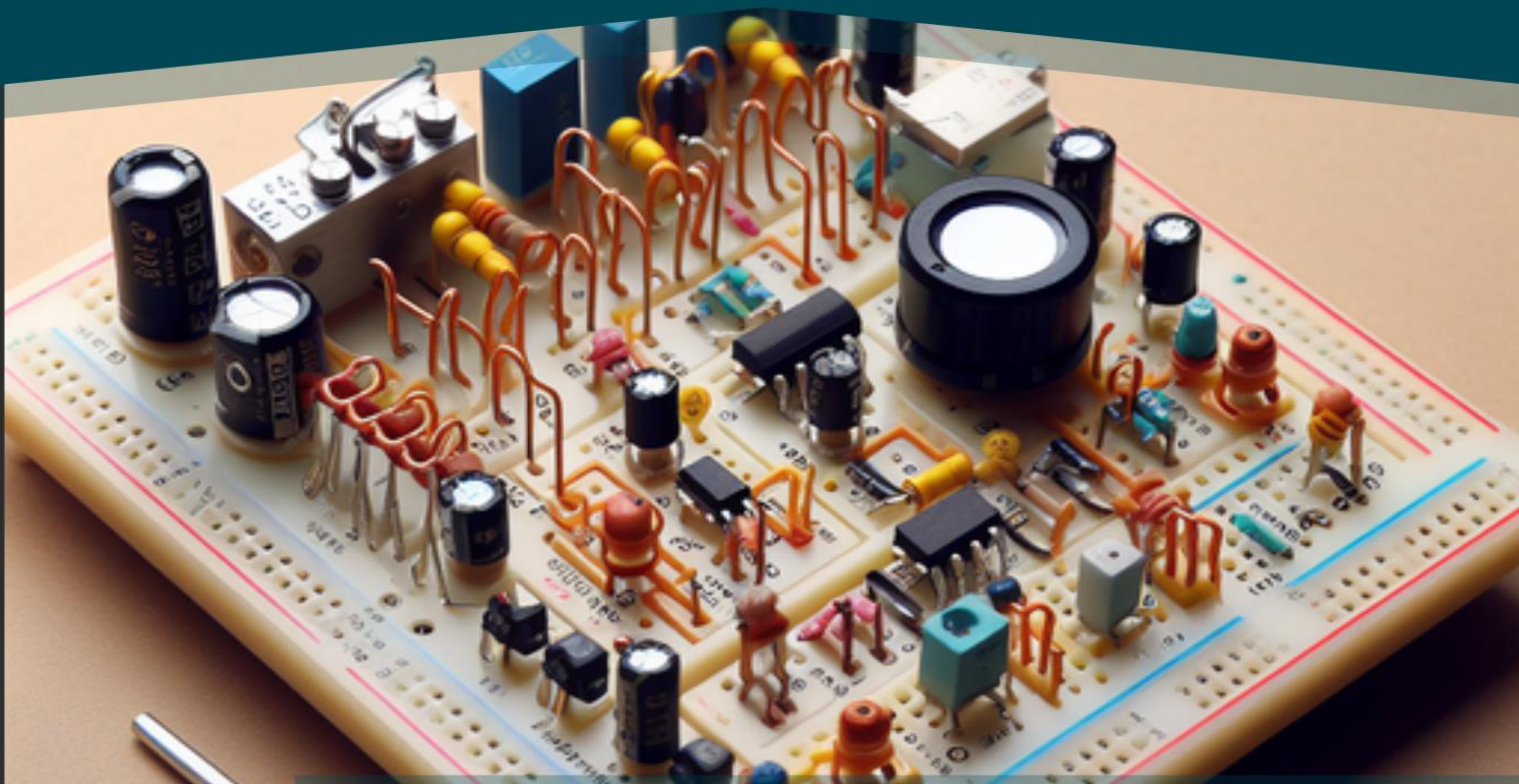
EE-313

ELECTRICAL DEVICES AND CIRCUITS



Project Report

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PRESENTED TO

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Title

Making a Discrete Audio Amplifier

Project Statement

Design an audio amplifier which will take input from a small microphone and can drive a small speaker. A condenser microphone can be used. The audio amplifier must be based on discrete devices and if needed audio transformers may be used. However, op-amp or IC amplifiers CANNOT be used. Moreover, base your design on locally available MOSFETs and BJTs.

Justify selection of transistors for each specific stage.

Design Specifications:
1. AC output power =1 to 3 Watt (8 Ω Speaker)
2. Frequency response of the amplifier should be 100 Hz to 12 KHz at 3 dB level.
3. The audio amplifier should qualify the given experimental testing standard.

DC Power Supply: ±12 V
Overall Amplifier Gain: 1000 V/V (60 dB)

Pre-Amplifier Specifications:
• $Z_i > 1M\Omega$, $Z_o \geq 5k\Omega$

Power Stage:
• $R_L = 8\Omega$ • $V_o = 5$ Vrms

Introduction

This project revolves around the design of a discrete-component audio amplifier, excluding the use of op-amp or IC amplifiers. The primary focus is on implementing locally available MOSFETs and BJTs to construct both the pre-amplifier and power stage. The aim is to create a functional audio amplification system capable of processing input from a condenser microphone and driving a small speaker effectively.

The pre-amplifier stage will be carefully crafted to ensure an appropriate input impedance (Zi) greater than 1MΩ and an output impedance (Zo) exceeding 5kΩ. This stage plays a crucial role in preparing the signal for further amplification, setting the foundation for optimal performance.

Simultaneously, the power stage will be designed with specific attention to meet the overall amplifier gain requirement, while addressing power delivery to an 8Ω load with a desired output voltage of 5 Vrms. The selection and justification of discrete devices, such as MOSFETs and BJTs, for each stage will be pivotal in achieving the project's goals.

This project amalgamates theoretical principles of discrete audio amplifier design with practical considerations to deliver a robust and effective audio amplification system.

Components

Different components are being used in our project. There are a few basic component types that are present in our circuit:

1. AUX Cable/ Microphone
2. Capacitors
3. Resistors
4. NPN BJTs
5. Potentiometers
6. Power Transistors
7. Heat Sinks
8. Speaker
9. Power Resistors

1. **AUX Cable / Microphone:**

An auxiliary cable, commonly known as an aux cable, is a versatile audio cable widely used to transmit analog audio signals between electronic devices. The cable typically features a 3.5mm or 1/8-inch stereo jack on both ends, making it compatible with a variety of audio sources such as smartphones, laptops, and audio playback devices. The aux cable facilitates a direct connection, enabling the transfer of audio signals without the need for wireless technology. Its simplicity and widespread compatibility make it a convenient solution for connecting devices to audio systems, car stereos, or other audio playback equipment. In our circuit, the AUX cable would be used to provide audio input.

