Project 1: Oscillator Amplifier

Ahmad Malik & Nicholas Singh

Fall 2022

ECE-393 Junior Lab

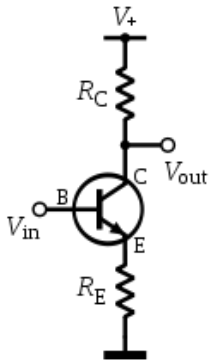
Professor Koo

Project Requirements:

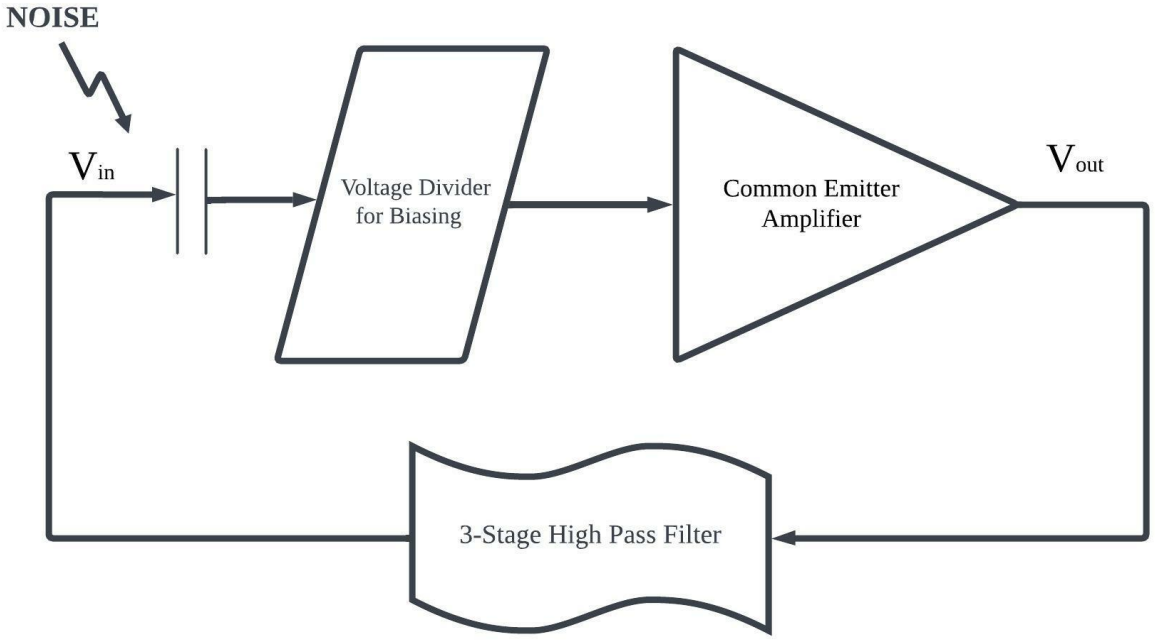
The goal of this project was to build a transistor amplifier. To receive full marks, our amplifier should be able to handle over 30 kHz, generate a gain of 50v/v (~30db) or higher, output a peak-to-peak amplitude of >5v , all while consuming less that 120mW of power.

Design:

We chose to design our amplifier using a common-emitter topology with a degeneration resistor:



It will also employ a voltage divider for biasing the amplifier's base so the transistor operates in forward active region. After amplifying the signal through the transistor, the signal is fed into 3 stages of a passive RC high pass filter which should filter the signal such that only frequencies higher that 30 kHz should pass through. The output of this filter is then fed into the base of the transistor through coupling capacitor, thus completing the oscillator. The oscillator is kick-started due to the ambient noise in the environment. Below is the amplifier block diagram to demonstrate this process.



Amplifier Resistors:

To determine the resistor values, R_C and R_E for the common emitter Amplifier, we first had to decide on the input voltage and input current which is approximately Ic. We arbitrarily decided that **Vcc = 15v** and the transistor we would use is the 2n2222. For a common emitter amplifier the gain Av is given by:

$$A_v = -\frac{R_C}{\frac{1}{gm} + R_E}$$

According to the 2n2222 datasheet, the transistor has a much higher current gain β (corresponds to a higher gm and thus a higher gain) when the collect current Ic operates between 10mA and 100mA. We want to chose a current in that range, but since our transistor can't draw beyond 9mA of current otherwise the power would be >120mW, we chose a safe 8mA of current. FYI β is represented by hfe in datasheet; at room temp, β is about 200 if the Ic is around 8mA.

