ELECTRONIC WORKSHOP -2
Project-1
AUDIO POWER AMPLIFIER

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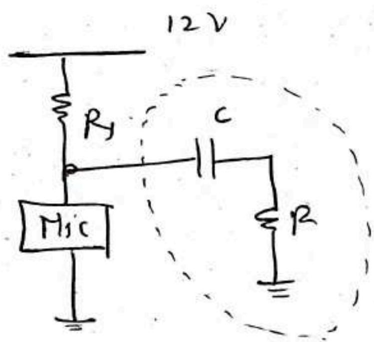
Aim : To design an audio power amplifier with Mic as the input and Speaker as the output

Specification of the mic :
1) Operating voltage : 3.3 to 5V
2) Current capacity : 0.3 to 0.5mA

Selection of the Resistors and Capacitors in Mic circuit :
Calculations :

Testing of the mic:

Circuit -



taking:
Current : 0.4mA
Operating Voltage = 4V.

$$R_1 = \frac{12-4}{0.4mA} = \frac{8000}{0.4} = \frac{80,000}{4} = 20k$$

Taking cut off for a High Pass filter $f_c = 5Hz$

$$5 = \frac{1}{2\pi RC}$$

$$C = 1\mu F, \quad R = \frac{1}{2\pi \times 10^{-6} \times 5} = \frac{10^5}{\pi} \simeq 31.83k$$

$$\Rightarrow R_1 \simeq 22k \quad \text{and } C = 1\mu F$$

$$R \simeq 35k$$

The output signal from the mic has to go through 4 stages for its audio power amplification :

1) Pre amplifier (Differential amplifier)
2) Gain Stage
3) Filter
4) Power amplifier

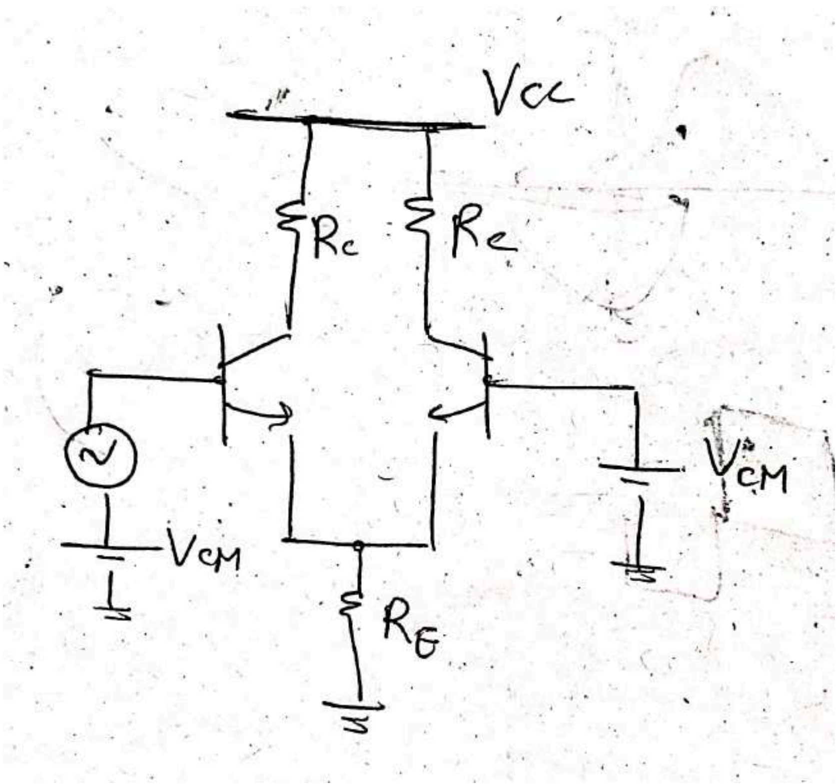
For the pre amplifier stage and the gain stage, either BJT or MOSFET could be used. For a better input swing and high amplifications, BJT is preferred over the MOSFET.

Stage 1 : Differential Amplifier

Two main uses of using differential amplifier are :

1) Remove the common mode noise added to the mic output internally.
2) One advantage is that differential amplifier provides gain along with cancelling noise which helps in amplification. Major amplification is handled during the 2nd stage.

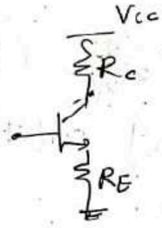
Differential Amplifier Circuit :



Calculation of the DC parameters, Rc and RE(Sample)

stage1:

diff amp:

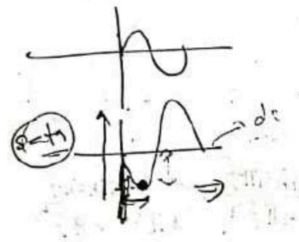


$\boxed{V_{IN} = 11.6\,mV}$

$gain = 50 = \dfrac{R_c}{1/g_m + R_E}$

$\Rightarrow \boxed{I_c \approx 11.773\,mA}$

$\boxed{g_m \approx 0.452\ mA/V}$



$\Rightarrow V_{cc} - I_cR_c - I_cR_E - (gain)(V_{IN}) > 700\,mV$

(forward active)

