EW 2 :PROJECT 1
THE DESIGN OF AN AUDIO AMPLIFIER

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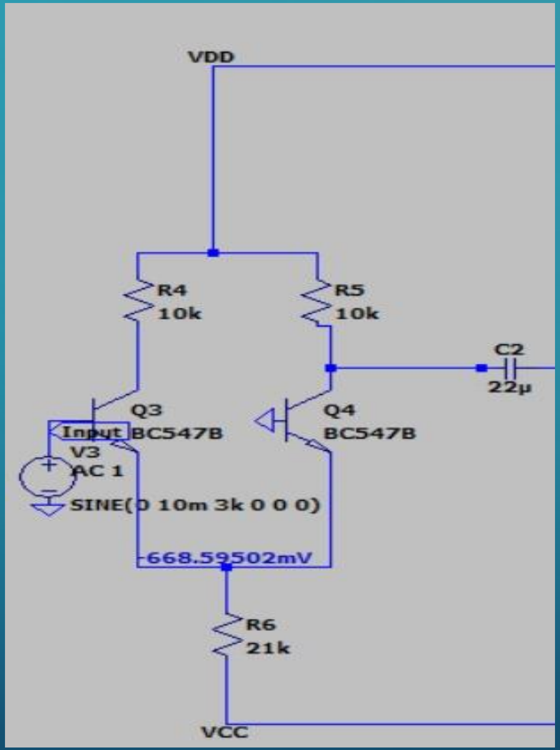
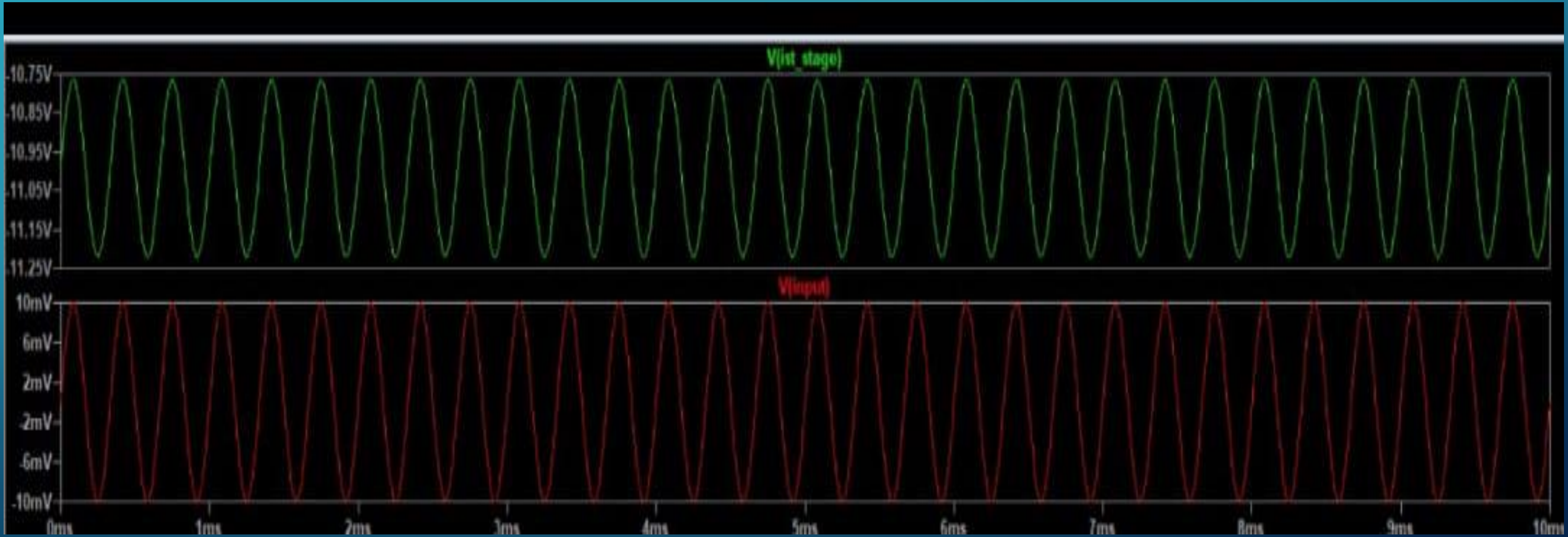
THE WORKING SIMULATION RESULTS:- PRE DIFFERENTIAL AMPLIFIER TO CANCEL OUT NOISE



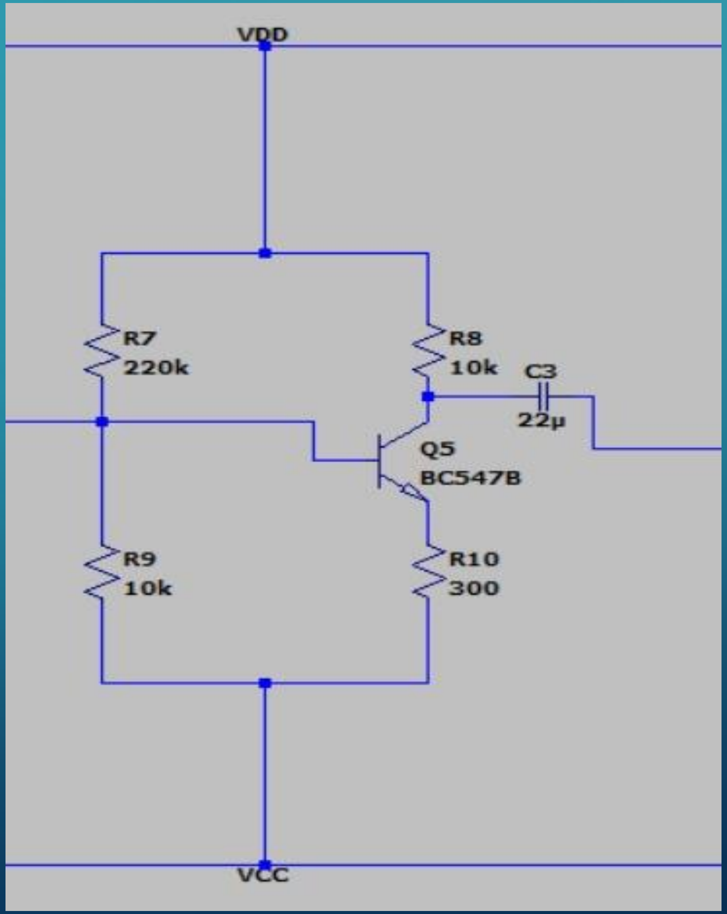
RESULT OF LTSPICE SIMULATION OF FIRST STAGE :-FOR INPUT 10 MILLI VOLTS AMPLITUDE SINUSOIDAL INPUT



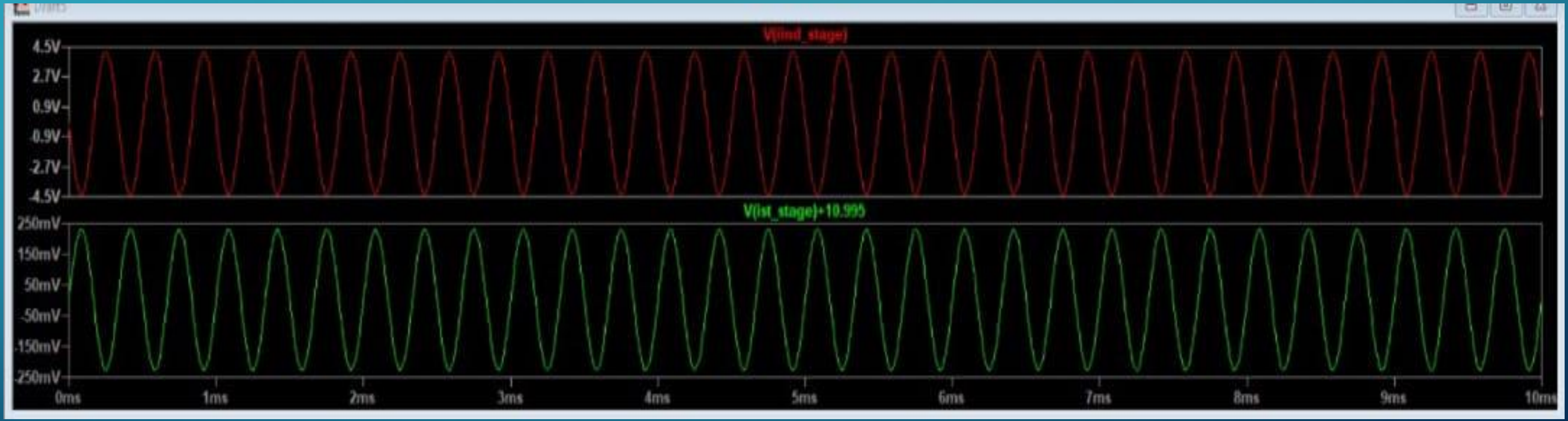
GAIN OF THE FIRST STAGE IN SIMULATIONS:-

- INPUT VOLTAGE:- PEAK TO PEAK =20 MILLI VOLTS
- OUTPUT VOLTAGE PEAK TO PEAK =2*(-10.77+10.95)VOLTS=0.36 VOLTS
- GAIN OF FIRST STAGE=OUTPUT VOLTAGE(PEAK TO PEAK) DIVIDED BY INPUT VOLTAGE PEAK TO PEAK.
- GAIN=0.36/0.02=18
- SO ROUGHLY GAIN OF 1ST STAGE IS 20.

CIRCUIT OF SECOND STAGE MAIN AMPLIFIER THE COMMON EMITTER AMPLIFIER:-



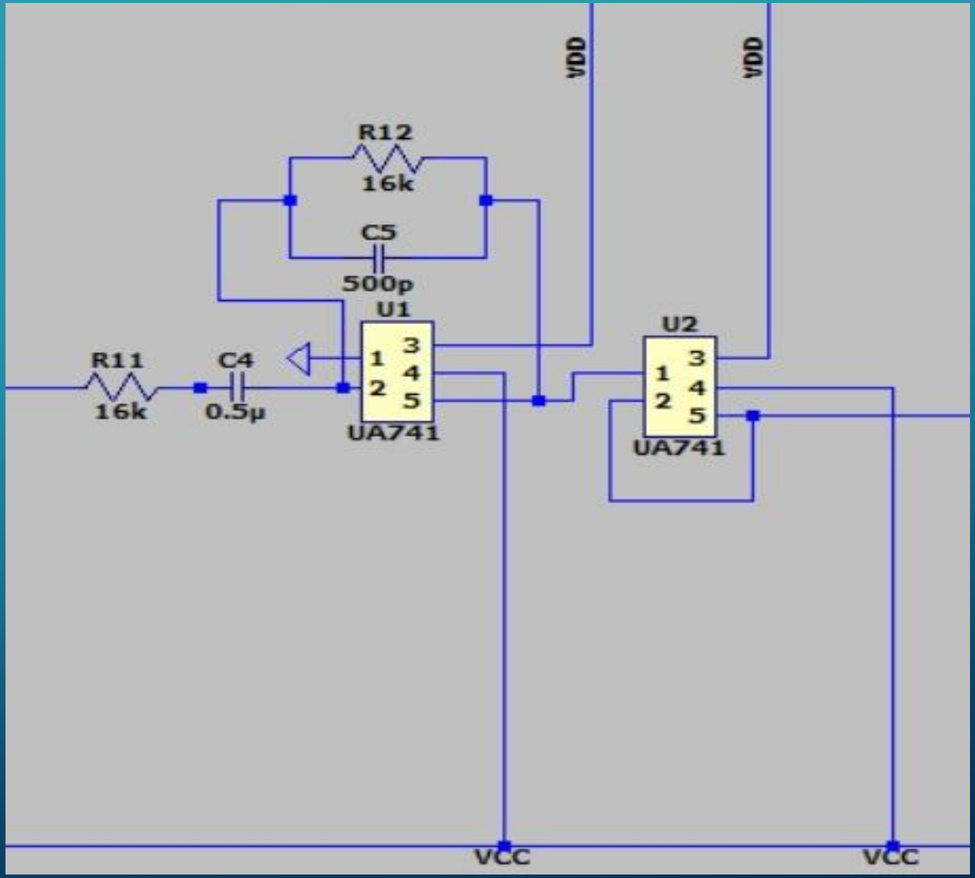
SIMULATION OF 2^{ND} STAGE BY GIVING OUTPUT OF 1^{ST} STAGE TO SECOND STAGE AS INPUT:-



