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Laboratory 4: BJT characteristics, Small Signal Amplifiers

Introduction:

We will use this lab to analyze the characteristics of BJTs in a similar way that we did for FETs. We will analyze the different regions of operations of the transistor, though we will be mostly looking to keep the component in forward active. Just like FETs and diodes we will take a look at the small signal models and operation of these devices. Through analysis, simulation, and experimental tests we will look at and compare the real and ideal traits of the BJTs

Exercise 4.1:

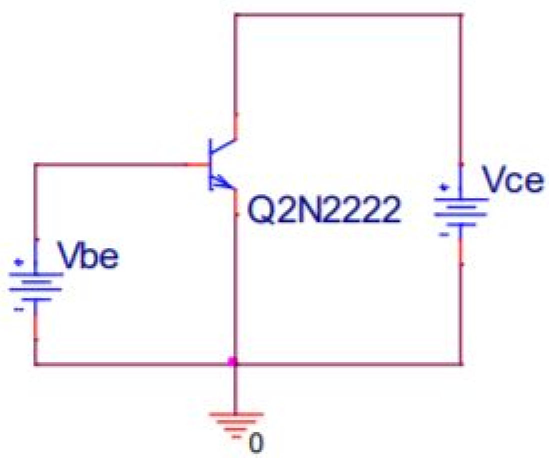


Figure 4.1.1 LTSpice Circuit for IV curves

Figure 4.1.2 IV Curve for Vbe sweep

Vbe was set to 1.5V, and Vce was set to 2V. Then Vbe to the Primary Sweep with voltage range 0 < VBE < 0.75V, with the IV curve shown above. At approximately 600mV the transistor turns on, this is consistent with ideal diode characteristics.

Figure 4.1.3 IV curve for Vce primary sweep

Then the primary sweep was set to Vce from 0 to 2V, with Vbe as the secondary sweep with values 0.6, 0.62, 0.64, 0.66, 0.68, 0.7, resulting in the IV curve above. The transition voltage is about 26 mV.

Exercise 4.2

The following circuit was implemented on the discovery board, with V1 set to 1.5V then 1.75V and finally 2V. V2 was set to a triangle wave with a frequency of 100Hz, VMax of 3V, and a Vmin of 0V.