Meanwhile a breadboard-based microphone refers to a microphone setup that is connected and tested on a breadboard, a fundamental tool in electronics prototyping. In this configuration, the microphone, usually a condenser microphone for audio applications, is integrated into a circuit on the breadboard. The breadboard provides a platform for easy assembly and testing of the microphone circuit, allowing for quick modifications or adjustments. This setup is commonly employed in the initial stages of electronic projects, enabling engineers and hobbyists to experiment with microphone circuits before finalizing a more permanent design. The breadboard-based microphone setup serves as a practical and flexible approach for prototyping and testing various microphone configurations in an electronic circuit. This is an alternative method to provide audio input to our amplifier circuit.

Figure 1: AUX Cable

Figure 2: Electret Condenser Microphone

2. **Capacitors:**

A capacitor is an essential passive electronic component with the primary function of storing and releasing electrical energy in a circuit. Comprising two conductive plates separated by a dielectric material, typically an insulator, capacitors are characterized by their ability to accumulate and hold an electric charge. When connected to a voltage source, electrons gather on one plate, creating an electric field across the dielectric. This stored charge can be discharged when needed, releasing energy back into the circuit. Capacitors find widespread use in various electronic applications, from smoothing power supplies and filtering signals to timing circuits and energy

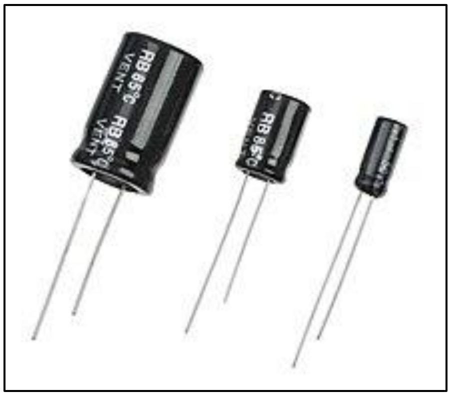


Figure 3: Different Values of Capacitors were used in our circuit

storage systems, contributing significantly to the functionality and stability of electronic devices. In our circuit, capacitors were being used in the capacity of bypass and coupling capacitors to control the frequency response of our audio amplifier.

3. **Resistors:**

Resistors are fundamental electronic components designed to impede the flow of electric current within a circuit. Composed of materials with specific electrical resistance, resistors limit the current passing through them in accordance with Ohm's Law (V = I * R), where V is voltage, I is current, and R is resistance. Resistors play a crucial role in controlling current levels, voltage division, and determining the operational characteristics of electronic circuits. Available in several types, such as fixed resistors and variable resistors, they find applications ranging from setting bias points in transistors to protecting components from excessive current. The versatility of resistors makes them indispensable in electronic design, contributing to the precision and functionality of countless electronic devices. In audio amplifier, the resistors are used for the BJT DC biasing, Gain control and current control.

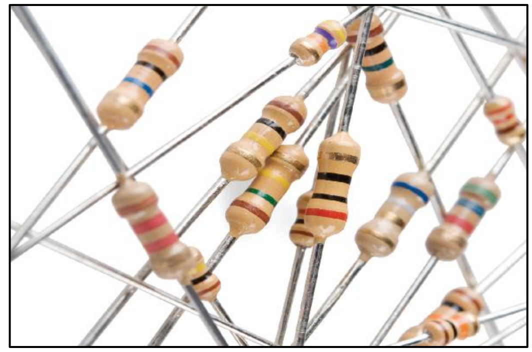


Figure 4: Various value resistors are being used in our circuit

4. **NPN BJTs:**

NPN (Negative-Positive-Negative) Bipolar Junction Transistors (BJTs) are a type of semiconductor device widely used in electronic circuits for amplification and switching purposes. The NPN BJT comprises three layers of semiconductor material—P (positive), N (negative), and P—forming two PN junctions. In an NPN BJT, the central layer (N-type) serves as the collector, the adjacent P-type layer acts as the base, and the outermost N-type layer functions as the emitter. When a small current flows from the base to the emitter, it controls a much larger current flowing from the collector to the emitter. This current amplification capability makes NPN BJTs crucial in various applications, including audio amplifiers, signal processing, and digital logic circuits. Their simplicity and efficiency contribute to their widespread use in electronics. In our circuit, we decided to use 2N3904 as it is very commonly used in BJT-based circuits. These were the basis of our 3-stage pre-amplifier stage. The reason that we decided to use 3 stages is so that we can balance the gain in a sequential manner, without adding any additional pressure on any BJT and eradicate the possibility of the BJTs heating up or excess current escaping. Additionally, due to the use of 3-stages we had a greater range of gain at our disposal which we can easily control and mitigate any differences between our hardware and software circuits.

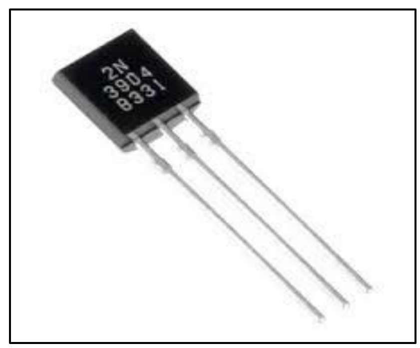


Figure 5: 2N3904 NPN BJT

5. **Potentiometer:**

A potentiometer, often referred to as a pot, is a variable resistor with three terminals, commonly used to control electrical resistance in a circuit. By adjusting the rotational position of its shaft, the potentiometer alters the voltage or current flowing through it, providing a simple means of tuning and adjusting electronic devices. Potentiometers find extensive applications in volume controls, dimmer switches, and various analog control circuits. In our circuit, we are using potentiometers after the bypass capacitor and ground. This would help to maintain our DC biasing while also being able to control our BJT pre-amplifier stage gain for each individual NPN BJT.

Figure 6: Gain Control Potentiometers

6. **Power Transistors:**

Power transistors, such as the TIP122 (NPN) and TIP127 (PNP), are high-power, Darlington pair transistors commonly used in electronic circuits requiring substantial current amplification and voltage regulation. The TIP122 is an NPN-type power transistor, with three layers of semiconductor material. It is well-suited for applications where a high current gain is necessary, making it suitable for power amplifiers and motor control circuits. On the other hand, the TIP127 is a PNP-type power transistor, serving similar purposes but with a reversed current flow. These transistors are popular choices for driving loads like motors and solenoids due to their ability to handle higher power levels in various electronic applications. These are used in the class AB power stage so that our audio signal has low crossover distortion and is more efficient.

