AUDIO AMPLIFIER

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Agenda – Audio Amplifier

- An Audio Amplifier is an analog circuit that takes a small audio signal as input and increases its amplitude without changing its quality or waveform. It is usually used to amplify signal obtained from a microphone by boosting its power to a level required to be playable by a speaker.

Design Strategy & Approach

- The design strategy involves solving 4 parameters:

a) Frequency response

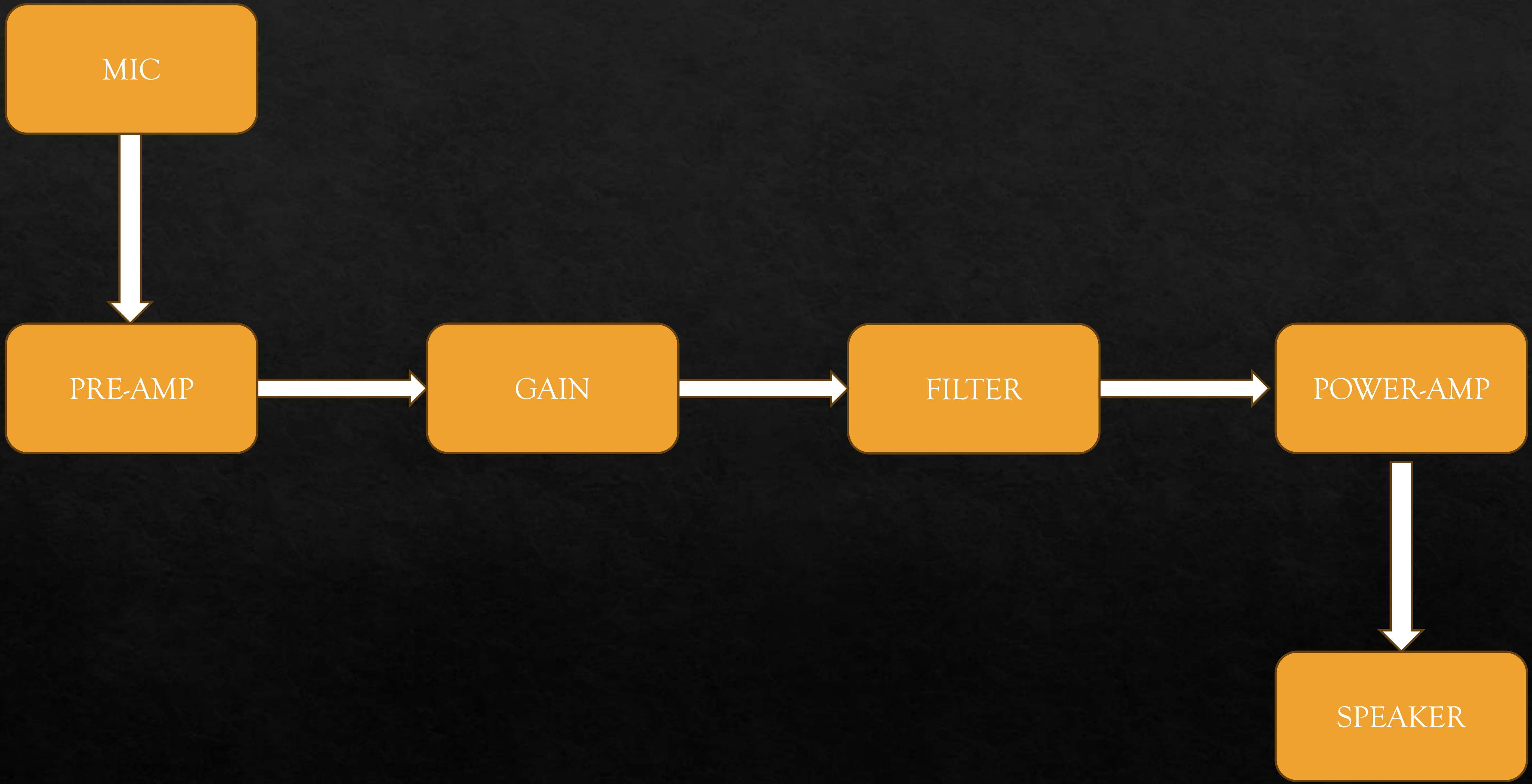
b) Noise

c) Gain

d) Distortion

To control these parameters, the circuit of audio amplifier is divided into 4 stages:

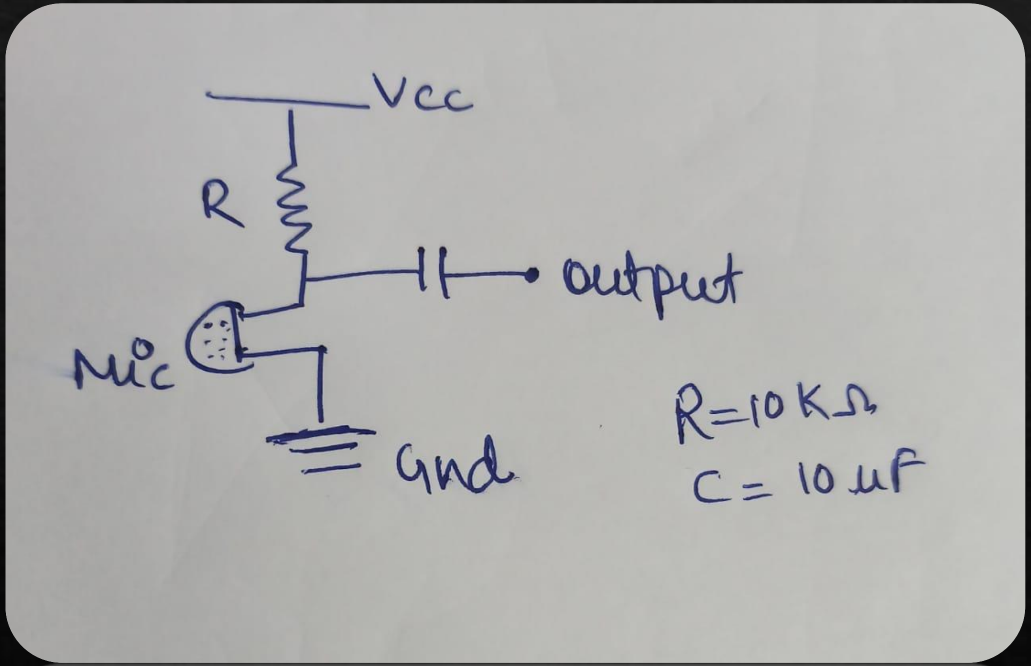
1) Pre-Amplifier - to amplify a quiet mic-level signal up to a louder line–level signal
2) Gain Stage - Increasing the gain while maintaining the stability of the amplifier
3) Filter – to have frequencies between the range of 50Hz – 20kHz
4) Power Amplifier - amplifier designed to increase the magnitude of power of a given input signal.

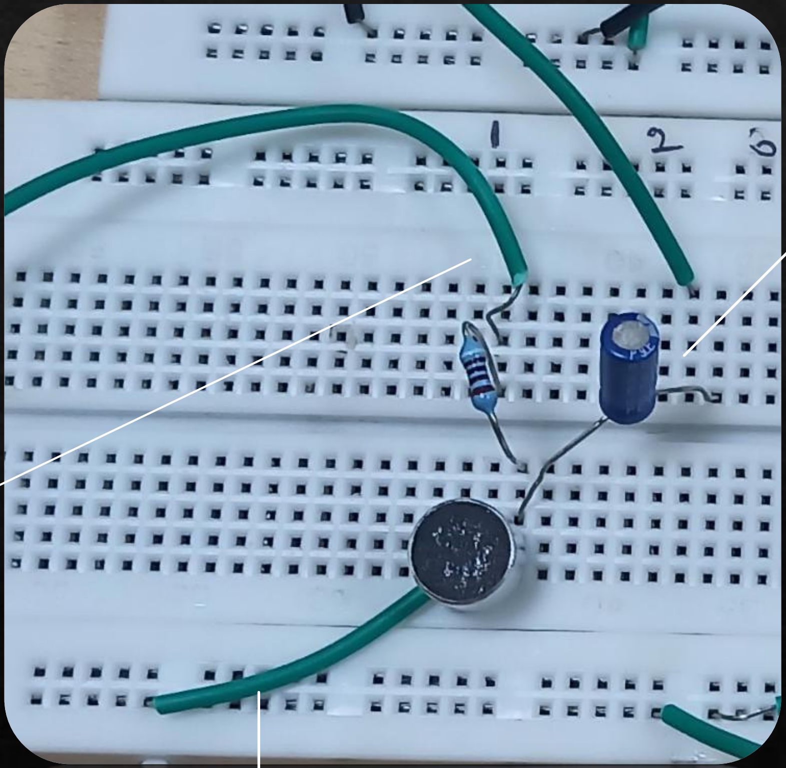

MIC
PRE-AMP
GAIN
FILTER
POWER-AMP
SPEAKER

Microphone

- The first component required to drive the audio amplifier is the Microphone, from where the input is fed into the circuit for further processing. During recording, energy conversion occurs in several stages. Firstly, sound waves from the instrument cause vibrations in the microphone's diaphragm, which in turn translates these acoustic vibrations into an electrical signal. This resulting signal, known as mic-level, is typically quite faint.