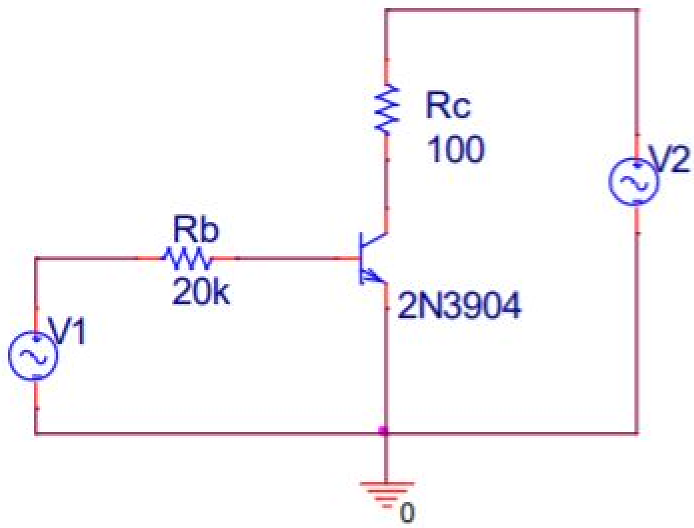


Figure 4.2.1 Discovery Board Circuit

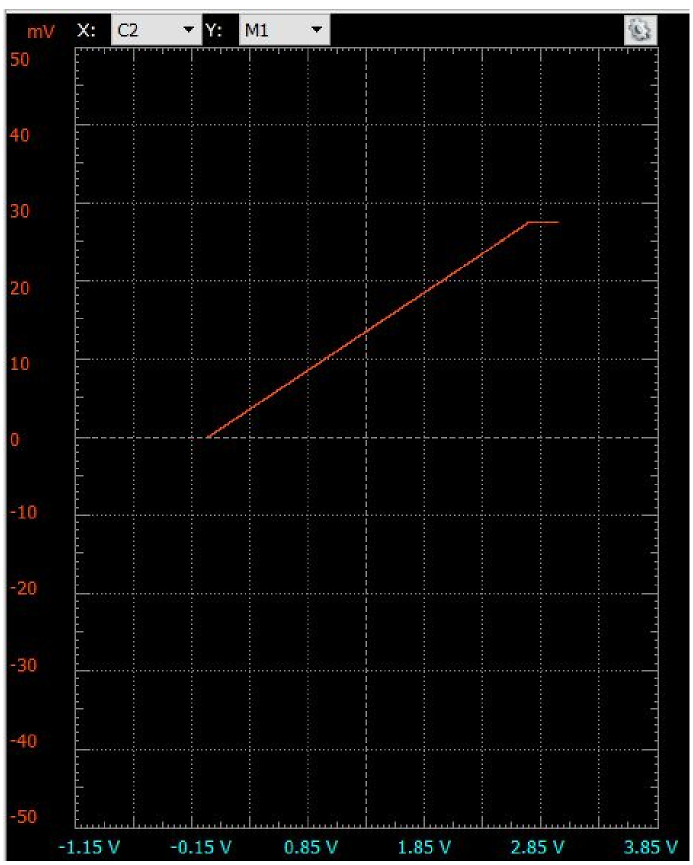


Figure 4.2.2 IV curve V1=1.5V

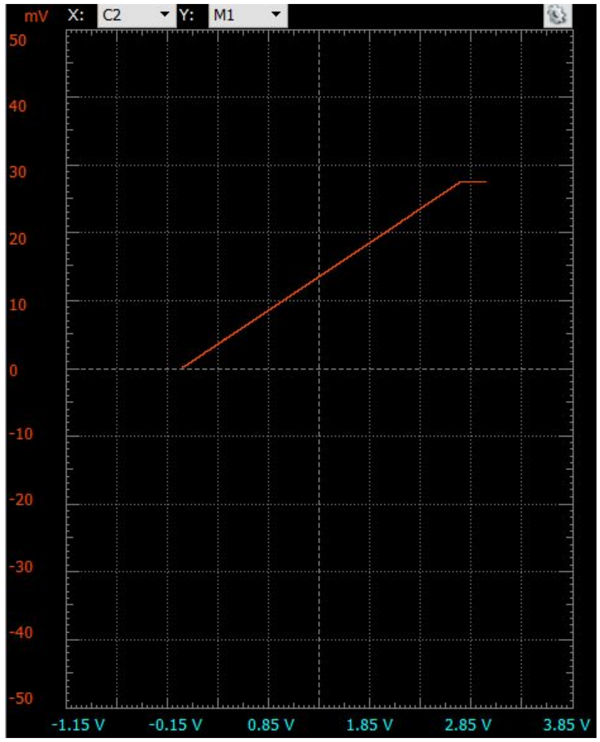


Figure 4.2.3 IV curve V1=1.75V

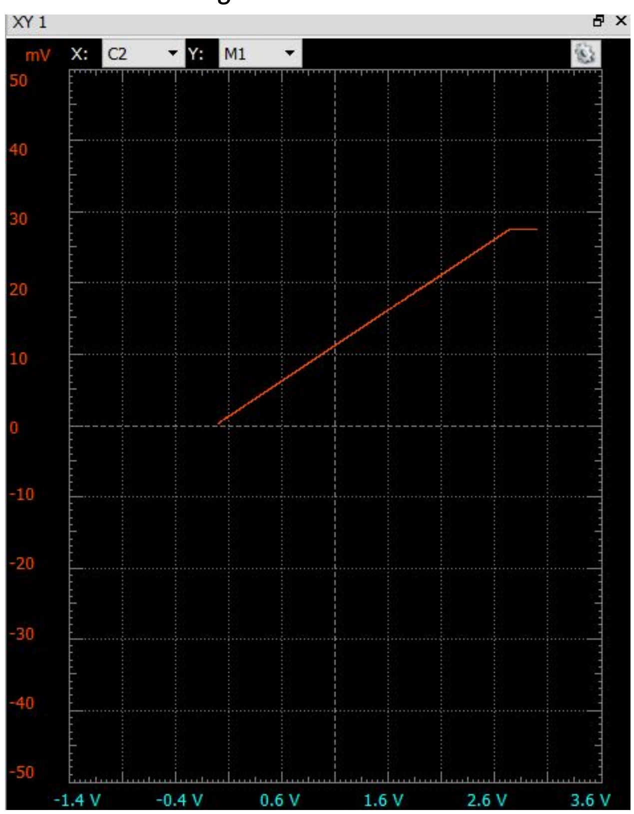
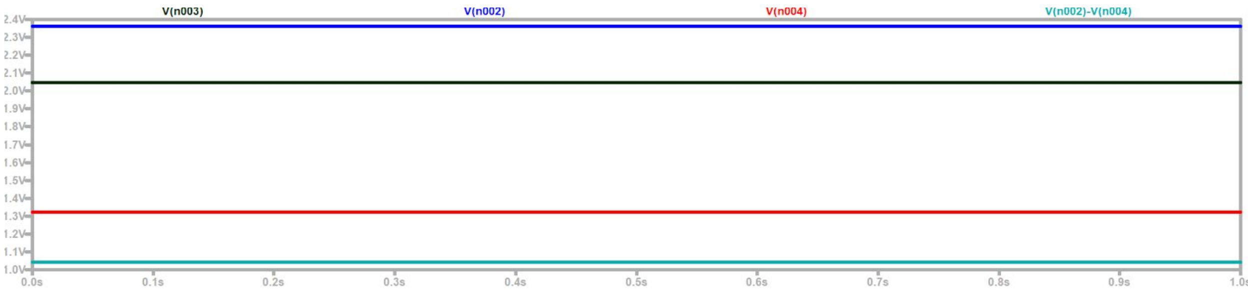