$\Rightarrow \cancel{12 - 11.773}$

$12 - (50 \times 11.6m) - (700m) > (11.773m)(R_c + R_E)$

$\Rightarrow \cancel{12} \ 11.3 - 0.58 > (11.773m)(R_c + R_E)$

$\boxed{R_c + R_E < 910.55\,\Omega}$

$\Rightarrow gain = 50 = \dfrac{R_c}{1/g_m + R_E}$

$\Rightarrow R_E + 1/g_m = \dfrac{R_c}{50}$

$\cancel{910.55 - R_c + 2.212 = \dfrac{R_c}{50}}$

$\Rightarrow \dfrac{R_c}{50} - 1/g_m < 910.55 - R_c$

$\Rightarrow R_c + \dfrac{R_c}{50} < 910.55 + 2.212$

$\Rightarrow \cancel{R_c} \quad \cancel{R_c + 0.02}$

$R_c + 0.02R_c < 912.762$

$\Rightarrow 1.02R_c < 912.762$

$\Rightarrow R_c < \dfrac{912.762}{1.02}$

$\Rightarrow \boxed{R_c < 894.864\,\Omega}$

$R_E < 910.55 - 894.864$

$\boxed{R_E < 15.686\,\Omega}$

1.074V

23.2

$0 + V_{IN} = 700\,mV + I_cR_E$

$= 0.7 + (11.773m)(15)$

$= 0.876\,V$

$\boxed{R_E = 15\,\Omega}$

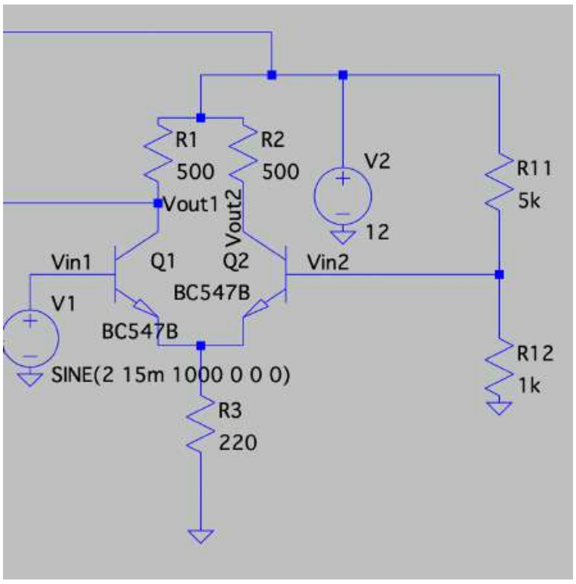
$R_c = 50(2.212 + 15)$

$= 50(17.212)$

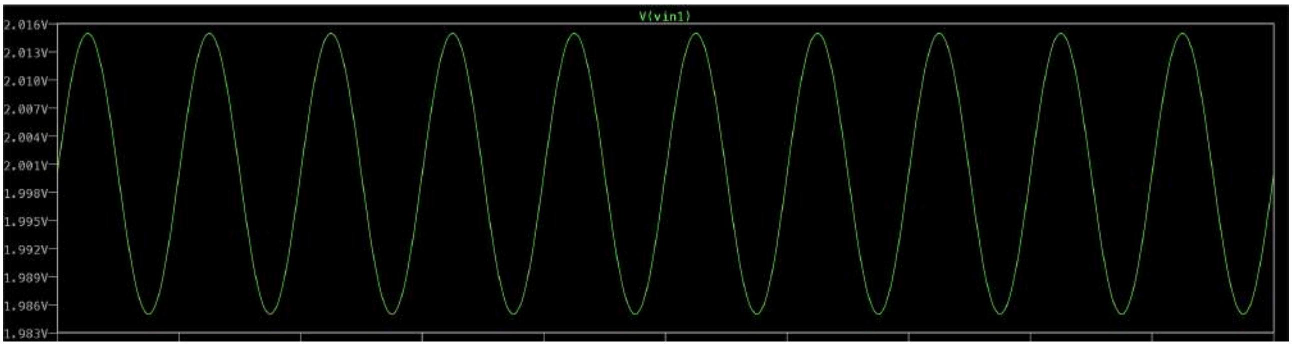
$= \cancel{258}\ 860.6\,\Omega$

$\boxed{R_c = 860.6\,\Omega}$

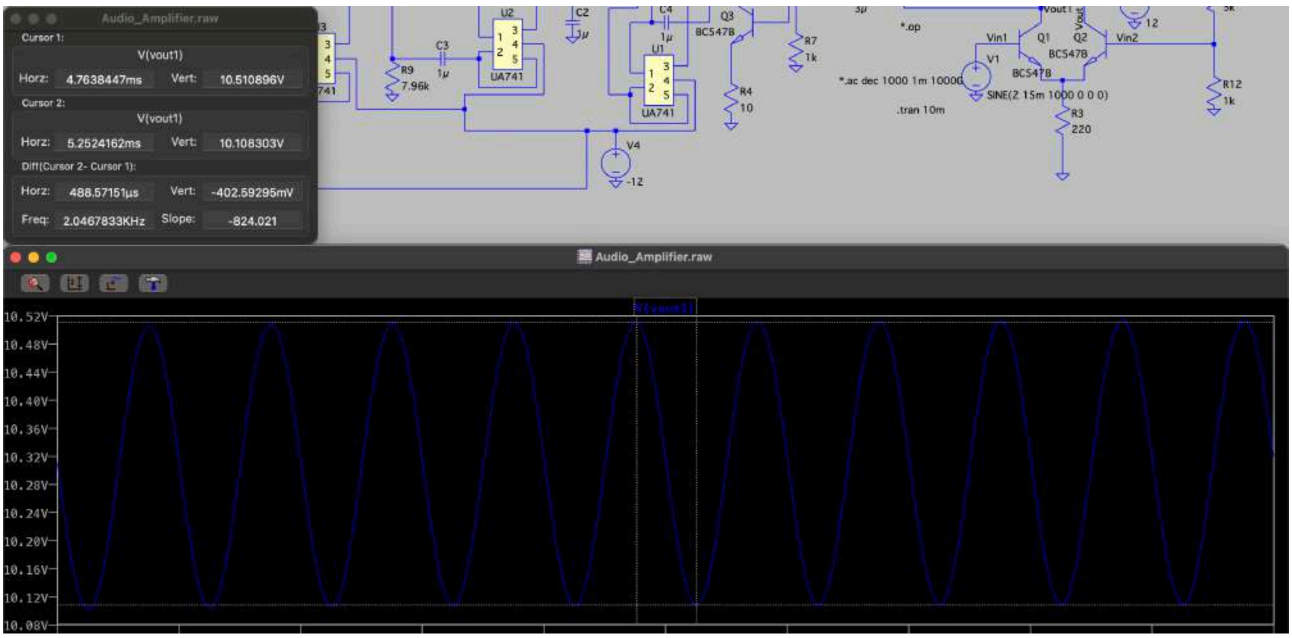
<u>LT spice Equivalent Circuit :</u>



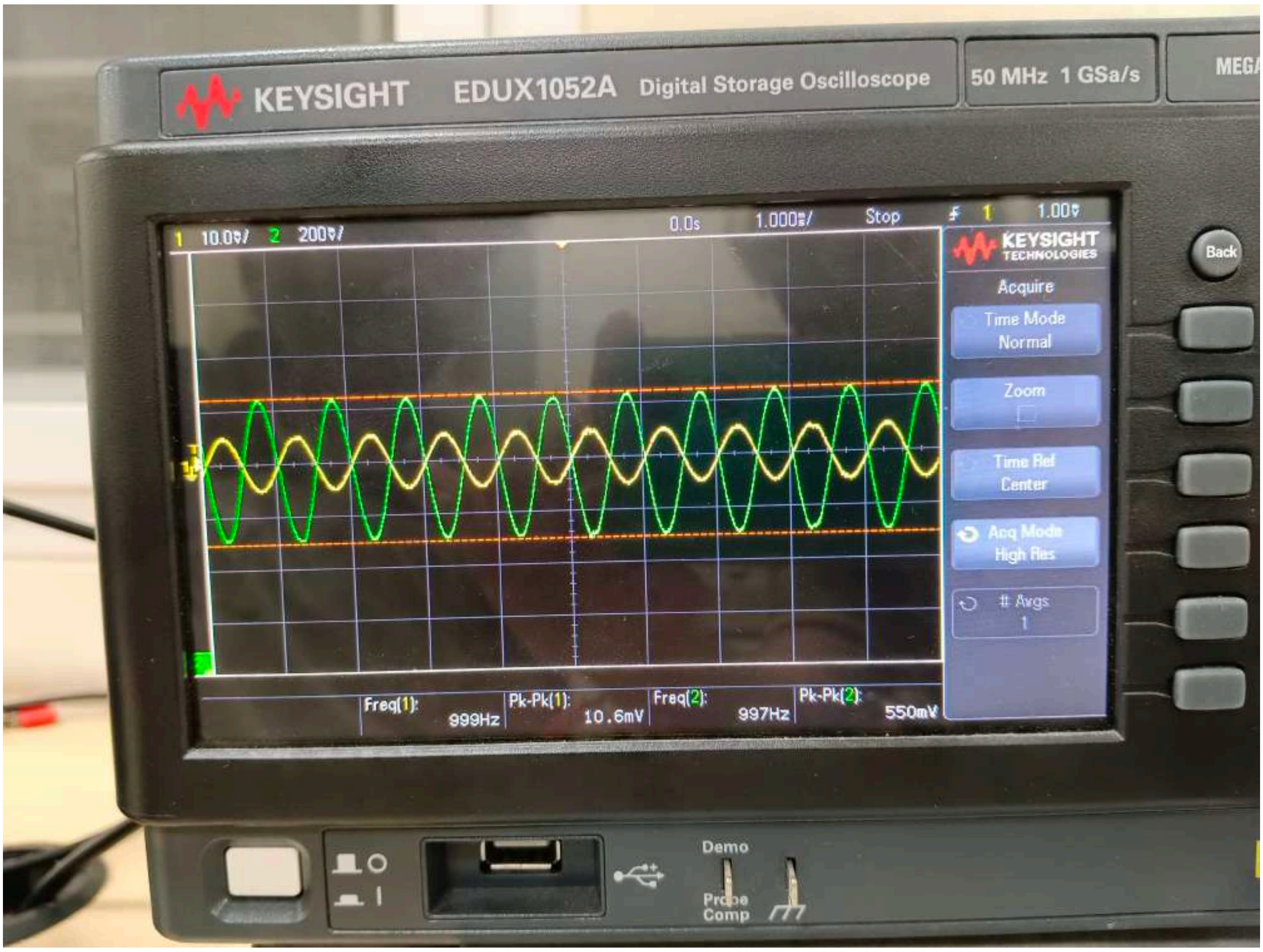
Simulation parameters : input Vpp = 30m



Output transient plot :