Microphone





Vcc

output

Gnd

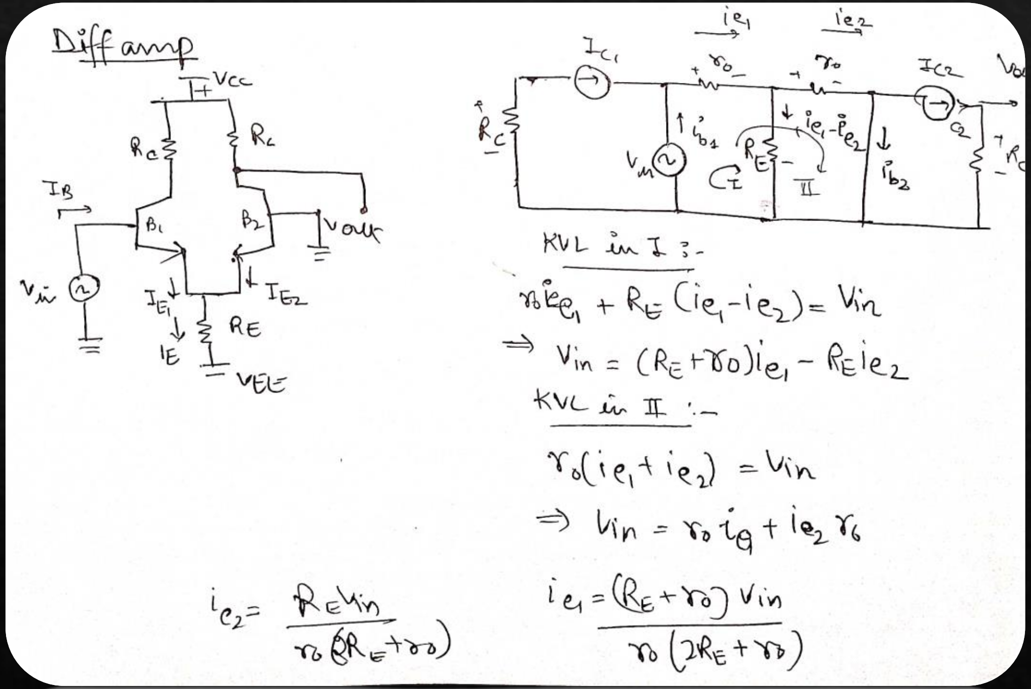
Pre - Amplifier

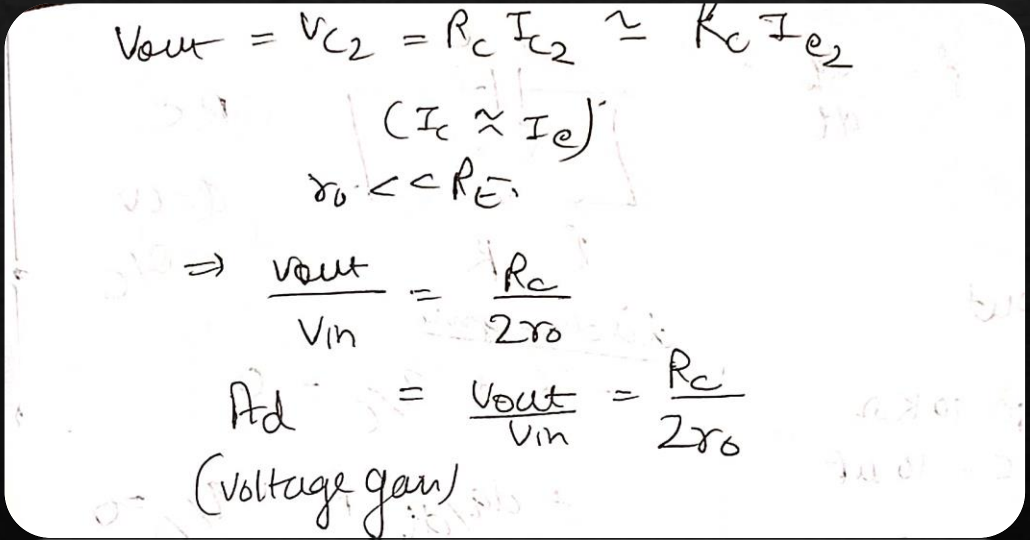
- An input from the microphone cannot be directly sent to the power amplifier as this would result in an extremely noisy signal that is incapable of driving the load (speaker). Hence, we use a pre-amp to amplify a quiet mic-level signal up to a louder line–level signal which is standard for transmitting analog signal b/w equipment. Here the pre-amp is supposed to have a high impedance (so that even a very small amount of current can be sensed) and a low output impedance (to make sure there is no voltage drop at the output).
- We have implemented a pre-amplifier using DIFFERENTIAL AMPLIFIER in the single-ended unbalanced output configuration.

Differential Amplifier

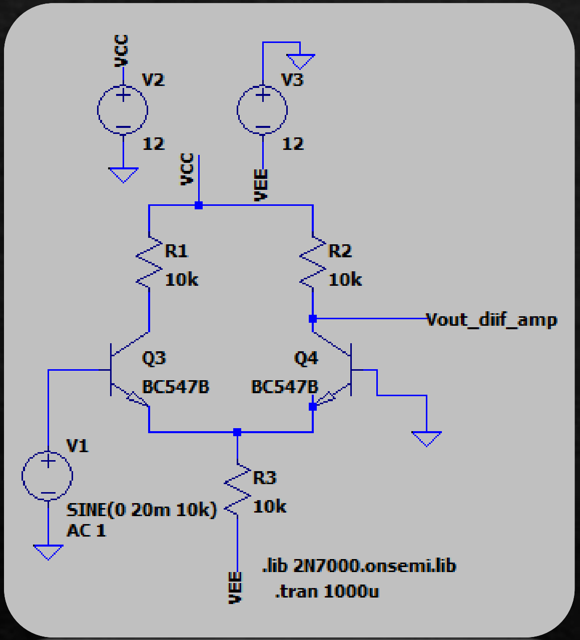
- A differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. The noise is generally created by wires and cables, due to electromagnetic induction (common-mode noise), diff amp suppresses this noise.
- We are constructing diff amp using BJTs, both inputs are given to it but the output is taken from only one of the two collectors.
- An amplified version of the difference in both signals will be available at the output. The voltage gain is half the gain of the dual input, balanced output differential amplifier.

