Project 1

LTSpice Tutorial and BJT Amplifier

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June 18, 2021

ECE 322L
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1 Introduction

This project introduces the design and simulation of a particular NPN transistor. The transistor used in this project is the 2N3904 bipolar junction transistor. The project will begin by finding the transistor characteristics through simulation. Afterwards, there will be the design of a Common-Emitter amplifier using calculations from theory and the characteristics found from simulation. Finally, there will be simulations to see if the theory holds and that the expected or close to the expected values are found.

2 Part 1(A): DC Characteristics

The following circuit was implemented to find the DC characteristics of 2N3904 transistor:

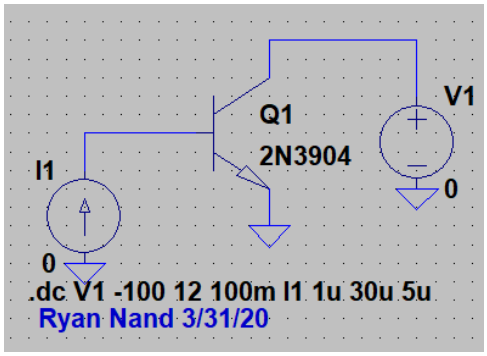

Figure 1: Ic Vs. Vce Schematic

The simulation is a DC sweep ranging the current source (I1) from 1 μA to 30 μA at 5 μA step intervals and the voltage source (V1) from -100 V to 12 V at 100 mV step intervals.

The following is the Ic Vs. Vce plot extrapolated to find the early voltage of the transistor:

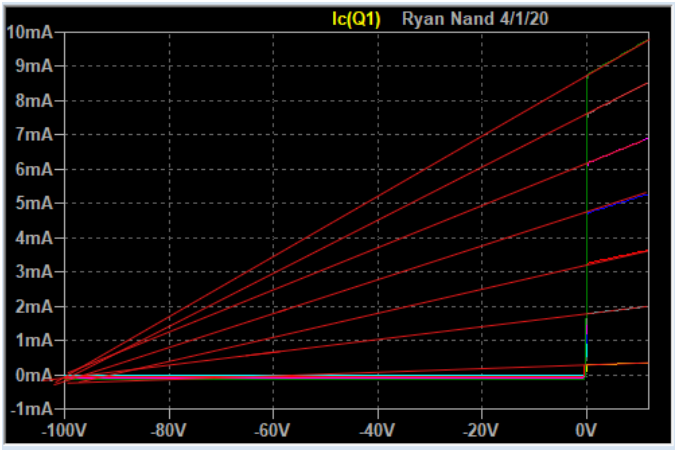

Figure 2: Ic Vs. Vce

As you can see from the previous plot. The early voltage is about 100 V.

This next circuit is for finding the current gain of the transistor, also known as β.

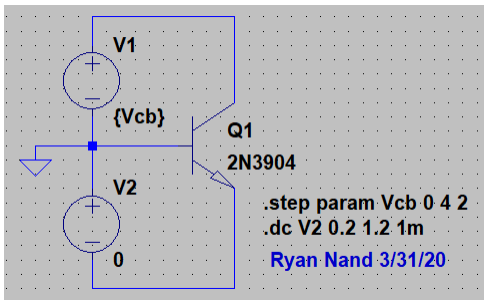

Figure 3: β Schematic

The next figure is the plot we want from the circuit above. It is known as a Gummel plot.

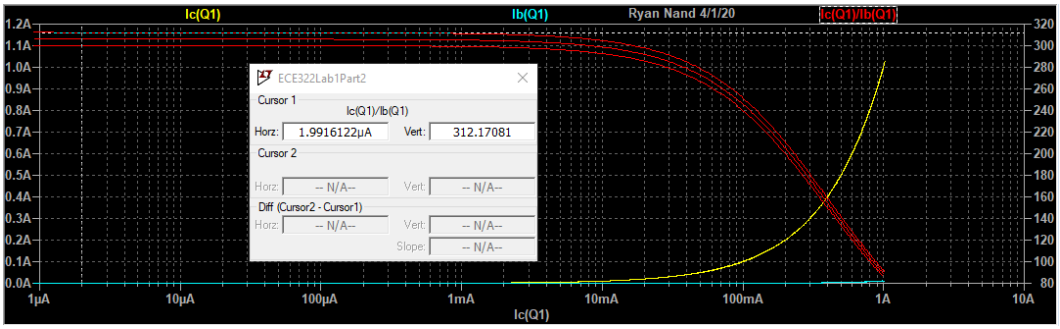

Figure 4: Gummel Plot

From this plot we can see that the β is about 300. The β is at it's maximum when Ic is very low or close to zero. In the micro-amp range.