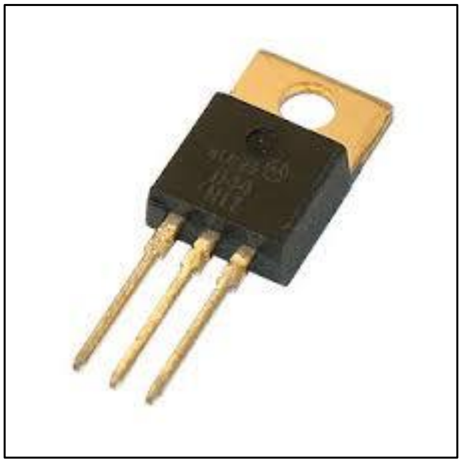


Figure 7: Power Transistors

7. **Heat Sink:**

The large singular heatsink in this design serves a crucial role in maintaining thermal equilibrium within the Class AB power stage, where TIP122 and TIP127 transistors, along with their corresponding diodes, are mounted. The primary objective is to ensure that all components are consistently at the same temperature, mitigating thermal runaway and preventing base current from dropping to levels where the transistors behave as diodes. This strategic thermal management is especially important in Class AB configurations, as it minimizes variations in transistor characteristics due to temperature fluctuations.

Figure 8: Large Heatsink

By integrating diode connected TIP122 transistors in the power stage, they effectively replace traditional diodes. This substitution aligns the thermal behavior of these diode-connected transistors with that of the TIP122 and TIP127 power transistors on the same heatsink. This synchronization aims to enhance the overall stability and reliability of the power stage, ensuring that the components operate within their specified temperature ranges. The large heatsink serves as an efficient heat dissipation solution, preventing thermal imbalances that could otherwise compromise the performance and longevity of the Class AB power stage.

8. **Speaker:**

A speaker configured for prototyping purposes refers to a system integrated into an electronic testing platform. This setup is commonly employed for experimenting with audio circuits before creating a finalized design. The speaker is connected to the circuit, allowing for easy modification, and troubleshooting during the initial stages of development. This approach provides a flexible and convenient way to prototype speaker circuits, enabling engineers and hobbyists to assess and refine their designs before moving on to more permanent implementations.

Figure 9: Speaker is used as our load to provide our audio output

9. **Power Resistors:**

Power resistors are specialized resistive components designed to handle higher levels of electrical power within electronic circuits. Unlike standard resistors, power resistors are constructed with robust materials and configurations that allow them to dissipate heat effectively. These resistors find application in circuits where high-power loads are present, such as in power amplifiers, power supplies, and electronic systems dealing with substantial current. Power resistors are characterized by their ability to withstand elevated temperatures and are often designed with larger surface areas or enhanced cooling mechanisms to efficiently dissipate the heat generated during operation, ensuring reliability and longevity in demanding applications. We used power resistors as our output so that we can observe our output signal easily without the output load heating up or causing any damage.

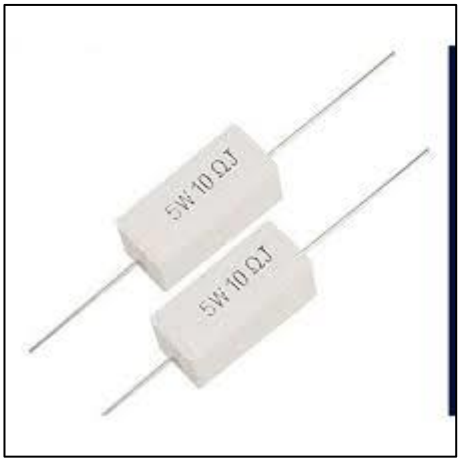


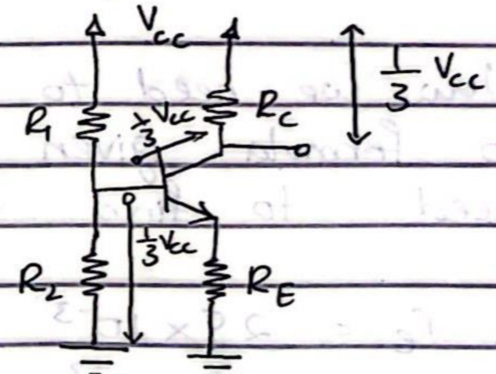
Figure 10: 5W Power Resistor

Formula and Calculations

CALCULATIONS:-

- For transistor 1:-

$I_E = 1mA$; $\beta = 100$; $\alpha = \frac{\beta}{\beta+1} = 0.99$



$I_B = \frac{I_c}{\beta}$

$I_c = \alpha I_E$

$I_c = 9.9 \times 10^{-4} A$

$I_B = 9.9 \times 10^{-6} A$

$R_c = \frac{(\frac{1}{3})(12)}{9.9 \times 10^{-4}}$

$= 4.04 \, k\Omega$

$R_E = \frac{4 - 0.7}{1 \times 10^{-3}} = \frac{3.3}{1 \times 10^{-3}}$

$= 3.3 k\Omega$

$I_{R_2} = (0.1) I_E$

$= 1 \times 10^{-4} A$

$R_2 = \frac{4}{1 \times 10^{-4}}$

$= 4 \times 10^{4}$

$= 40 k\Omega$

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$I_{R_1} = I_{R_2} + I_B$

$= 1\times10^{-4} + 9.9\times10^{-6}$

$= 1.099\times10^{-4}A$

$R_1 = \dfrac{12-4}{1.099\times10^{-4}}$

$= 72.793k\Omega$

Now, we need to calculate R_{in}. For this, according to formula given in lecture 13 of EOC. We need to find r_e

$r_e = \dfrac{25\times10^{-3}}{1\times10^{-3}}$

$= 25\Omega$

$R_{in} = (\beta+1)(r_e + R_e)$

$= (101)(25 + (3.3\times10^3 \parallel 171))$ $\because 171\Omega$ is a potentiometer at emitter

$= (101)(185.576)$

$= 18945\ \Omega$

$= 18.945k\Omega$

This is too small than our bare minimum requirement of $R_{in} > 100k\Omega$ for BJT pre-amplifier stage. Now, we need to change biasing conditions by atleast following factor.

$k = \dfrac{100\times10^3}{18.945\times10^3}$

$= 5.28$

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Hence, we reduce I_E by almost a factor that is similar - We chose about a factor of 4 as recalculation is easier while maintaining same biasing.