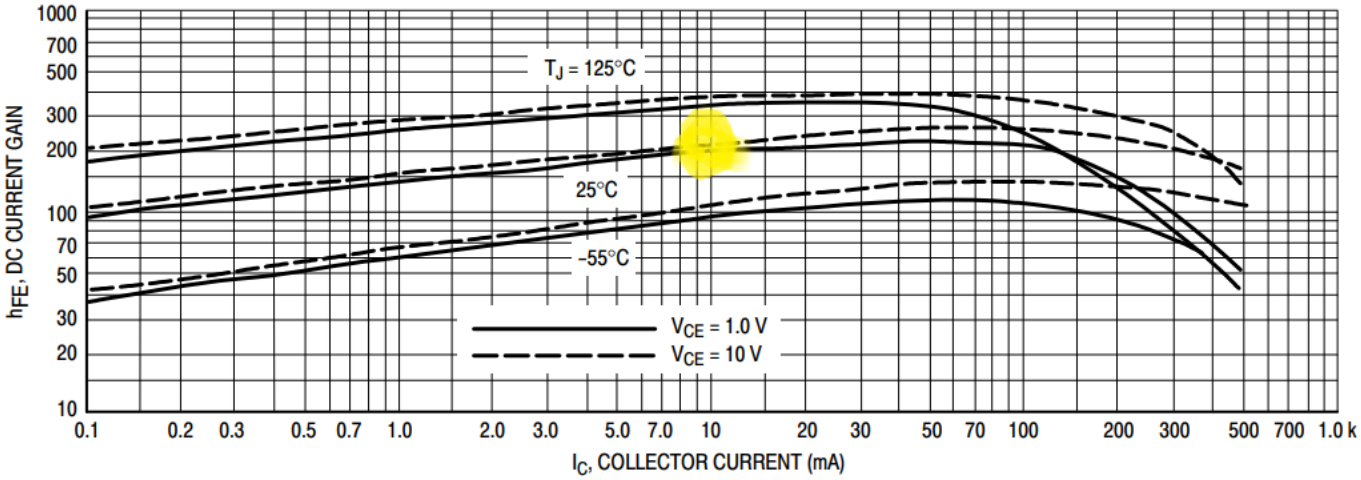


Figure 3. DC Current Gain

Assuming that the emitter voltage is around 1v, that would mean that , $R_C \approx 1.7k\Omega$. For simplicity, we employed a 1.5kΩ resistor as, R_C. Since we decided the emitter voltage will be 1v and $I_E \approx I_C \approx 8mA$, then $R_E \approx 130\Omega$. Due to availability, we used a 150Ω resistor for R_E .

Calculations:

$$\boldsymbol{I_E \approx I_C \approx 8mA}$$

$$R_C \approx \frac{V_{cc}-V_E}{I_c} = \frac{15v-1v}{8mA} = 1725\Omega$$

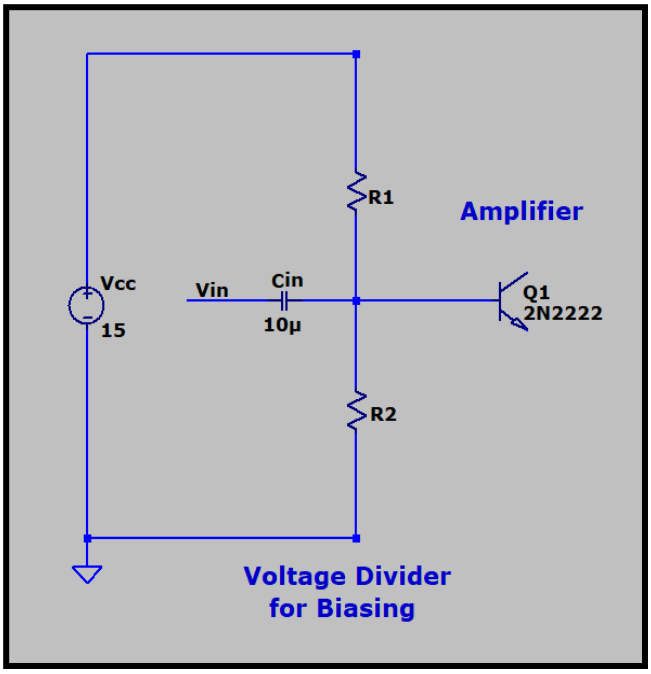
$$\boxed{R_C \approx 1.5k\Omega}$$

$$R_E \approx \frac{V_E}{I_c} = \frac{1v}{8mA} = 125\Omega$$

$$\boxed{R_E \approx 150\Omega}$$

Voltage Divider Biasing:

To keep the transistor in forward active region so that the input signal can be amplified, the base of the transistor amplifier must be biased to a certain voltage, V_b. Out transistor will use two resistors to act as voltage dividers R_1 and R_2.



The emitter voltage is:

$$\boldsymbol{I_E \approx I_C \approx\ 8mA}$$

$$V_E = R_E * I_E = 150\Omega * 8mA$$

$$V_E = 1.2v$$

The base voltage V_B should be a diode voltage drop higher than V_E so:

$$V_B = V_E + 0.7v$$

$$V_B = 1.9v$$

To calculate the resistor values for R_1 and R_2, we must calculate the base current using β. We will assume it is between 150 to 200, so about 175 based on our Ic and the room temperature.

$$I_C \approx 8mA$$

$$\beta I_B = I_C$$

$$175 * I_B = 8mA$$

$$I_B = 45.7\mu A$$

For stability, R_2 must have at least 10 times the base current running through it than V_B.