At this point, we have everything we need as far as DC characteristics go. Moving onto AC characteristics.

3 Part 1(B): AC Characteristics

For this part we will establish a Bode plot to show the frequency response of the transistor. The following circuit is used to do so.

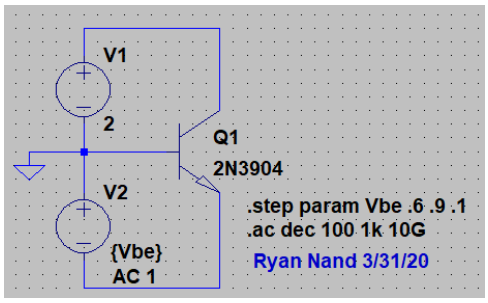

Figure 5: Bode Schematic

This produced the following bode plot:

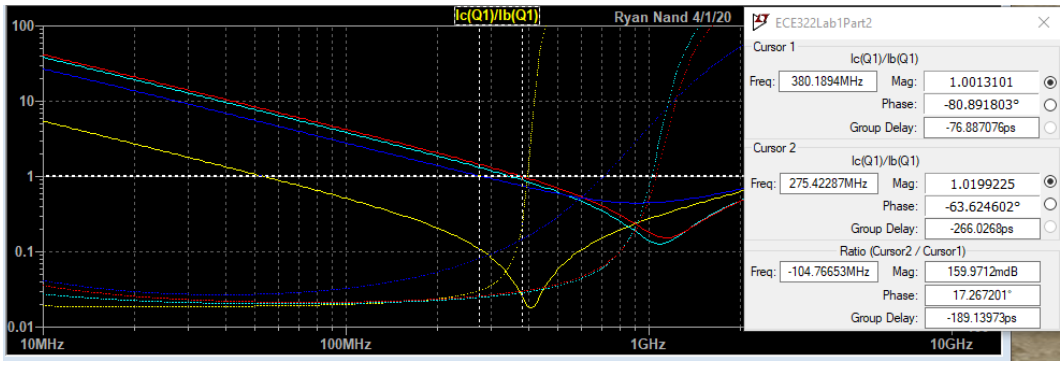

Figure 6: Bode Plot

As you can see that we used multiple steps of Vbe to establish the Bode plot. From .6 V to .9 V at .1 V increments to be exact. Also, used an AC decade sweep from 1 kHz to 10 GHz.

The unity-gain frequency is about 300 MHz. This concludes all the characteristics needed to design the CE amplifier.

4 Part 1(C): Amplifier Characteristics

This section is to establish understanding of what we are looking for from the CE amplifier. In other words, a practice of how to simulate the CE amplifier after designing one.

Here is the schematic of the CE amplifier used to simulate. The simulation is an AC sweep from 100 mHz to 1 GHz.

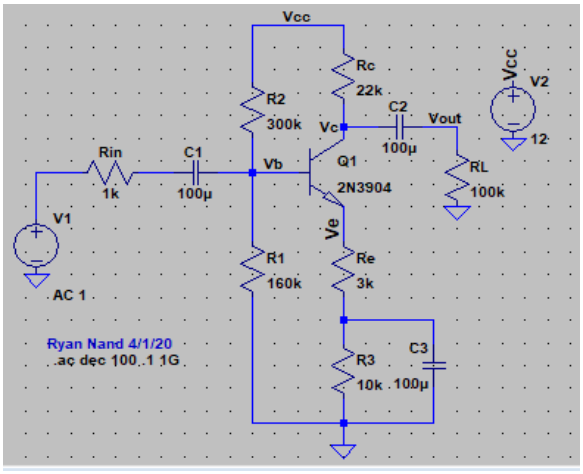

Figure 7: CE Amplifier

This next plot shows the output seen at Vout. From this we can see the bandwidth of the amplifier.