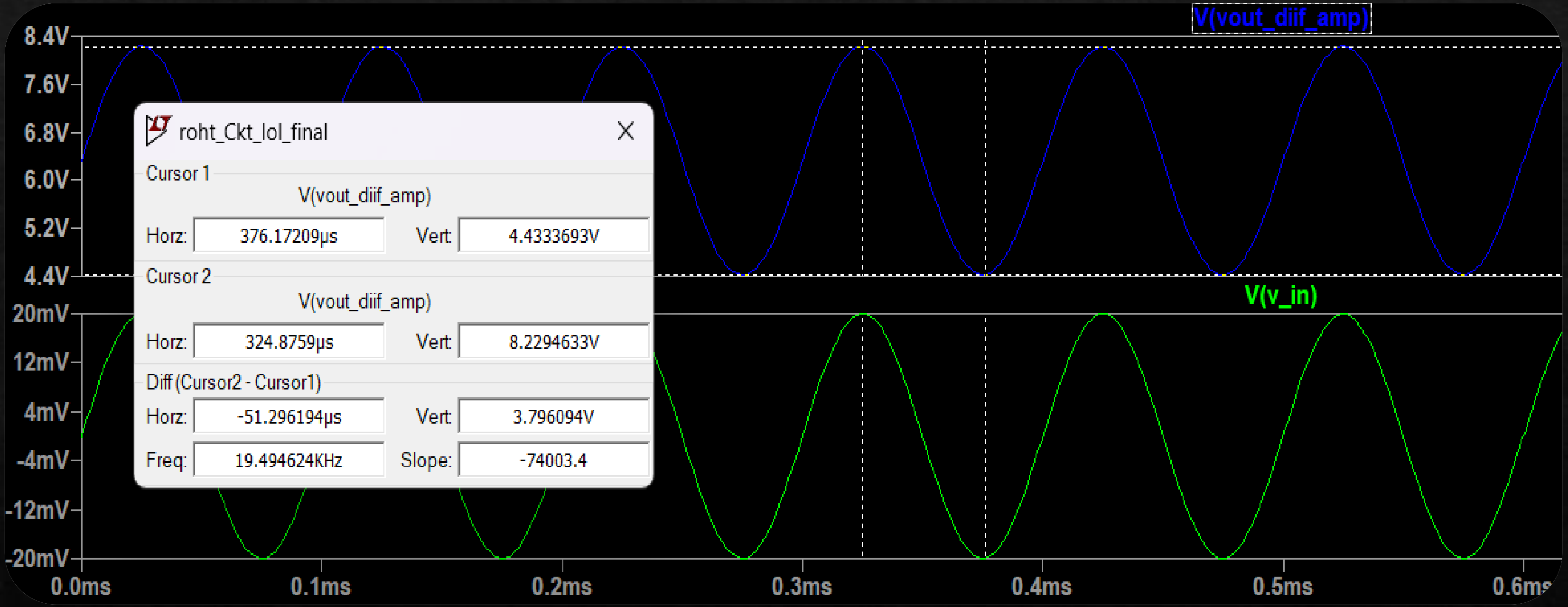
Calculations





Simulations





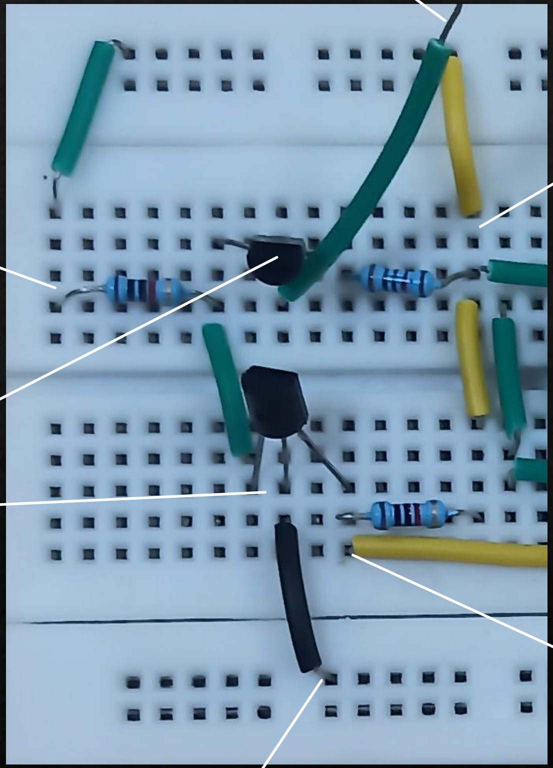
Gain = (3.79*1000)/40 = 94.75

Circuit

Input

VCC = 12

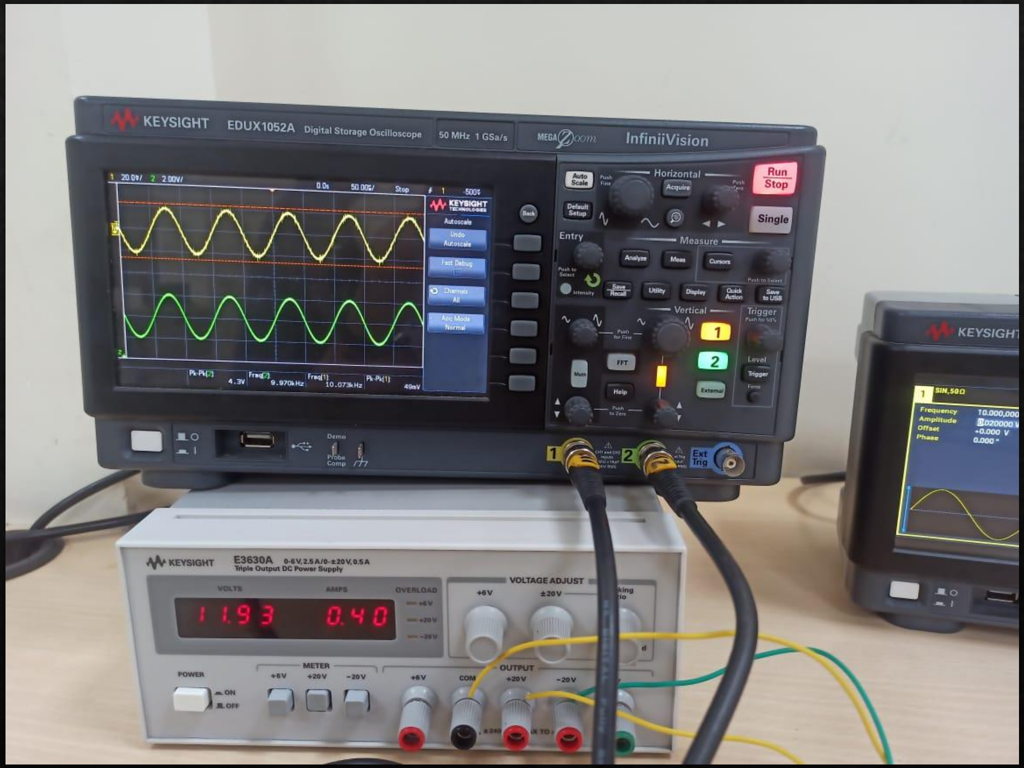
VEE = -12



BJT

Vout

Gnd

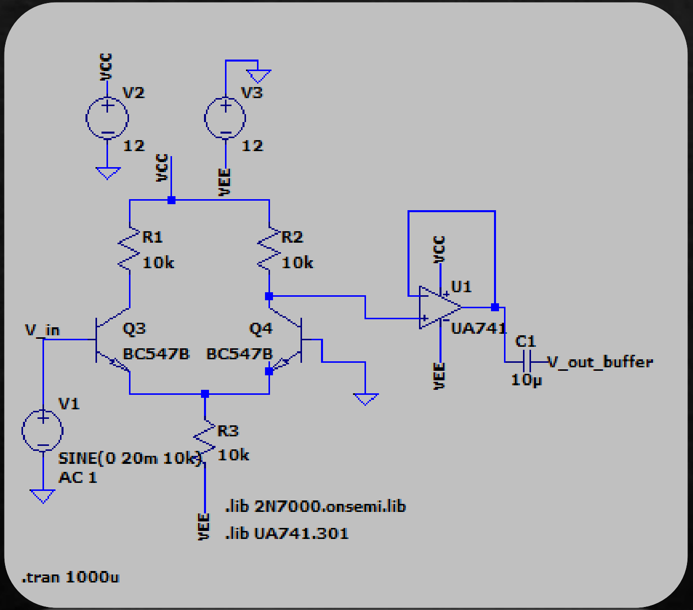


Gain = (4.3*1000)/40 = 107.5

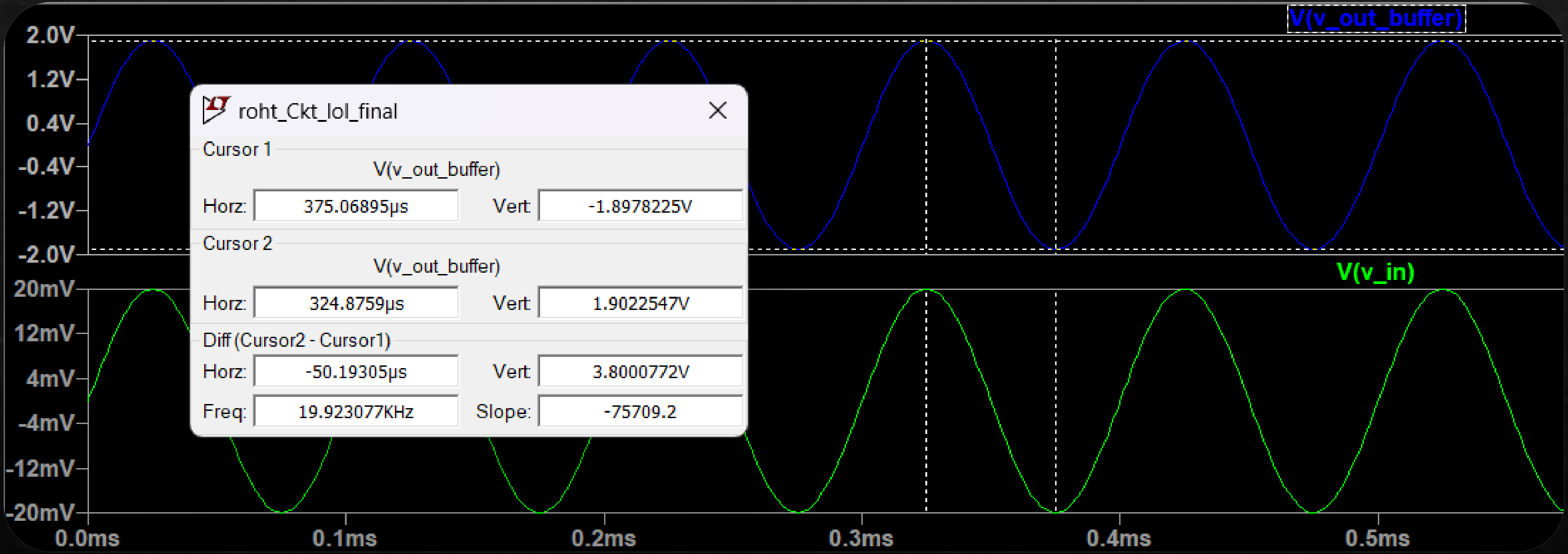
Buffer

- A buffer is used for matching impedance. The output impedance of a pre-amplifier must be matched with the input impedance of the CE Amplifier.
- While using a buffer between the differential amplifier and CE Amplifier, it makes the output impedance of diff amp = input impedance of CE Amp = ∞
- Thus, we are using a unity gain non-inverting buffer using Op-Amp in this case to act as a buffer
- A capacitor is also used to reduce DC offset.

Simulation



VCC
V2
12
V3
12
VCC
VEE
R1
10k
R2
10k
VCC
U1
UA741
V_in
Q3
BC547B
Q4
BC547B
C1
10µ
V_out_buffer
VEE
V1
SINE(0 20m 10k)
AC 1
R3
10k
.lib 2N7000.onsemi.lib
.lib UA741.301
VEE
.tran 1000u



V(v_out_buffer)
2.0V
1.2V
0.4V
-0.4V
-1.2V
-2.0V
V(v_in)
20mV
12mV
4mV
-4mV
-12mV
-20mV
0.0ms
0.1ms
0.2ms
0.3ms
0.4ms
0.5ms
roht_Ckt_lol_final
Cursor 1
V(v_out_buffer)
Horz: 375.06895µs Vert: -1.8978225V
Cursor 2
V(v_out_buffer)
Horz: 324.8759µs Vert: 1.9022547V
Diff (Cursor2 - Cursor1)
Horz: -50.19305µs Vert: 3.8000772V
Freq: 19.923077KHz Slope: -75709.2