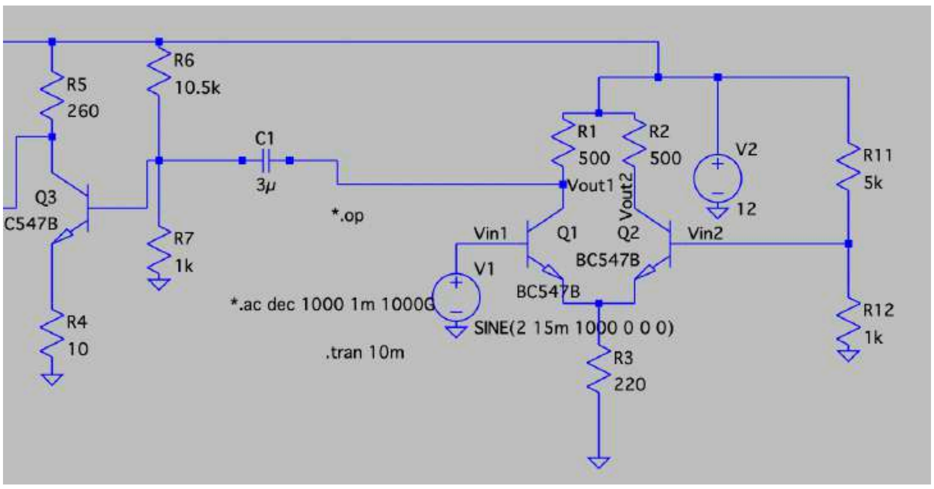


Oscilloscope input and output transients of Diff amplifier (Stage1)



Gain obtained from stage 1 = 550/10.6 = 51.866
Therefore Stage 1 gain = 50
Biasing : For the transistor to turn on, the VBE should be > 700mV so, the biasing was given to the transistor through a voltage divider from the main power supply 12V.

Cascade between the differential and CE amplifier :



The CE amplifier is used for the main amplification stage, which is another BJT, which has its own offset for the certain desired amplification. Between stage 1 and stage 2 we have connected a capacitor which removes the DC voltage of the output and brings it to zero. One another advantage is it acts like a high pass with very low cut off so, that we can remove low frequencies even before using a filter.

<u>Stage 2 : Main Amplification gain stage :</u>

Stage 2:

$\boxed{v_{IN} = 0.529V}$

gain = 12

$= \dfrac{R_c}{1/g_m + R_E}$

15×46

$12 - (11.773m)(R_c) - (12)(0.529V) - (11.773m)(R_E) > 700m$

$\Rightarrow 11.3 - 6.348V > (11.773m)(R_c + R_E)$

$R_c + R_E < \dfrac{4.952}{11.773} \times 1000$

$\boxed{R_c + R_E < 420.623\,\Omega}$

$\boxed{\dfrac{R_c}{R_E} \approx 12}$

$12 = \dfrac{R_c}{1/g_m + R_E}$

$\Rightarrow R_E = \dfrac{R_c}{12} - 1/g_m < 420.623 - R_c$

$\Rightarrow \dfrac{13R_c}{12} < 420.623 + 2.212$

$\Rightarrow \boxed{R_c < 390.3\,\Omega}$

$R_E < 420.623 - 390.3\,\Omega$

$\boxed{R_E < 30.323\,\Omega}$

$\boxed{R_E = 20\,\Omega}$; $\boxed{R_c < 400.623\,\Omega}$

$R_c = 12(2.212 + 20) = 12(22.212) = 266.54$

$\boxed{R_c = 266.54\,\Omega}$

input = 23.2 mV
output = 5.62
gain = $\dfrac{5.62 \times 1000}{23.2}$ =

Loop: $V_{IN} = 700mV + \left(\dfrac{11.773}{1000}\right)(20)$

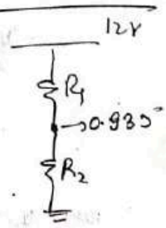
$= 0.7 + 0.235$

$\boxed{V_{IN} = 0.935V}$

Volt = 0.529 × 12

$\boxed{V_i = 6.348}$

$0.7 + (11.773)($
$= 0.7 + 0.117$
$= 0.817$



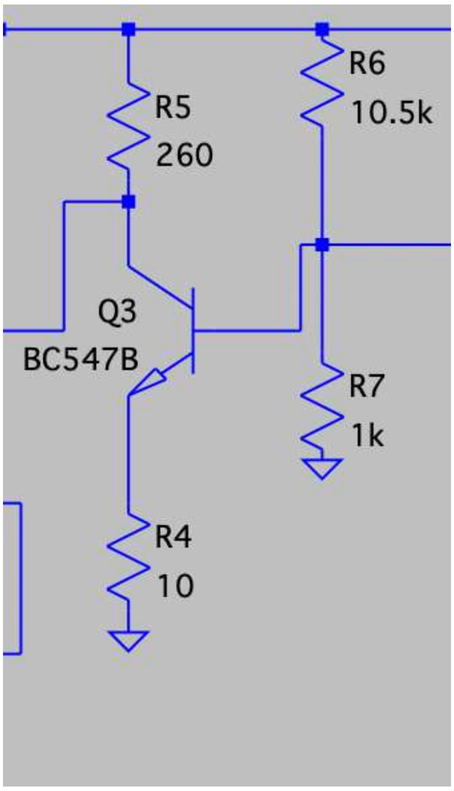
$\dfrac{12R_2}{R_1}$

$\dfrac{12R_2}{R_1 + R_2} = 0.935$

$11.065 R_2 = 0.935 R_1$

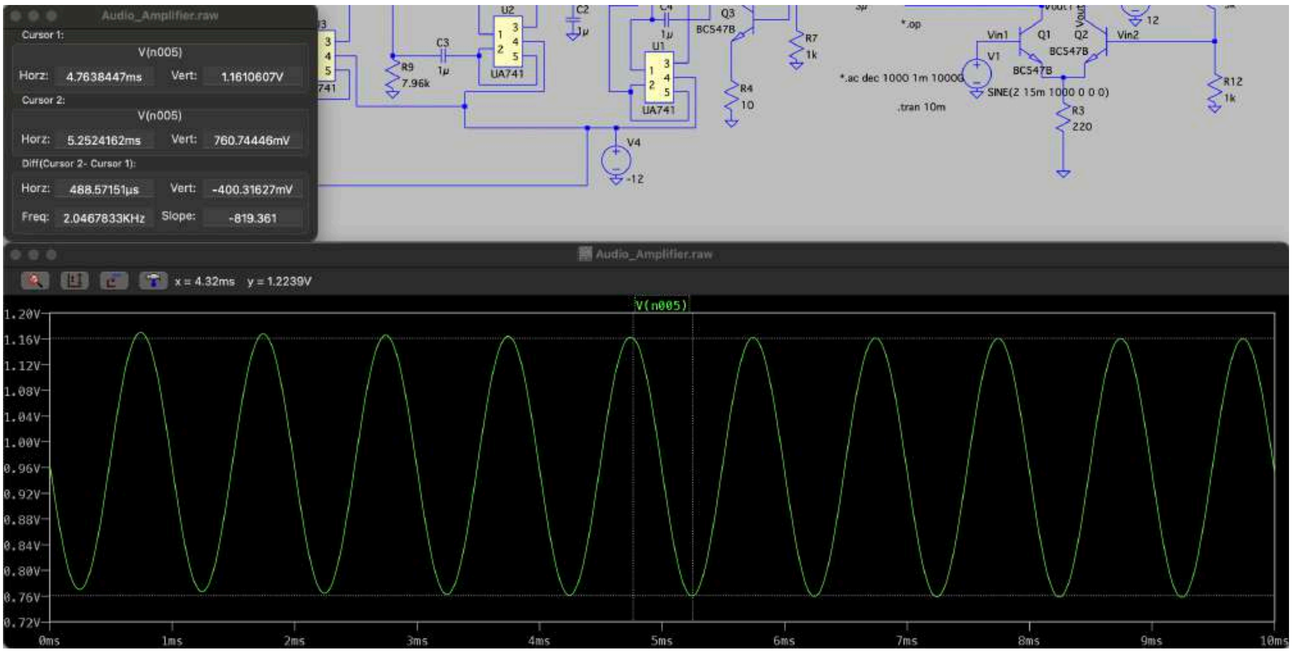
$\boxed{\dfrac{R_1}{R_2} = 11.834}$

<u>LT spice equivalent circuit :</u>

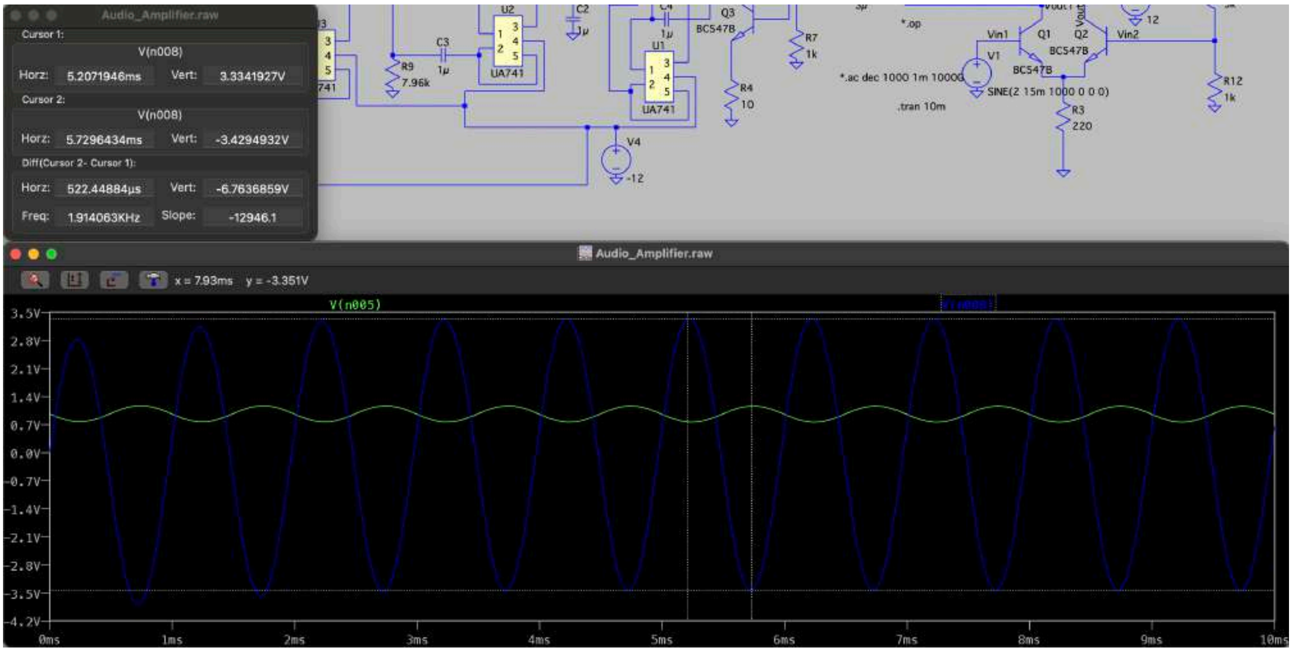


Input and output tansient plot :

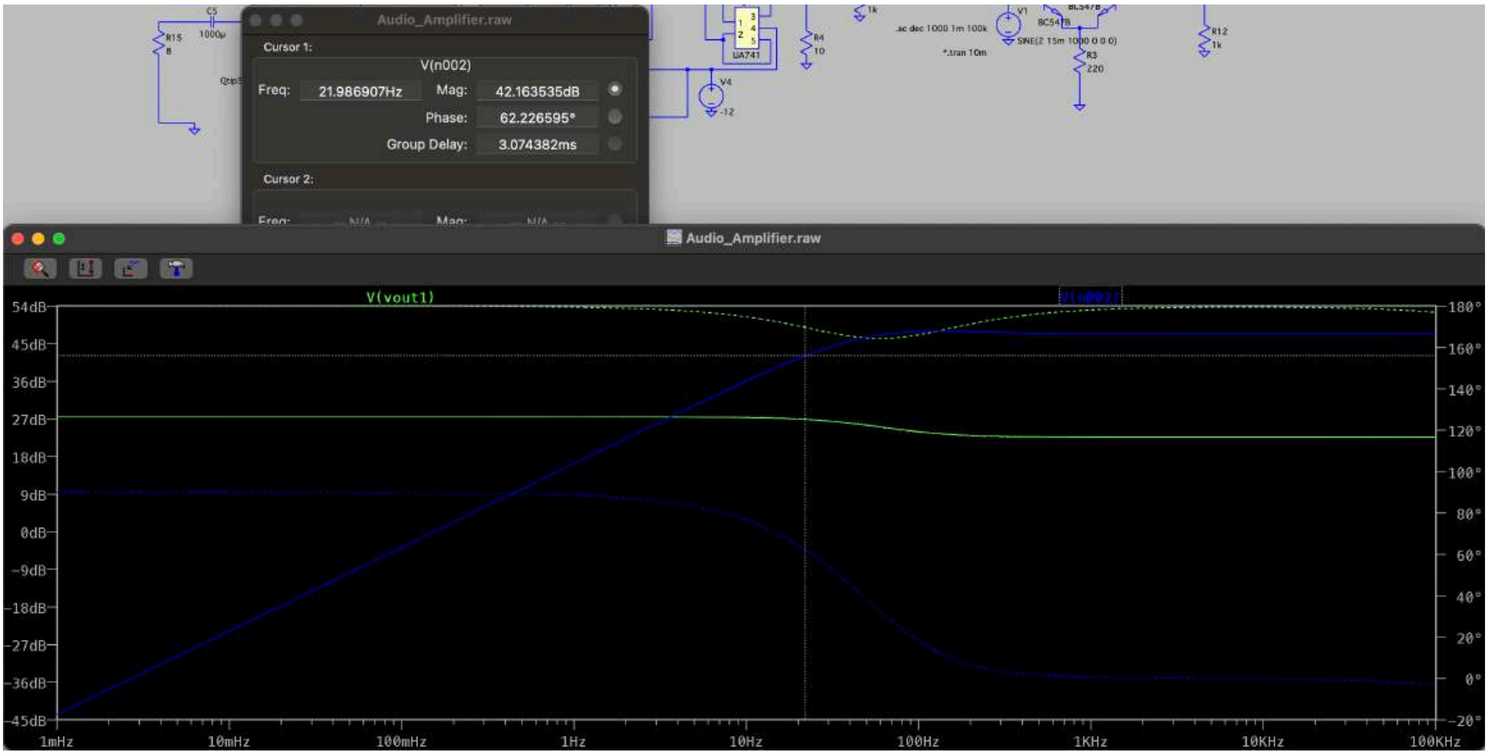
<u>CE stage input = DC removed differential output + Offset for CE</u>