$I_E = \frac{1\times10^{-3}}{4}$ $\quad$ $I_C = \frac{100}{101} \times 2.5\times10^{-4}$

$= 2.5\times10^{-4} A$ $\quad$ $= 2.475\times10^{-4} A$

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

$= 2.475\times10^{-6} A$

$R_E = \frac{3.3}{2.5\times10^{-4}}$

$= 13.2 k\Omega$

$R_C = \frac{4}{2.475\times10^{-4}}$

$= 16.161 k\Omega$

$R_2 = \frac{4}{0.1\times2.5\times10^{-4}}$

$= 160 k\Omega$

$I_{R_1} = I_{R_2} + I_B$

$= (0.1\times2.5\times10^{-4}) + (2.475\times10^{-6}) = 2.7475\times10^{-5} A.$

$R_1 = \frac{8}{2.7475\times10^{-5}}$

$= 291.174 k\Omega$

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⊙ For transistor 2:-

We know that our 2^{nd} BJT is also powered by a single power supply. So its biasing resistance values at $I_E = 1 \times 10^{-3} A$ and $\beta = 100$ would be same as transistor 1. However, to mitigate the loading effect of 2^{nd} transistor on our 1^{st} transistor. We have found through our research that one possible solution can be impedance matching. Therefore, we have kept the R_{in} of 2^{nd} transistor almost similar to R_c of 1^{st} transistor. To do so, we have increased our biasing conditions by a factor of 2 or we have used value of $I_E = 2 \times 10^{-3} A$.

Therefore,

$$R_c = \frac{4.04 \times 10^{-3}}{2}$$

$$= 2.02\,k\Omega$$

$$R_E = \frac{3.3 \times 10^{3}}{2}$$

$$= 1.65\,k\Omega$$

$$R_1 = \frac{72.793 \times 10^{3}}{2}$$

$$= 36.3965\,k\Omega$$

$$R_2 = \frac{40 \times 10^{3}}{2}$$

$$= 20\,k\Omega$$

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• For transistor 3:-

Now, we move onto the 3rd and final pre-amplifier stage transistor. Based on our criteria, it should have a low output impedance and our biasing needs to be high as this stage is most being effected by loading effect of power stage. This is a double power supply stage where our biasing calculations need to consider positive and negative signal swing. Based on there only being the availability of a 2W and 8Ω speaker in market, we set our signal swing and output signal accordingly.

We know,

$$P = \frac{V^2}{R}$$

$$2 = \frac{V^2}{8}$$

$$V = \sqrt{16}$$

$$V = 4\,V$$

$$V_{rms} = 4\,V.$$

Hence V_{Peak} of our signal should be about 5.7V if we don't want to damage our speaker. Now, to find input impedance of our class AB power stage and we plotted the R_{in} of power stage using our

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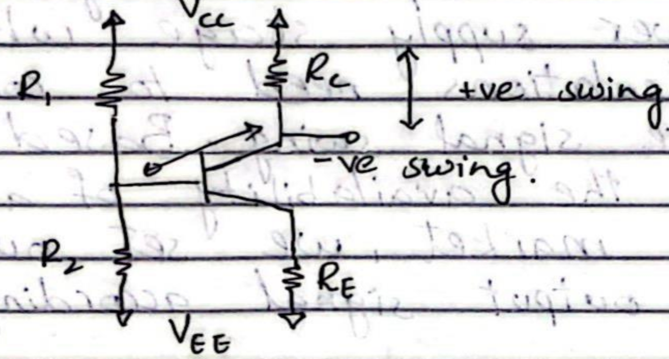
simulation software. R_{in} values were most stable in the audible frequency range at values about $R_{in} = 270\Omega - 280\Omega$. Therefore, we once more move towards impedance matching. So that our 3rd stage is not too much disturbed by power stage loading effect. Therefore, circuit would be something like this,



Based on our assumptions and calculations V_{R_c} should be 6V. V_{CB} should be equal to 6V and R_c should be 280Ω. β will be kept 100.

$$I_c = \frac{6}{280}$$

$$= 2.143 \times 10^{-2} A$$

$$I_E = \frac{2.143 \times 10^{-2}}{\alpha}$$

$$= 2.164 \times 10^{-2} A.$$

$$I_B = \frac{I_c}{\beta} = \frac{2.143 \times 10^{-2}}{100}$$

$$= 2.143 \times 10^{-4} A.$$

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$V_B = 0$; $V_{BE} = 0.7V$; $V_E = -0.7V$; $V_{CB} = 6V$

$V_C = 6V$; $V_{R_1} = 12V$; $V_{R_2} = 12V$; $V_E = 11.3V$

$$R_E = \frac{11.3}{2.164 \times 10^{-2}}$$

$$= 522.2\ \Omega$$

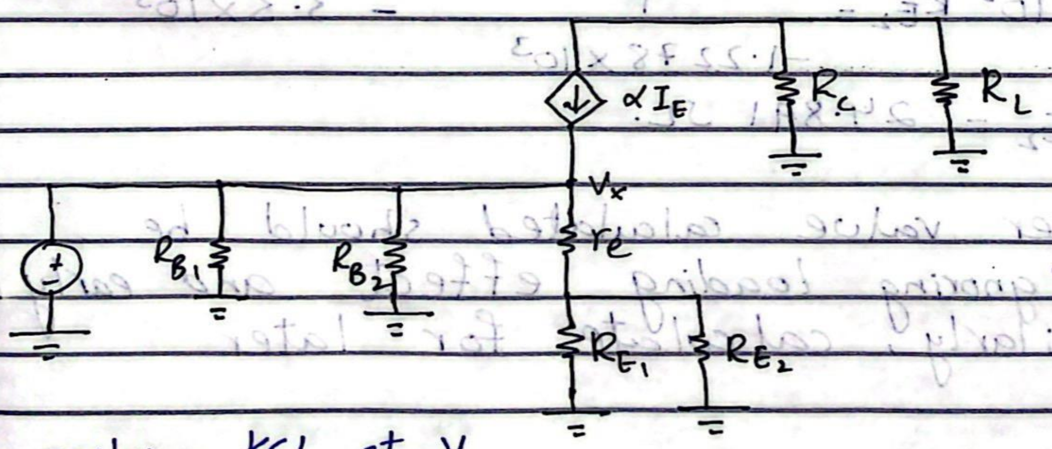
$$R_2 = \frac{12}{0.1 \times 2.164 \times 10^{-2}}$$

$$= 5.545\ k\Omega$$

$$R_1 = 5.045\ k\Omega$$

In power stage we got best output by using resistance of about $5k\Omega$

To find value, we need to set our potentiometer at, we will calculate the transfer function.