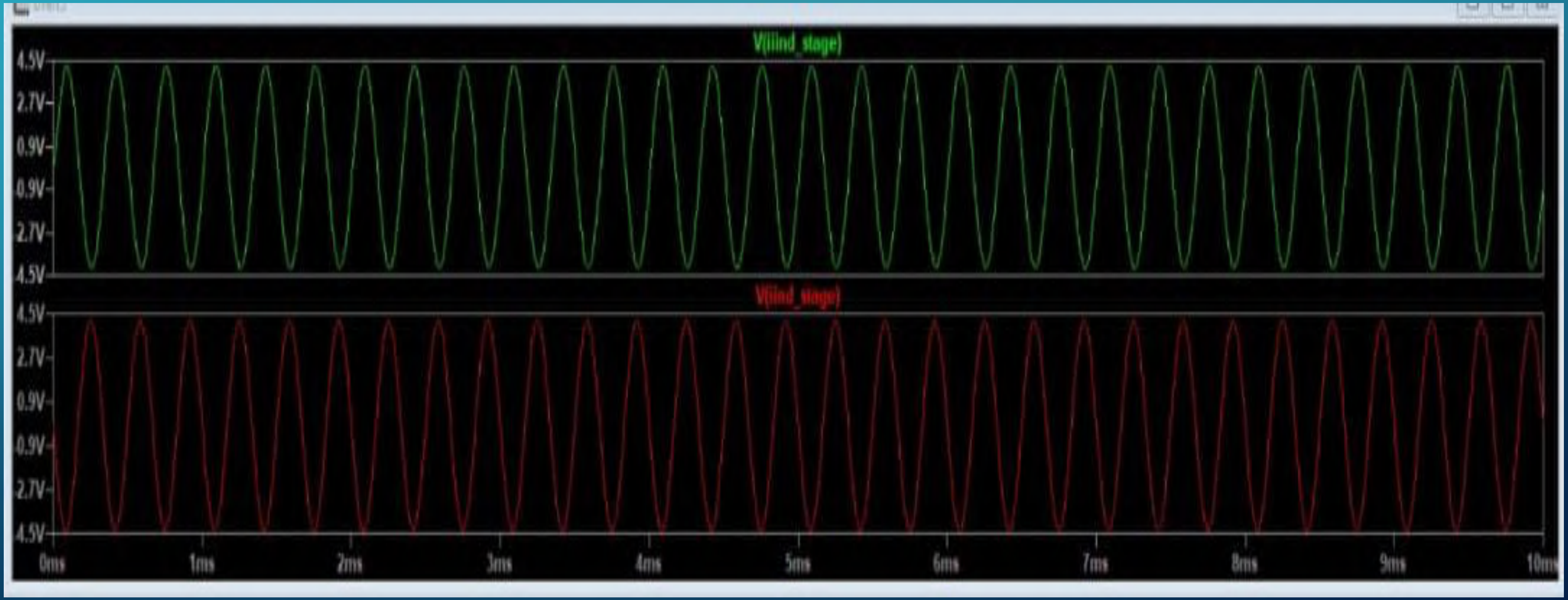
GAIN OF THE SECOND STAGE IN SIMULATIONS:-

- INPUT PEAK TO PEAK VOLTAGE=0.36 VOLTS
- OUTPUT PEAK TO PEAK VOLTAGE =8.7 VOLTS
- GAIN AS DEFINED EARLIER =8.7/0.36=24 APPROXIMATELY
- NET GAIN HOWEVER IS 435.
- ALSO NOTE THAT THERE IS A PHASE SHIFT OF 180 DEGREES SINCE AS Vin INCREASES COLLECTOR CURRENT HENCE FALL ACROSS RESISTOR INCREASES DECREASING OUTPUT VOLTAGE LEADING TO A PHASE SHIFT OF 180 DEGREES.
- THE FINAL OUTPUT OF THE SECOND STAGE IS PEAK TO PEAK 8.7 VOLTS
- WHICH IS THEN PASSED ON TO THE BUFFER.

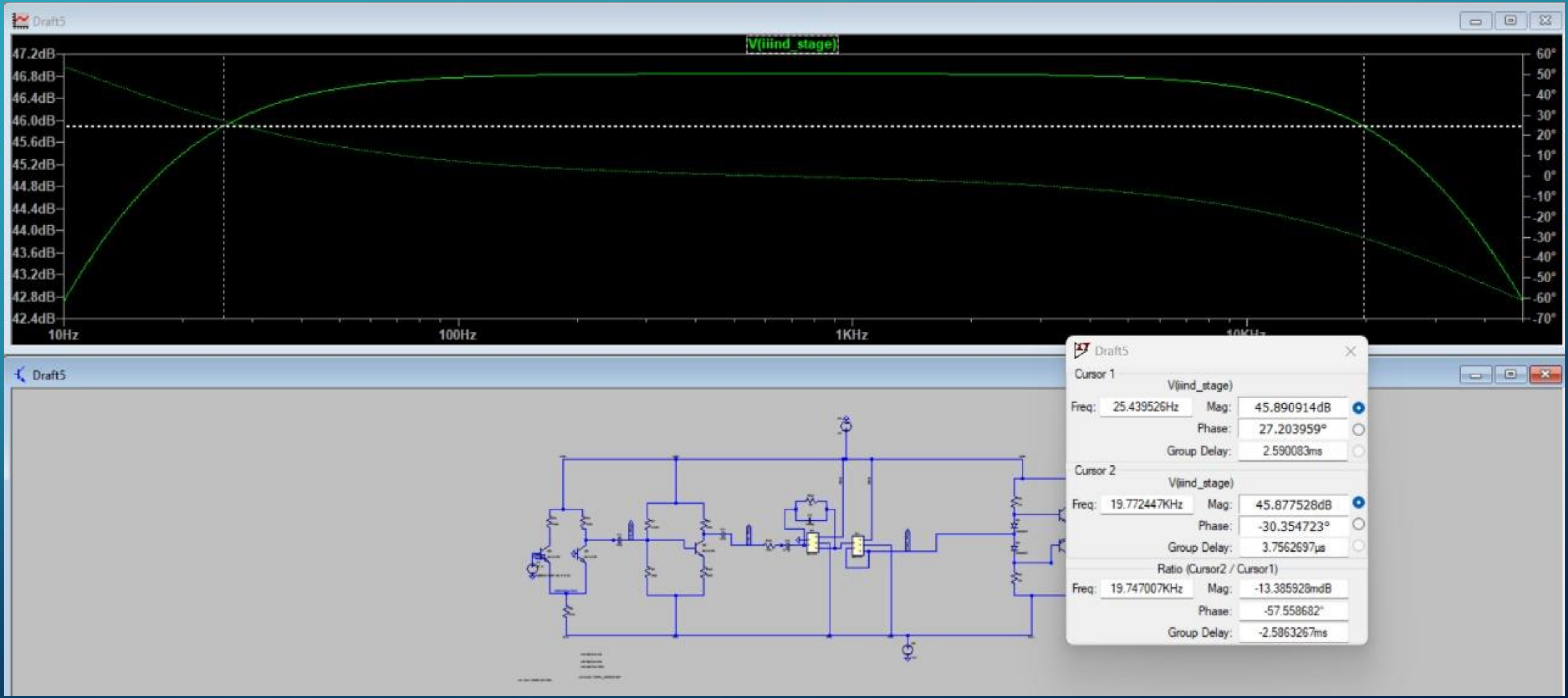
THIRD STAGE THE ACTIVE FILTER AND BUFFER FOR CAPTURING APPROPRIATE FREQUENCIES:-