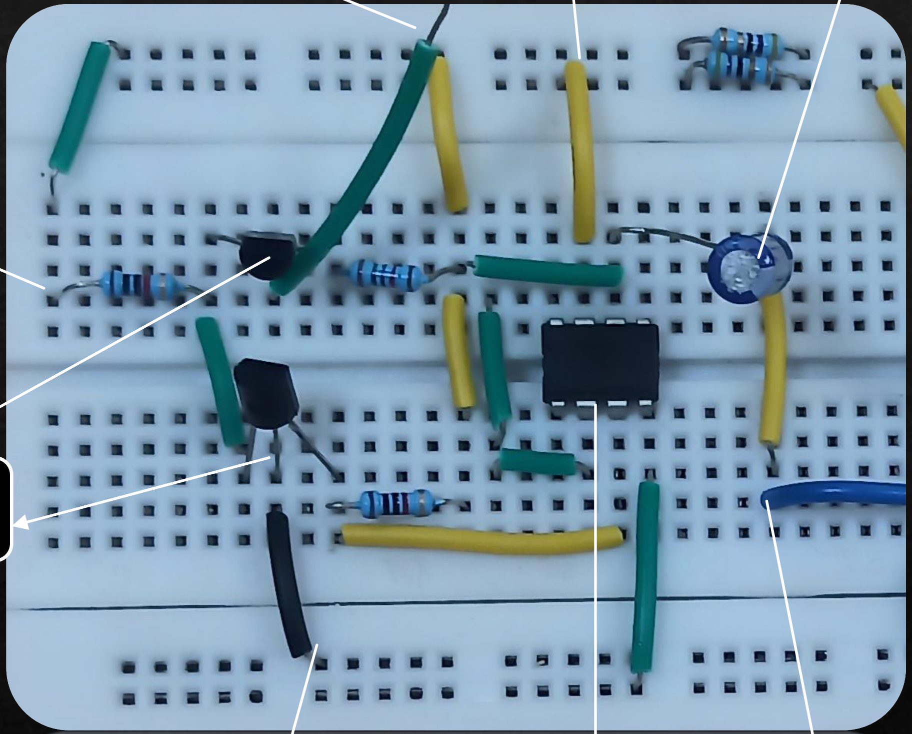
Circuit

Input

VCC = 12

C = 10uF

VEE = -12

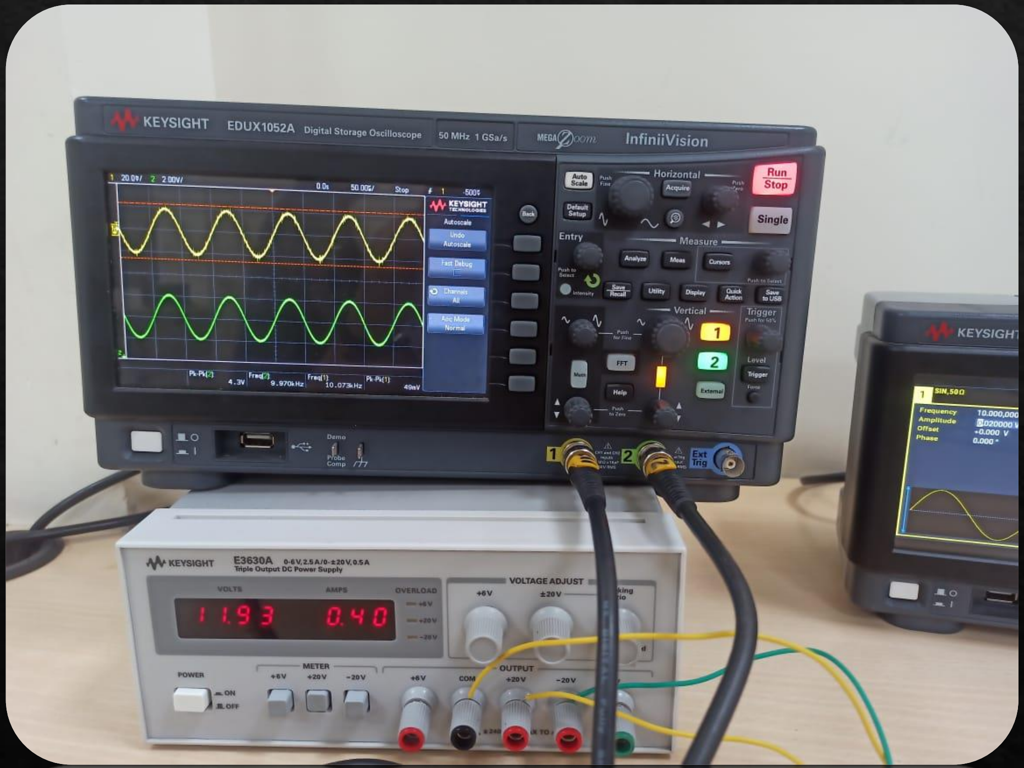


BJT

Gnd

Op-Amp

Vout



Gain Stage

- We are using a multi-stage cascade system for amplification for the following reasons:
  a) Increasing the gain while maintaining the stability of the amplifier
  b) To achieve better noise immunization

Here we are using a CE Amplifier to meet the below-mentioned requirements:

1) High input impedance to avoid loading problems and to avoid the passage of input current through it so that input signal is available for amplification

2) High Voltage gain

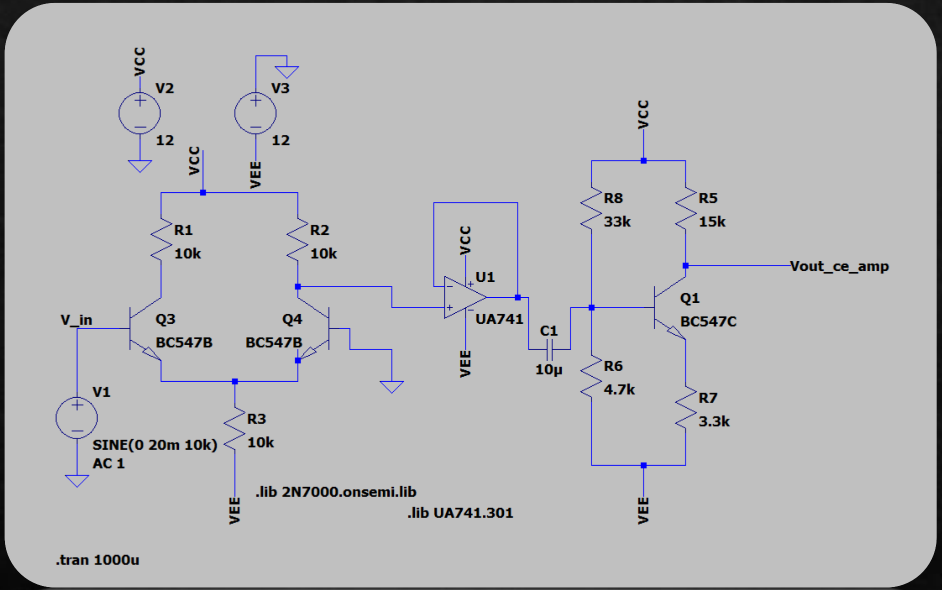
3) Low Current gain

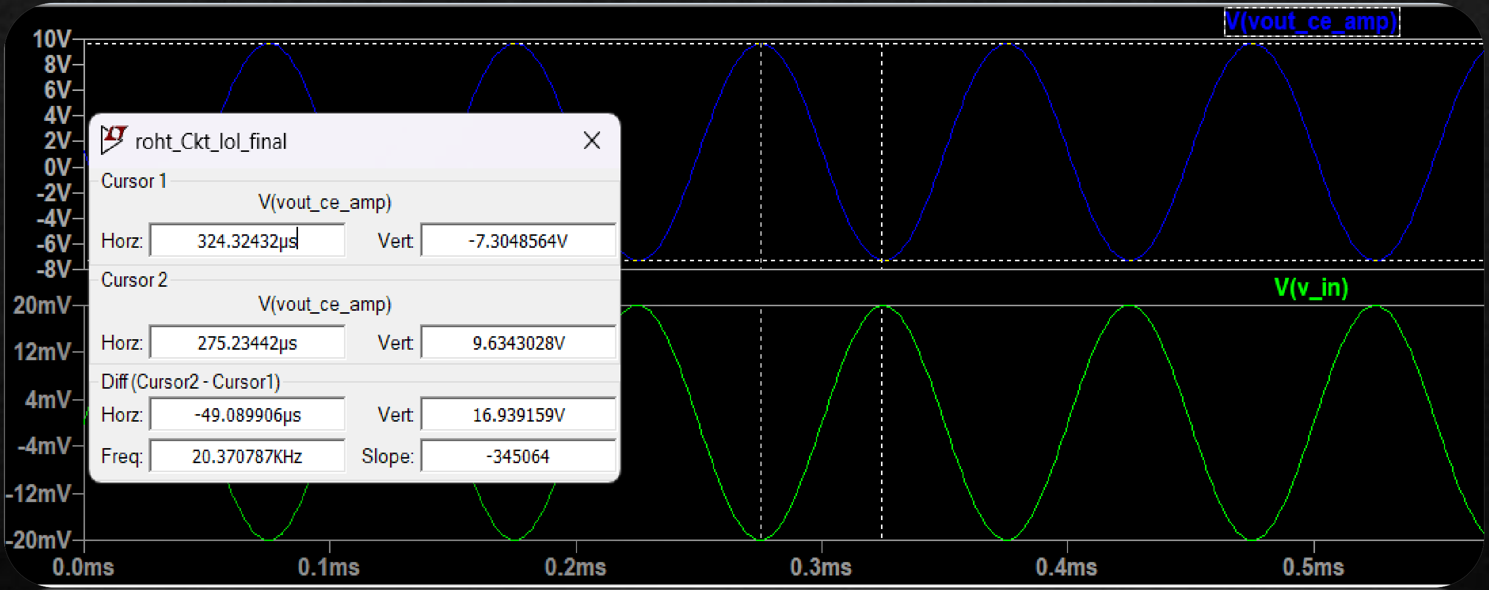
4) Low Output impedance

Common Emitter Amplifier

- There is a phase relationship of 180^o in input and output.
- The gain will be quite high in case of CE Amp but after connecting the subsequent components, there will be loading which will cause the amplification to reduce.
- In our case there is a reduction in CE Amp output from 17.7 Vpp to around 10 Vpp.
- CE Amp works in Linear Region.

