EW II: Project 1 - Audio Amplifier

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Audio amplifier is a circuit used to increase the strength of audio signals to drive speakers. They can be built in a variety of configurations and can be used to build custom amplifiers according to the needs of the user.
This document will provide information about the design methodologies, implementation and encountered problems with solutions used in our project.

Design:

The design of the audio amplifier consists of different blocks having individual functionalites, which when cascaded together work simultaneously to give us the required output.

Requirements / specifications:

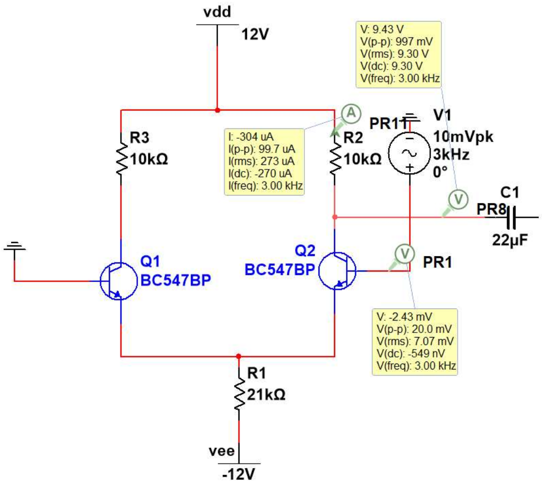
Primary goal of the circuit is to take analog input from a microphone and process the signal through the amplifier in order to amplify and strengthen it enough to drive a speaker, having an impedance of $\underline{6.4\Omega}$ and to obtain a power output of around $\underline{2W}$ from it.

Pre-Amplifier:

A pre amplifier, also known as a preamp, is an amplifier used to boost a low-level signal before it is sent to a power amplifier. In audio amplification, a differential amplifier is often used as a preamp due to its ability to reject common-mode noise and improve the signal-to-noise ratio. The differential amplifier uses two input signals that are 180 degrees out of phase and amplifies the difference between them, effectively rejecting any noise that is present on both inputs. The output of a differential amplifier is a differential signal that is then typically converted to a single-ended signal using a voltage-to-current converter. The preamp is crucial in audio systems as it sets the foundation for the overall quality of the sound by improving the signal-to-noise ratio and providing the necessary gain to drive the power amplifier.

The Pre-Amp stage/block is used to amplify the signal enough to be passed through the next block (gain stage) which will do the main amplification of the signal. The Pre-Amp should be able to provide a significant gain, and should also have the ability to get rid of unwanted noise passed through from the microphone block.
We have used a differential amplifier built with BJT's (BC547) which performs the pre amplification, and being a differential amplifier will reject any noise present in the circuit by default by subtracting the added/superimposed noise signals between the two terminals of the pre amp.

The input from the mic is expected to be around $10mV_{pp}$, which is then simulated by using an analog AC source of the peak to peak amplitude $20mV$.



The capacitor present on the output line is a coupling capacitor, which, as seen removes the DC offset that comes as a side effect of the Pre-Amp amplification. A differential amplifier's gain has the relation:

$$Gain \; \alpha \; (V_1 - V_2)$$

but here V_2 is grounded and = $0V$.

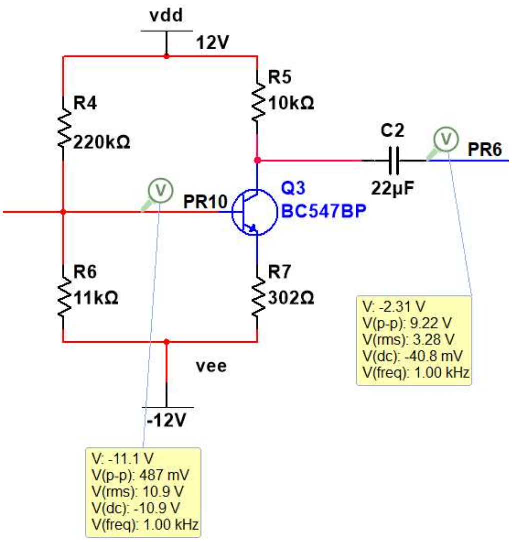
Observed gain:

$$A_1 = \frac{998mV_{pp}}{20mV_{pp}} \approx 49.9$$

Gain stage (CE Amplifier):

The Common Emitter (CE) Amplifier is a bipolar junction transistor (BJT) circuit configuration that is widely used in electronics. In a CE amplifier, the input signal is applied to the base terminal while the collector is connected to the output load. The emitter terminal is common to both the input and output signals. The gain of a CE amplifier is controlled by the ratio of the load resistor to the collector resistor, and it can provide both voltage and power amplification. The CE configuration is widely used in a variety of applications, including audio amplification, radio frequency amplification, and instrumentation amplifiers.