OUTPUT OF THE THIRD STAGE ON LTSPICE:-



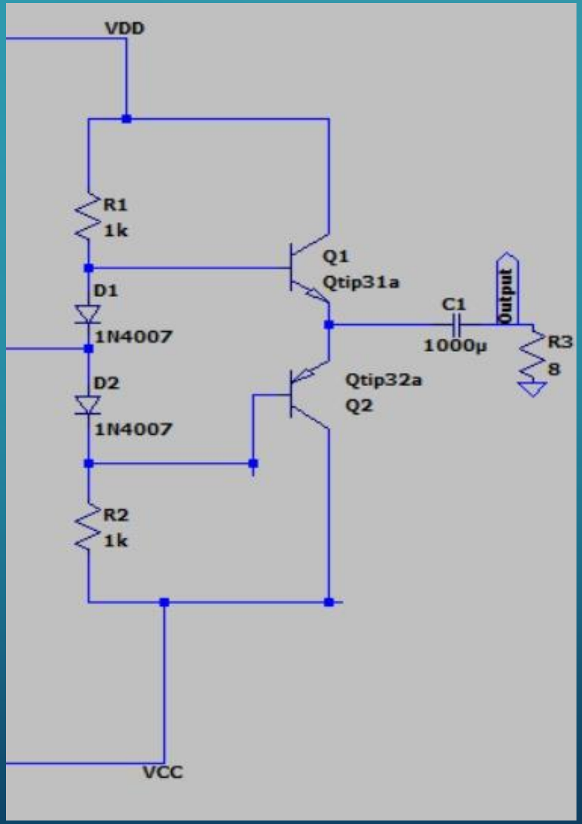
FREQUENCY RESPONSE AFTER THE THIRD STAGE OF ACTIVE FILTER AND BUFFER:-



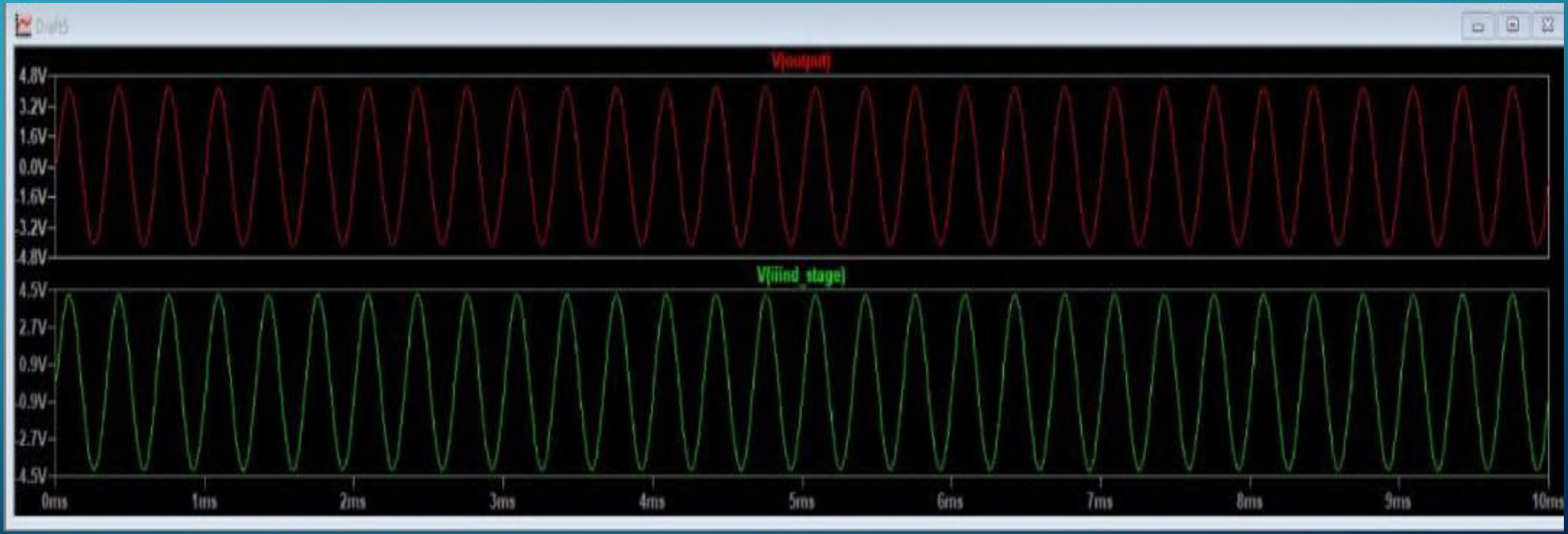
OUTPUT RESULTS AND ANALYSIS FOR THE THIRD STAGE:-

- THE GAIN IS APPROXIMATELY SAME SINCE WE ARE NOT PERFORMING ANY AMPLIFICATIONS IN THIS STAGE.
- CLEARLY THE FREQUENCIES IN THE FREQUENCY RESPONSE AS SHOWN IS CAPTURING THE LOWER BOUND 20 HERTZ AND HIGHER BOUND 20 KILO HERTZ .
- NOTE IN THE ACTIVE FILTER VALUES OF RESISTORS AND CAPACITORS ARE CHOSEN FOR FILTER TO WORK PROPERLY ,WILL BE DISCUSSED IN DESIGN STARTEGY.

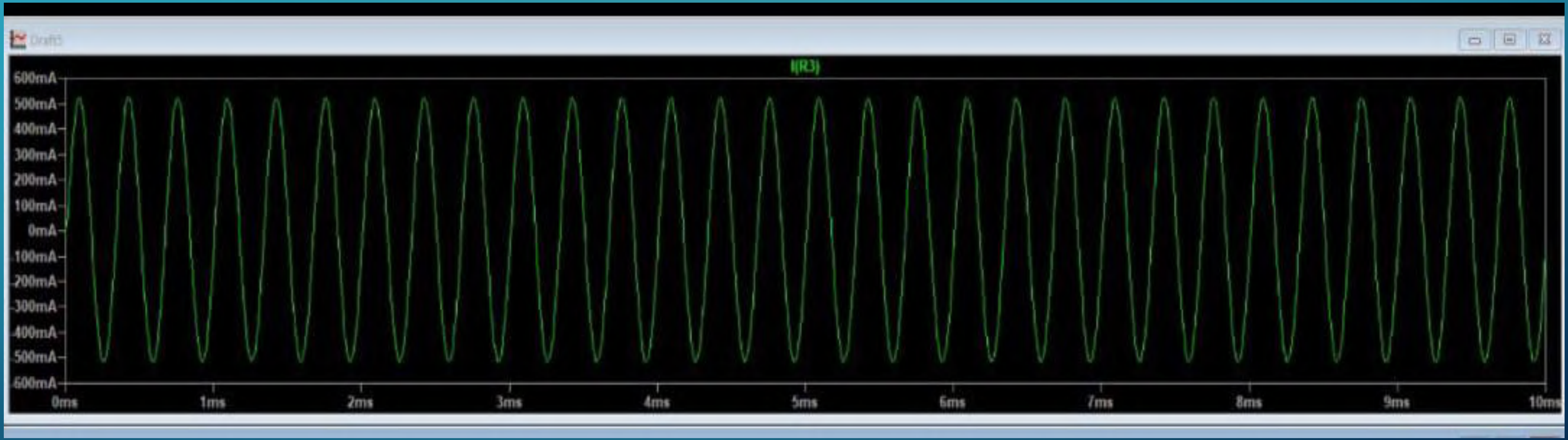
THE LAST/FOURTH STAGE: THE POWER AMPLIFIER FOR ENSURING PROPER CURRENT TO DRIVE THE SPEAKER



THE OUTPUT OF THE FOURTH STAGE :-



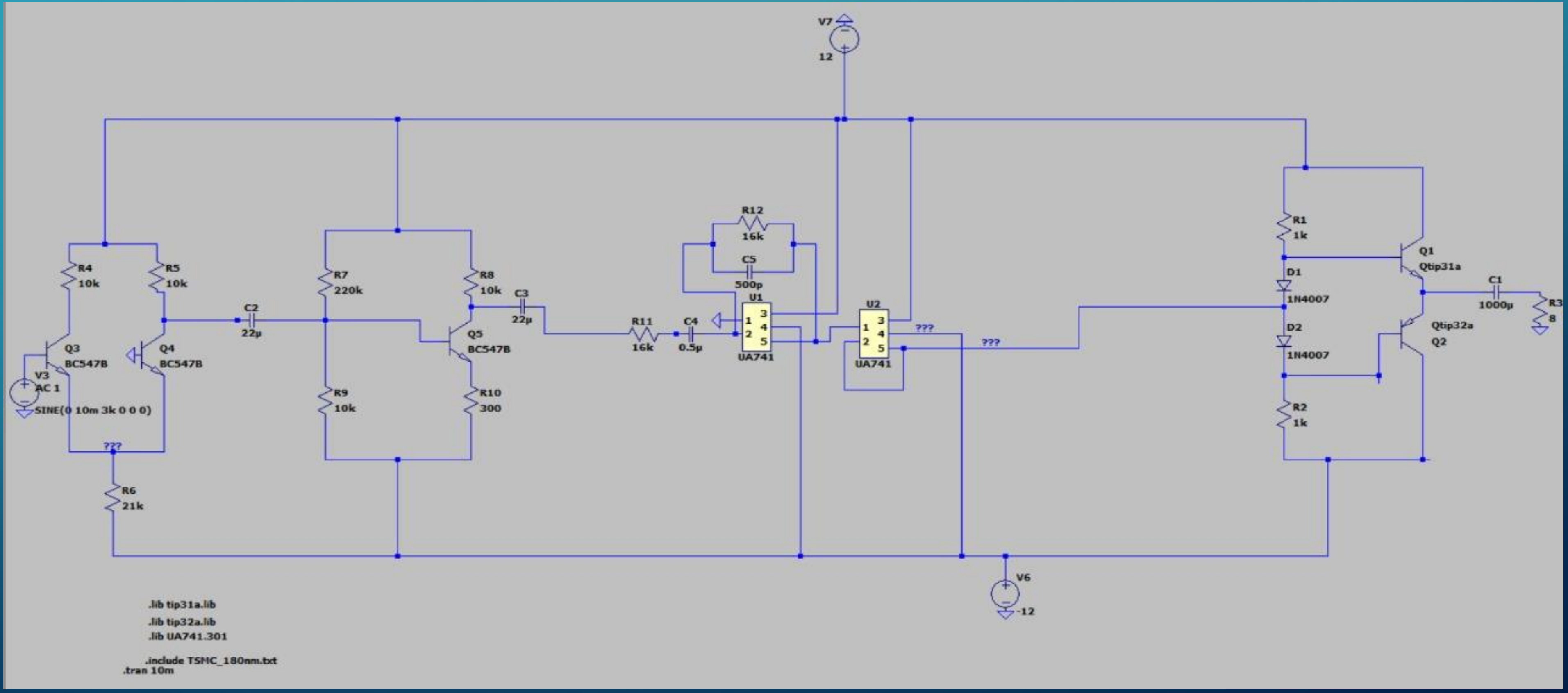
THE CURRENT FLOWING READINGS FROM LTSPICE:-



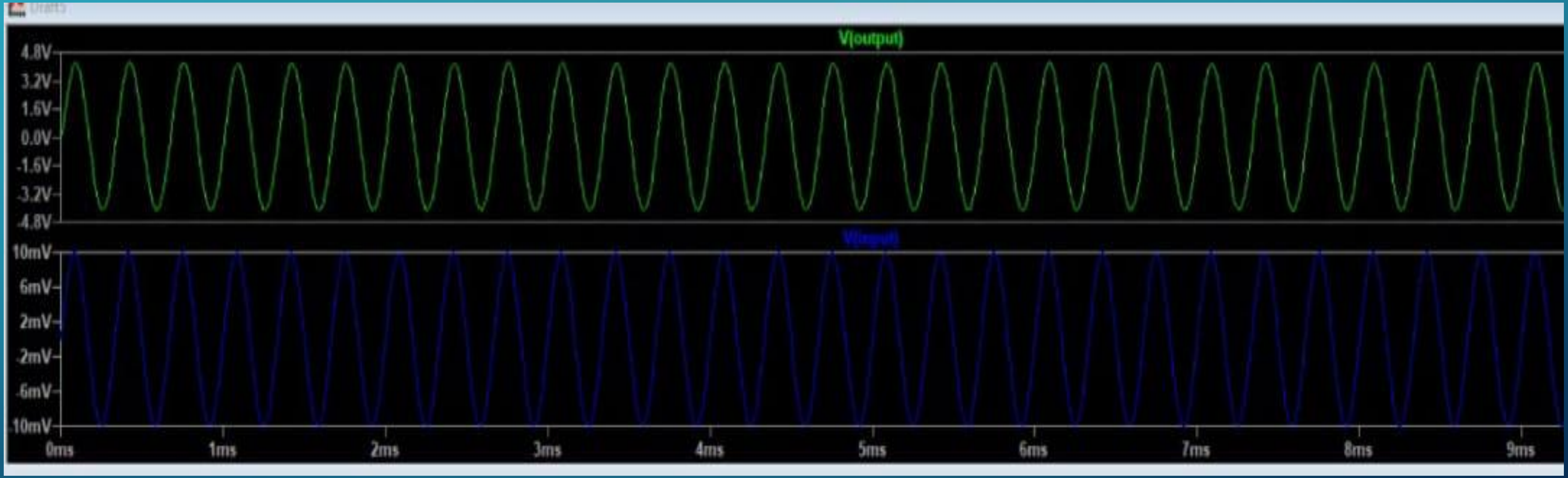
RESULT ANALYSIS FOR THE FOURTH STAGE:-

- THE GAIN IS APPROXIMATELY SAME SINCE WE ARE NOT PERFORMING ANY AMPLIFICATIONS IN THIS STAGE.
- THE CURRENT IN THE CIRCUIT HAS INCREASED SUCH THAT POWER=CURRENT*VOLTAGE(OUTPUT) IS SUCH THAT IT IS ABLE TO DRIVE THE SPEAKER AND WE ARE ABLE TO HEAR PROPERLY.