$$R_2 = \frac{V_B}{10 * I_B} = \frac{1.9v}{10 * 45.7\mu A} = 4156\Omega$$

$$\boxed{R_2 \approx 4.2k\Omega}$$

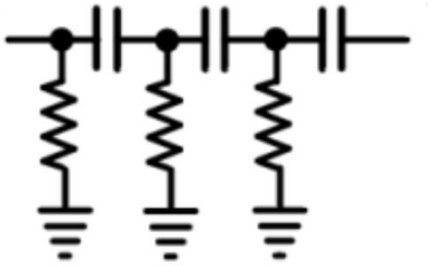
By voltage division and nodal analysis, R_1 can be found:

$$R_1 = \frac{V_{cc} - V_B}{11 * I_B} = \frac{15v - 1.9v}{11 * 45.7\mu A} = 26051\Omega$$

In practice, we found that when $R_1 = 26051\Omega$, the peak-to-peak gain was not ideal. So experimentally and in simulation, we increased R_1 until we reached a better gain. We found that a resistance of 40kΩ was more than adequate for our amplifier. Thus:

$$\boxed{R_1 \approx 40k\Omega}$$

High Pass Filter:



For a single stage high pass filter employing an RC circuit, the cut-off frequency is:

$$f_c = \frac{1}{2\pi RC} \quad with\ \emptyset = -60°$$

For 3-stage high pass filter employing an RC circuit, the cut-off frequency is:

$$f_c = \frac{1}{2\pi RC\sqrt{6}} \quad with\ \emptyset = -180°$$

We chose $f_c \geq 50kHz$ and chose R = 3.3kΩ. To find the corresponding capacitance value:

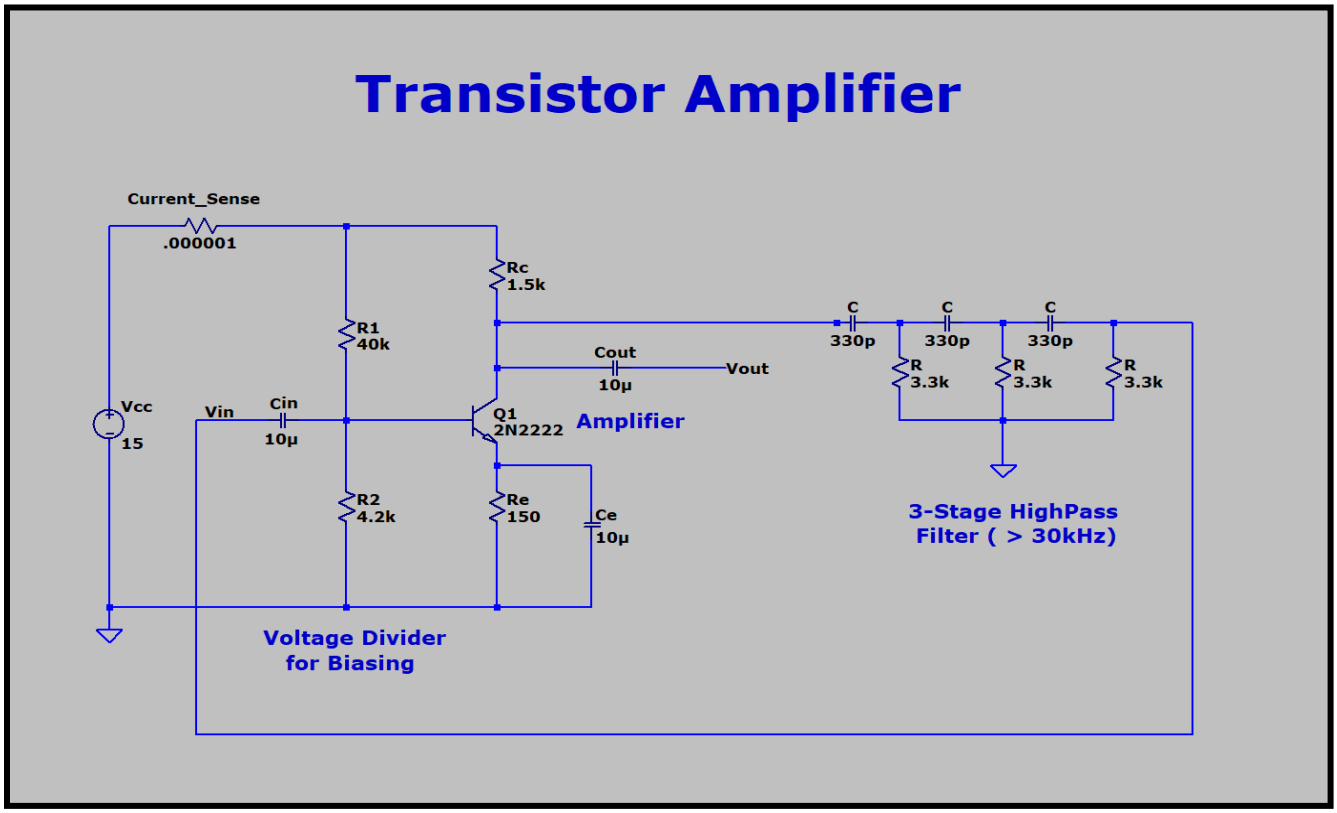
$$C = \frac{1}{2\pi R f_c \sqrt{6}} = \frac{1}{2\pi * 3.3k\Omega * 30kHz * \sqrt{6}} = 394\ pF$$