The gain stage block is what is placed after the Pre-Amp in order to amplify the signal to a much higher voltage that will be required to drive the speaker. This is where the signal attains the gain primarily.



In order to reach the threshold voltage of the transistor, a voltage divider is used between V_{dd} and $-V_{ee}$ with certain values in order to obtain the required amount of gain, which here, comes out to be:

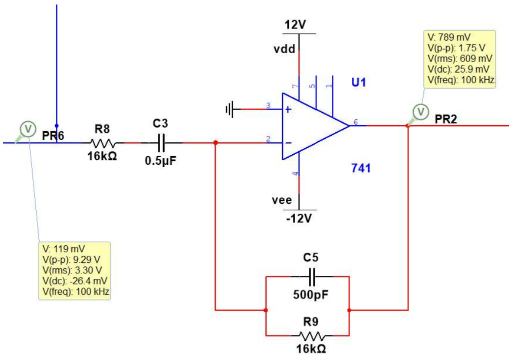
$$A_2 = \frac{9.22V_{pp}}{487mV_{pp}} \approx 18.93$$

Now the total gain achieved in the circuit → $A_{tot} = A_1 * A_2 = 944.607$

Active Band Pass filter:

An active band pass filter is a type of electronic filter that allows signals within a certain frequency range to pass while rejecting signals outside of that range. Unlike passive filters, active band pass filters use active components such as operational amplifiers to provide amplification, allowing them to filter a wider range of frequencies. The gain of the filter can also be controlled, making it useful for applications that require amplification of signals within a specific frequency range.

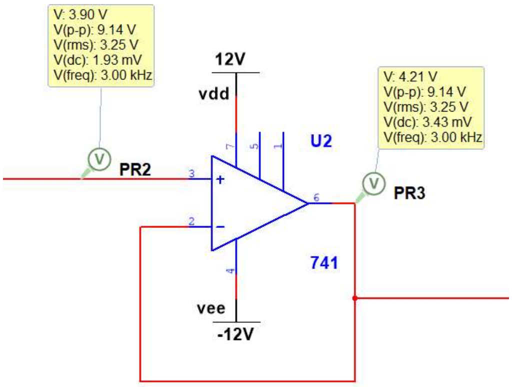
We require a filter in order to filter out unwanted frequencies from the signal, effectively denoising the signal. Here a band pass flter is used, with the specifications of: $f_{c-LowPass} = 20kHz$ and $f_{c-HighPass} = 20Hz$. This frequency range is chosen so that the output of the amplifer matches the human range of hearing.



Used active band pass filter design

Here the design used is called an active band pass filter which contains RC filters for both low pass and high pass filtering, which are then combined into one circuit using an OpAmp.
As it can be seen, the filter attenuates the signal whose frequencies lie outside the frequency range of the filter.

Unity gain buffer:



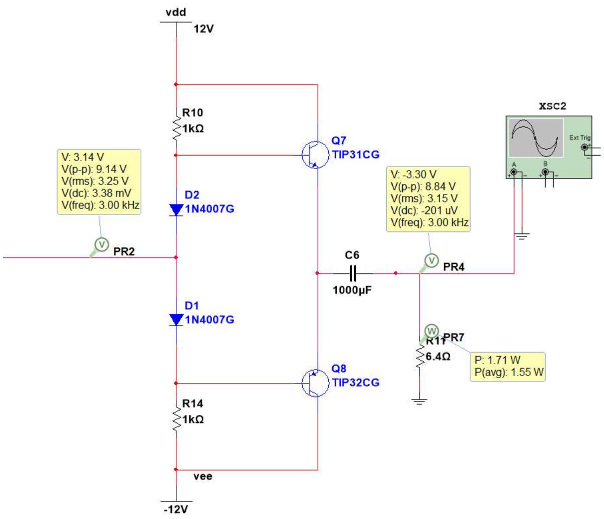
A unity gain buffer, also known as a voltage follower, is a type of amplifier circuit that has a gain of 1, meaning it does not amplify the input signal. The primary function of a unity gain buffer is to isolate the load from the source, preventing the load from affecting the source impedance and causing signal degradation. A unity gain buffer typically consists of an operational amplifier (op-amp) or a transistor configured in a common-source or common-emitter configuration. The output of a unity gain buffer is in phase with the input signal and is typically used to drive high impedance loads, such as long cable runs, without introducing signal degradation. The unity gain buffer is commonly used in a variety of applications, including audio amplification, instrumentation systems, and industrial control systems, where signal isolation and signal integrity are important.