THE COMPLETE CIRCUIT-



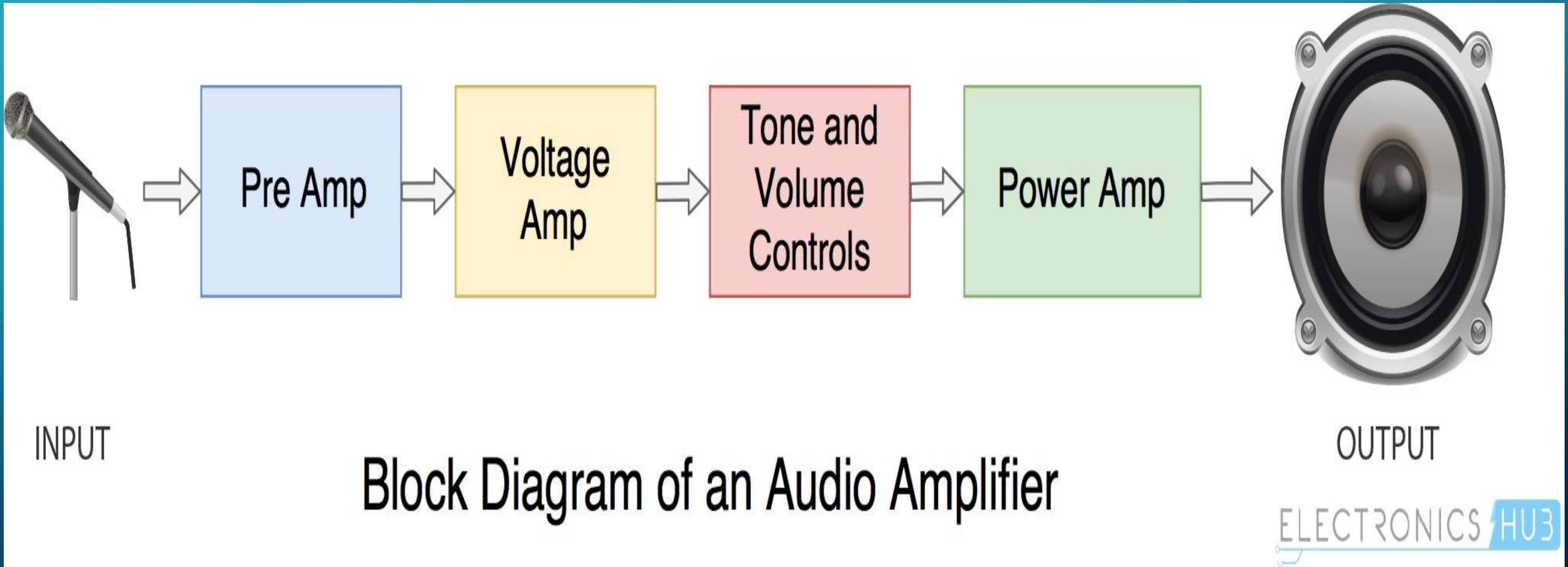
COMPLETE CIRUCIT OUTPUT:-



TOTAL CIRCUIT GAIN :-

- INPUT VOLTAGE BEFORE FIRST STAGE=20 MILLI VOLTS PEAK TO PEAK
- OUTPUT VOLTAGE AFTER FOURTH STAGE=8.7 VOLTS
- GAIN=8.7/0.02=435
- SO APPROXIMATELY THE NET GAIN OF THE CIRCUIT IS 435.

THE DESIGN STRATEGY:-



GENERAL DESIGN STRATEGY:-

- An audio amplifier is a device which takes input audio signal and gives out the amplified audio at the output side.
- We are interested to design an amplifier with following specifications:
  - Supply: 12V
  - Input: 10-20 mV peak to peak
  - Gain: G_1 x G_2 above 500
  - Frequency: Audible range (20Hz - 20KHz)
  - Power: Strictly less than 0.5 watt
- **Note:** Filter and the power amp doesn't affect the gain

FIRST STAGE PRE OR DIFFERENTIAL AMPLIFIER:-

- A pre-amplifier converts weak electrical signal into an output signal strong enough to be noise-tolerant and strong enough for further processing. They are often placed close to the sensor to reduce the effects of the noise and the temperature.

A. ***Description of the model***

- The pre-amp used in our design is a differential amplifier which consists of two identical npn BJTs with current biasing in the form of current mirror which is connected at the common emitter side.

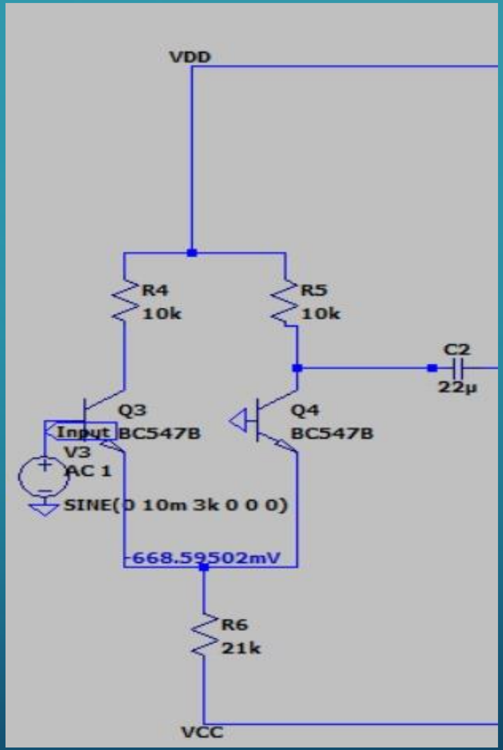
A. ***Working of the model***

- The differential amplifier has two inputs and gives out the amplification of the difference between the input voltages as the output. When we use a differential amplifier, it responds to the only difference signal between input terminals and ignores all common mode signals such as noise pick-up and ground voltages.
-

DIFFERNTIAL AMPLIFIER (1ST STAGE)

- Current mirror is constructed by placing two identical npn BJTs with their bases connected together which is then connected to the collector of one of the BJT which is connected to V_{DD} via a resistor R_X . Also their emitters are connected to negative supply so that current flowing in both the collectors are same. Hence we can control the current flowing in one collector which is connected to the amplifier by adjusting R_X.*THIS CIRCUIT ALSO IMMENSELY HELPS IN NOISE REDUCTION AND CANCELLATION.*
- A capacitor is used at the output of the differential amplifier to reduce the DC offset

DIFFERENTIAL AMPLIFIER FIRST STAGE:-



BASIC DESIGN STRATEGY:-

- Differential Amplifier

The Differential Amplifier primarily has two transistors with the same emitter/source and same collector/drain currents. Thus the circuit is designed to cancel out the common-mode voltage and give the difference as the output result. By grounding the base/gate of one transistor and giving input to the other transistor, the differential amplifier can remove the common noise present in the circuit and act as an amplifier for the input signal

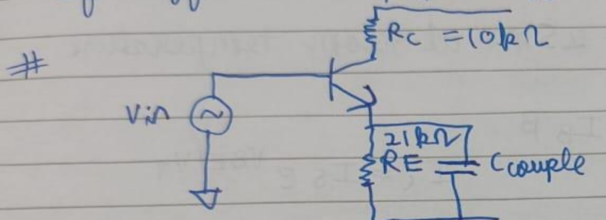
SMALL SIGNAL AND DC ANALYSIS FOR THE FIRST STAGE:-

implemented in hardware

\# Small signal analysis of differential amplifier:-

$V_{DD} = 12$ Volts

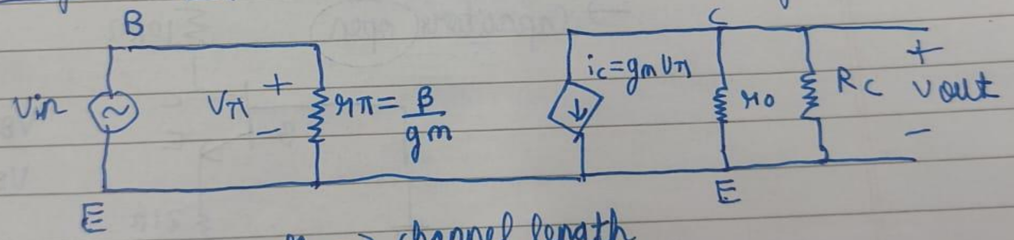
\#



$R_C = 10k\Omega$ ①
$R_E = 21k\Omega$ ②
$V_{DD} = +12V$ ③
$V_{CC} = -V_{DD} = -12V$ ④

$V_{CC} = -V_{DD} = -12$ Volts

AC Analysis:- Capacitors — short circuit
DC values ground



$r_o \rightarrow$ channel length modulation

$$V_{out} = -i_c (r_o \| R_c)$$

$$V_{out} = -g_m V_\pi (r_o \| R_c)$$

$$V_{in} = V_\pi = V_\pi$$

(CONTINUED) SMALL SIGNAL ANALYSIS

$$A_V = \text{gain} = \frac{V_{out}}{V_{in}} = -g_m(r_o \| R_C)$$

r_o

ignoring R_o:

The gain will become $= -g_m R_C$

$$g_m = \frac{I_C}{V_T} = \frac{\beta I_B}{V_T}$$

CONTINUED SMALL SIGNAL ANALYSIS

due to symmetry

$g_m = \frac{I_C}{V_T} = \frac{I_{net}}{2V_T}$

$V_T = 25mV$ at room temperature

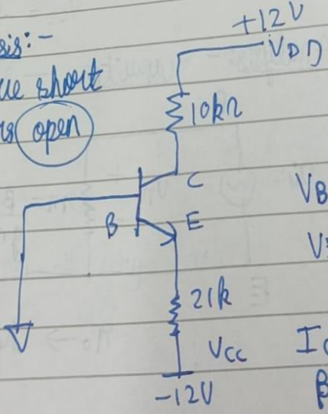
$I_C = I_B \beta$

$I_C = I_S e^{V_{BE}/V_T}$

DC Analysis:-

→ AC source short

→ Capacitors open



$V_{BE} \cong 0.7V$

$V_E = -0.7V$

$I_C \cong I_E$

$\beta >> 1$

Using $\boxed{I_E = I_B + I_C}$ and

and $I_C = I_S e^{V_{BE}/V_T}$

So $I_E = \frac{12 - 0.7}{21k} \cong 0.53$ milli A

CONTINUED SMALL SIGNAL ANALYSIS GAIN VERIFIED WITH SIMULATIONS

\# Using $\boxed{I_E = I_B + I_C}$ and

and $I_C = I_S e^{V_{BE}/V_T}$

So $I_E = \frac{12 - 0.7}{21k} = 0.53\,mA$

$\equiv 0.53$ milli A

We get $I_C = 47.5\,\mu A$

So $g_m = \frac{I_C}{V_T} = \frac{47.5 \times 10^{-6}}{25 \times 10^{-3}} = 1.9 \times 10^{-3}$