$$C = 330pF$$

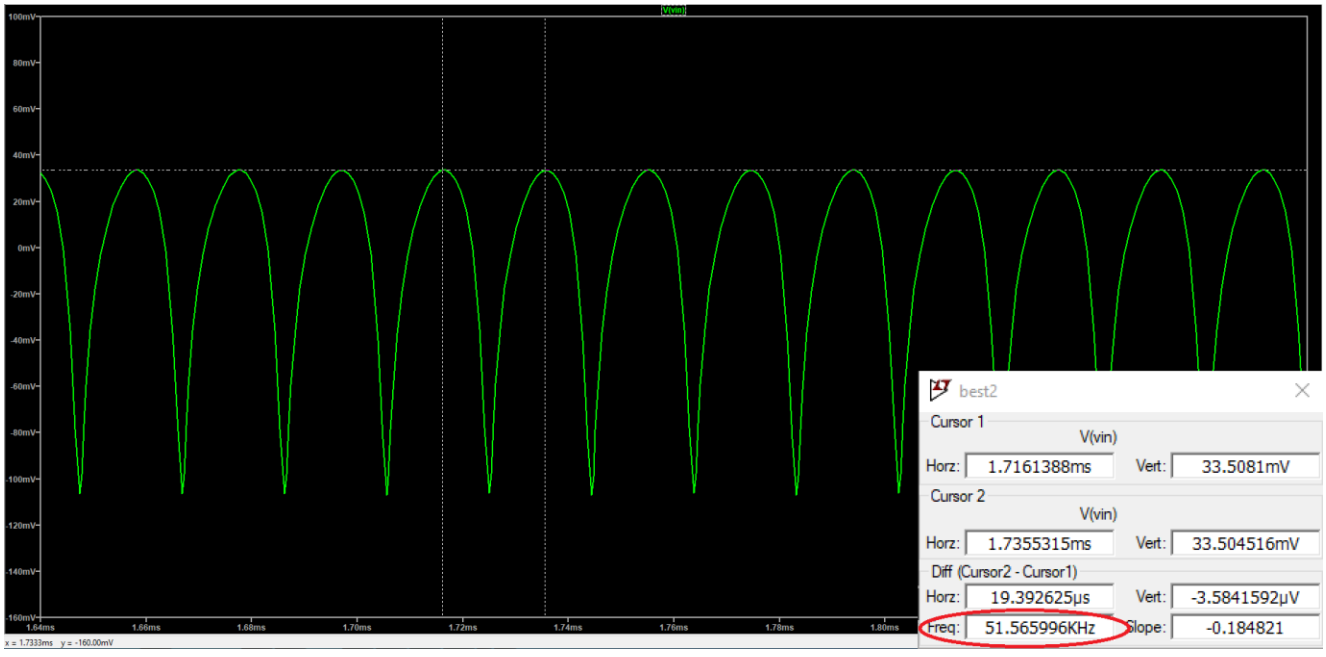
Coupling Capacitors

Our amplifier used 10µF coupling capacitors throughout its design. The Cin/Cout capacitors, their purpose is to remove the DC value from AC value, leaving only the AC value with no DC offset. Further, R_E uses C_E in parallel with it to increase its gain. It does this because at high frequencies, the capacitor acts as a short resulting in the denominator of the common emitter amplifier gain equation to decrease, thus increasing the gain.

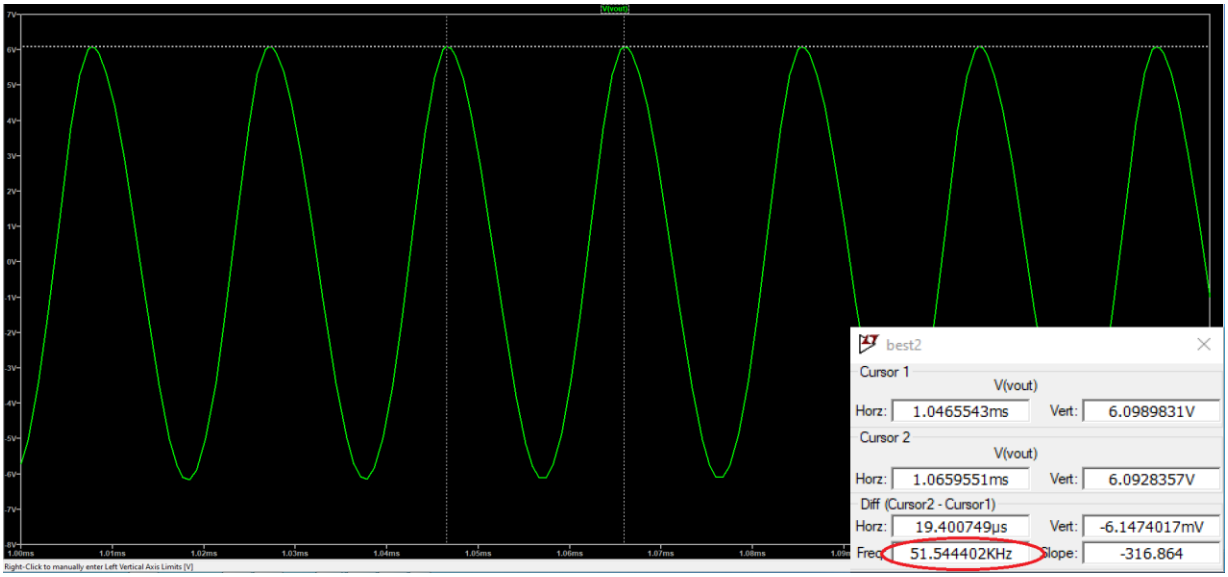
Final Schematic:



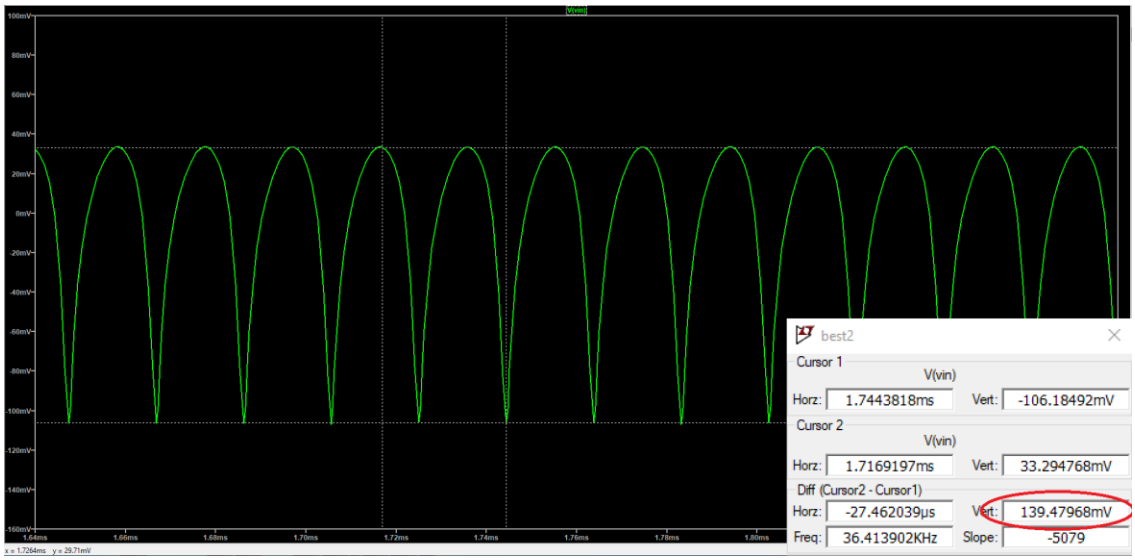
LTspice Simulations:



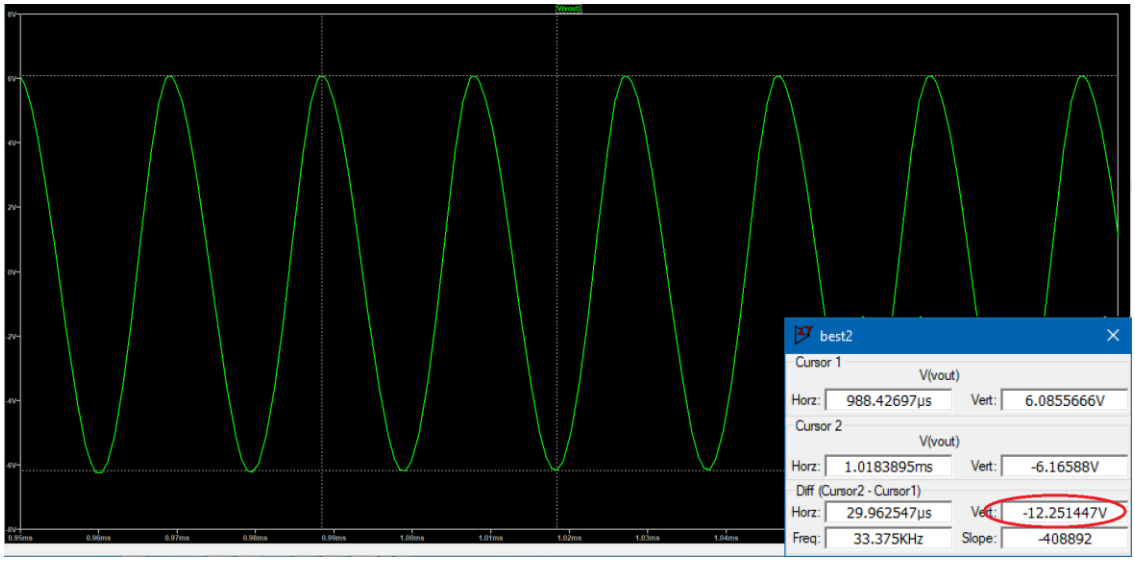
The above graph shows the output of the high pass filter which feeds into the input of the amplifier. The input has frequency: 51.5 kHz.