Usually, when cascading two blocks of the circuit, if output and input impedances of both do not match, then the signal can get attenuated significantly. So, in such cases, a buffer is required in order to drive the other parts of the circuit without modifying the signal itself. A gain of unity is preferred so that the signal's waveform and amplitude do not get affected on passing through the buffer and the signal is basically passed on through. Here the unity gain buffer is used to drive the power amp without having signal attenuation after the filter.

Power Amplifier:

A power amplifier is an electronic device used to amplify the strength of an electrical signal, typically for driving speakers or other loads. The design used here is a Class-A power amplifier, and these are preferred for their low distortion and high linearity. Power amplifiers are typically used in the final stage of an audio system to drive speakers and provide high power output with minimal distortion. The power amplifier design must consider various parameters, including load impedance, power output, and frequency response, to ensure the amplifier can deliver the desired power to the load with minimal distortion.

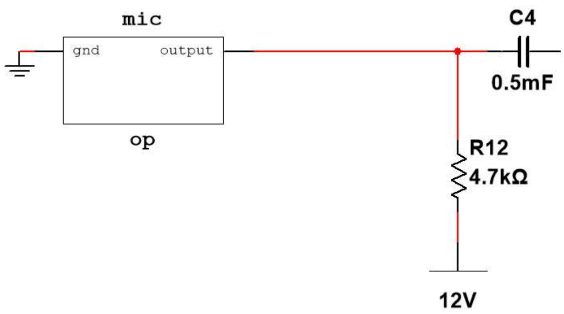
High peak to peak voltage alone is not enough to drive a speaker directly. To obtain significant power output, high current is needed The power amplifier 'amplfies' the power output of the circuit by increasing the current output of the circuit



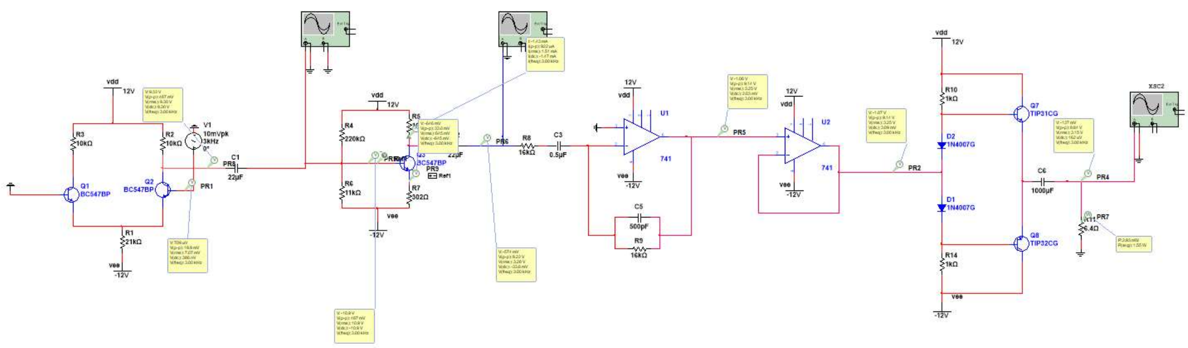
Here, the loudspeaker is simulated by using a resistor of resistance 6.4Ω, which is equal to the impedance of the speaker provided. Obtained power output (simulated) = $1.55W$