So gain $= |-g_m R_C| = -1.9 \times \cancel{10^{-3}} \times 10 \times \cancel{10^{3}}$

$= |-19| \equiv 20$

OUTPUT OF FIRST STAGE
SO GAIN IS 320/11.3=28.31 ON OSCILLOSCOPE

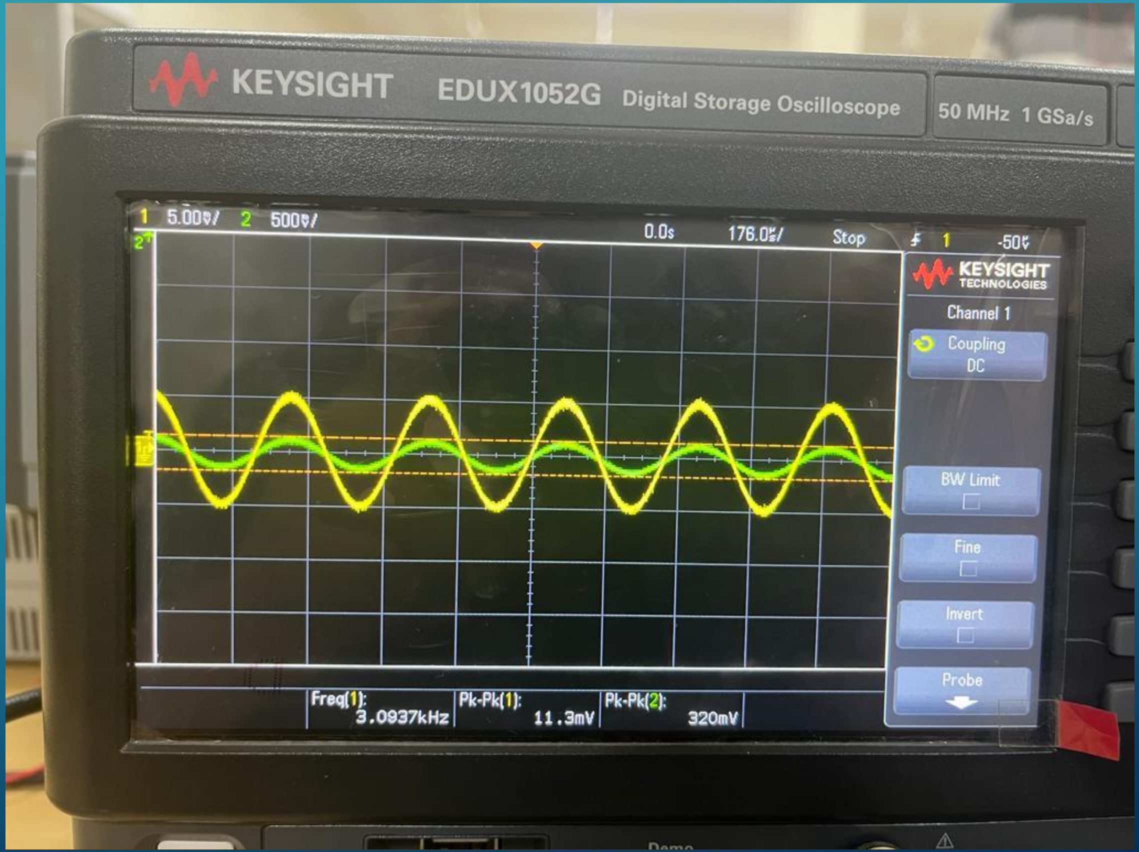
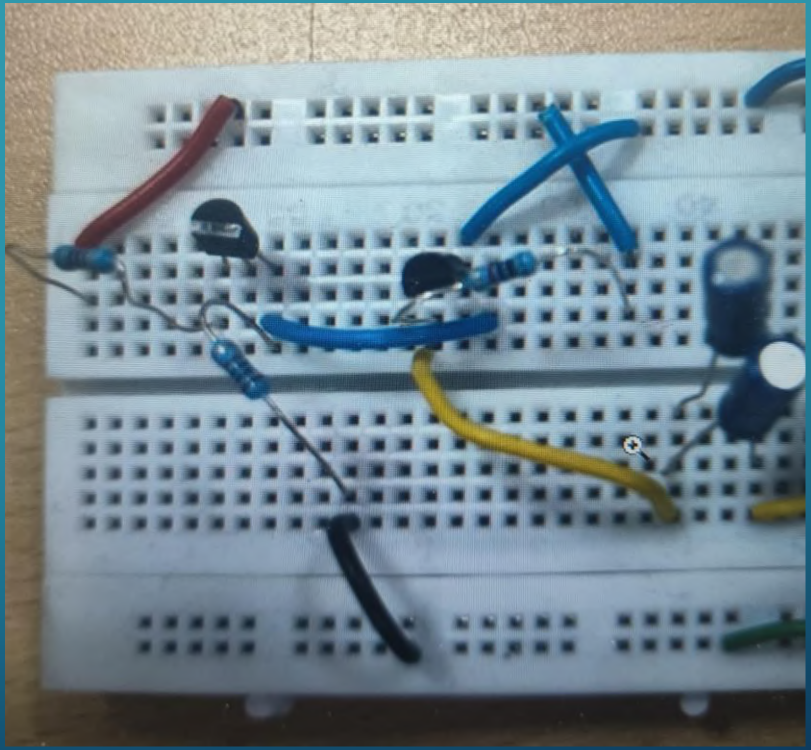


PHOTO OF THE HARDWARE OF FIRST STAGE:-



SECOND STAGE:- COMMON EMITTER AMPLIFIER

Taking into consideration the supply voltage limitations and imperfections in real-world devices, the output of the differential amplifier can be further boosted by using a simple amplifier made using transistors. A common emitter (CE) amplifier has been used in this design.

If the resistor RE (Fig. 4) is not placed, then the negative voltage supplied (VEE) will be directly acting as the emitter voltage and the capacitor (despite it being a by-pass capacitor) wouldn't play any significant role in comparison to the emitter resistance. This results in a huge threshold value for the input current to flow in or for the transistor to turn on. Hence, we maintain a certain resistor value impending to have a potential drop sufficient enough for the transistor to stay on.

SECOND STAGE DESIGN STRATEGY:-

The pre-amplified signal in the previous stage is then fed into the gain stage where it is amplified to a higher extent so that the magnitude of the signal is enough for power amplification.

A. <u>Description of the model</u>

The gain stage used in our design is a common-emitter amplifier which is designed using the npn transistor working in common-emitter mode with the capacitors and the resistors.

DESIGN STRATEGY (SECOND STAGE):-

In common emitter amplifier, the input signal is given from the base and the output is drawn from the collector. As the emitter is commonly connected to both input and output side, we say it as CE prototype. A coupling capacitor is placed between the pre-amp and the CE amplifier to avoid load-effect.

We bias the base of the BJT using the voltage divider to make sure that the base-emitter junction is in forward bias.

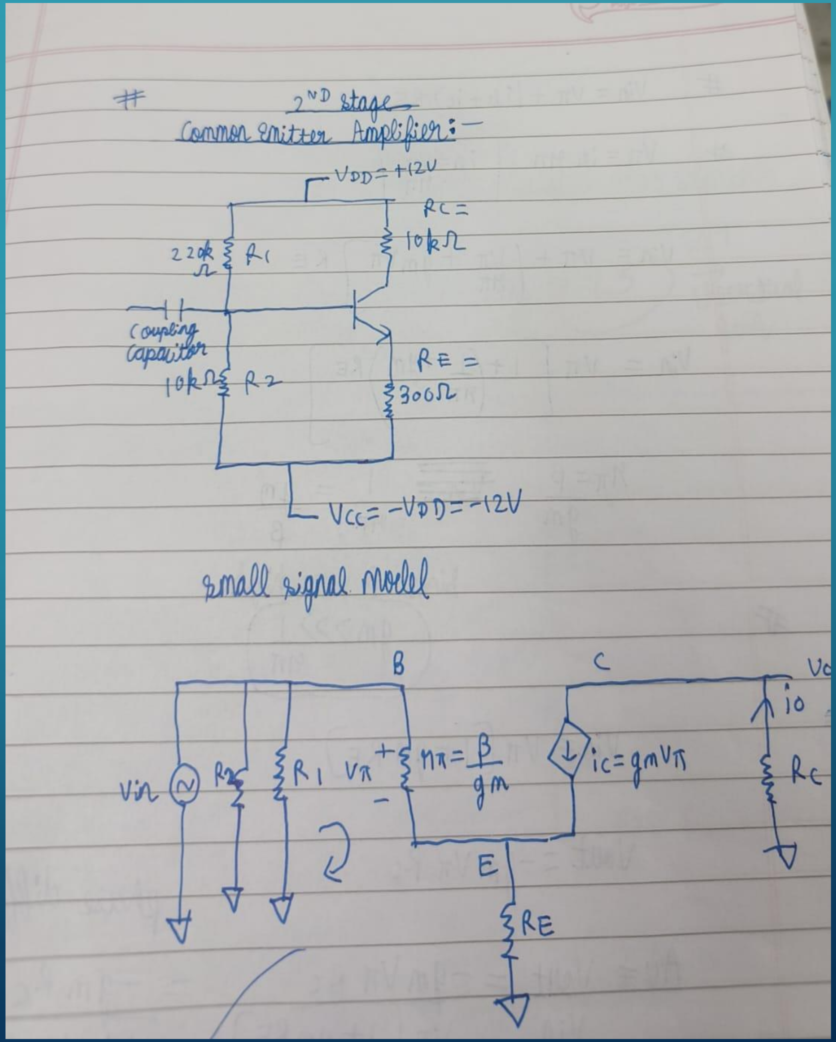
Also, the gain is proportional to the load resistor and the collector resistor.

DESIGN STRATEGY SECOND STAGE:-

The collector resistor also helps in biasing the collector voltage such a way that the collector-base junction is in reverse bias. As, base-emitter junction is in forward bias and the base-emitter junction is in reverse bias,

the BJT acts as an amplifier.