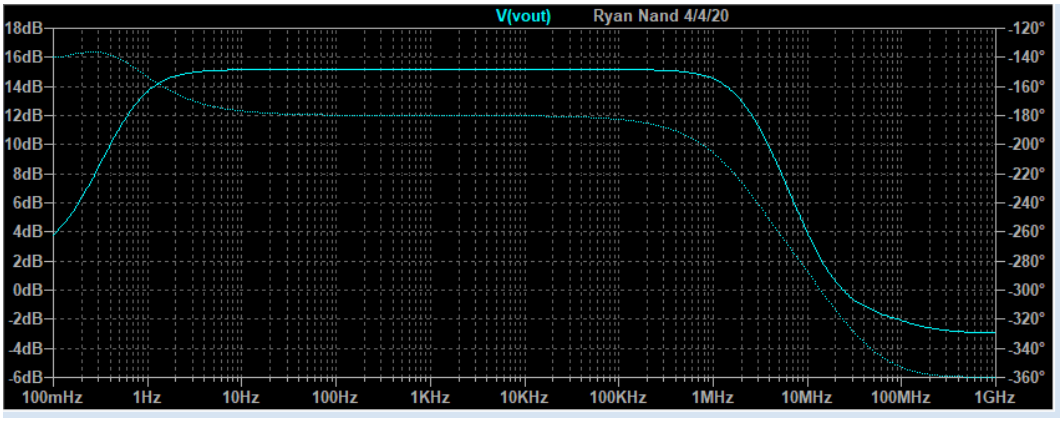

Figure 8: CE Amplifier Output

A gain of about 5.6 from the bandwidth of 1 Hz to 1 MHz. Equation for decibels is $dB = 20log(x)$

Now we can take a look at the input and output impedance of the amplifier. These plots are the following.

Since we are using a 1 VAC source, we can simply use 1/I(V1) to find the input impedance of the amplifier.

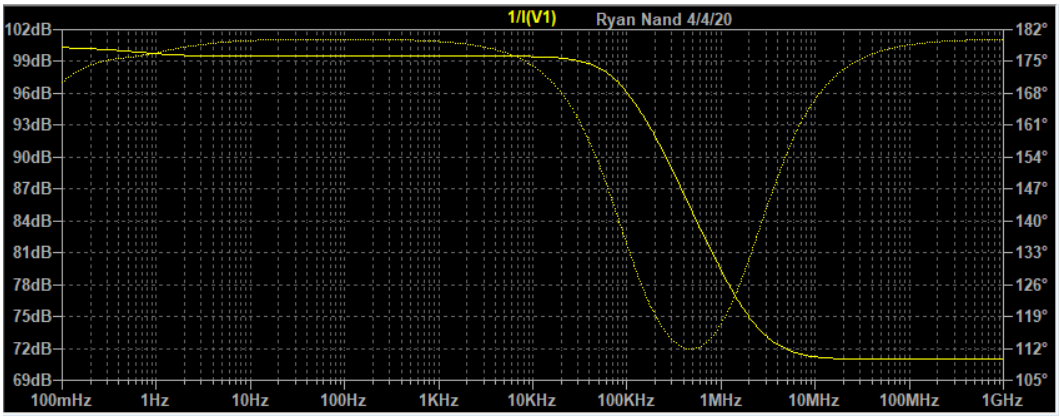

Figure 9: CE Amplifier Input Impedance

An input impedance of about 100 kΩ. Note: the schematic resistor Rin is not the

input impedance for the amplifier. Equations will be shown before the design section.

There are two ways of finding the output impedance. I will show schematics of both and then the plots it produces respectively.