Figure 4.2.4 IV curve V1=2V

1. Yes the transition voltage is consistent with expectations, it is about 2.9V, this value is more than the simulated value.
2. For V1 = 1.5V the base current is given by the formula $\frac{V1-Vbeon}{Rb}$, $\frac{1.5V-.7V}{20k}$ =.04mA.
   For V1 = 1.75V, $\frac{1.75V-.7V}{20k}$ =.0525.
   For V1 = 2V, $\frac{2V-.7V}{20k}$ =.065mA.
3. For 1.5V = 6mA
   For 1.75V = 9mA
   For 2V = 11mA
4. β = Ic/Ib
   For 1.5V = 150
   For 1.75V =171
   For 2V =169
   All of these β values are in the range of 100-300 indicated on the spec sheet, although on the lower side.

Exercise 4.3:

LTSpice Bias Circuit:



1. The Black voltage is the Base Voltage to the BJT. It is clearly at least on. Blue and Red are the voltages at the C and E pins of the transistor. The teal is the voltage difference, Vce for the BJT. It is clearly in the forward active region.

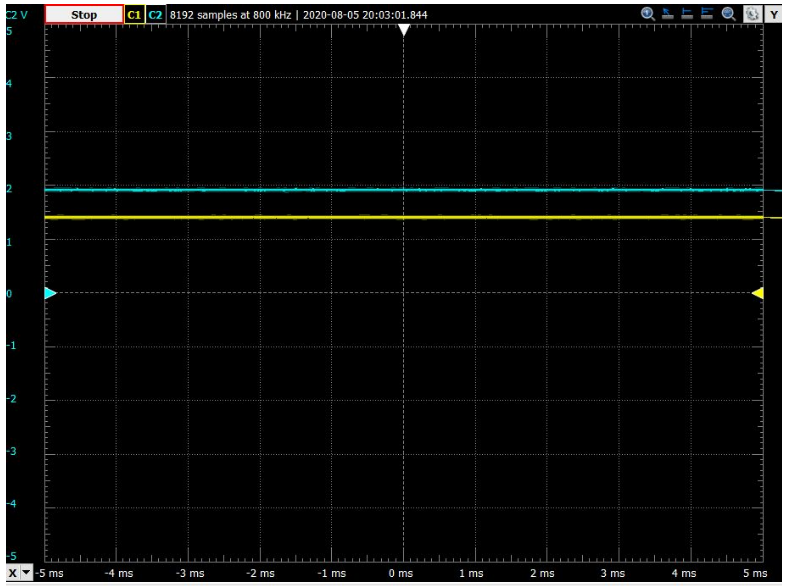
2. The Blue and the Black are the Emitter and Collector current respectively. Thus the base current is the difference between the two (RED). We see that $I_B = 45.24\ \mu A$.