SMALL SIGNAL ANALYSIS AND CALCULATIONS:-



CALCULATIONS THEREFORE PHASE SHIFT=180 DEGREES IS SEEN DUE TO MINUS SIGN:-

$V_{in} = V_\pi + (i_b + i_c) R_E$

$V_\pi = i_b r_\pi$ $\boxed{i_b = \frac{V_\pi}{r_\pi}}$

$V_{in} = V_\pi + \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) R_E$

$V_{in} = V_\pi \left[1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right]$

$r_\pi = \frac{\beta}{g_m}$ $\cancel{V_{in}}$ $\frac{1}{r_\pi} = \frac{g_m}{\beta}$

since β very high

$g_m >>> \frac{1}{r_\pi}$

$V_{in} = V_\pi [1 + g_m R_E]$

$V_{out} = -g_m V_\pi R_c$

$A_v = \frac{V_{out}}{V_{in}} = \frac{-g_m V_\pi R_c}{V_\pi [1 + g_m R_E]} = \frac{-g_m R_c}{1 + g_m R_E}$

phase difference 180 degrees

seen in results

OUTPUT OF HARDWARE SECOND STAGE ON OSCILLOSCOPE WITH 180 DEGREE PHASE SHIFT GAIN IS EQUAL TO 4780/10.9=438 NET GAIN THEORETICAL:435 FROM FIRST:-

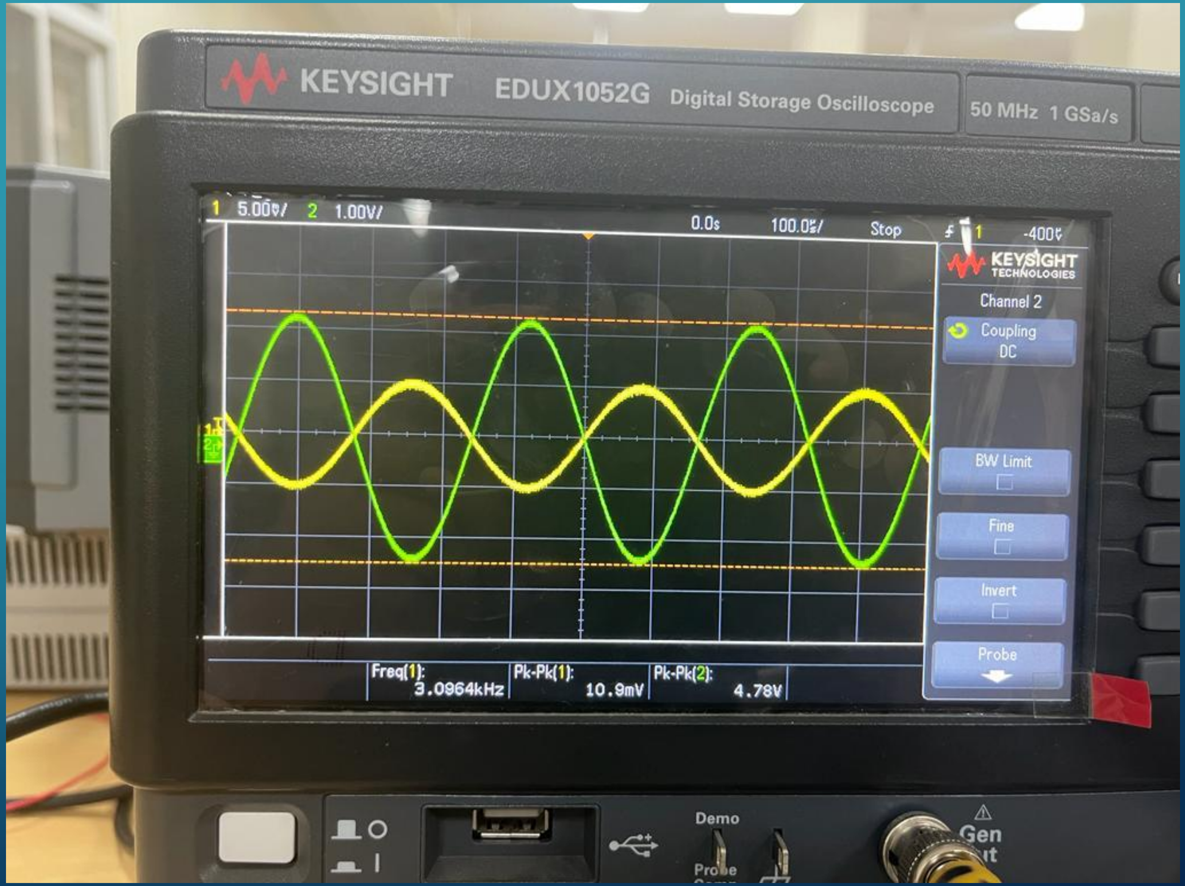
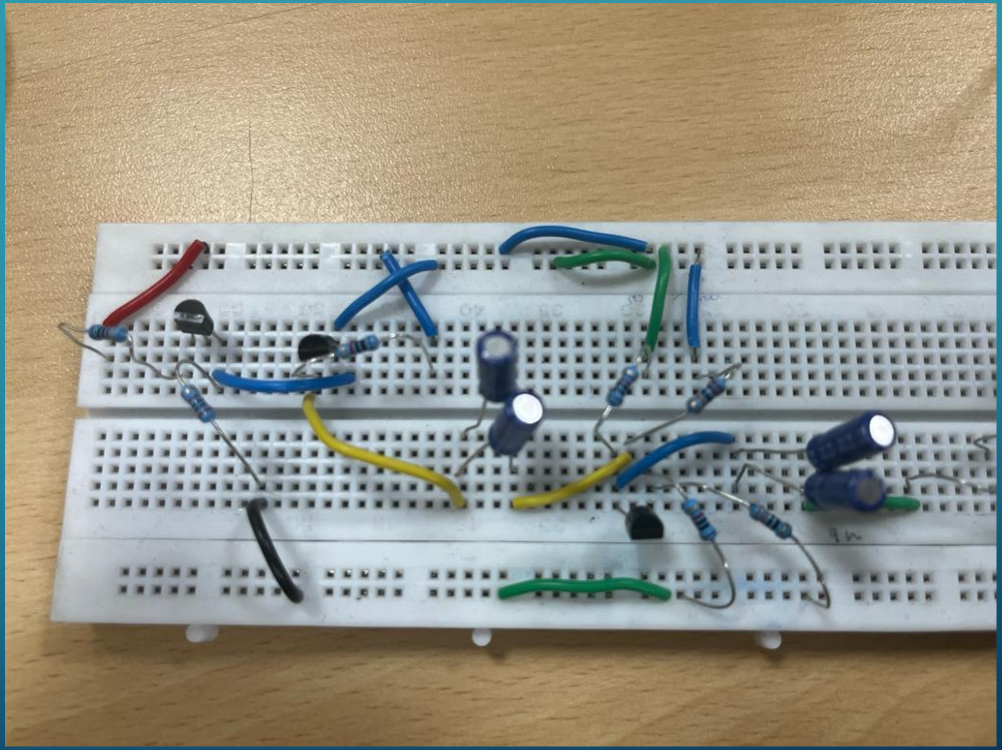


PHOTO OF HARDWARE OF SECOND STAGE



THIRD STAGE ACTIVE FILTER AND BUFFERS:-

The signal which is amplified still contains high-frequency and the low-frequency noise which needs to be filtered. Hence we send the amplified signal into an active bandpass filter which filter the noises of higher and lower frequencies. The desired cut-off frequencies for this filter is 20Hz (lower) and

20KHz (upper).

DESIGN STRATEGY:-

The active bandpass filter is designed such a way that the feedback branch is responsible to set the high-pass cut off frequency and the branch which is directly connected between input and negative terminal of op-amp is responsible for determining low-pass cutoff frequency.

DESIGN STRATEGY(CONTINUED)

The non inverting input terminal / positive terminal is grounded and the negative terminal is connected to output terminal for feedback. The voltage gain of filter $\boxed{A_V = \frac{R_1}{R_2}}$

$A_V = 1$ since we need no amplification

so $\boxed{f_{C_1} = \frac{1}{2\pi R_1 C_1}}$ $\boxed{f_{C_2} = \frac{1}{2\pi R_2 C_2}}$

$R_1, R_2, C_1, C_2 \rightarrow$ selected accordingly ** *

DESIGN STRATEGY CONTINUED

$$f_{c_1} = \frac{1}{2\pi \times 16 \times 10^3 \times 0.5}\,10^6 = \frac{10^3}{32\pi \times 0.5} = \frac{1000}{16\pi} = \frac{250}{4\pi} = \frac{125}{2\pi} \approx 20\,\text{HZ}$$

lower bound

$$f_{c_2} = \frac{1}{2\pi R_2 C_2} = \frac{10^{12}}{2\pi \times 16 \times 10^3 \times 500} = \frac{10^7}{160\pi} = \frac{10^6}{16\pi} = \frac{1000\,\text{kHZ}}{16\pi} \approx 20\,\text{kHZ}$$

higher bound

JUST AN OVERVIEW OF DIFFERENCE BETWEEN ACTIVE AND PASSIVE FILTERS

- **Passive Filters:**

1. **Components:**
    1. Passive filters use only passive components like resistors, capacitors, and inductors.
    2. No external power source is needed; they rely on the energy from the input signal.
2. **Frequency Response:**
    1. Passive filters can attenuate certain frequencies in the signal without amplifying them.
    2. They exhibit insertion loss and have limited capabilities for gain adjustment.

CONTINUED

- **Active Filters:**

1. **Components:**
    1. Active filters incorporate active components such as operational amplifiers (op-amps) in addition to passive elements.
    2. They require an external power source to operate.
2. **Frequency Response:**
    1. Active filters can both attenuate and amplify specific frequency components of the input signal.
    2. They offer greater flexibility in shaping the frequency response.

CONTINUED

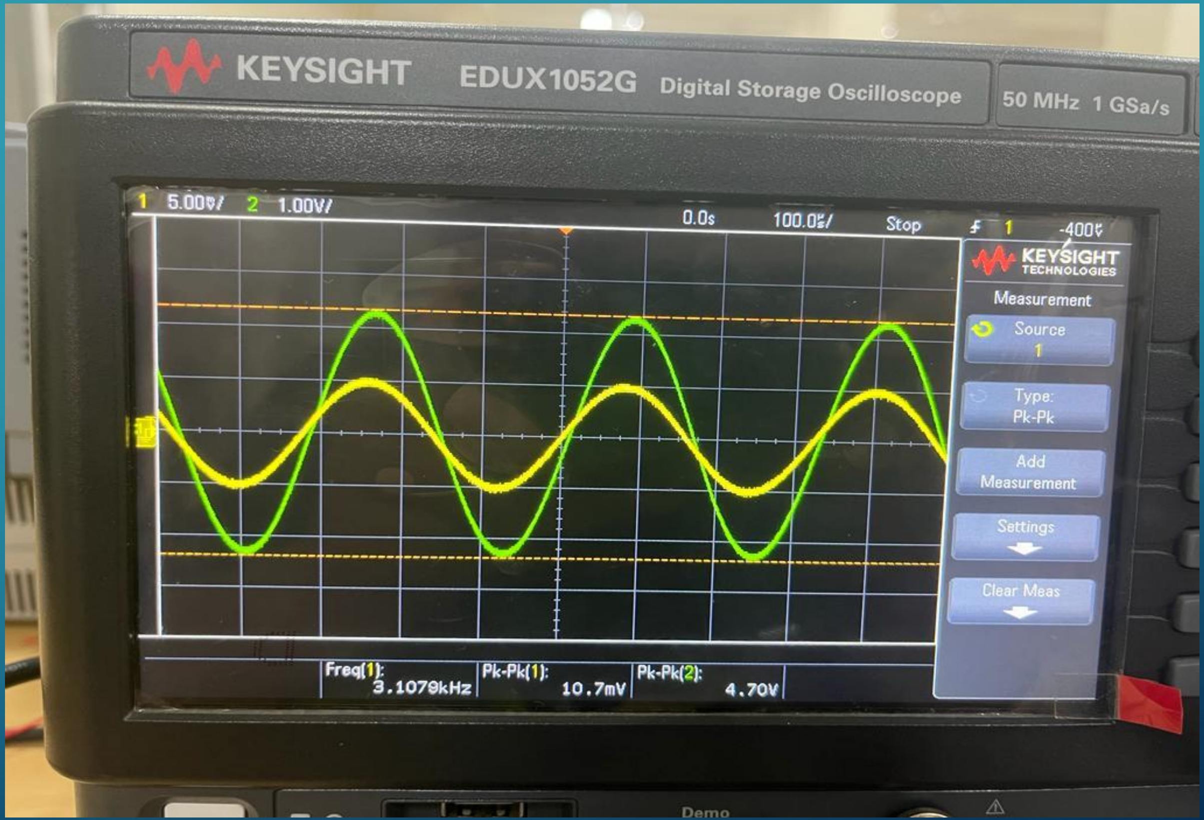
- **Applications in Audio Amplifiers:**
- Active filters are commonly used in audio amplifiers for several reasons:
    - **Gain Control**
    - **Precise Frequency Adjustment**
    - **Low output impedence**