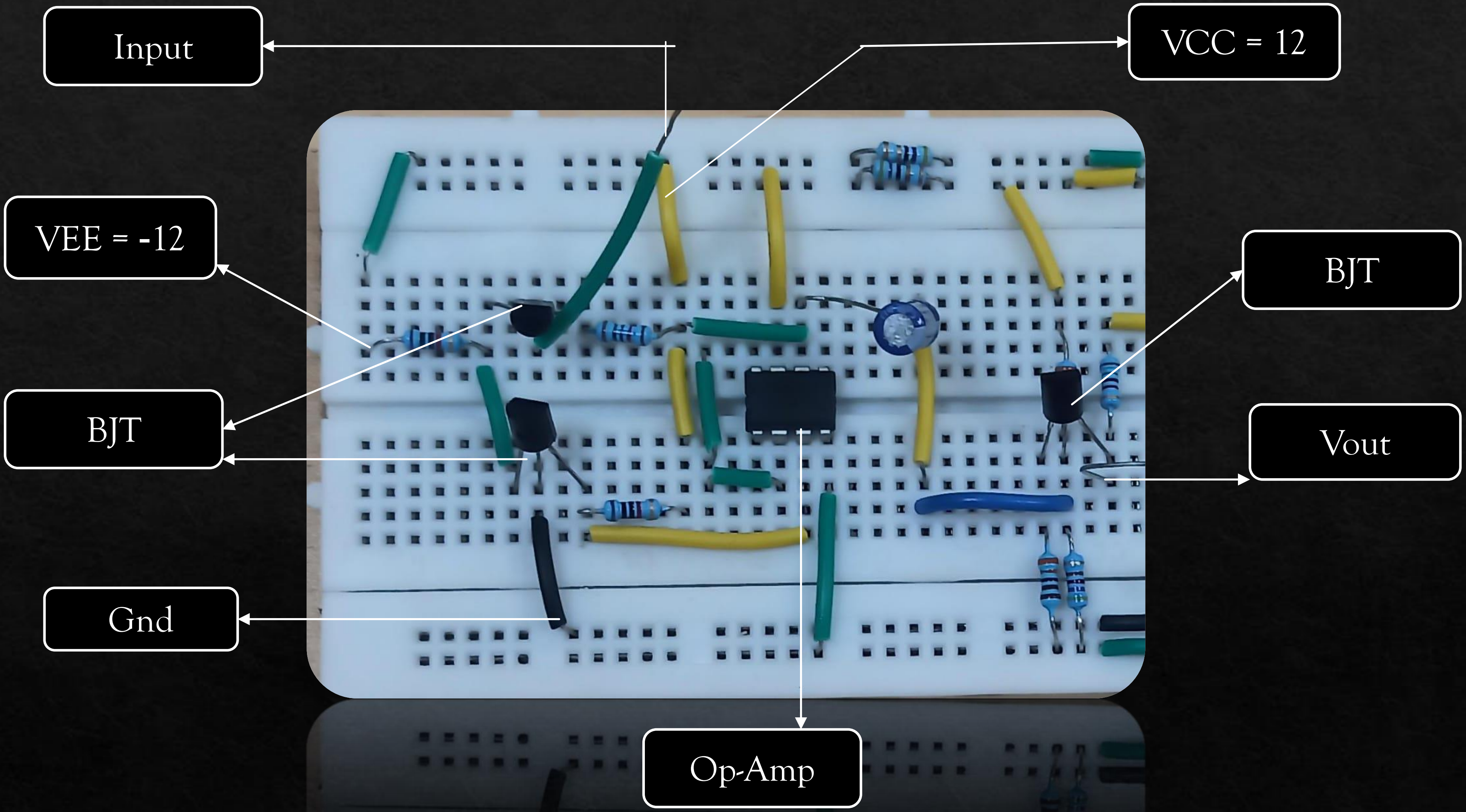
Simulations



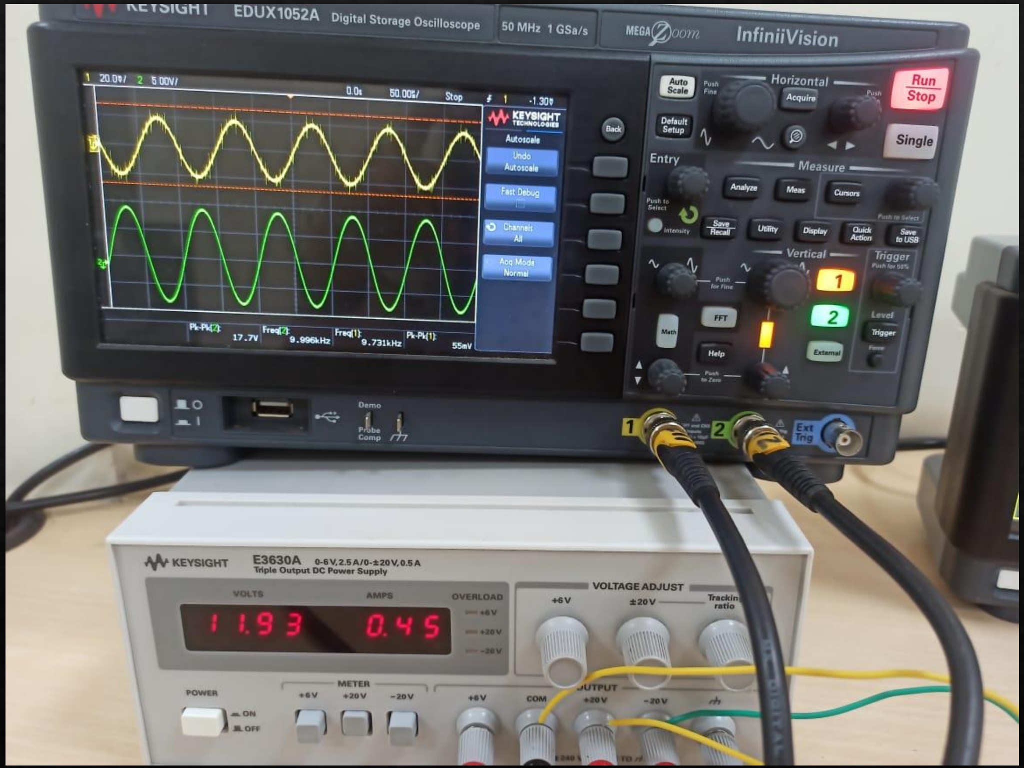


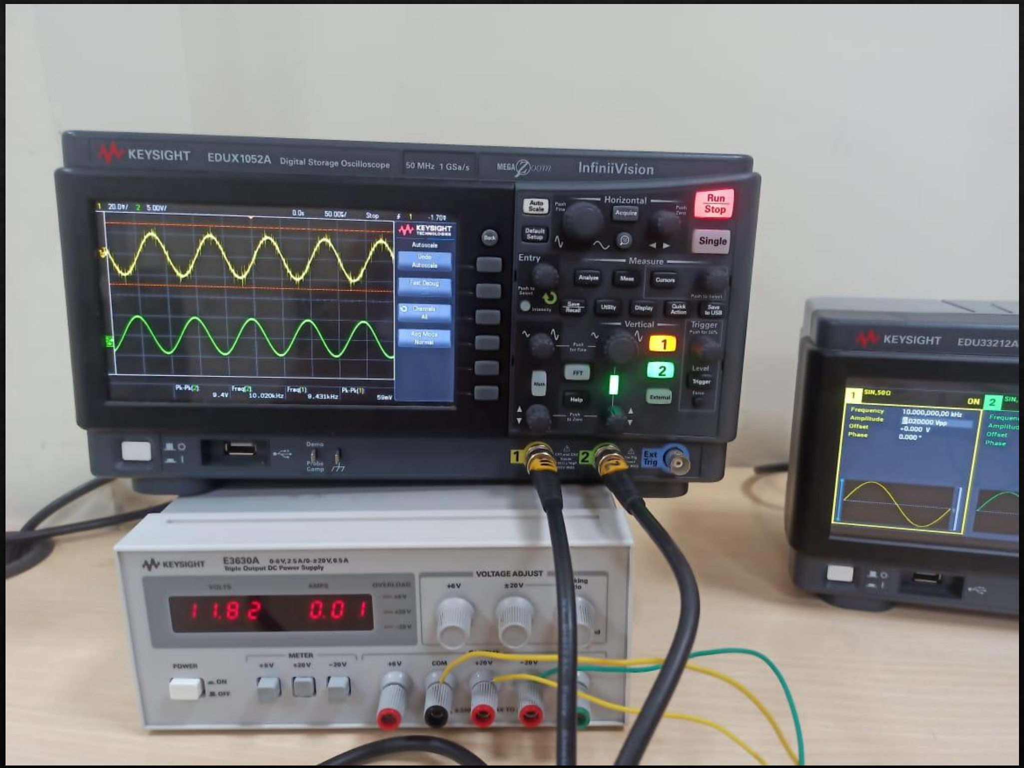
Gain = (16.9*1000)/40 = 422.5

Circuit



Circuit





Gain = (17.7*1000)/40 = 442.5

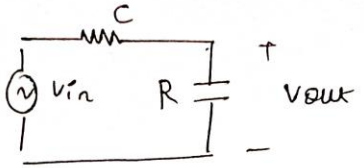
Gain = (9.4*1000)/40 = 235

Filter

- We need to filter out high-frequency noise and tune our signal according to our requirements. We need a frequency range of 50 Hz – 20 kHz for our circuit.
- Here we are using a low pass passive filter made of resistor and capacitor to eliminate frequencies above 20kHz. A high-pass for 50Hz hasn’t been used since there is negligible attenuation in the range of 0 to 50Hz.
- This is followed by a unity gain non-inverting buffer made using Op-Amp to act as a buffer between the filter and power amplifier. This is done to prevent any loading.
- In our case due to the presence of diff amp, CE amp the actual cutoff frequency will change. This happens due to parasitic capacitances of the previous components in the circuit.