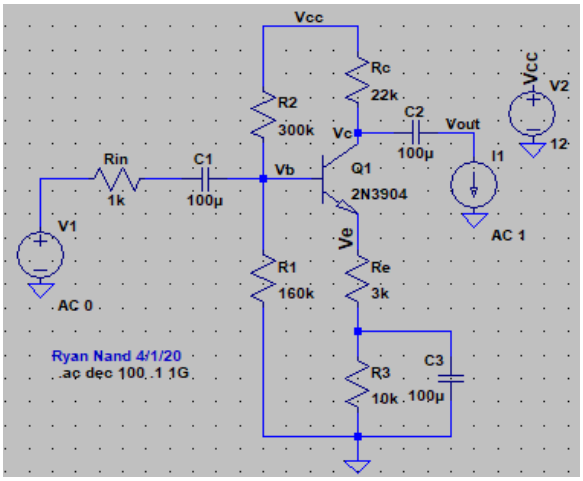

Figure 10: CE Amplifier Output Impedance Schematic 1

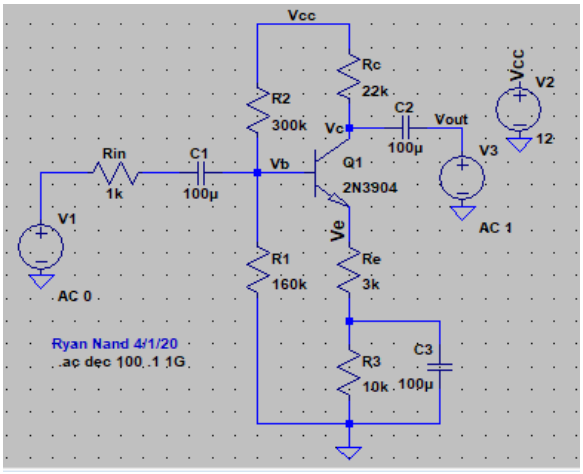

Figure 11: CE Amplifier Output Impedance Schematic 2

As you can see the load is replaced with a current source and a voltage source respectively. Both with a AC magnitude of 1.

Here are the plots for finding the output impedance with their respective methods. The first one is simply the voltage at Vout. The next is similar to how the input impedance was found. The AC magnitude of 1 over the current supplied by the source V3 gets the output impedance of the amplifier.

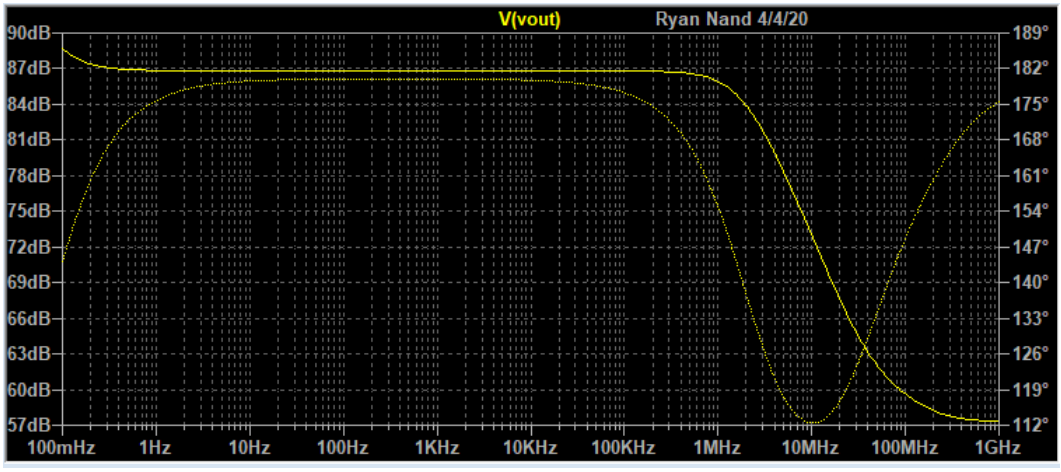

Figure 12: CE Amplifier Output Impedance Plot 1

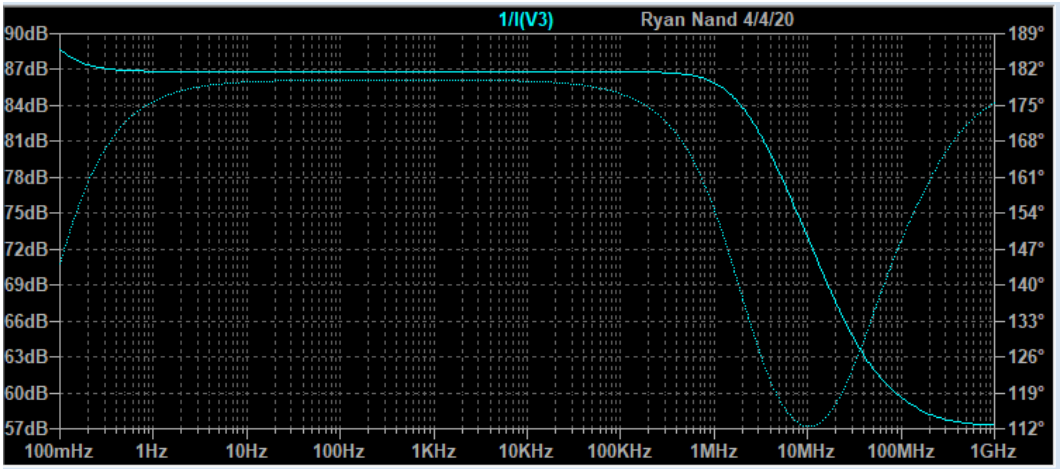

Figure 13: CE Amplifier Output Impedance Plot 2

As you can see, the plots both produce an output impedance of about 22.4 kΩ.