applying KCL at V_x

$$\alpha I_E = \frac{V_x}{R_1 \| R_2} + \frac{V_x}{r_e + (R_{E_1} \| R_{E_2})}$$

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$$\frac{-V_o}{R_C \| R_L} = V_x \left(\frac{1}{R_1 \| R_2} + \frac{1}{r_e + (R_{E_1} \| R_{E_2})} \right).$$

$V_x = V_{in}$ so,

$$\frac{V_o}{V_{in}} = -R_C \| R_L \left(\frac{1}{R_1 \| R_2} + \frac{1}{r_e + (R_{E_1} \| R_{E_2})} \right)$$

As we kept our gain at 20dB and transistors are inverting amplifiers so,

$$\frac{V_o}{V_{in}} = -10$$

$$-10 = -8.0805 \left(\frac{1}{291.174k \| 160k} + \frac{1}{25 + (13.2k \| R_{E_2})} \right)$$

$$1.2375 \times 10^{-3} = \left(9.6844 \times 10^{-6} + \frac{1}{25 + \left(\frac{(13.2k) R_{E_2}}{13.2k + R_{E_2}}\right)} \right)$$

$$1.2278 \times 10^{-3} = \frac{1}{3.3 \times 10^5 + 25 . R_{E_2} + 13.2 \times 10^3 R_{E_2}}$$

$$-13.225 \times 10^3 R_{E_2} = \frac{1}{-1.2278 \times 10^3} - 3.3 \times 10^5$$

$$R_{E_2} = 24.891\ \Omega.$$

potentiometer value calculated should be 24.891Ω ignoring loading effect and early effect. Similarly, calculate for later stages.

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We have set coupling capacitors at standard values of about 10–20 μF based on our research. Power stage capacitors are 47 μF as shown in Floyd book. We only need to calculate by-pass capacitors to find value of the capacitors.

$$C_1 = \frac{1}{(2\pi)(100)(13.2\times10^3 \,||\, 24.891)}$$

$$C_1 = \frac{1}{(2\pi)(100)(24.84)}$$

$$= 6.41\times10^{-5}\,F$$

all other by-pass capacitor values were calculated in similar way.