Calculations

Filter



$$V_{out} = \frac{R}{R + X_c} \cdot V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{R}{R + \frac{1}{j\omega C}} = \frac{jR\omega C}{j\omega RC + 1}$$

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{R\omega C}{\sqrt{1 + \omega^2 R^2 C^2}}$$

$$-3 = 20 \log_{10}\left(\left|\frac{V_{out}}{V_{in}}\right|\right)$$

$$-\frac{1}{2}\log_{10} 2 = \log_{10}\left(\left|\frac{V_{out}}{V_{in}}\right|\right)$$

$$\frac{1}{\sqrt{2}} = \frac{V_{out}}{V_{in}}$$

$$\frac{R\omega C}{\sqrt{1 + \omega^2 R^2 C^2}} = \frac{1}{\sqrt{2}}$$

$$2R^2\omega^2C^2 = 1 + R^2\omega^2C^2$$

$$R^2\omega^2C^2 = 1$$

$$\boxed{\omega = \frac{1}{\sqrt{RC}}}$$

Here $f = \frac{1}{2\pi\sqrt{RC}}$

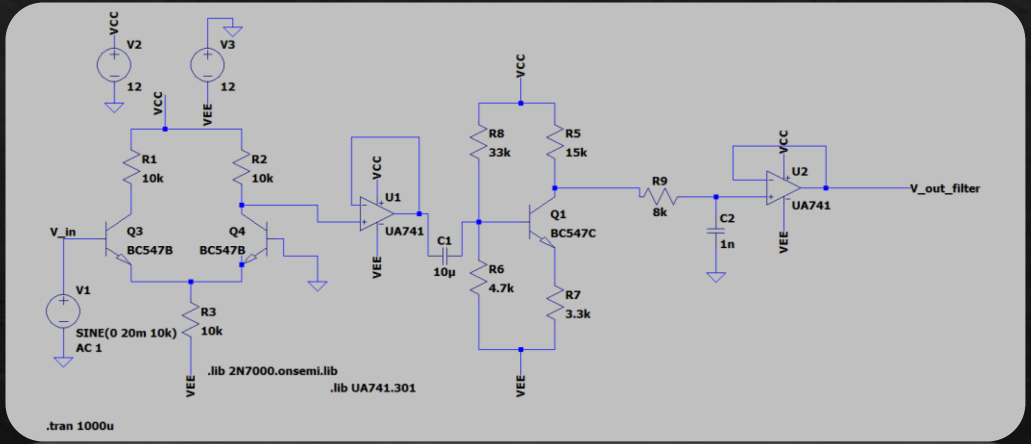
Since $f = 20\text{KHz}$

$$\frac{1}{2\pi\sqrt{RC}} = 20 \times 10^3$$

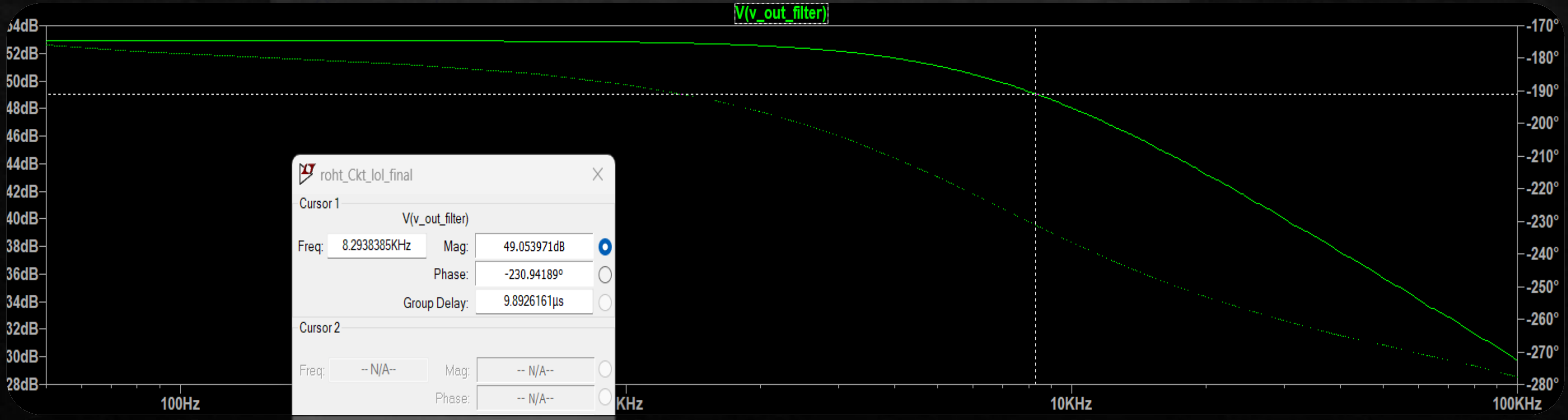
$R = 8K$

$C = 1nF$

Simulations

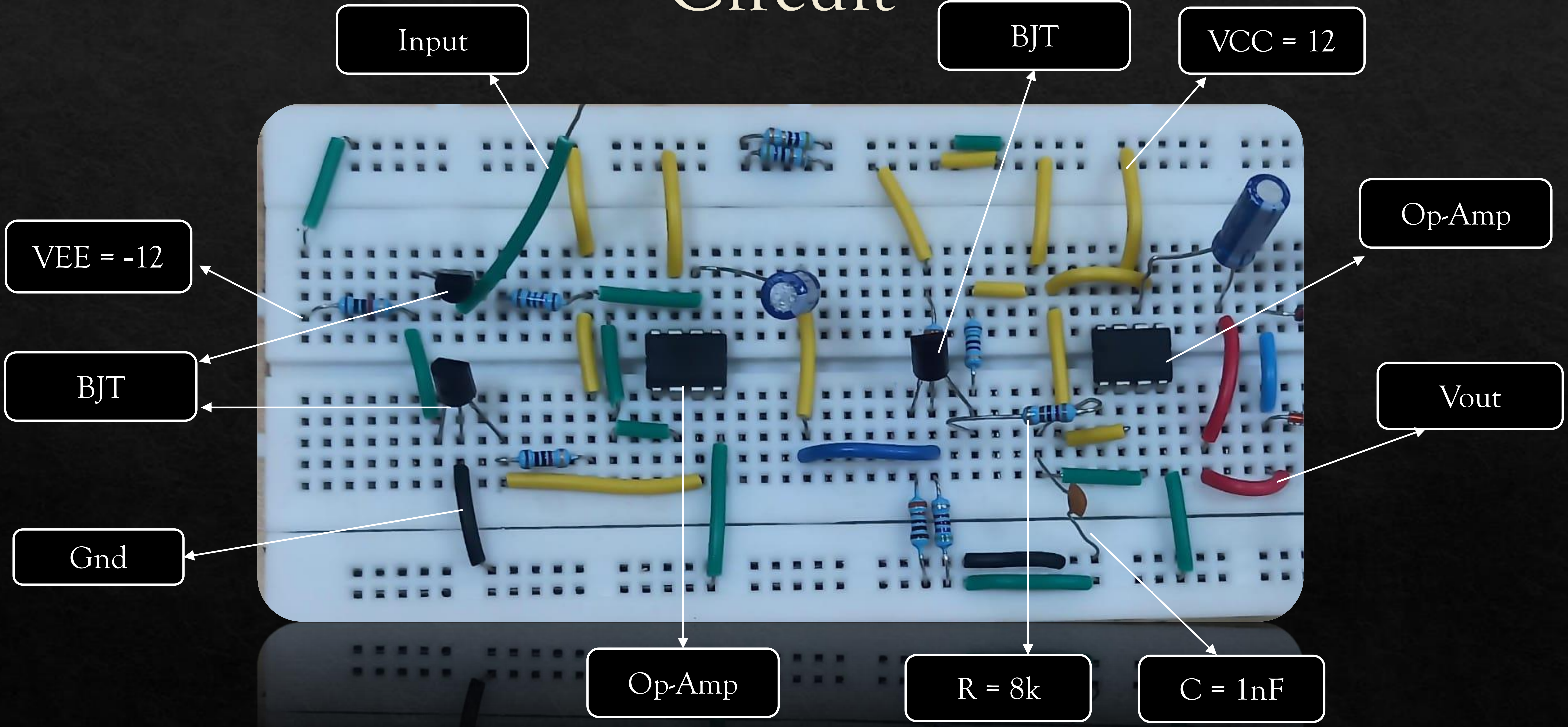


The cutoff frequency is the frequency at 3 dB below the highest frequency.
Here Max freq = 52.07 db
So cutoff freq will be measured at 49.07 dB.