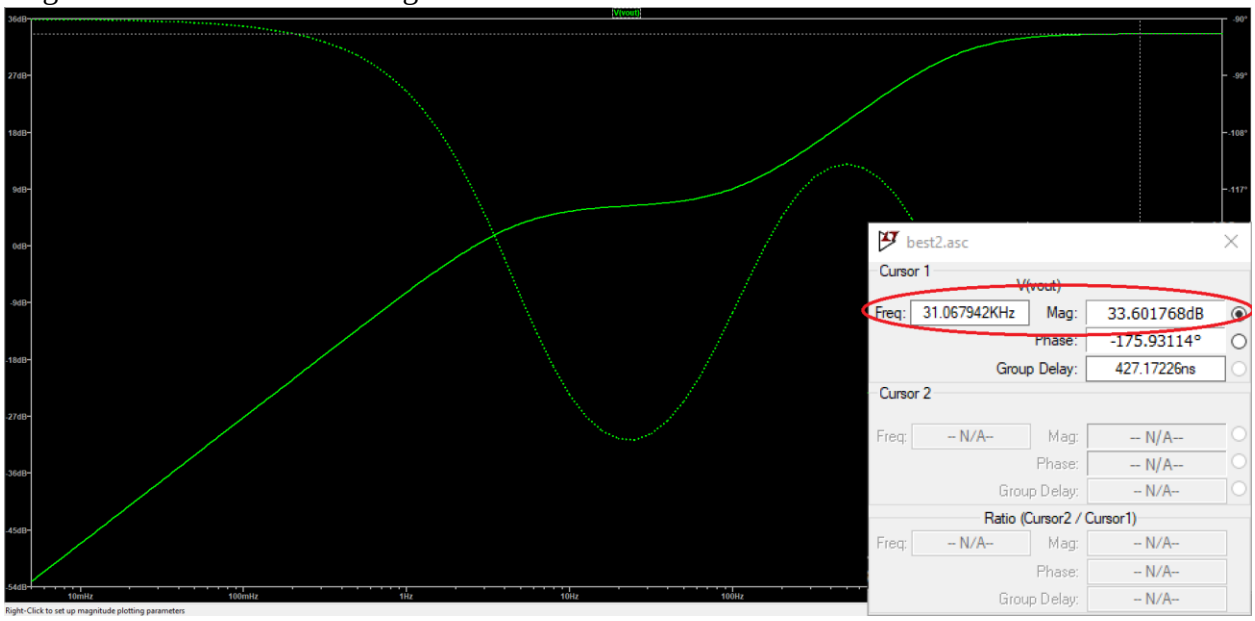
This graph above shows the output of the amplifier. It operates at 51.5 kHz with no problem.



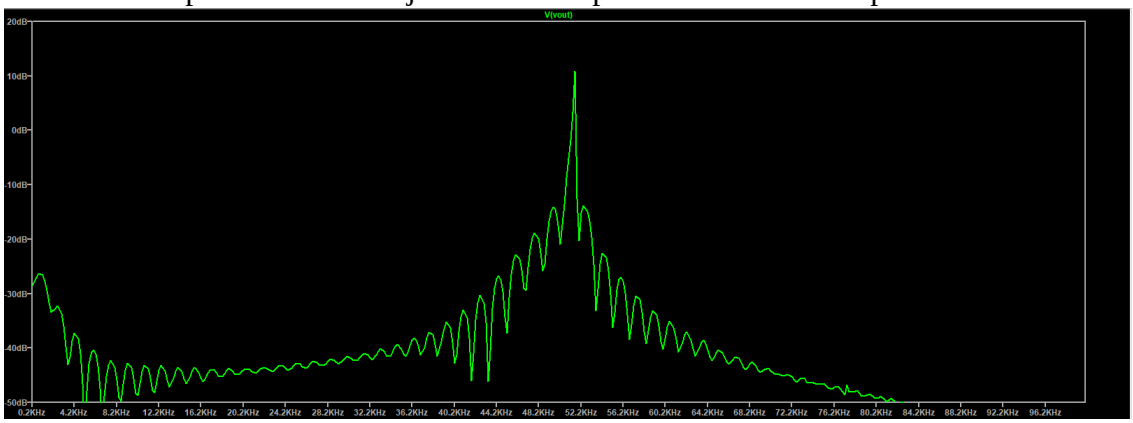
The graphs above and below show that the peak to peak gain between the input signal and output signal is 88.13 v/v, which is much higher than our requirement.