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Simulation

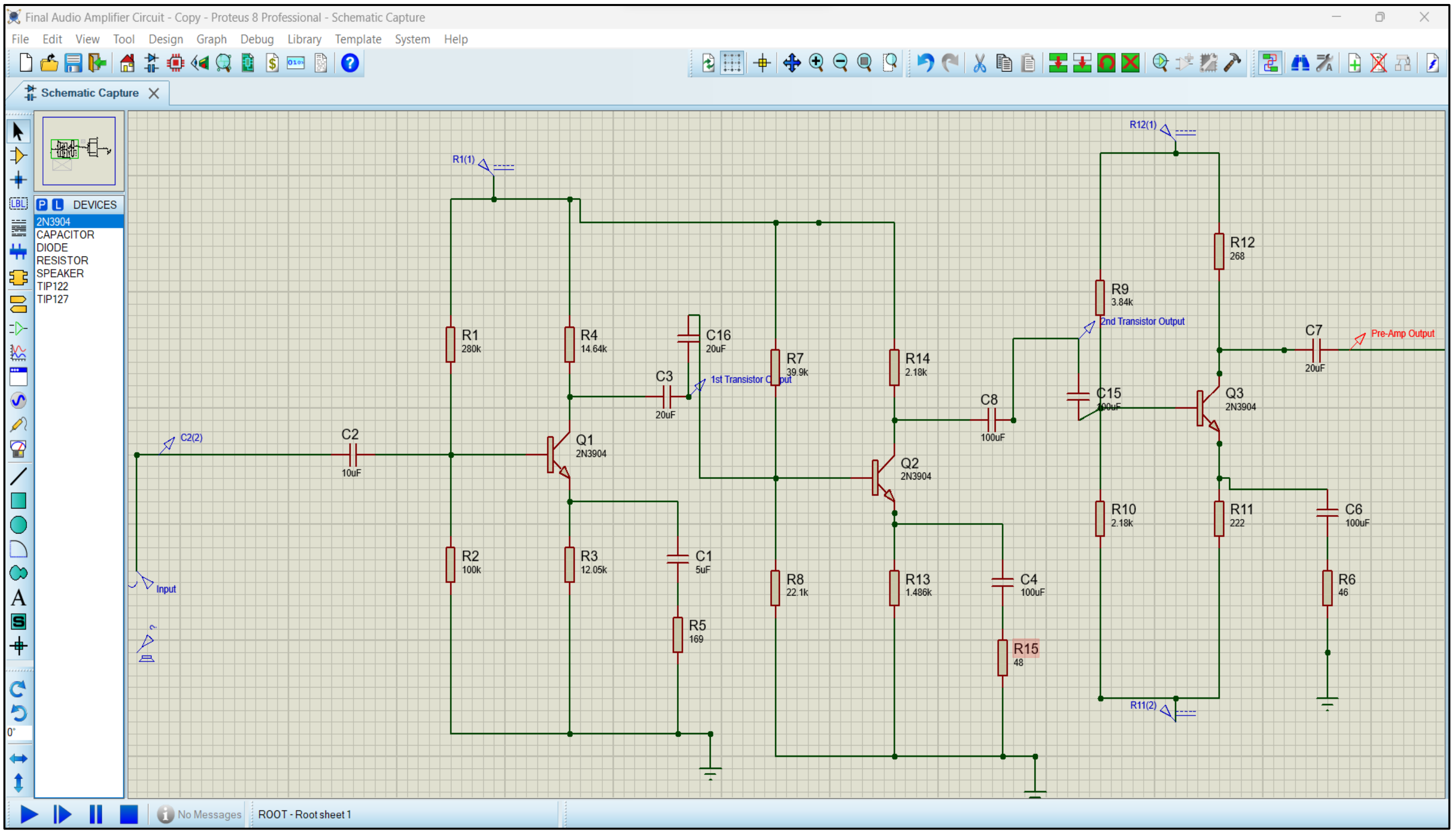


Figure 11: 3-Stage Pre-Amplifier Stage Circuit

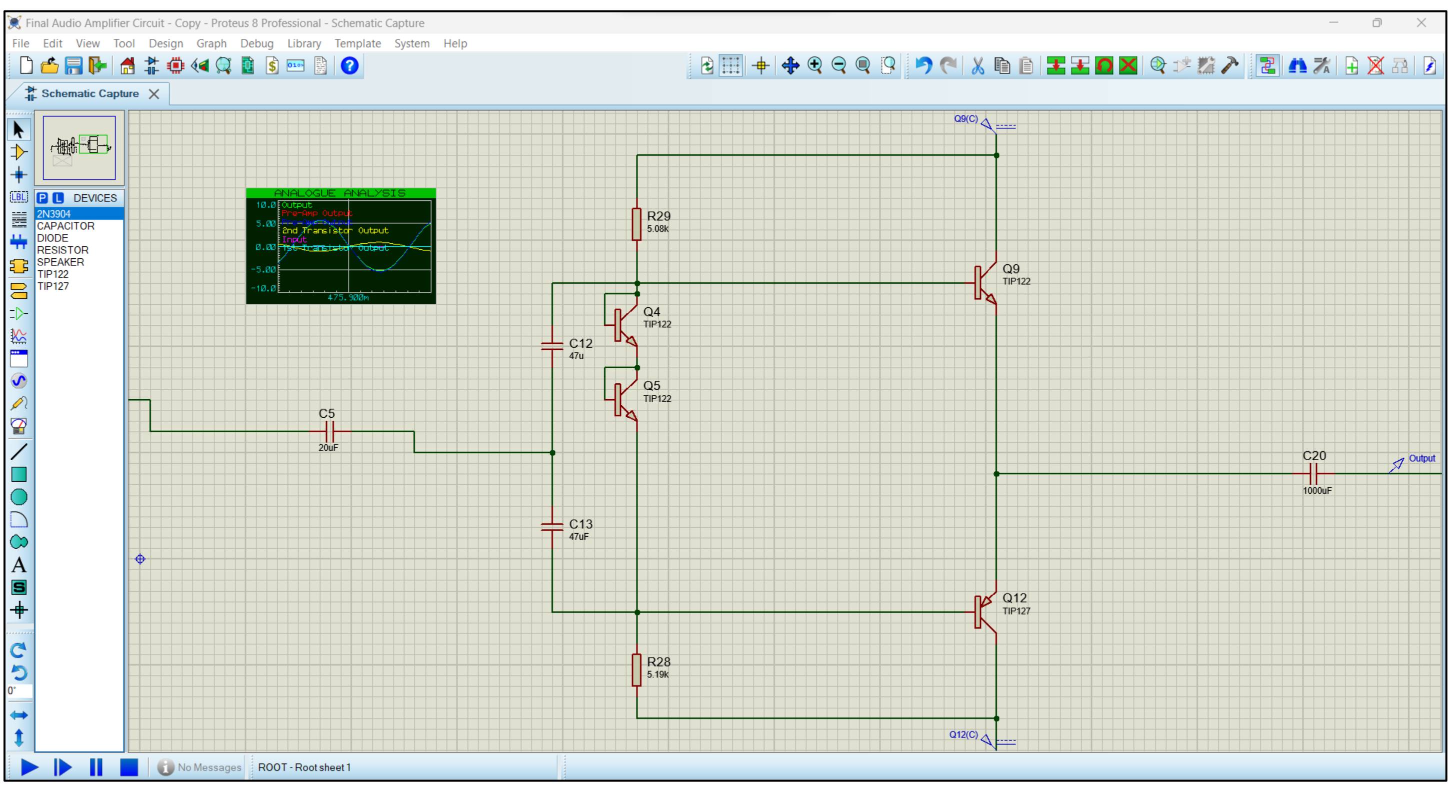


Figure 12: Class AB Power Stage