<u>CE output :</u>



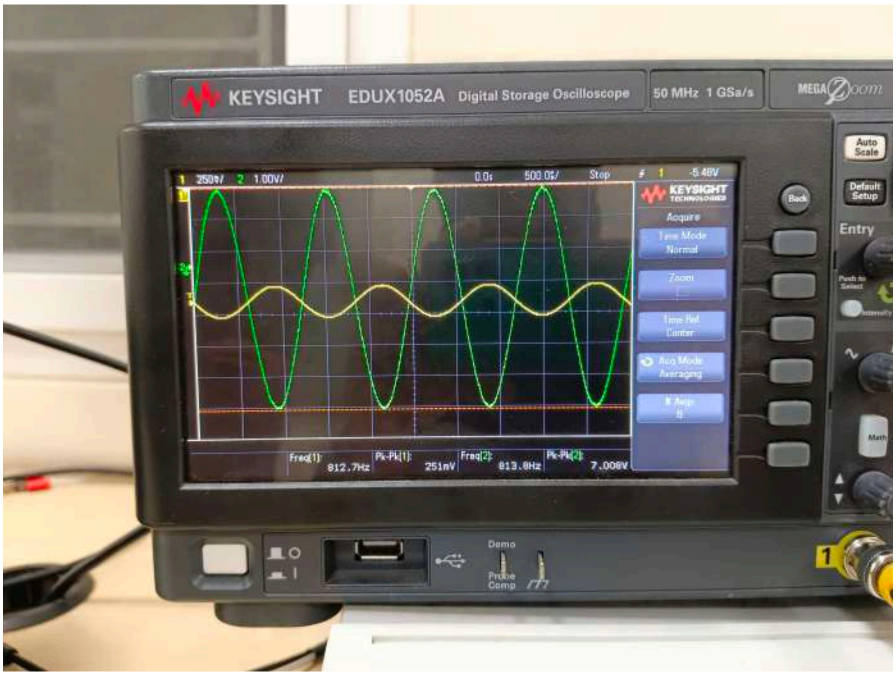
Input Vpp = 1.16V - 760.74mV ~ 400mV
Output Vpp = 3.33 + 3.42 ~ = 6.75V
Gain for 2nd stage = 6.75 / 0.4 = 16.875 (in LT spice)
<u>AC analysis for stage 1 and stage 2 combined (Simulated)</u>:



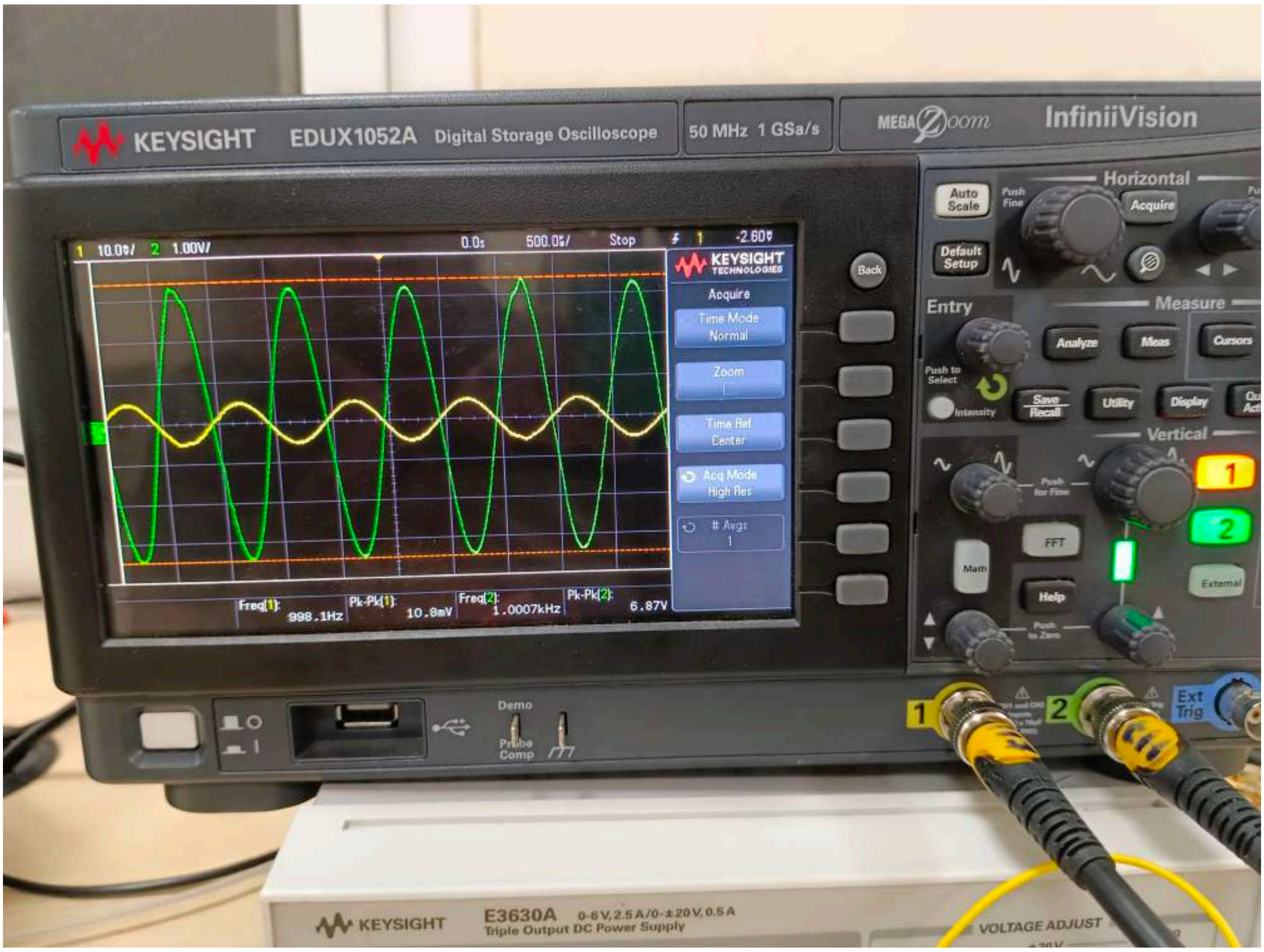
Green : Stage 1
Blue : Stage 2

For stage 2 we observe high pass characteristics because of using a capacitor to cascade stage 1 and stage 2.

Circuit implementation :
Oscilloscope input and output transient plots:
1) <u>Differential and CE outputs</u> :



2)<u>Mic Input and CE output</u>

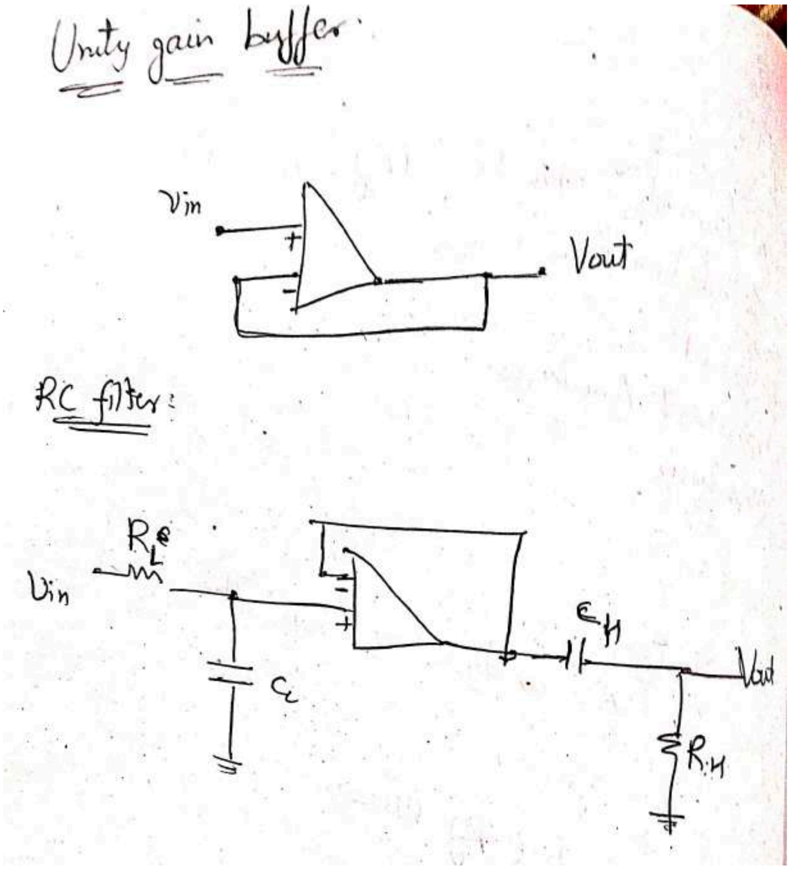


Stage 2: input Vpp = 251mV
Output Vpp = 7V
Gain = 7/0.251 = 27.888
Therefore Gain obtained for stage 2 = 27.888