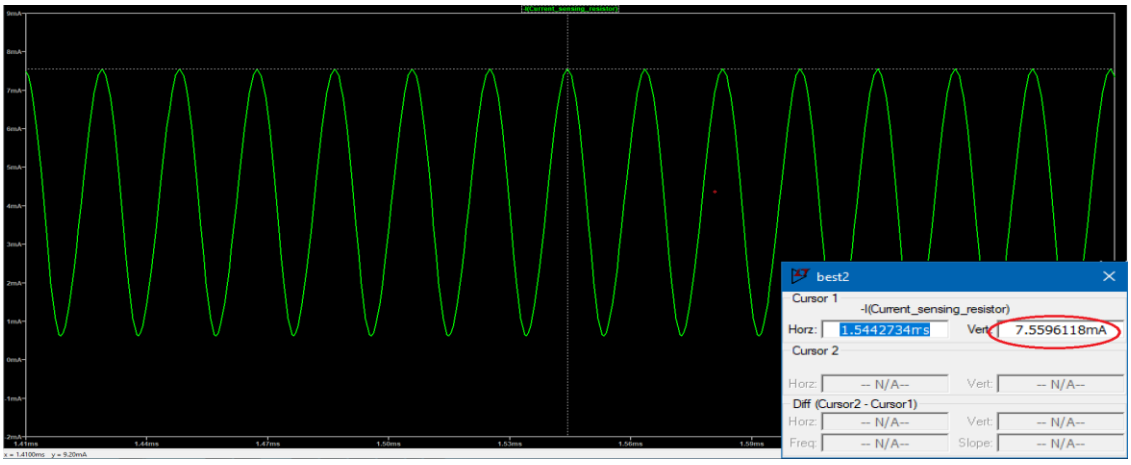
Magnitude Plot below shows a gain of 33db at 30 kHz.



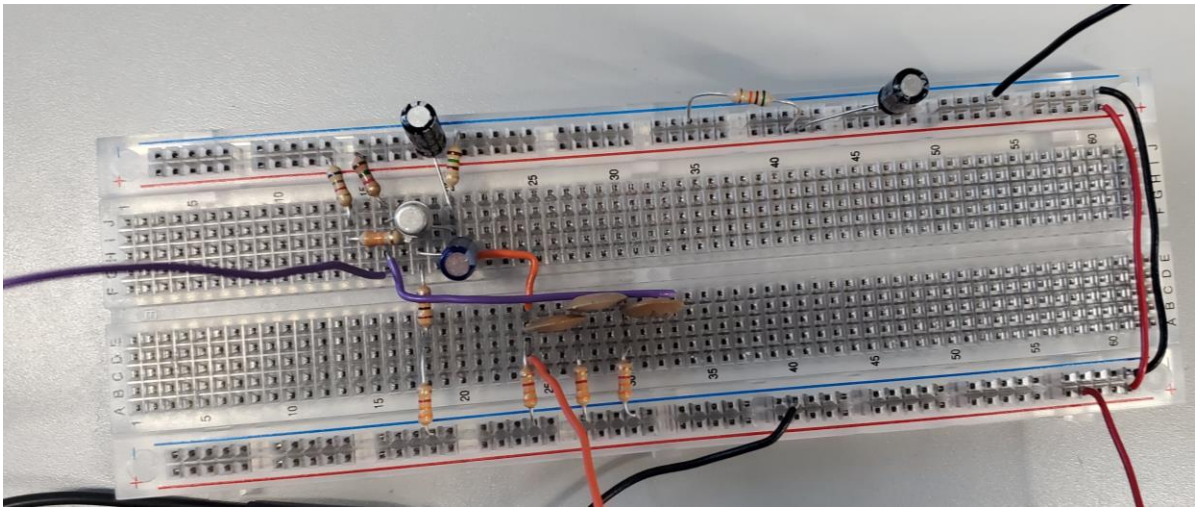
FFT of out amplifier with filter just for fun. It peaks at 50 kHz as expected.



Graph below shows that the current resistor (0.00001Ω) has a max current draw of 7.56mA. This means that the transistor draws a peak power of 113mw, which is within range.