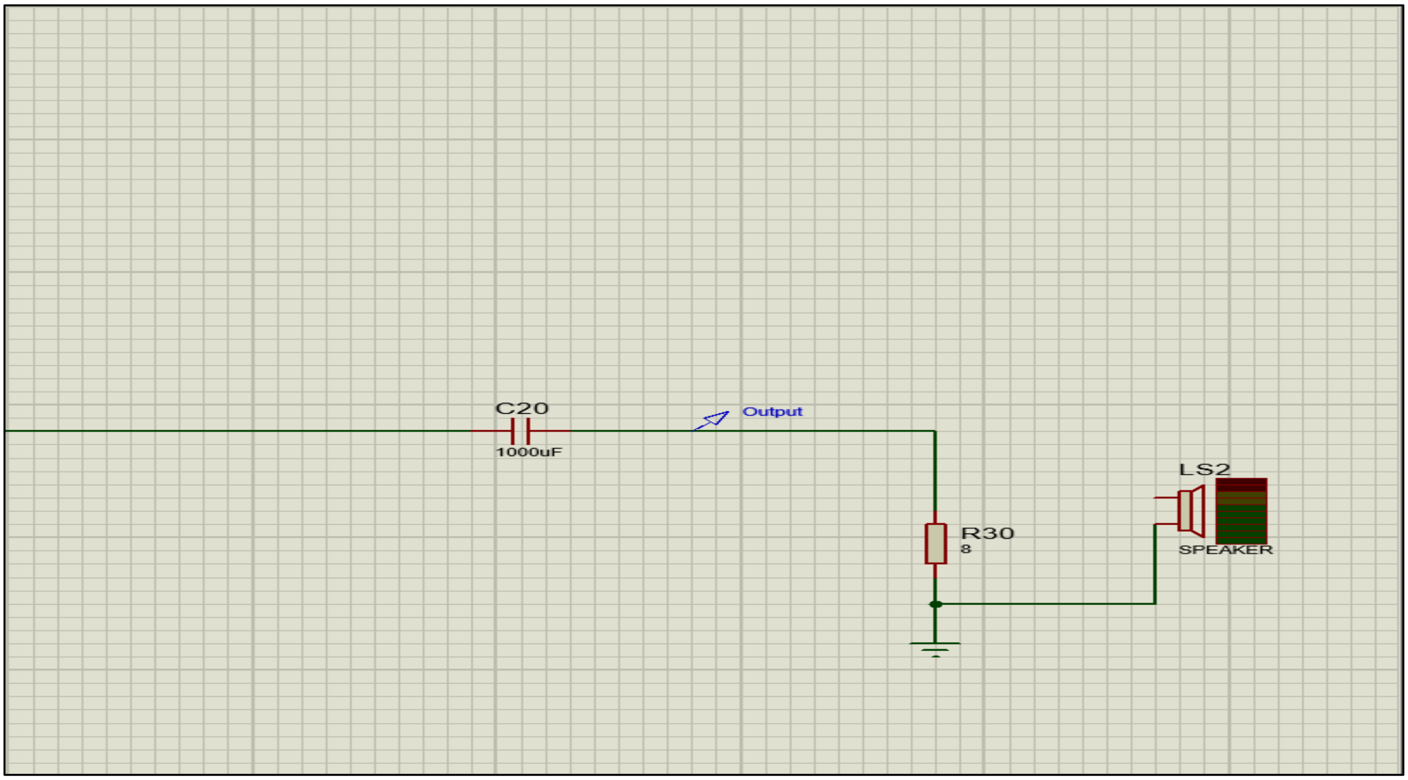


Figure 13: Output of Audio Amplifier

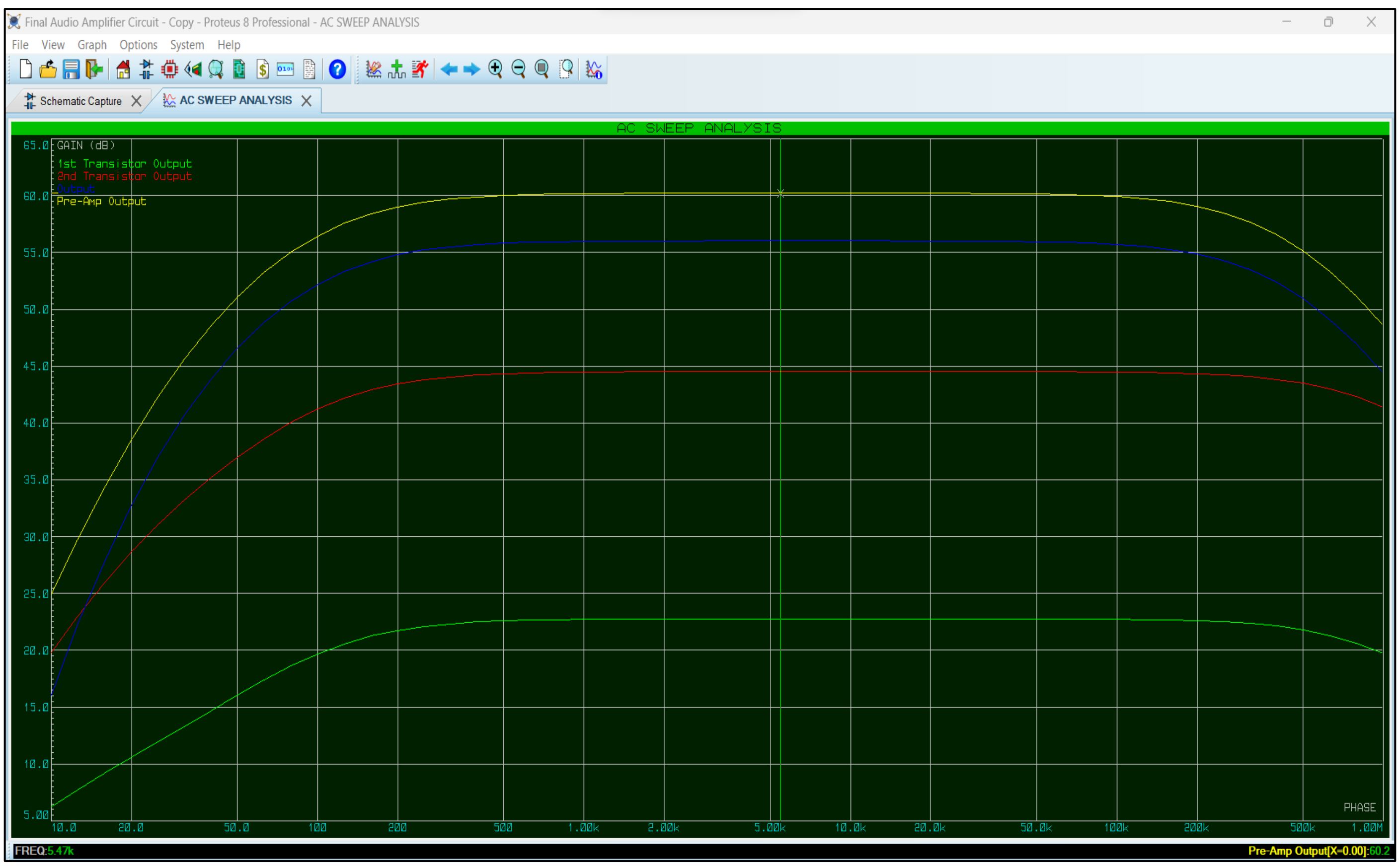


Figure 14: Frequency Response of our Circuit. FL at 100Hz and FH was approximately 1MHz