$r_\pi = 574.71$

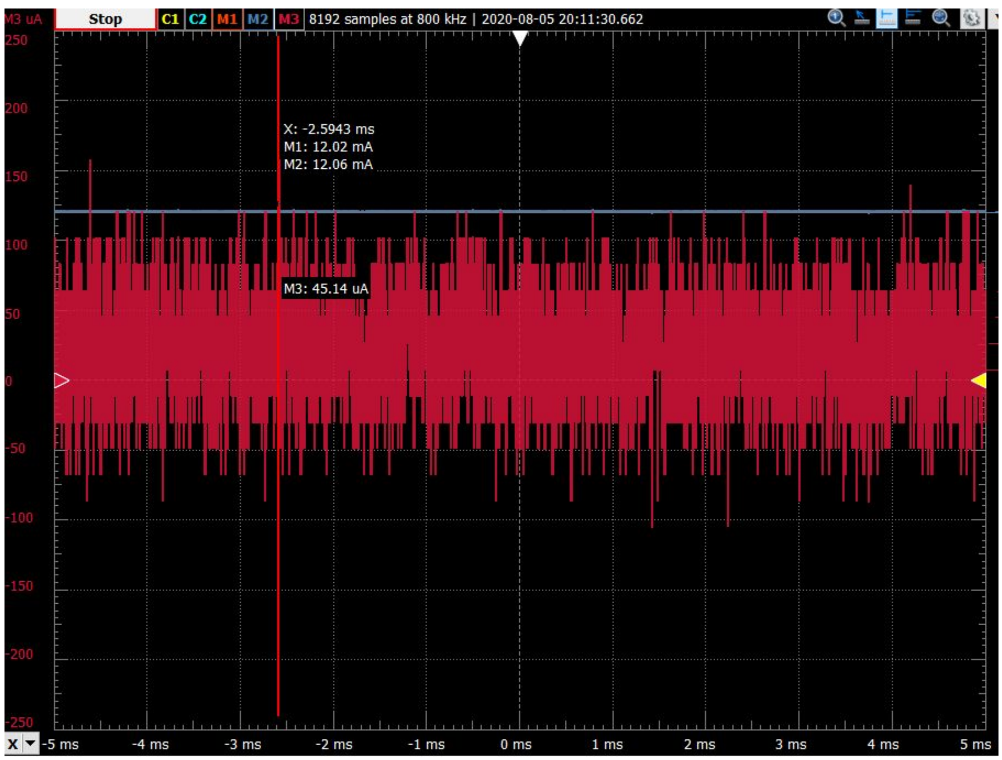
$g_m = (I_C/I_B)/r_\pi = 0.507$

$r_e = 1.97$

Discovery Board Bias Circuit:



In this image C1 (Yellow) = VCE and C2 (Blue) = Vb. We clearly see the transistor is on and forward active.



Knowing that $I_E = I_C + I_B \rightarrow I_B = I_E - I_C$, we show above channel M3. We get a value of roughly 45uA to 55uA. So we choose $I_B = 50\mu A$

Using that I_B we get

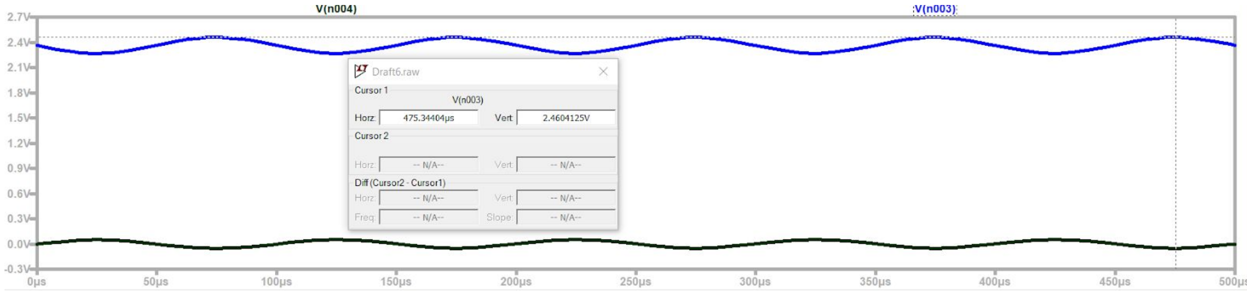
$r_\pi = 520$

$g_m = (I_C/I_B)/r_\pi = 0.462$

$$r_e = 2.16$$

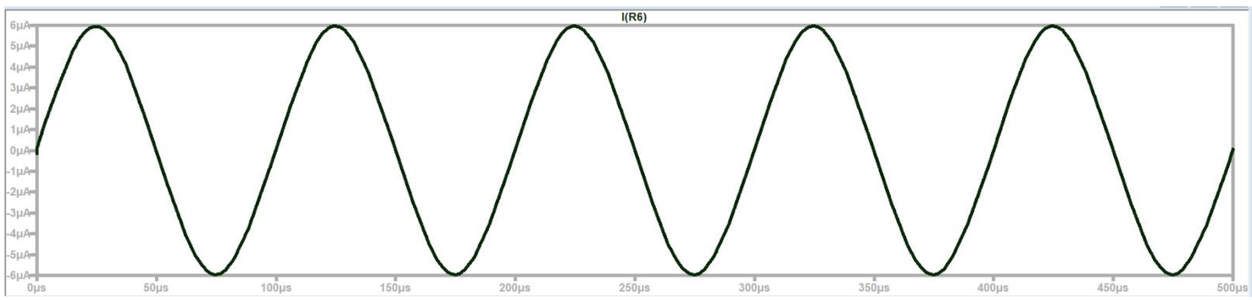
Exercise 4.4:

LTSpice of Common Collector Amplifier:



Input is 50mV amplitude, and our output is listed above. The gain we see is 49.2.

We can see that from this value the simulated results match the simulated β.