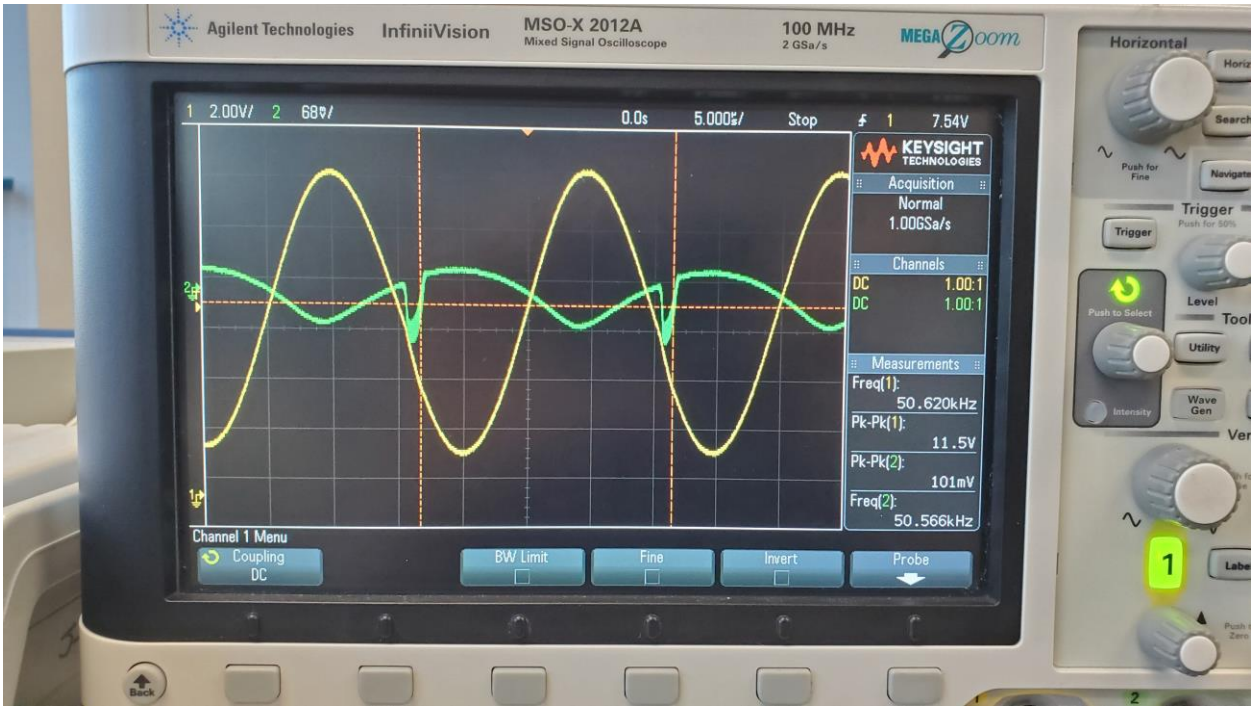


Lab Results

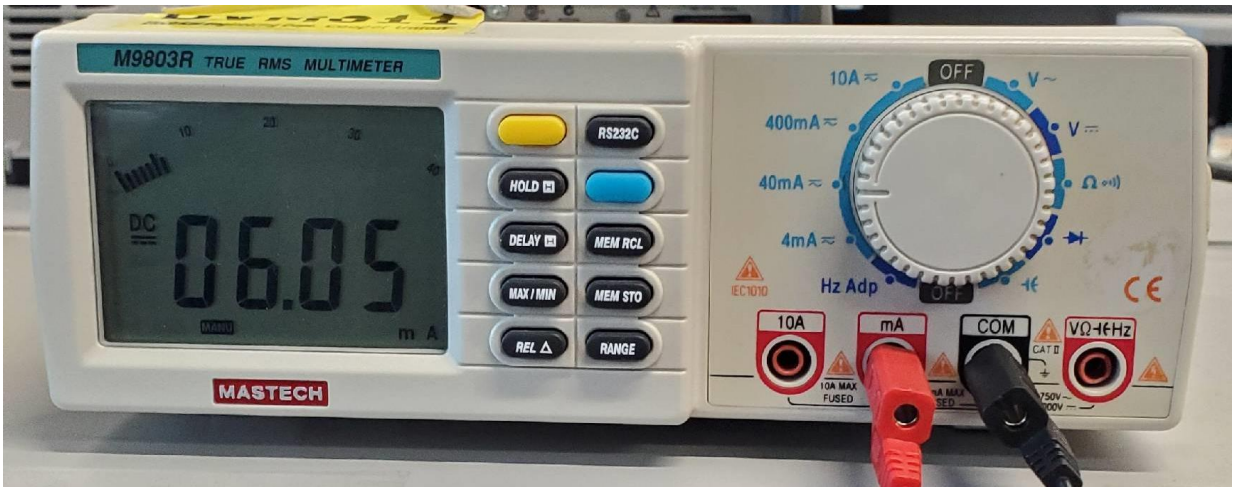


Finished amplifier oscillator circuit.

The oscilloscope shows the amplifier operating at around 47.4kHz, not too far from the simulation tests. The input waveform has a peak-to-peak value of 120mv and the output waveform has a peak-to-peak value of 12.5v. A gain of about 104v/v! However, there is clearly a distortion which we tried eliminating by reducing the noise by adding a capacitor on the main power rail. Unfortunately, we could not fully remove the defect in the input signal as shown in the next page. The noise is probably from the high resistance value we chose for R1.



The input waveform (green) looks closer to the simulation results after we try to mitigate the noise by adding a capacitor to the main rail, but there is still a defect. If we added to capacitor whose value was too large, it would eliminate the noise, thus preventing the oscillations.



Measuring the current drawn from the amplifier using the ammeter settings shows an average value of 6.05mA which is an average power draw of 90.75mW and within spec.

Table of Results

	Simulation	Measurement
Peak-to-Peak(Input)	139.5mv	120mv
Peak-to-Peak(Output)	12.25v	12.5v
Gain	88.13v/v	104v/v
Frequency	51.5 kHz	47.4kHz
Power Consumption	113mW	90.75mW