Amplification for the two stages combined :
Input Vpp = 10.8mV
Output Vpp = 6.87V
Gain for two stages = 6.87V/10.8mV ~~ 381

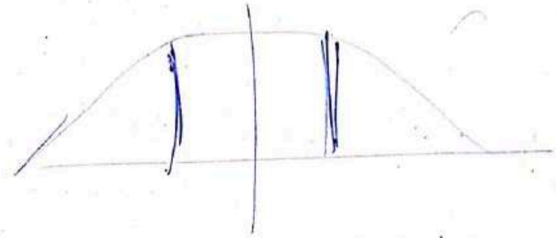
Stage 3 : FILTER :

Before going to the filter, between the CE stage and Filter, we are using a buffer so that the impedance of the circuit as seen from the CE stage is infinite. A buffer has infinite input impedance and very low output impedance which helps in transmitting the voltage without driving any current.
Coming to the Filter, two types of filter could be used, active and passive

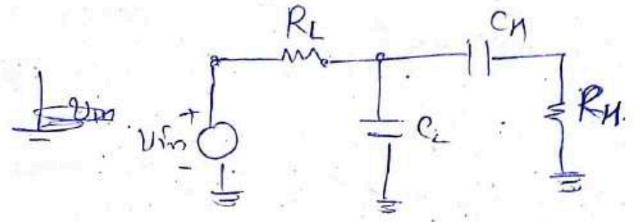


We have used an active filter, to provide infinite impedance as seen from CE stage.
Calculations for R and C according to cut off frequencies :

Band Pass:



Range: ~~10 Hz to 20 kHz~~ 20 Hz to 20 kHz



~~20kH 20k~~ 20

$$f_L = \frac{1}{2\pi R_L C_L}$$

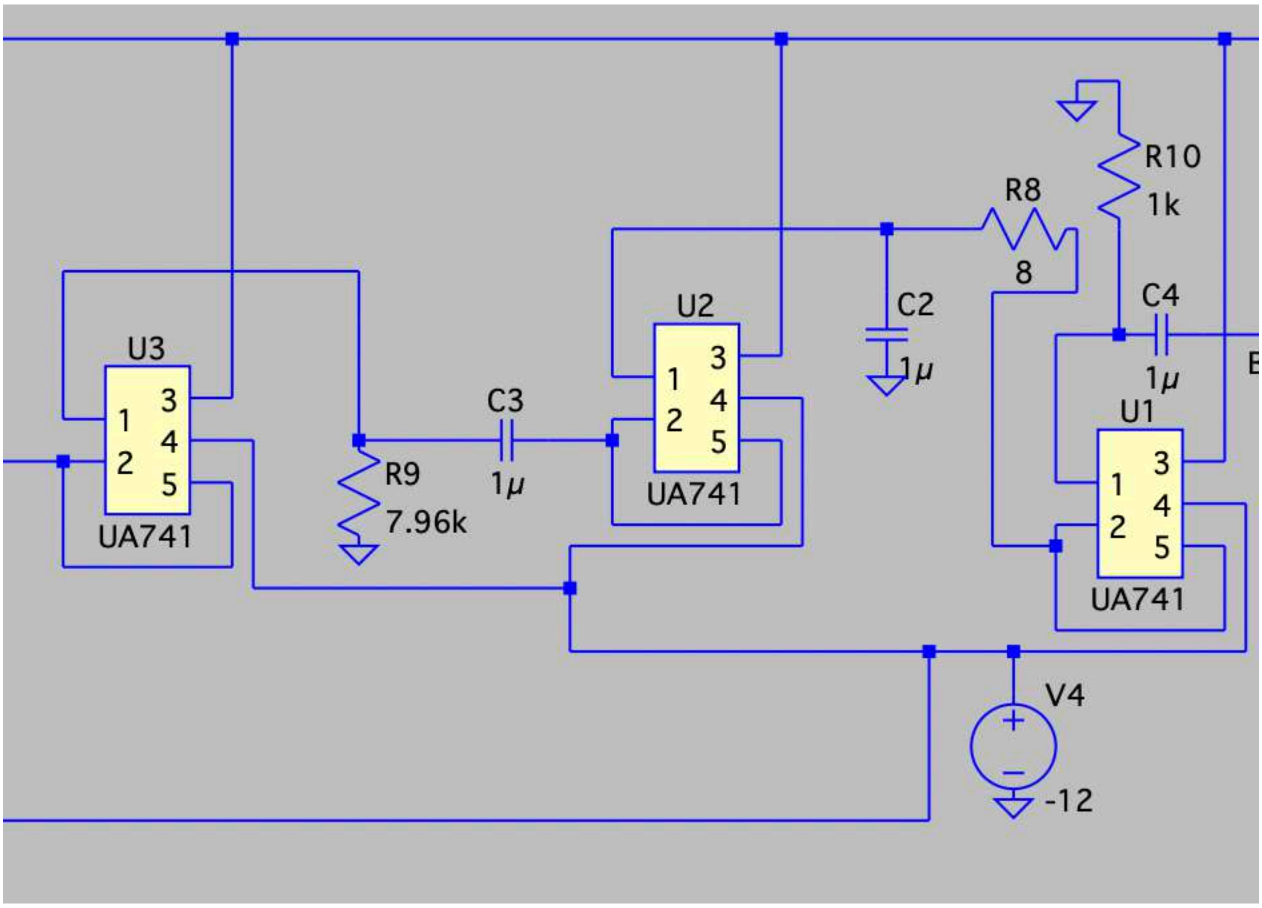
$$\Rightarrow R_L C_L = \frac{1}{2\pi \times 20 \times 10^3} = \frac{1}{4\pi \times 10^4}, \quad C_L = 1\mu F$$

$$\Rightarrow R_L = \frac{1}{4\pi \times 10^4 \times 10^{-6}} = \frac{100}{4\pi} = \frac{25}{\pi} = 7.96\Omega$$

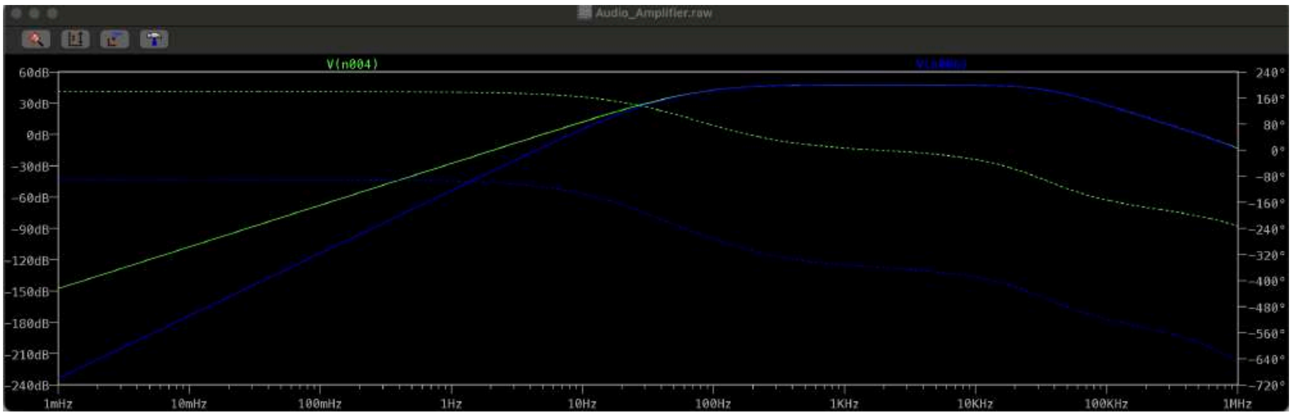
$$f_H = \frac{1}{2\pi R_H C_H}$$

$$\Rightarrow R_H = \frac{1}{2\pi \times 10^{-6} \times 20} = \frac{10^5}{4\pi} = 7961.78 = 7.96\,k\Omega$$