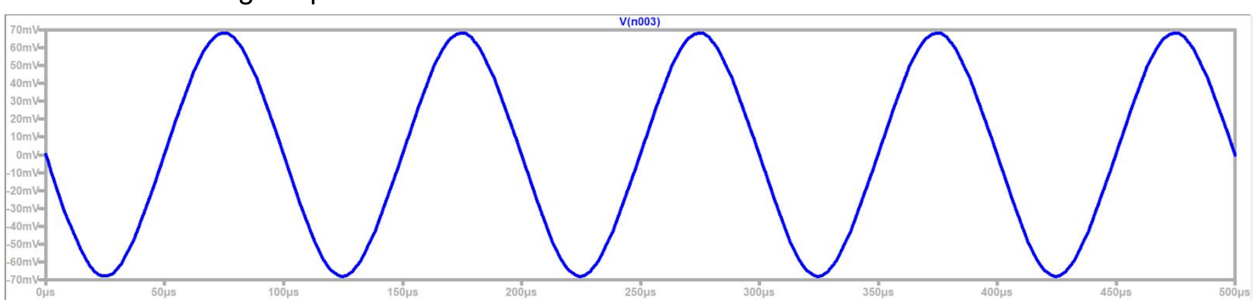


We calculate that Rth = Rin + Rig = 11k

From simulating the input current we see that Vth/I = Rin = 8333

The simulated results and calculated results do not match but are within an order of magnitude to each other.

Determining Output Resistance

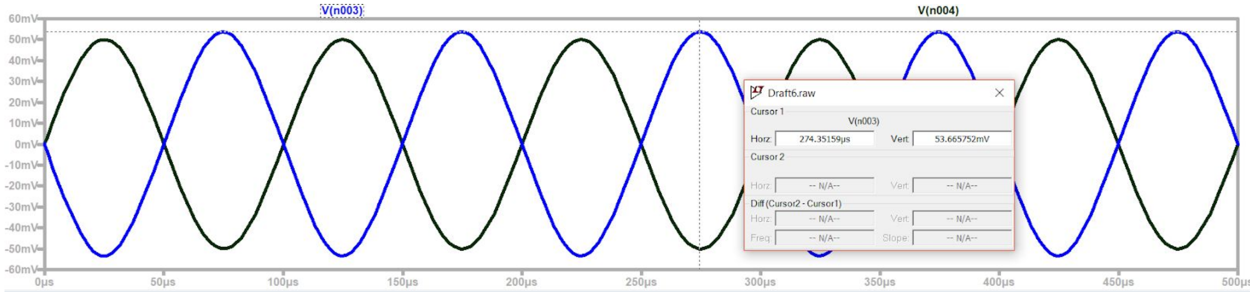


We place a 470 ohm resistor across the load. We solve for Rout below.

$$70mV = \frac{2.46(470)}{470+x} \; ; \; x = 16047\,\Omega$$

Using the Hybrid pi model we see that Rout is 200 ohms. Our results are quite off.

Determining Overall Gain

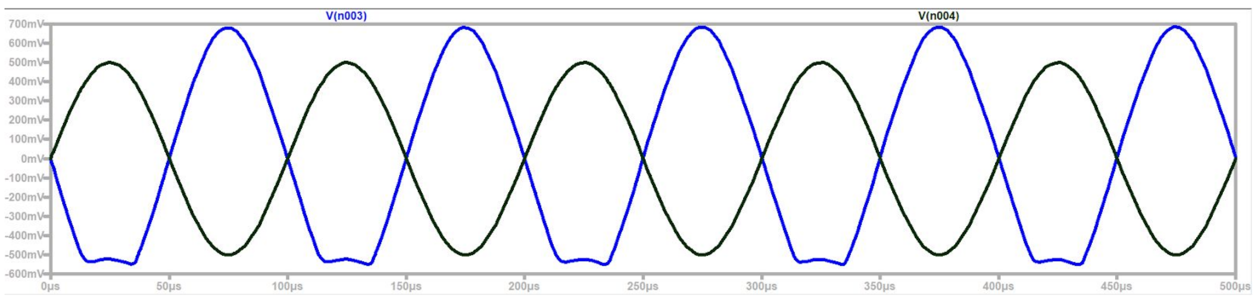


We have $-53mV/50mV \ = \ -1.072 \ = A_V$

$$A_V \ = \ \frac{R_{IN}}{R_{in}+R_{sig}}(A_{V_o})\frac{R_L}{R_{L:}+R_{out}} \ = \ -1.06$$

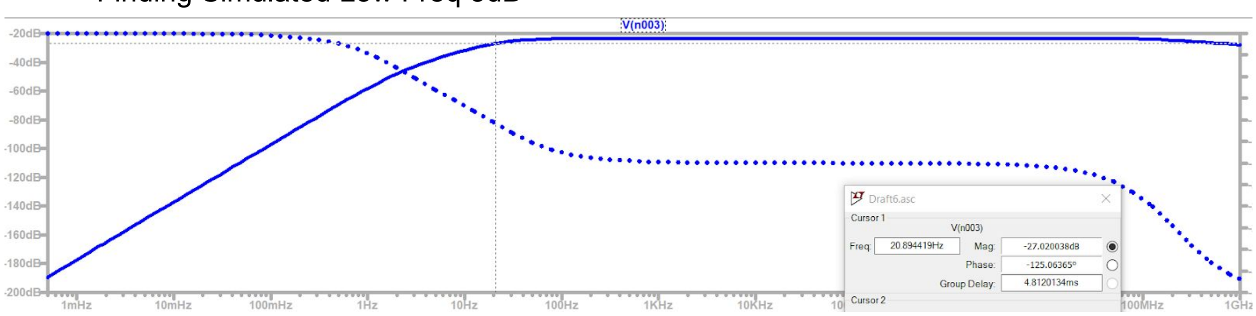
This is quite close to our simulated values.

