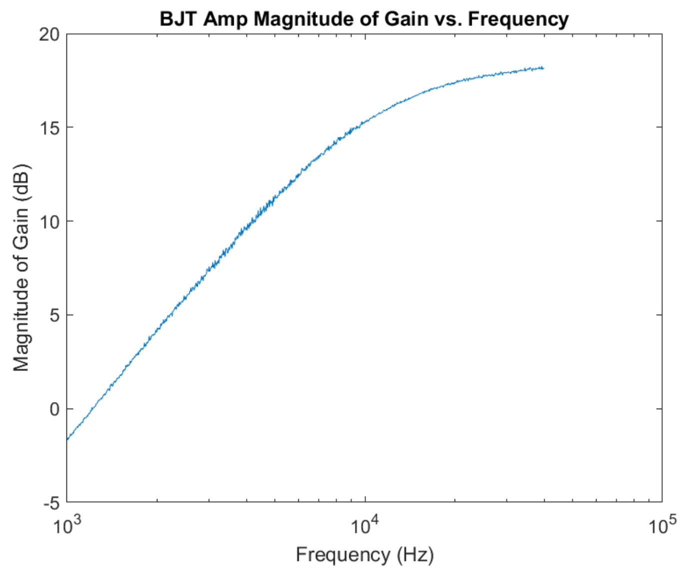

Figure 9: Measured BJT Common Emitter Amplifier Frequency Response

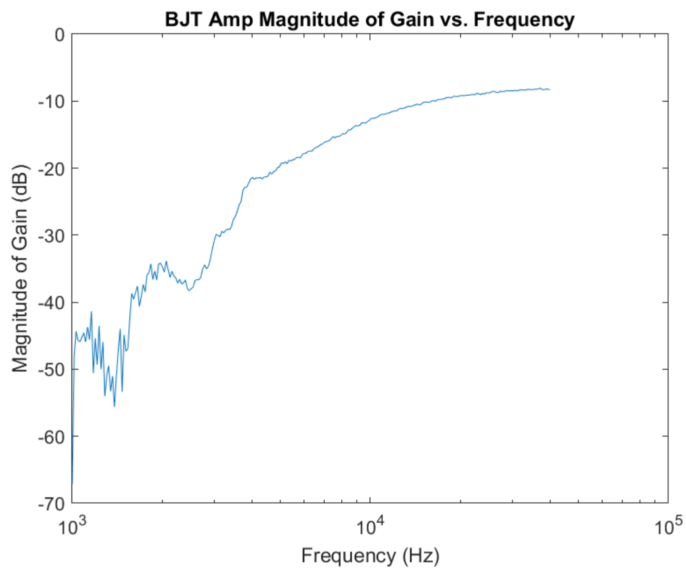

Figure 10: Measured BJT Common Emitter Amplifier Frequency Response with 50Ω Load

Does your experimental results match your simulation results in the pre-lab? If not, explain the possible causes for the discrepancy.

The simulation results match the measured values of the frequency response without load. With a load the expected values is also seen. In the loaded case, the gain of the amplifier is the output impedance over the equivalent emitter resistance. In this case that is approximately $50/100$, the the expected gain is 0.5 or -6.02dB. The measurements are roughly on the same order of this predicted gain. Some discrepancies in the measurement could be due to:

- Resistor tolerances in both the load and emitter legs
- Large deviation from the operating point

- The capacitive effects in both the equivalent model and in the coupling capacitors

Differential Amplifier

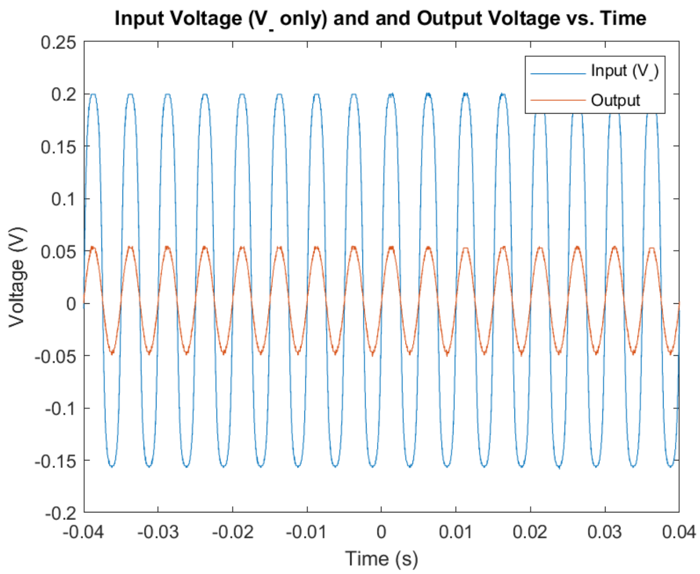

Figure 11: Transient Differential Amplifier Measurements

Does your measurement of gain and input impedance match the theoretical and simulation results? If not, provide possible reasons for the discrepancy.

Through the transient measurement, the gain was recorded as ≈ 4 which coincides phenomenally with the theoretical gain of the amplifier as well as the simulation results where the gain was 4. The theoretical input impedance of the differential amplifier is $R_{\text{in}} = 2\beta r_e$. This corresponds to $\approx 2(225)(13) = 5850$. The measured value of the input impedance was calculated with a 100mV input voltage and a 18.6μA current. This yields a measured input impedance of $\approx 5347.58\Omega$. The measured values closely matches this simulated and theoretical results. However, the measurement of this value was highly sensitive to the resistor values, the operating point, the similarity of the BJTs, and many other factors.