LT spice equivalent :



AC analysis :



Blue : Lpass + H pass

Frequency Response of the filter :

Stage 4 : Power amplifier :

A power amplifier is an electronic device that amplifies the power of an input signal so that it is strong enough to drive the output device, typically a speaker. It is the final stage in the amplifier chain, and it directly drives the speaker. In order to work effectively, the input signal to the power amplifier must be above a certain threshold. Therefore, the input from a microphone is usually pre-amplified using differential and common source amplifiers before being sent to
the power amplifier.
There are majorly 4 types of Classes in power amplifier:

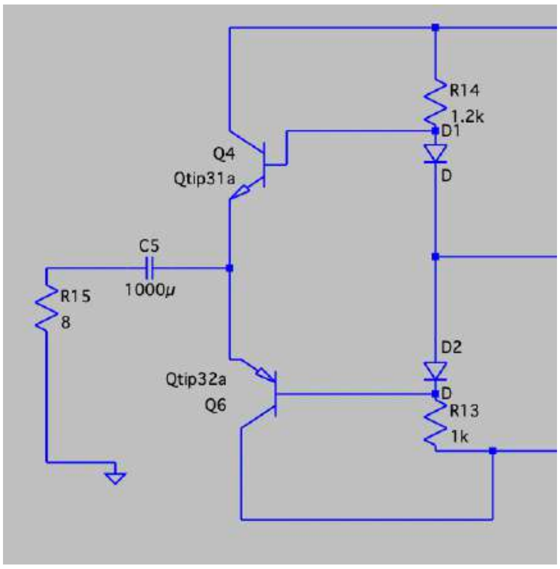
o **Class A**: A Class A amplifier is a linear analog amplifier that operates by conducting current for the entire cycle of the input signal, regardless of its amplitude. This leads to minimal distortion and high linearity in the amplification process. While these amplifiers have excellent linearity and low distortion, their efficiency is low as some of the input power is wasted as heat. They are commonly utilized in high-fidelity audio systems due to their high linearity and low distortion characteristics.

○ **Class B**: A Class B amplifier is an analog amplifier that divides the input signal into two parts, which are then amplified separately using separate active devices. This results in higher efficiency compared to Class A amplifiers as the active devices only conduct current for one half of the input signal's cycle. This approach, however, leads to non-linearity and distortion as the active devices switch between the two halves of the signal. Class B amplifiers are frequently used in applications where efficiency is a priority, such as radio transmitters.

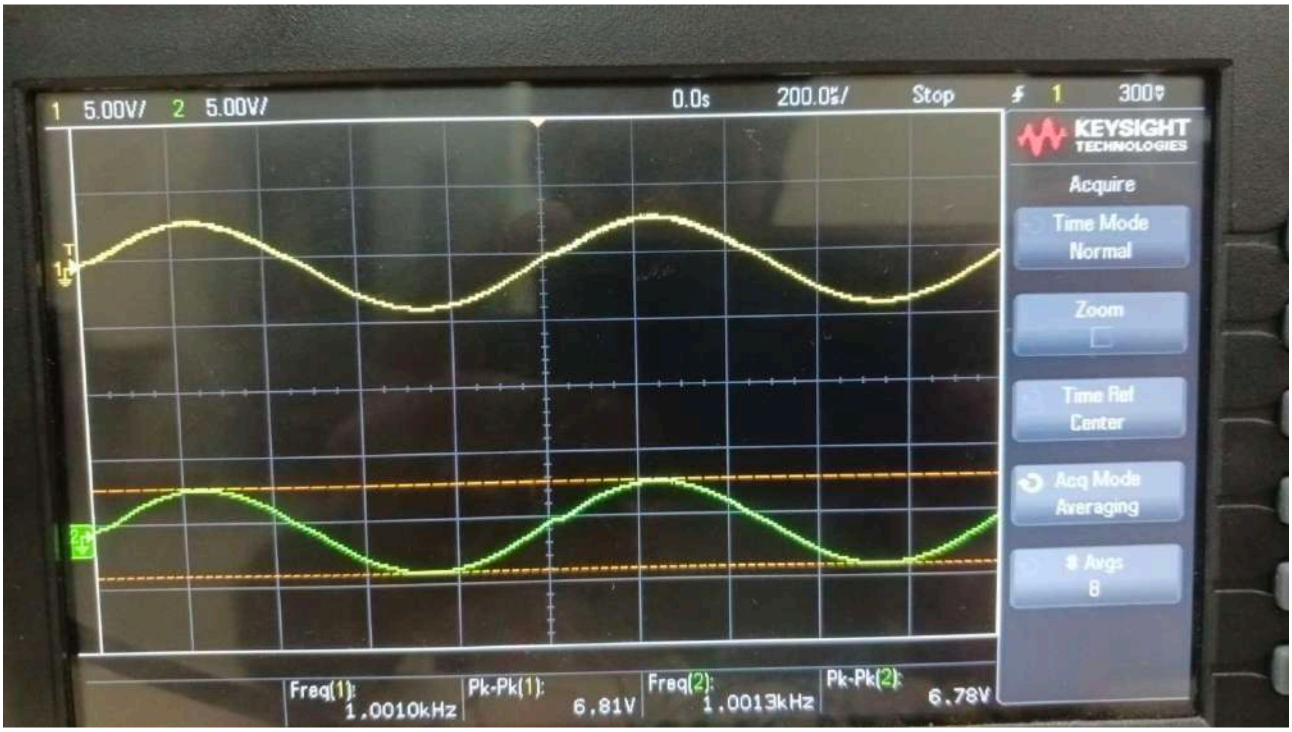
Class AB: A Class AB amplifier is an analog amplifier that balances linearity and efficiency by incorporating elements from both Class A and Class B amplifiers. The active device in a Class AB amplifier conducts current for over half but less than the entire cycle of the input signal, resulting in improved linearity compared to Class B amplifiers. However, this also results in higher power consumption when inactive and reduced efficiency compared to Class B amplifiers. Class AB amplifiers are often used in applications where both linearity and efficiency are significant factors, such as audio and power amplification.

Class C: A Class C amplifier is a type of analog amplifier that is designed to prioritize efficiency. The active device in a Class C amplifier conducts current for less than half of the input signal cycle, leading to significant power savings. This makes Class C amplifiers ideal for applications where power consumption is a concern, such as radio transmitters. However, this also results in severe non-linearity and distortion, making Class C amplifiers unsuitable for applications that require linearity, such as audio amplification. To overcome these limitations, Class C amplifiers are often used along with tuning circuits that shape the input signal, improving linearity.