5 Equations For CE Amplifier Design

Equations:
The amplifier gain is:

$$A_v = (g_m R_L)/(1 + g_m R_E) \tag{1}$$

In this case since R_3 is infinite:

$$R_L = R_C||R_3 = R_C \tag{2}$$

Small signal parameters:

$$g_m = I_C/VT = 40I_C \tag{3}$$

$$r_\pi = \beta/g_m \tag{4}$$

Transistor input resistance:

$$r_{iB} = r_\pi + (\beta + 1)R_E \tag{5}$$

For full voltage swing:

$$I_C R_C = V_{CC}/2 \tag{6}$$

CE amplifier input resistance:

$$R_{in} = R_{iB}||R_B \tag{7}$$

Where R_B is

$$R_B = R_1||R_2 \tag{8}$$

Common 4 - resistor bias BJT needed equations:

$$V_{CC} = I_C R_C + V_{CE} + I_E(R_E + R_3) \tag{9}$$

$$V_{eq} = I_B R_B + v_{BE} + I_E(R_E + R_3) = V_{CC}(R_1/(R_1 + R_2)) \tag{10}$$

$$I_C = I_E = I_B\beta \tag{11}$$

6 Part 2: CE Amplifier Design

Here are the given values required for the CE design:
$V_{CC} = 12$ V, $\beta = 300$, $R_{in} = 100$ kΩ, $|A_v| = 100$

The process is as follow:

1. Solve for small signal parameters g_m and r_π by choosing a value for I_C

2. If r_π is less than R_{in} value then R_E is needed. Use the gain equation to solve for R_E.

3. Now use the equation for the transistor's input resistance (R_{iB}) to check if resistance value is more than the amplifier's resistance value (R_{in}). If it is then proceed to next step, otherwise, start over with a new I_C

4. Set $I_C R_C$ to a value that is a little greater than half of V_{CC}. For example, in this design 6.2 V was used. Using equation (9) we plug in the values and solve for $V_{CE} + I_E(R_E + R_3)$. Whatever that value is we divide by two so that V_{CE} is half of $I_E(R_E + R_3)$. Using $I_E(R_E + R_3)$ solve for R_3.

5. Using equation (7) solve for R_B. Using equations (10) and (11) solve for V_{eq}. Afterwards, using both found values and equations (8) and (10) solve for R_1 and R_2 simultaneously.

This next schematic shows the values found using the initial values and the process above.

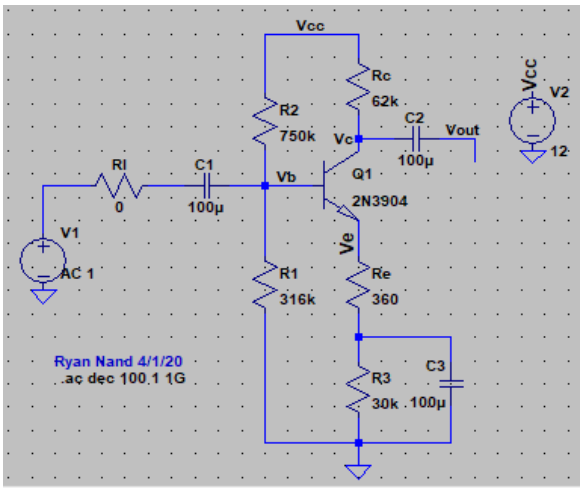

Figure 14: CE Amplifier Design 1

The following plot shows why the circuit is not acceptable. A gain of about 95 is too low.