Increasing Input until the waveform is change



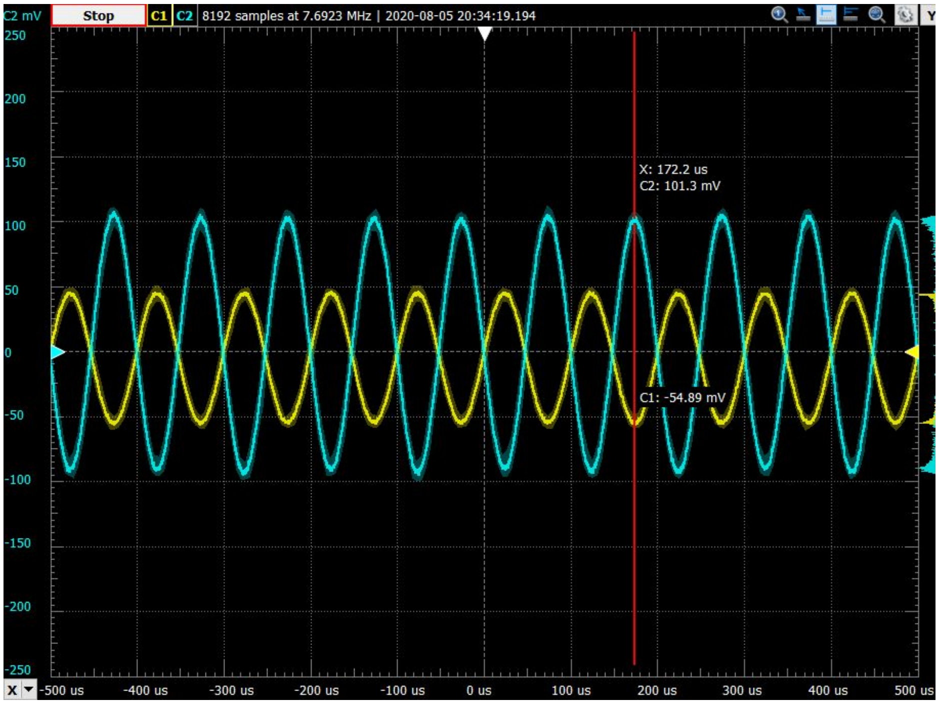
We start to see variations around 0.5V amplitude for the signal. The reason this is causing changes is because the increased signal is now heavily affecting what kind of IB we get into the Base, thus changing the IC of the BJT. Changing the IC will mean changing the VCE voltage, and at this large of a signal, it is a significant change.

Finding Simulated Low Freq 3dB



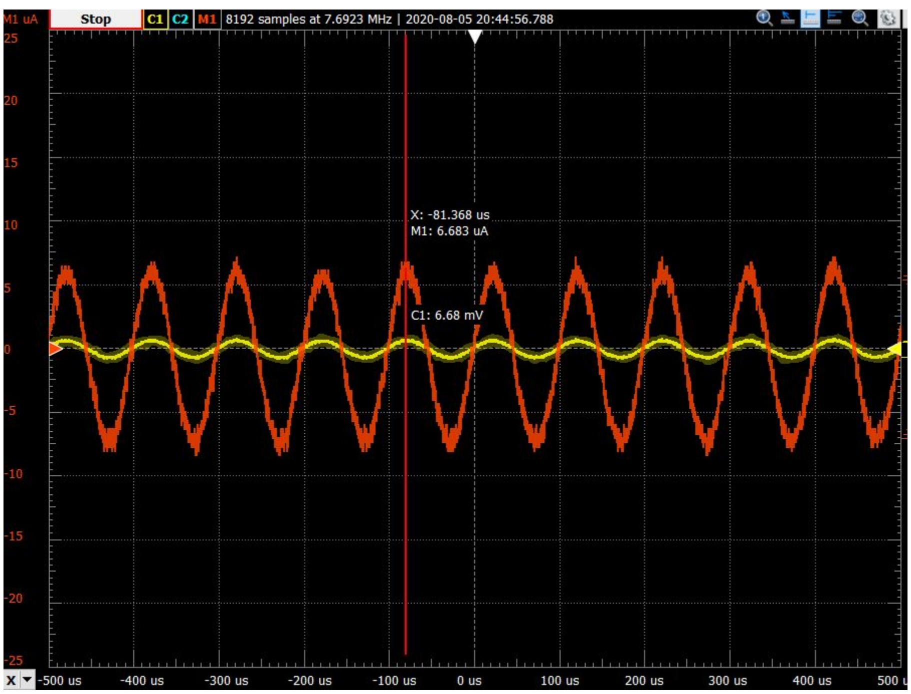
We see that the low freq is roughly 20 hz. Thus the decade it is a part of is the 10Hz decade. There is no simulated high freq rolloff.