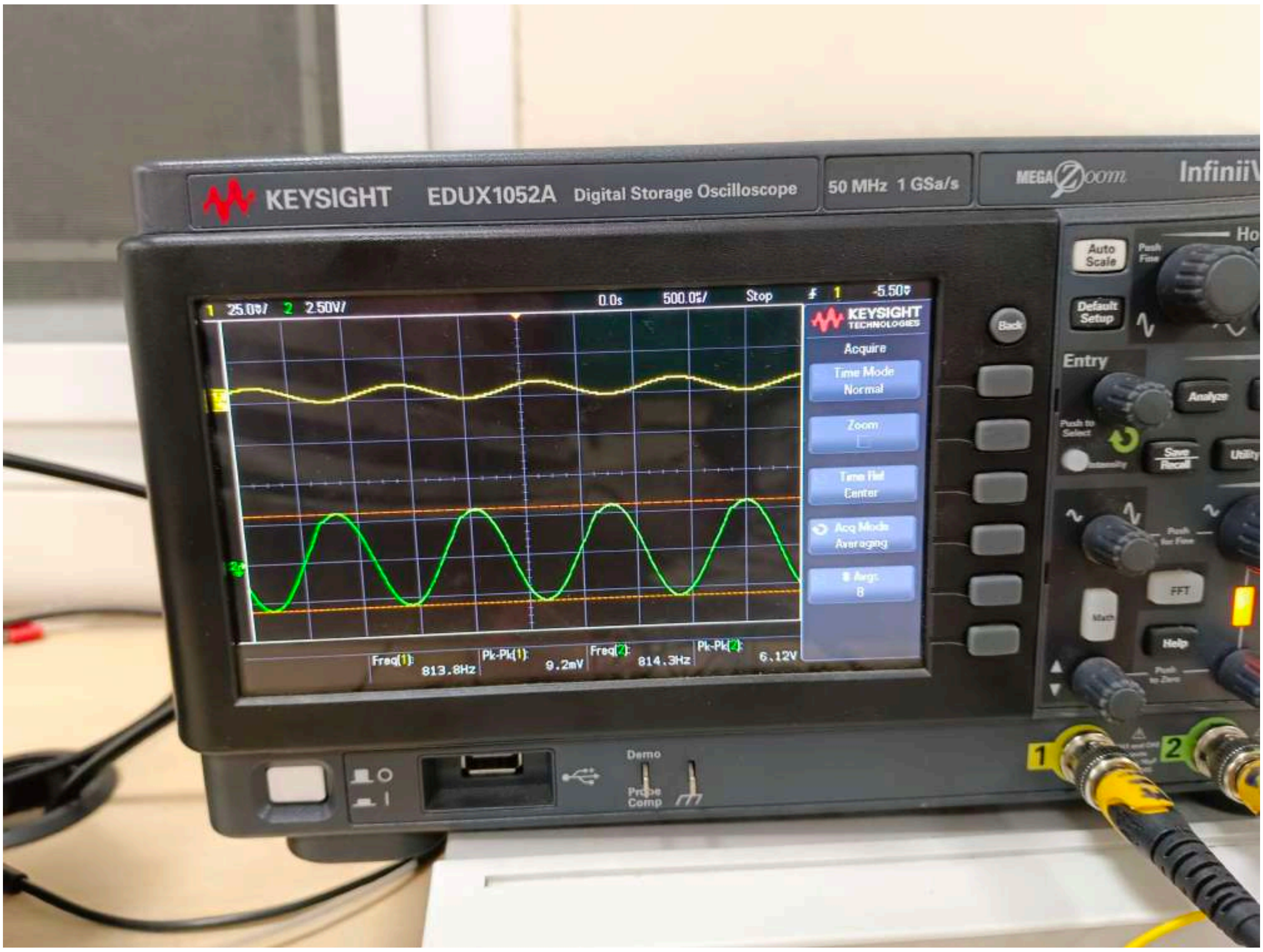
A circuit that utilizes resistors in series with each diode is used to produce small power inputs. This type of circuit is able to work because Class A amplifiers operate with low current outputs and Class B amplifiers work with high current outputs. The two transistors in the output stage of the amplifier are pre-biased with the use of diodes. For high input currents, one of the two transistors is turned on and the other is off (the npn transistor is turned on for positive input cycles and the pnp transistor is turned on for negative input cycles). Meanwhile, for low input signals, both transistors are on due to their pre-biasing.
The output from the filter block is sent to the power amplifier after being passed through a coupling capacitor to eliminate any DC bias.
The average power produced is approximately 2 W. Which is sufficient to drive speaker.



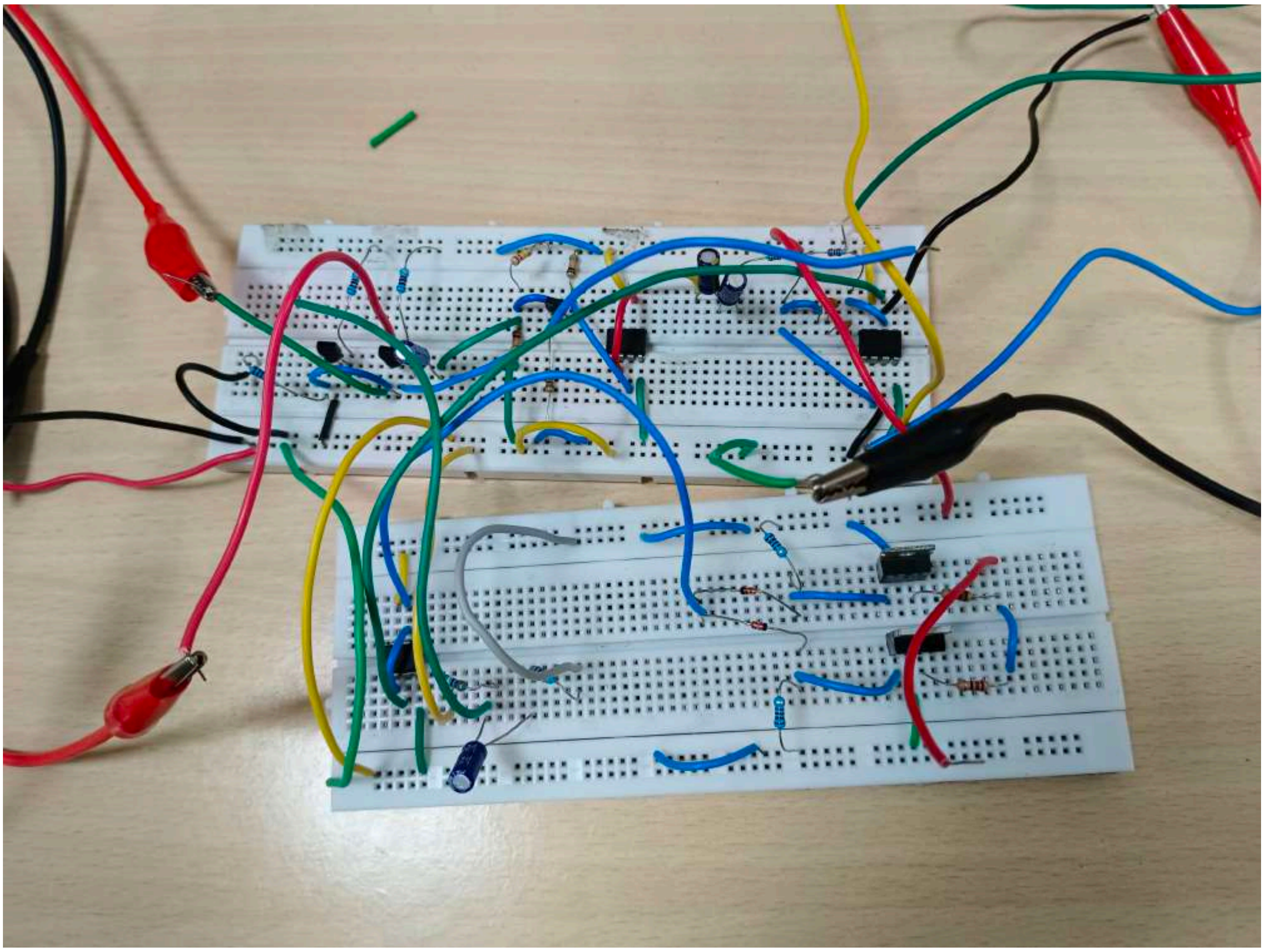
Power amp and filter output :



Voltage does not change much but the current gets amplifier to drive the speaker.
Final input and power amp output:



Hardware Circuit :



Mic to speaker video link :
While implementing the hardware for the gain stages, we face a few issues regarding the clipping of the signal outputs
On the upper side and the lower side, clipping on the upper side implies that the BJT is entering cut off mode which could be prevented by decreasing Rc value and clipping on lower side implied Saturation which could be cleared by increasing Re value.
Bias was given through voltage dividers

[WhatsApp Video 2024-02-23 at 23.38.45 (1).mp4]