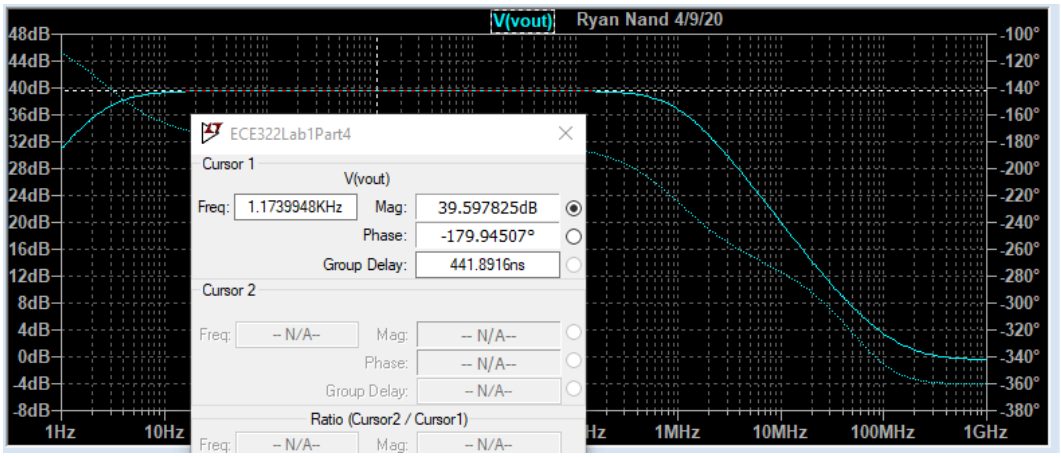

Figure 15: CE Amplifier Design Output 1

With this new schematic the values of gain and the amplifier's input resistance was increased by 5 percent. Therefore, the gain used to do the calculations was 105 and the amplifier's input resistance was 105 kΩ.

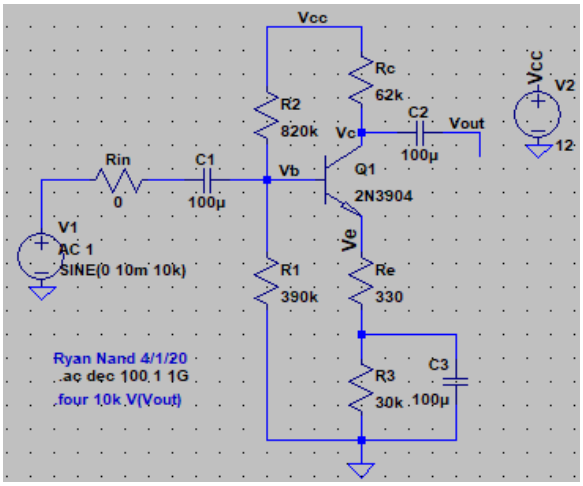

Figure 16: CE Amplifier Design 1

These next few plots show why this circuit is acceptable. It's the output, amplifier's input resistance, and output resistance respectively.