Discovery Board of Common Collector Amplifier.



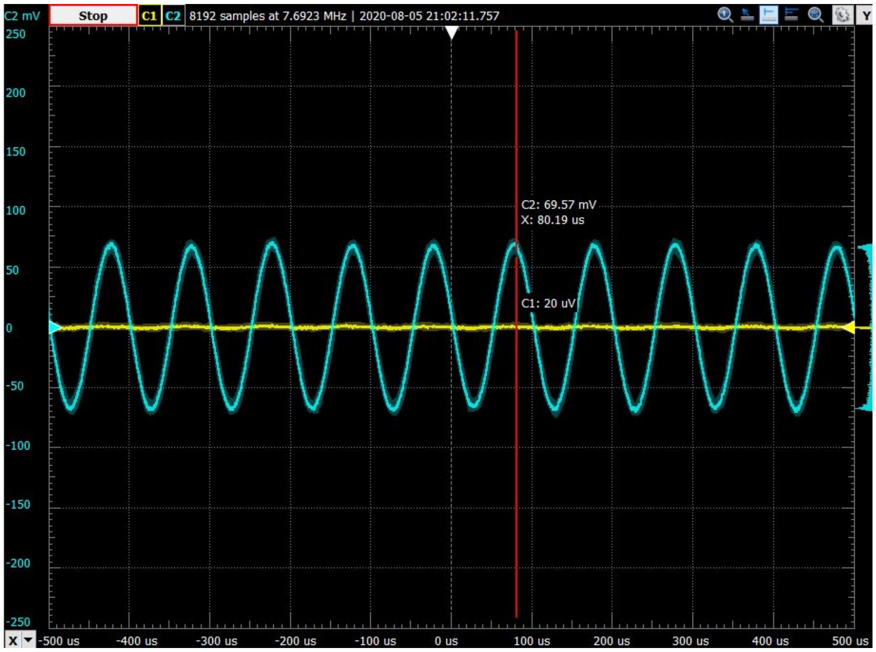
The Output to Input ratio is shown above (Blue/Yellow) = 2 = A_{V_o}

Results are varying from simulation to experimental.



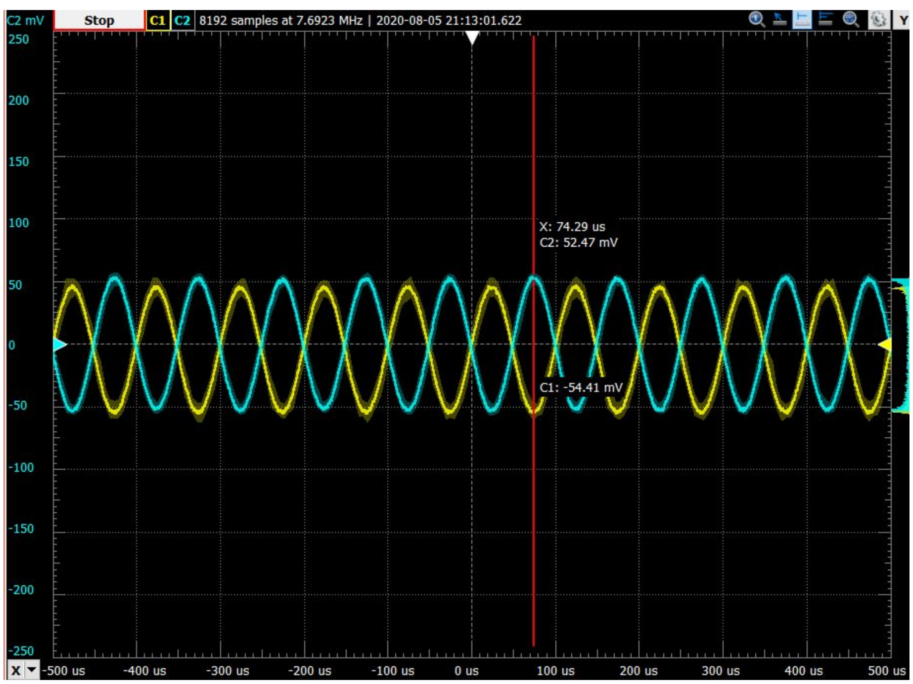
We have roughly $5\mu A$ for input current. Thus we have $V/I = R$; $R \approx 10k\ ohms$. This is similar to calculated and simulated values.