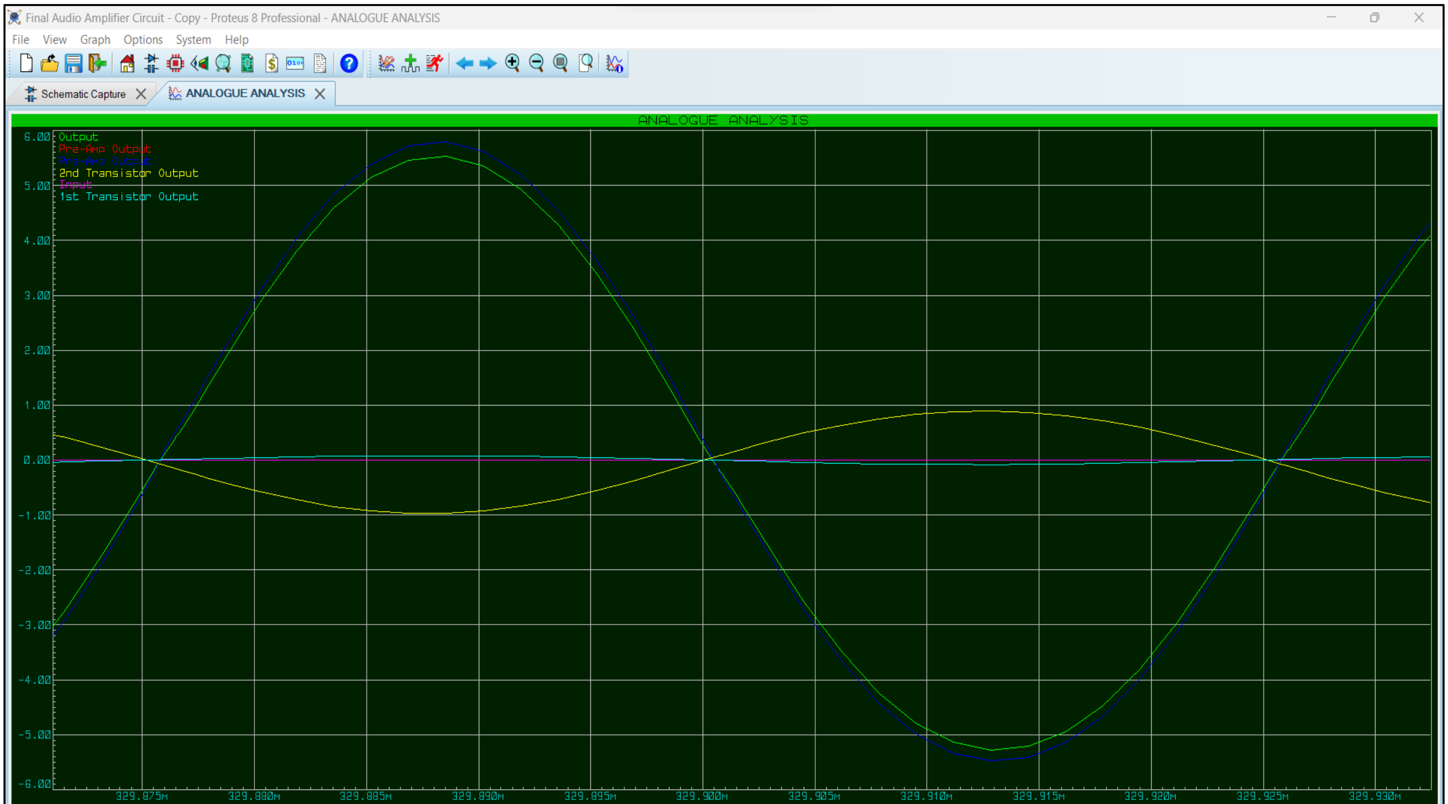
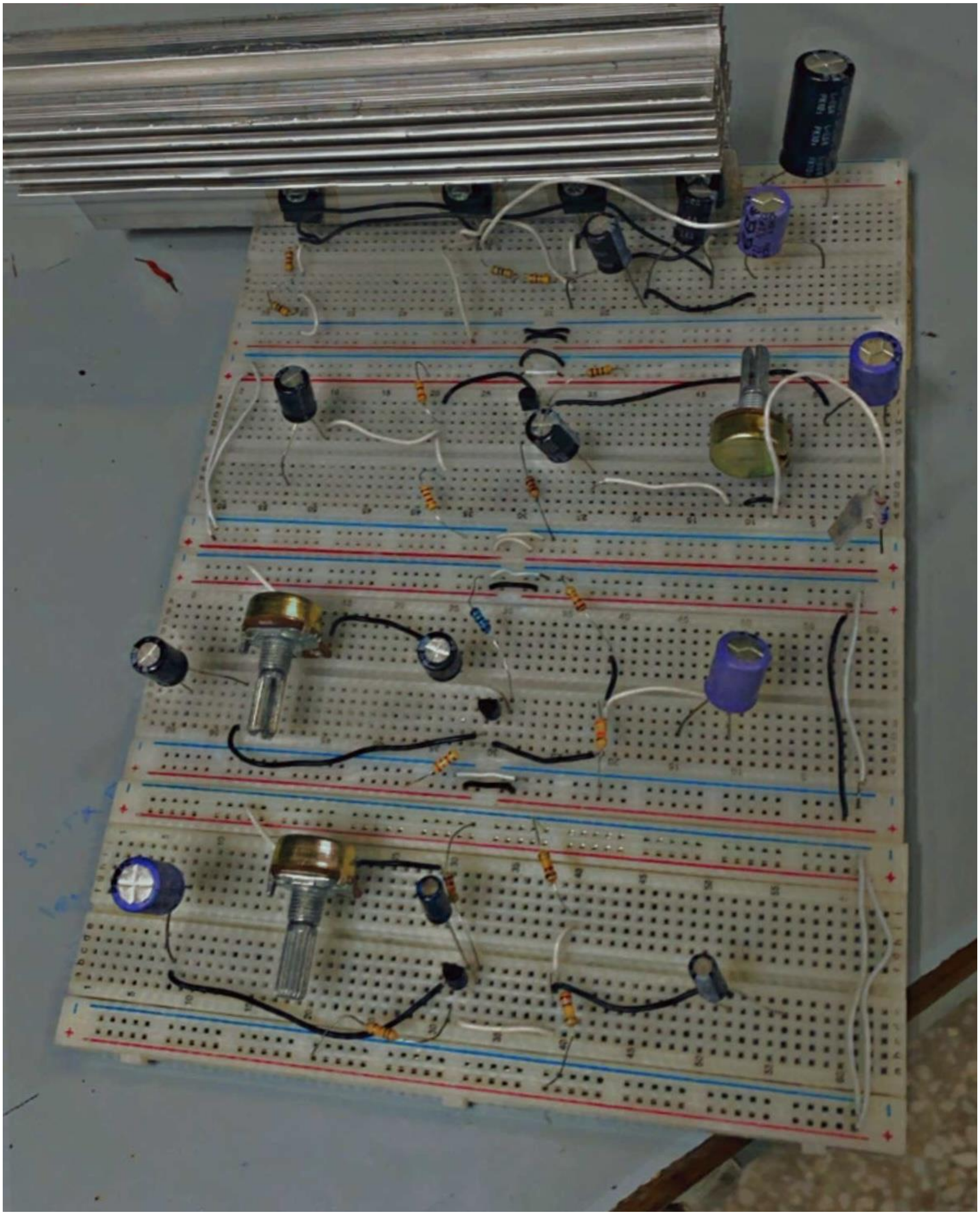


Figure 15: Analogue Signals at different points of our circuit

Note: The resistance values shown in the simulation depict the real and accurate values of our components as measured using a DMM.

Hardware



Conclusion

In conclusion, the discrete audio amplifier, featuring a three-stage preamp with 2N3904 transistors providing 20dB gain each and a Class AB power stage with TIP122, TIP127 transistors, and diode-connected TIP122 components, has demonstrated a successful integration of theoretical design and practical considerations. The preamp stages significantly boosted sensitivity, while the Class AB power stage, coupled with diode-connected transistors on a shared heatsink, ensured thermal stability. This well-engineered amplifier meets performance criteria, offering a balanced and efficient audio amplification solution for diverse applications.