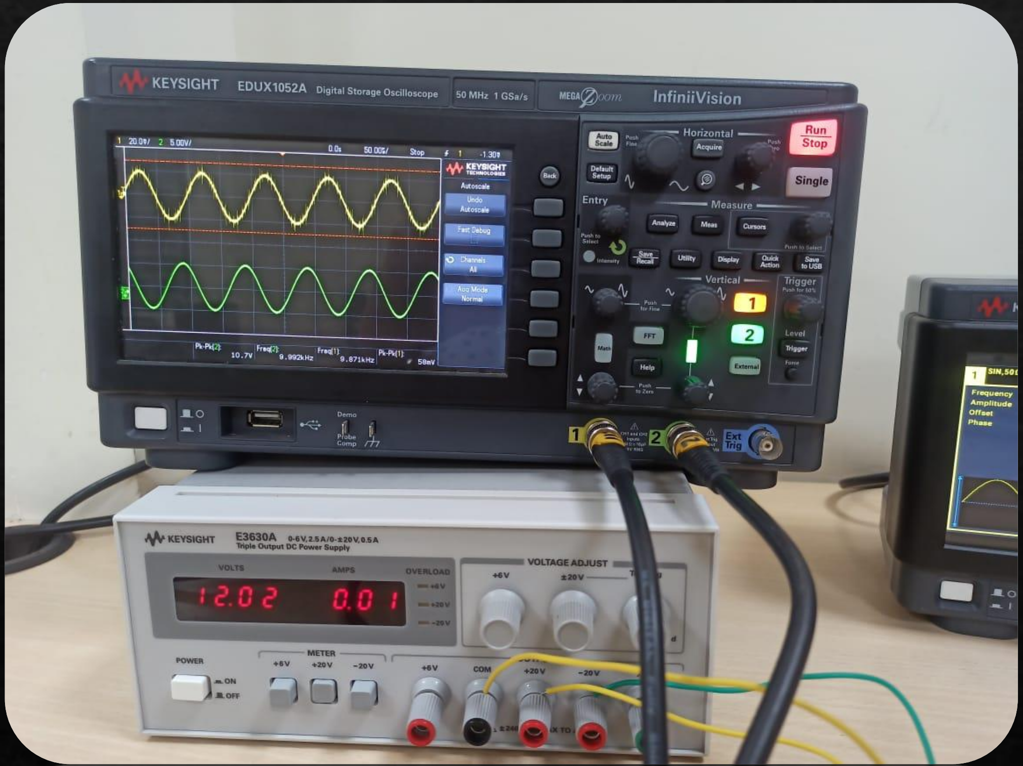


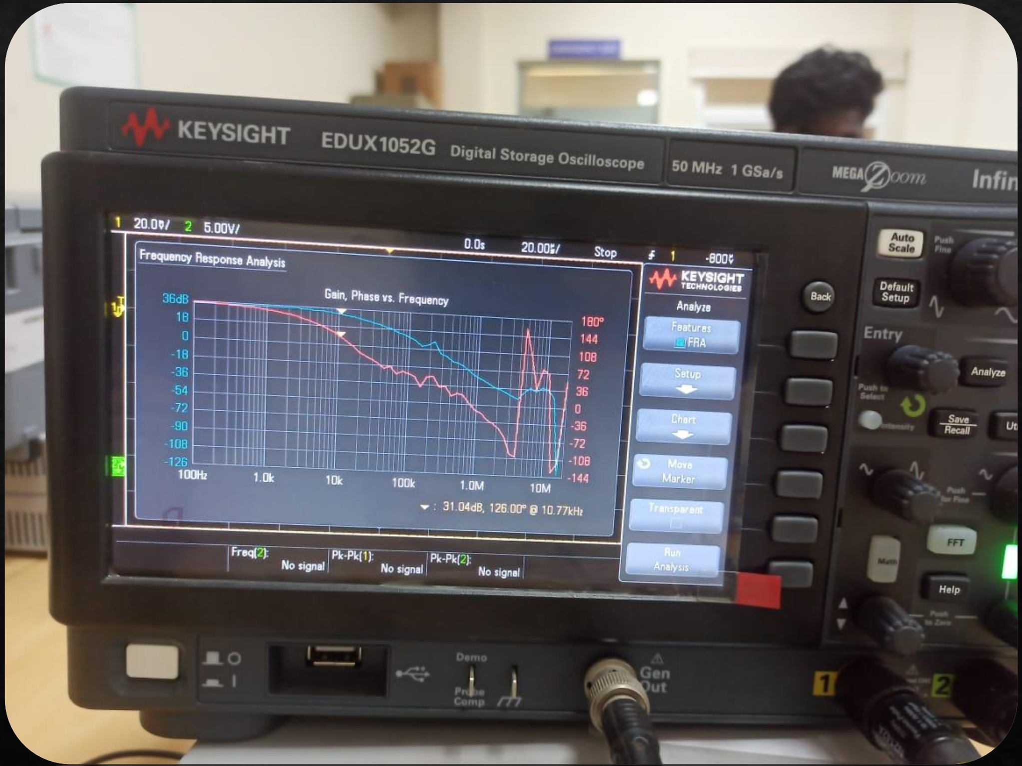
Cutoff freq = 8.29 kHz

Circuit



Circuit





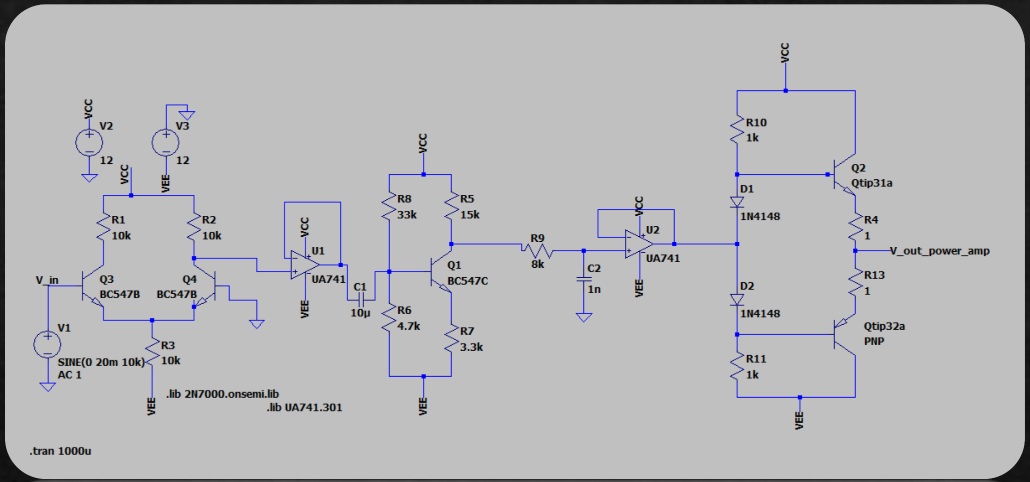
Cutoff freq = 10.77 kHz

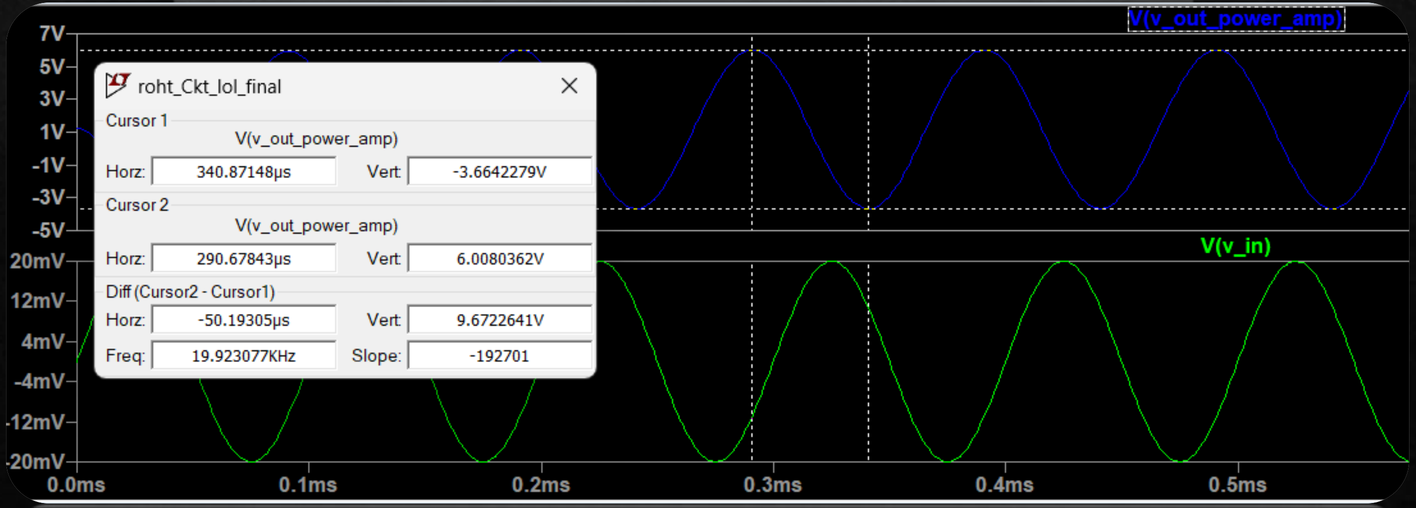
Power Amplifier

- Power Amplifier is an electronic amplifier designed to increase the magnitude of power of a given input signal.
- The power of the input signal is increased to a level high enough to drive loads of output device, here speaker. It is the final block of this amplifier chain to drive the speaker directly.
- The input signal to a power amplifier needs to be above a certain threshold. So, instead of directly feeding the input from the mic to the power amplifier, it is first pre-amplified using a differential amplifier and CE amplifier and is sent as input to the power amplifier.

- Here we are using a Class AB amplifier, which is used to overcome the issues brought up by Class A and Class B amplifiers.
- Class A amplifier is a normal voltage amplifier that only amplifies the power very little, making its efficiency very less.
- The class B amplifier was made to increase that efficiency but the problem with it is at low voltages of the input, both the transistors turn off and the output also becomes zero which gives distortion (cross-over distortion).
- To fix this, a Class AB amplifier is used which removes the distortion by using 2 diodes between 2 transistors so that there is a constant potential difference between them to make sure at least one is always on.
- We choose resistor values also to divide the voltage and bias the transistors and how much power we want to pass through the speaker.
- The collector of these transistors is large and the base, and emitter regions are heavily doped. The collector current is far greater than the base current to ensure optimal gain. It has a lower output impedance to ensure minimal voltage loss and an increase in power delivered to the load. The voltage gain is taken to be around unity in this stage while the current increases, leading to an overall increase in the power of the signal.
- We are also using two resistors of 1 ohm after power transistor to prevent them from overheating.