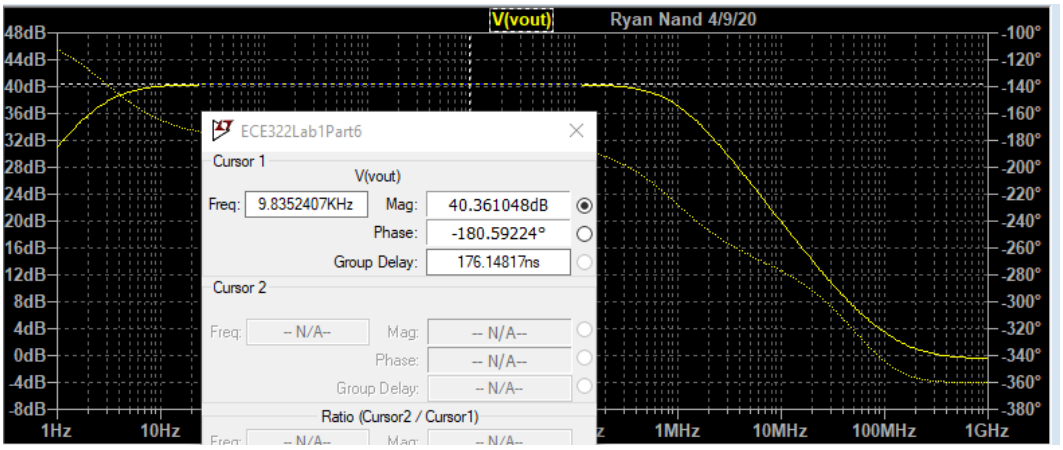

Figure 17: CE Amplifier Design Output 2

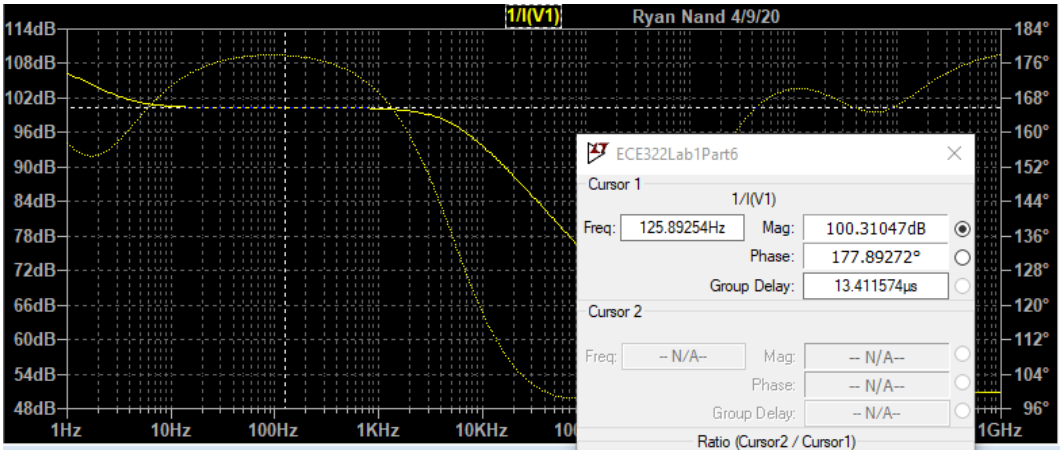

Figure 18: CE Amplifier Design Input Resistance 2

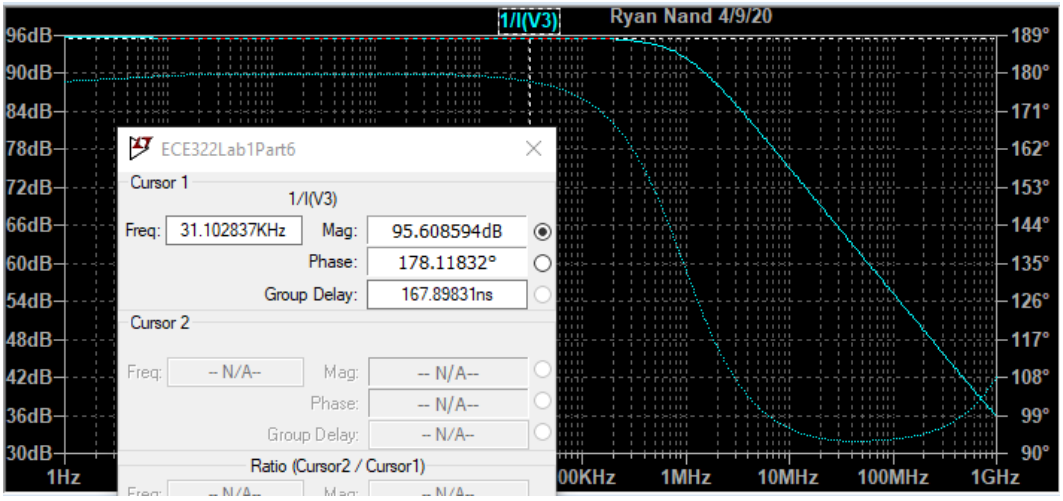

Figure 19: CE Amplifier Design Output Resistance 2

As you can see from the plots above, there is a gain greater than 100 and the amplifier's input resistance is greater than 100 kΩ.

The last constraint was that the total harmonic distortion is less than 2 percent. Under the following restrictions the THD was met:

Input: 10 mV with 10 kHz

The LTSPice simulation was a transient response from 0 to 1 ms. Also, had to include the ".four 10k V(Vout)" command to find the THD in the error log.

The above produced a THD of 1.66 percent, which is acceptable.

However, if the input was increased to 20 mV the THD becomes 3.26 percent, which is unacceptable.

Finally, when adding $R_I = 1$ kΩ and $R_L = 100$ kΩ the gain dropped to 64. A big drop in gain.

7 Conclusion

In the end some changes had to be made in order to get acceptable amplifier values. Looks like when designing with transistors there are many variations that can change the values. So following the theories and then simulating small changes to the design gets you closer to the values required. It is trial and error at that point. It makes sense seeing how many different transistors there are for different types of designs.

So if I were to do this project again. I would try to spend less time on finding the transistor characteristics and more time on designing the amplifier. Especially, seeing how most transistors have the characteristics already recorded in data sheets or in the LTSpice models. However, it was good practice.