Calculating Rout



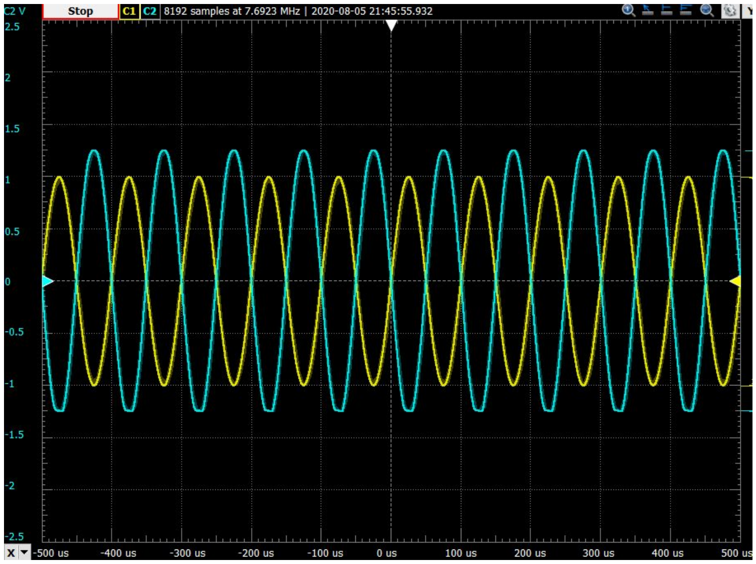
From the above reports of Vout and the voltage divider formula we get $70mV\ =\ 100mV\,(470)/(470+R_{out})\ \ \rightarrow R_{out}\ =\ 201$. This is very close to the calculated value, but off from the simulation.

Overall Gain



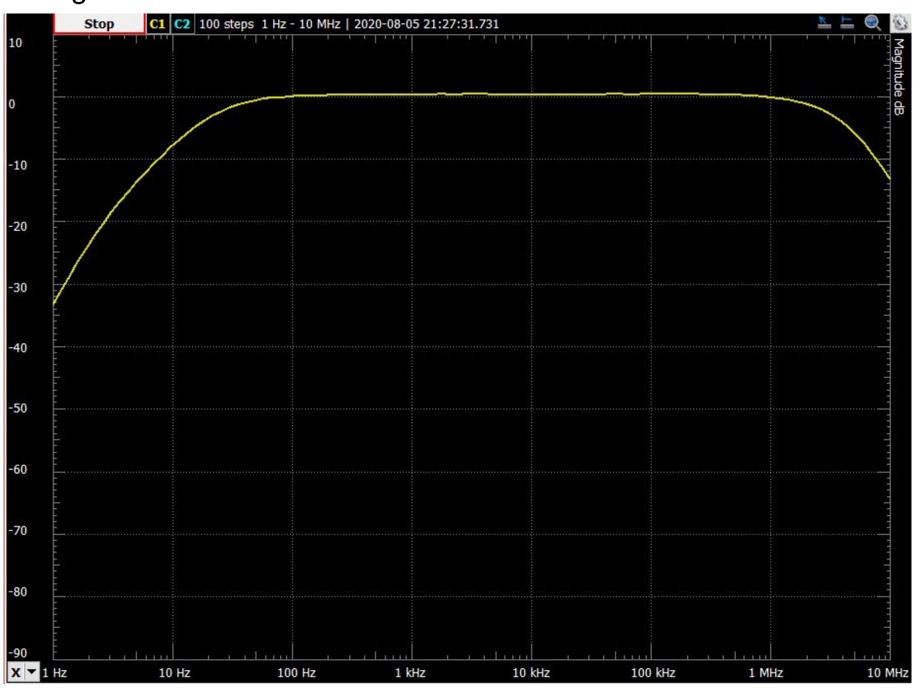
We see that $V_{out}/V_{in}\ =\ 1.05\ = A_V$. This is very close with calculated and simulated values.

Determining Output Distortion



For the Real BJT we see that starting at 1V we start to see deformation of the sine wave.

Determining 3dB Rollof



We have a 3dB rolloff at around 20Hz and a high freq rolloff at 1MHz. The simulation and experiment agree with the low freq roll off but the high freq is different. This is because their is internal capacitance in the BJT which means there is another pole that has to be considered.

We calculate the low freq to be $1/(10^{-5} * R_{in}) = 12Hz$. This is consistent with both simulated and experimental.

Conclusion:

BJTs are an interesting use case of a transistor. They don’t completely outclass FETS in their use cases but they have a very distinct use case which makes them interesting. They are able to amplify current in a predictable manner. And just like Fets they are able to be configured in many ways as amplifiers. They do have problems, like internal capacitance causing high freq roll off. And that their current gain is not unlimited, meaning they have a limited operation range. But for what they bring to the table, they are able to produce a lot of results just from their consistent current gain feature.