Simulations



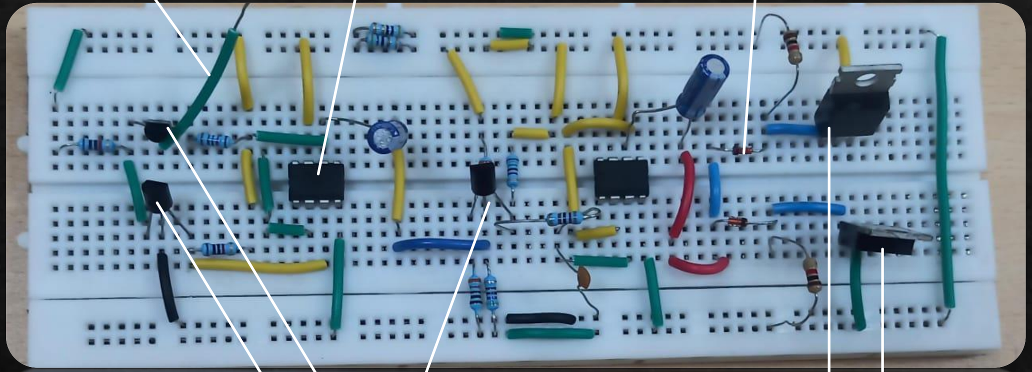


Circuit

Input

Buffer

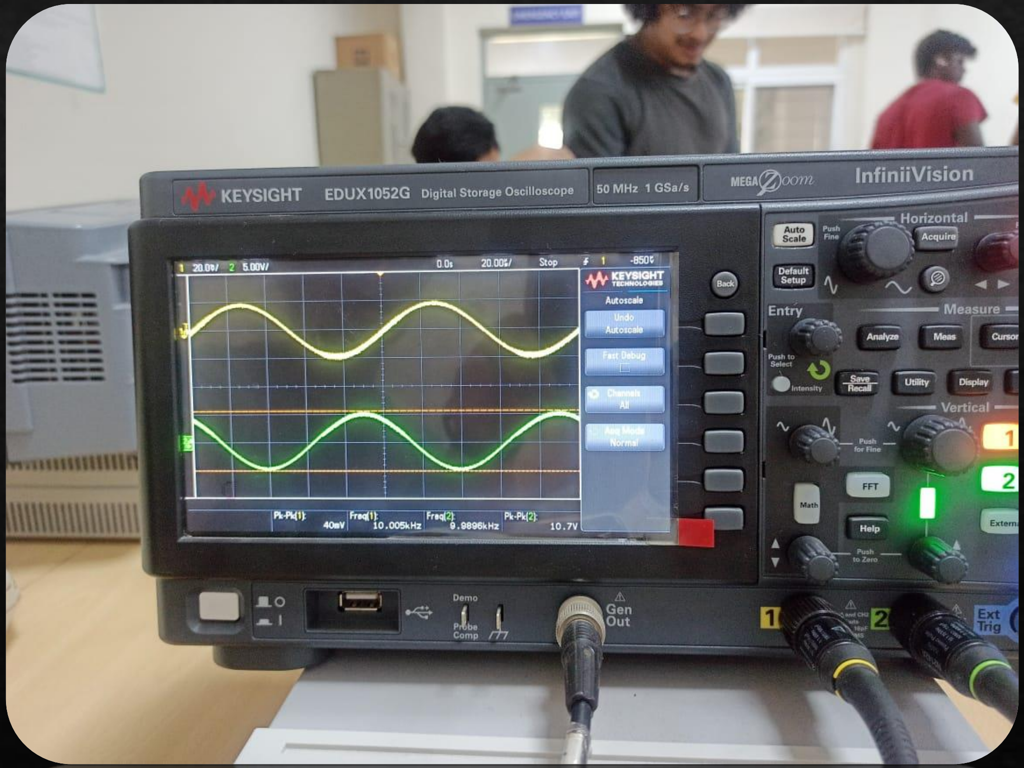
Diodes



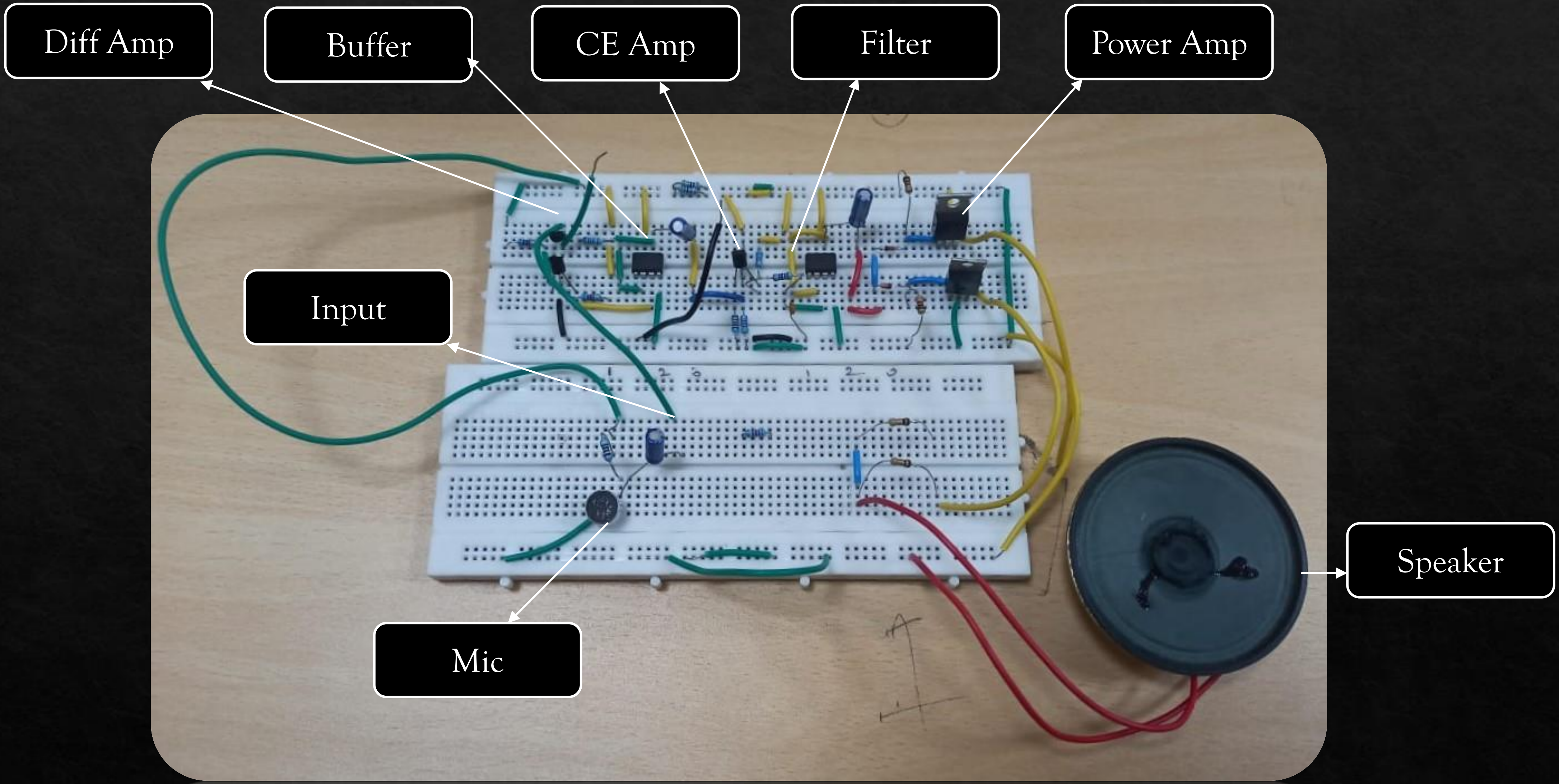
BJT

Power Transistor

GAIN = (10.7*1000)/40 = 267.5



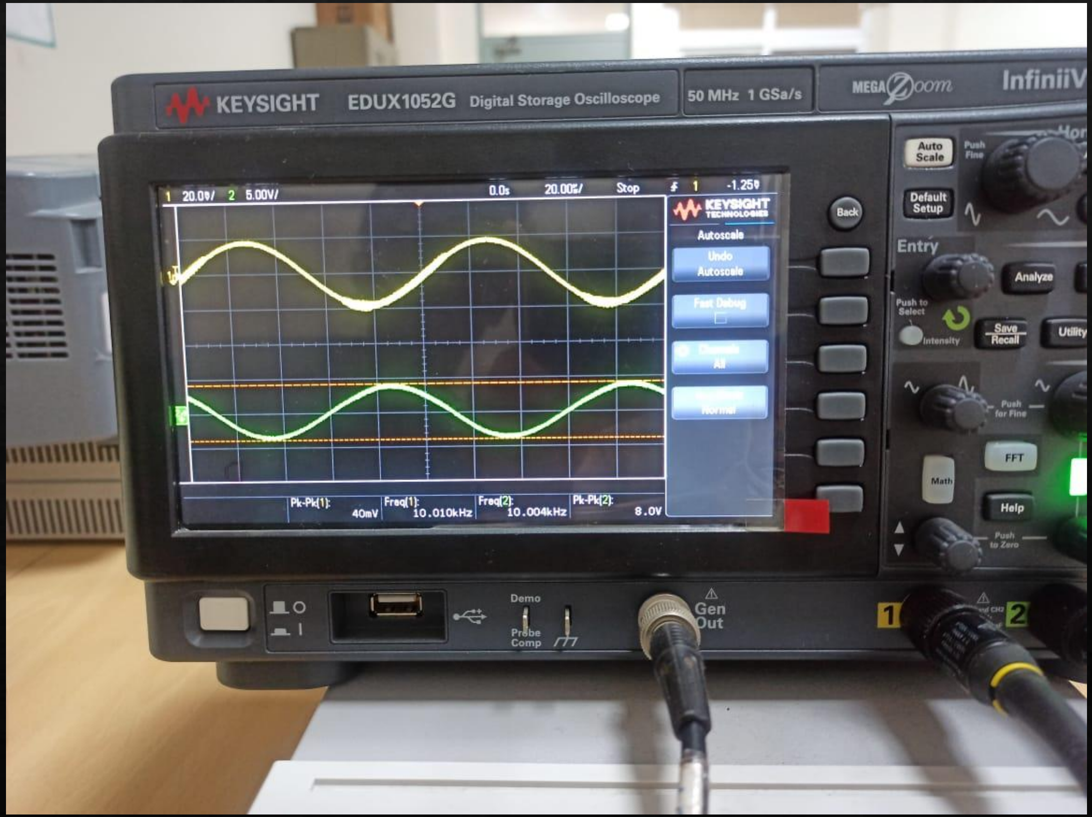
FINAL CIRCUIT



FINAL OUTPUT

Input is 40mVpp (peak to peak)

Output is after connecting speaker



FINAL GAIN = (8*1000)/40 = 200

Main Observations & Learnings

- BJTs over MOSFETs: It is better to use BJTs rather than MOSFETs because MOSFETs need to operate in the saturation region ($Vds \leq Vgs - Vth$), but this region is quite narrow to operate within our high input voltage ($Vcc = 12\,V$). Therefore, it becomes difficult to bias MOSFETs effectively.
- Importance of Buffer: It makes sure to negate the loading effect.
- CE Amp: There is a phase shift of 180 degrees between the input and output because V_in is directly proportional to I_d and $Vout = Vin - Icc$ *R
- Power Amplifier working: It is used to pull down the Vcc (+12V) to Vmax (Maximum peak of the input signal) and pull up the Vee (-12V) to Vmin (Minimum peak of the input signal), now since the input and output voltages are same, we can change the current by varying the resistance values, finally leading to increased power.
- Biasing importance: BJT only operates in the linear region ($Vce \leq Vbe - Vth$)