USE OF OPAMP AS BUFFER PREVENTS LOADING EFFECT:-

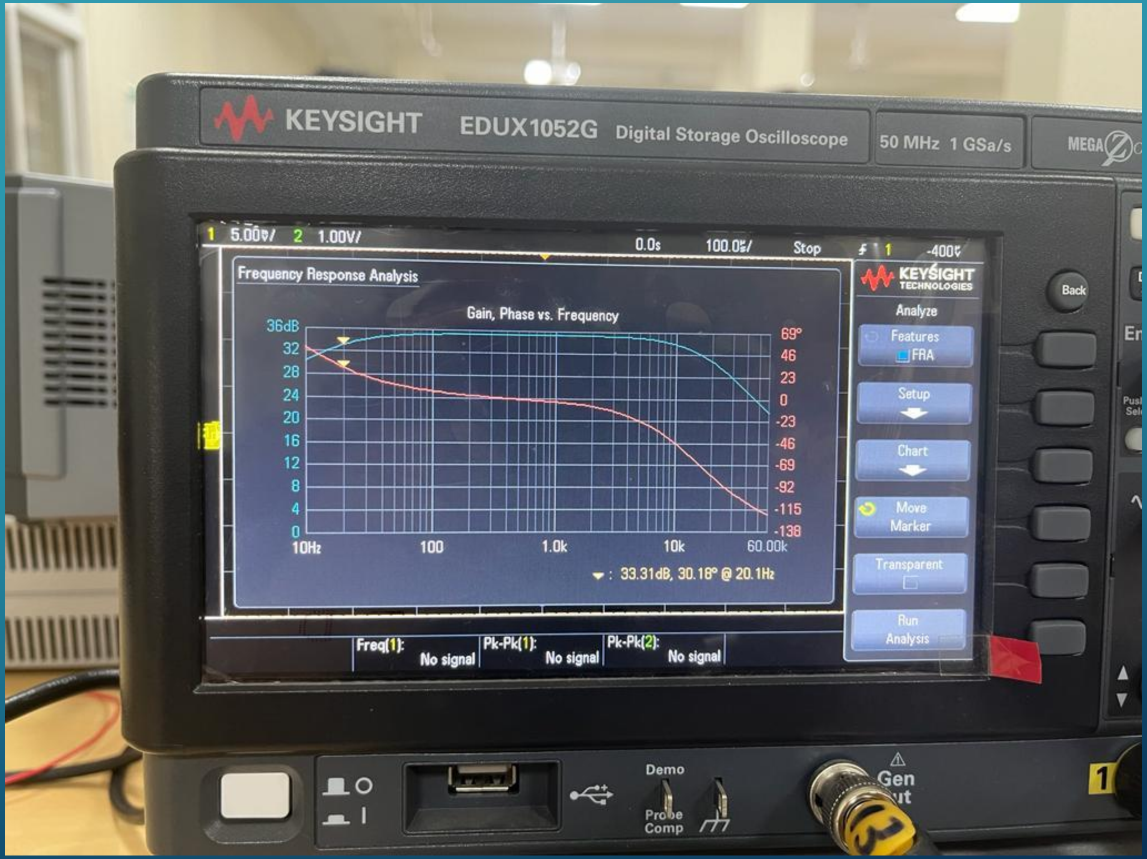
- An operational amplifier (op-amp) used as a buffer is a circuit configuration where the op-amp is employed to isolate or separate the input and output signals. In this setup:

1. **Input Impedance:**
   1. The op-amp's high input impedance prevents loading of the input signal source.
2. **Output Impedance:**
   1. The op-amp provides a low output impedance, ensuring efficient signal transfer to the next stage or load.
3. **Unity Gain:**
   1. The buffer is typically configured for unity gain, meaning the output voltage mirrors the input voltage.
4. **Isolation:**
   1. The buffer isolates the input and output circuits, preventing changes in the load from affecting the signal source.

OUTPUT FROM OSCILLOSCOPE

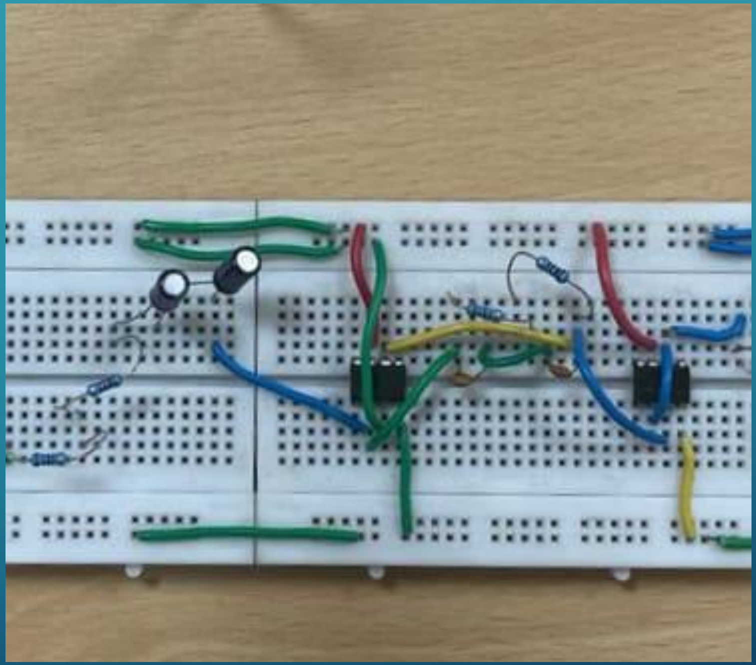


FREQUENCY ANALYSIS CATCHING F1=20HZ AND F2=20 KILO HERTZ LOWER BOUND FREQUENCY



CONTINUED UPPER BOUND FREQUENCY

CIRCUIT FROM HARDWARE



STAGE 4 POWER AMPLIFIER

- <u>Power Amplifier</u>
- 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

DETAILS ABOUT POWER AMPLIFIERS

- There are majorly 4 types of Classes in power amplifier:

=> 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

CONTINUED

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

CONTINUED

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.

CONTINUED

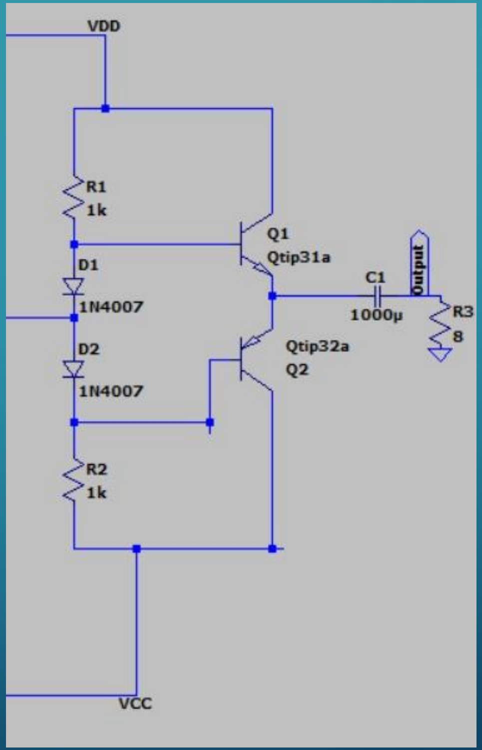
Class C:

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

DESIGN STRATEGY

- 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.

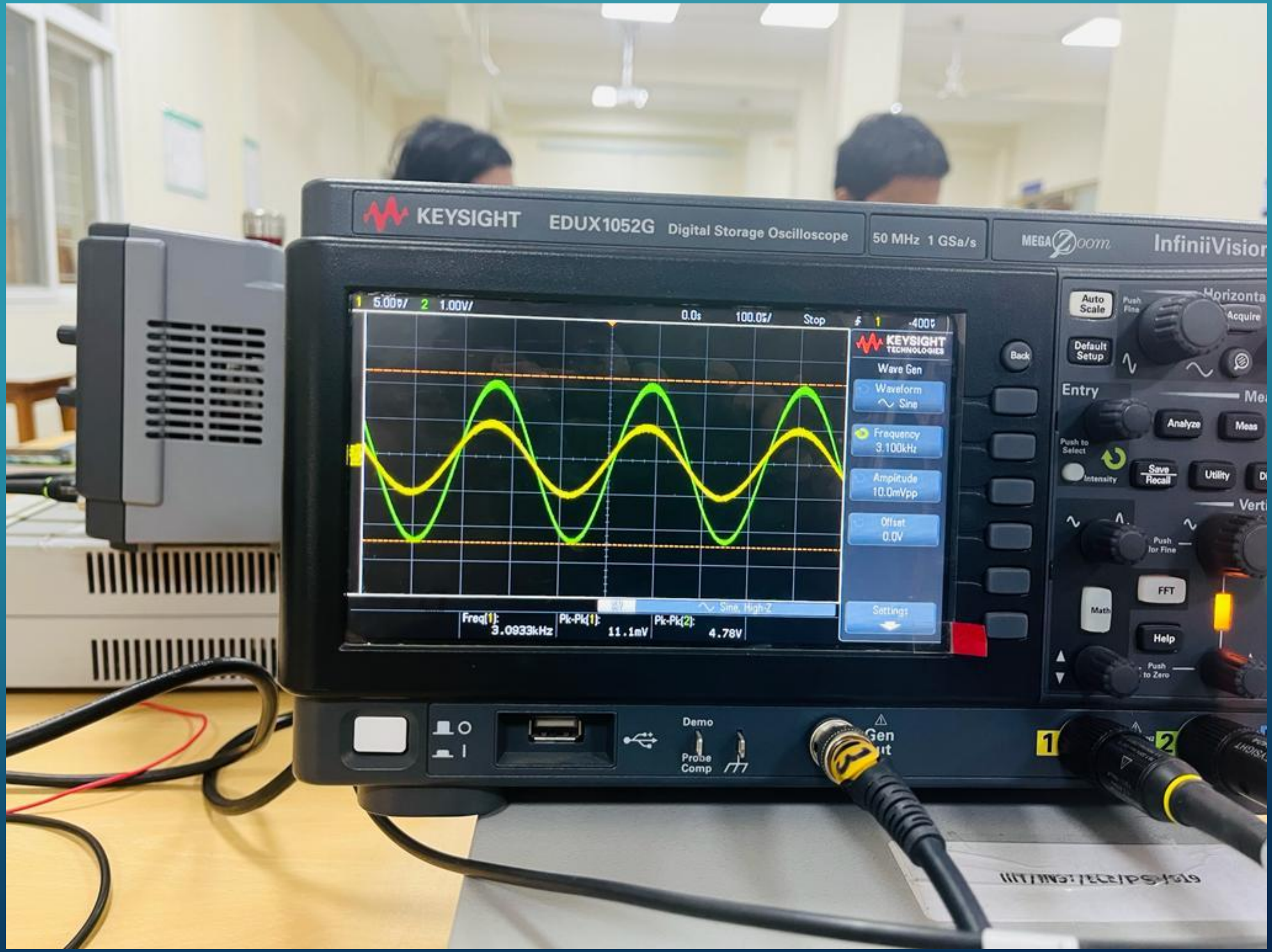
CIRUCIT DIAGRAM (LTSPICE)



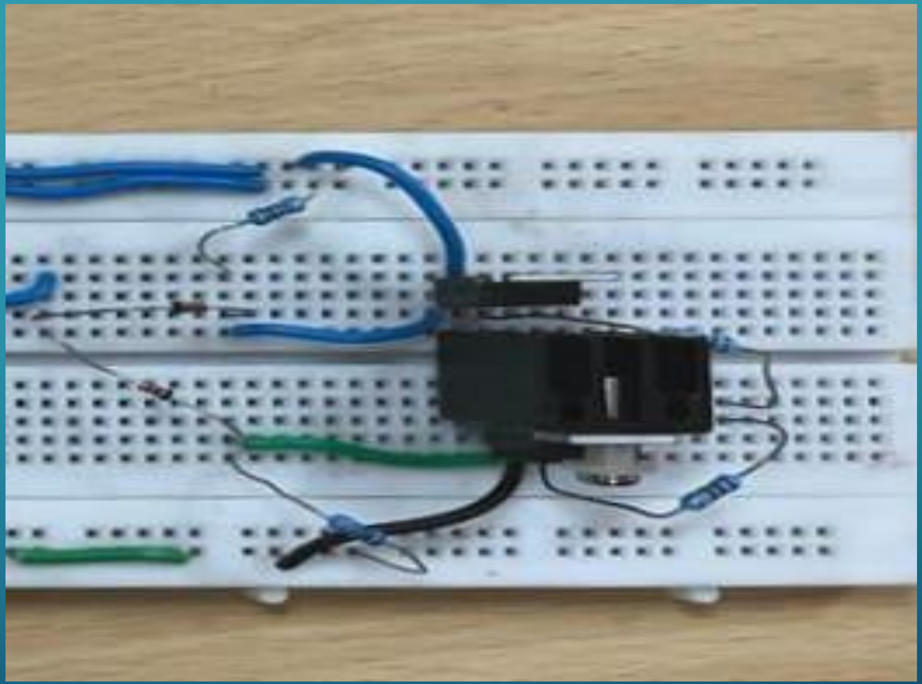
WHY USE OF CLASS AB POWER AMPLIFIERS? TO DECREASE " CROSS OVER DISTORTION":-

- **Reduced Crossover Distortion:**
- One of the primary advantages of Class AB amplifiers is their ability to minimize crossover distortion. Crossover distortion occurs when there is a gap between the positive and negative halves of the input signal, leading to distortion at the crossover point. Class AB amplifiers use a small bias current to operate the output transistors in a slightly conducting state, reducing the crossover distortion compared to pure Class B amplifiers
- ALSO IT HELPS IN IMPROVING EFFICIENCY GENERATING HEAT AND ENHANCES LINEARITY

OUTPUT OF FOURTH STAGE (POWER AMPLIFIER) NET OUTPUT MEASURES CURRENT=0.03A



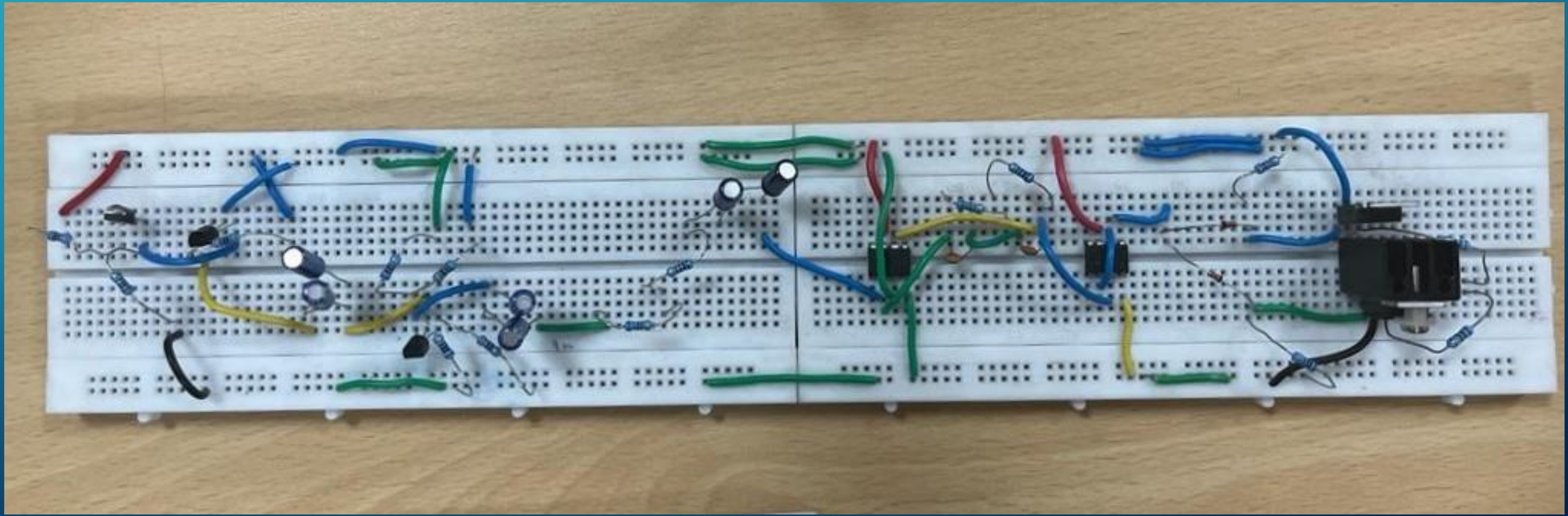
HARDWARE PHOTO FOURTH STAGE:-



HARDWARE FINAL WITH LAST PART AS POWER AMPLIFIER(WITH DIODES)

I=0.03 A AND OUTPUT =4.7 V
NET POWER=V*I=0.18 WATTS ALMOST 0.2 W AND WE NEEDED LESS THAN 0.5 WATT TO DRIVE SPEAKER SO DONE.

- FINAL HARDWARE PHOTO:



CMRR COMMON MODE REJECTION RATIO

The common mode rejection ratio (CMRR) of a differential amplifier (or other device) is a metric used to quantify the ability of the device to reject common-mode signals.Ideally, a

differential amplifier takes the voltages, $V+$ and $V-$ on its two inputs and produces an output voltage,

$Vo = Ad * (V+ - V-)$,   where Ad is the differential gain.

However, the output of the differential amplifier can be better

described as:

- $Vo = Ad * (V+ - V-) + Acm * (V+ - V-)$

CMRR CALCULATIONS:-

CMRR Calculations:-

$A_{cm} \rightarrow$ common mode gain

\# $\boxed{CMRR = \frac{A_v}{A_{CM}}}$

\# A_{CM} on simulation $\frac{940\mu V}{20mV}$

A_v we know ≈ 20

so $CMRR = \frac{A_v}{A_{CM}} = \frac{20}{0.047} \cong 425$

$CMRR\,(dB) = 20 \log_{10}(425) = 52.56\,dB$

IMPORTANCE OF TESTING ,DEBUGGING AND BIASING IN THE PROJECT

- **Testing:**
- **Functionality Verification:** Testing is essential to verify that all components of the audio amplifier work as intended. This includes checking inputs, outputs, signal processing stages, and power supply.
- **Performance Evaluation:** Through testing, engineers can evaluate the performance of the amplifier under different conditions, ensuring that it meets specified criteria such as frequency response, distortion levels, and signal-to-noise ratio.
- **Reliability Assessment:** Rigorous testing helps identify potential issues that might lead to failures over time. This includes stress testing to ensure the amplifier can handle prolonged use without degradation

DEBUGGING

- **Debugging:**
- HEPLS TO UNDERSTAND PROBLEMS OF LOADING EFFECT AND ALSO WHAT CHANGES IN VALUES OF COMPONENTS FOR THE RIGHT OUTPUT.
- **Issue Identification:** Debugging involves identifying and fixing any errors or malfunctions in the amplifier's hardware. This includes addressing issues related to circuit design, component placement, and manufacturing defects.
- **Optimization:** Debugging allows engineers to optimize the amplifier's performance by fine-tuning components, correcting errors, and improving efficiency

BIASING

- HELPS IN ENSURING THAT BJT REMAINS IN ACTIVE STATE FOR AMPLIFICATION AND ACHIEVING THE REQUIRED FUNCTIONALITY.
- **Biasing:**
- **Stability and Linearity:** Biasing is crucial for maintaining the stability and linearity of the amplifier. Proper biasing ensures that the amplifier operates within its linear region, minimizing distortion and improving the fidelity of the audio signal.
- **Temperature Stability:** Biasing also helps in achieving temperature stability, ensuring that the amplifier's performance remains consistent across varying temperatures. This is especially important for reliable operation in different environment

DATASHEET AND VARIATIONS IN COMPONENT VALUES

- A datasheet is a comprehensive document provided by electronic component manufacturers, offering technical specifications and information about a specific component. ITS ADVANTAGES GIVEN BELOW
- **Class of Operation:**
- **Class A, B, AB, D:** Choosing the appropriate class of operation based on the application requirements can optimize efficiency, power consumption, and linearity

CONTINUED

- **Topology:**
- **Single-Ended, Push-Pull:** Selecting different amplifier topologies influences factors such as distortion.
- **Feedback Configurations:**
- **Negative Feedback:** Adjusting the amount of negative feedback can impact parameters like distortion, Bandwidth etc.
- **Power Supply Design:**
- **Linear, Switching:** The choice of power supply type affects efficiency, size, and cost, impacting the overall design trade offs

ACKNOWLEDGEMENTS:-

We are grateful to Professors Spandan Roy and Anshu Sarje for providing us with this opportunity to enhance my learning and apply it practically. The successful completion of this project was made possible with the guidance and support of the course T.A.s.

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- Microelectronic Circuits by Adel Sedera and Kenneth Smith

THANK YOU!