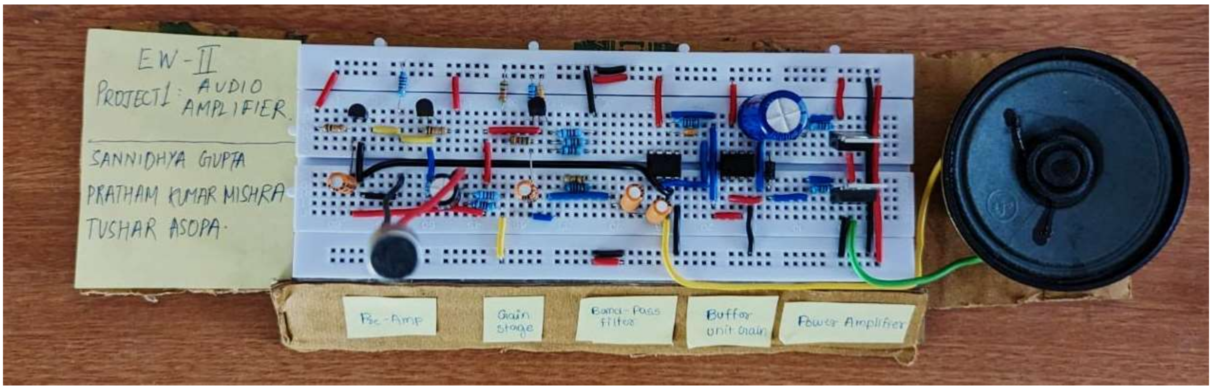
Hardware implementation:

Microphone circuit:



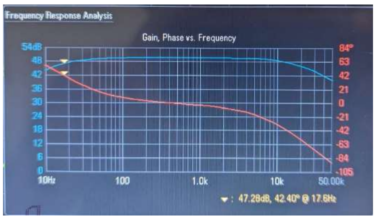
The circuit used in the simulation is replicated in the hardware.





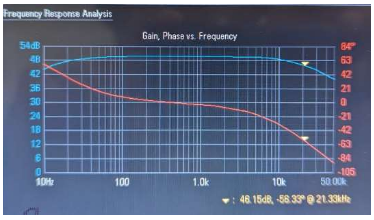
Due to slight deviations in the output of the hardware part, some of the resistances and capacitances have been tweaked slightly to obtain close to desired output

Frequency response of the circuit:



high pass filter (cutoff)

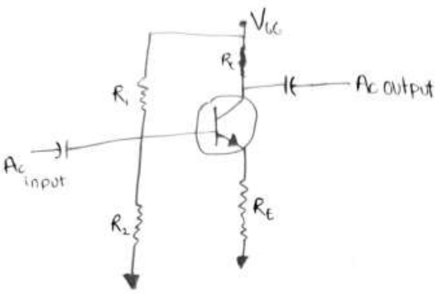
reference

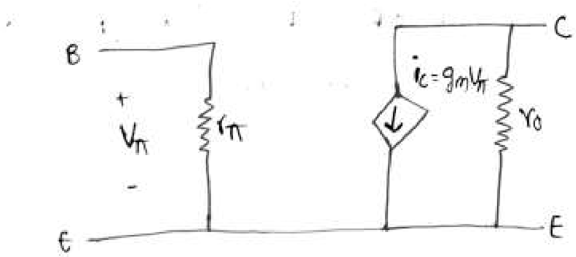


low pass filter (cutoff)

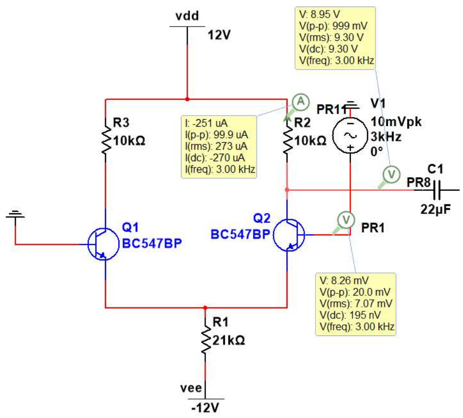
Calculations:

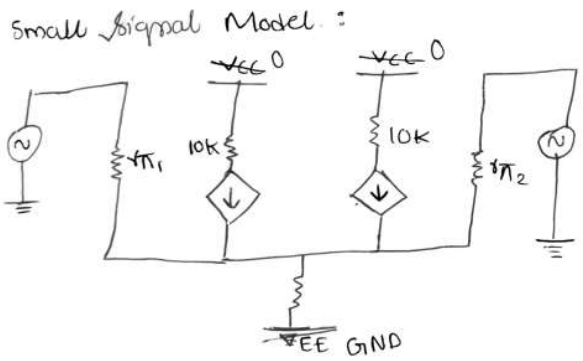
BJT (Bipolar Junction Transistor):





Pre-Amplifier:





The output voltages are given by:

$$V_{o1} = -g_{m1}V_{in1}R_c, \quad V_{o2} = -g_{m2}V_{in2}R_c$$

However in a Pre-Amp both the transistors are exactly matched, so the equation becomes:

$$V_{o1} = -g_m V_{in1}R_c, \quad V_{o2} = -g_m V_{in2}R_c$$

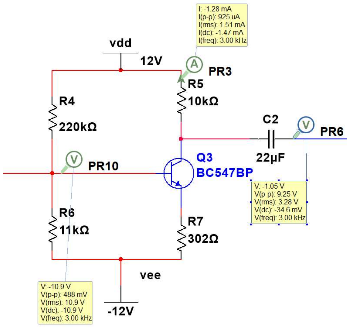
For calculating gain, we need to compute: $\frac{(V_{o1}-V_{o2})}{(V_{in1}-V_{in2})}$, which from the above equations comes out to be equal to:

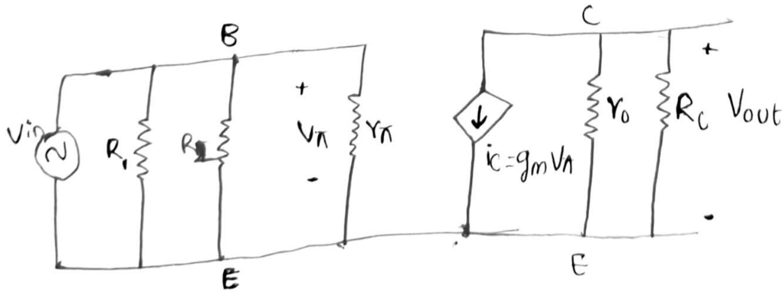
$$A_v = \frac{V_{o1} - V_{o2}}{V_{in1} - V_{in2}} = -g_m R_c = \frac{I_c}{V_T} * 10k\Omega$$

On measuring. value of collector current was found to be $270\mu A$, further putting the thermal voltage value in. we get: $A_v \approx 100$. However, since we are obtaining the output from only one terminal, we shall receive half the gain, $A_v \approx 50$, which is equal to the simulated value of gain.

Also the output impedance of the circuit, as seen from the small signal model of the circuit, comes out to be equal to $10k\Omega$.

Gain stage:





Gain calculations:

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

$$A_v = \frac{V_{out}}{V_{in}} = -g_m(R_e||R_c)$$

Since $g_m = I_c/V_T$, calculating we get value of it to be $= 0.05807$
$R_e||R_c$ comes out to be equal to $10k\Omega||302\Omega = 293.147\Omega$

Thus. gain comes out to be $A_v = -g_m(10k\Omega||302\Omega) = 17.02$

Input impedance comes out to be: $Z_{in} = 10476.19\Omega$
Output impedance comes out to be: $Z_{out} = 293.147\Omega$

Total Gain should come out to be = $50 * 17.02 \approx 900$, which is very close to the simulated circuit

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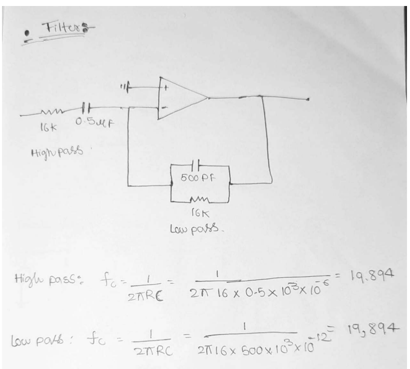
Active Band Pass filter:



Obtained cutoff (-3dB) frequencies:

Low Pass = 19894Hz
High Pass = 19.894Hz

Some important points:

Min-Max input range:

Theoretically, the circuit should allow amplitudes from zero all the way upto a certain point where gain and preamp stage start showing clipping of the output if output voltage gets too high. On measuring and analysing, we found out that the input range is: $3mV_{pp} - 24mV_{pp}$

Distortion analysis:

Distortion analysis in electronics refers to the measurement and analysis of the changes in waveform shape of an electrical signal as it passes through an electronic system or component. Distortion can be introduced into a signal by various sources, such as electronic components, power supply, or even the transmission line. There are various types of distortion, including amplitude distortion, phase distortion, and harmonic distortion, each of which can affect the signal quality and accuracy in different ways.

Methods to perform distortion analysis:

1. Oscilloscope Measurement: One of the most common methods is to measure the output waveform of a circuit using an oscilloscope. The oscilloscope can display the waveform and compare it to the input waveform to determine the amount and type of distortion.
2. Spectrum Analysis: Another method is to use a spectrum analyzer to perform a frequency analysis of the signal. The spectrum analyzer can show the relative strength of each frequency component in the signal, allowing engineers to identify any harmonics or other forms of distortion that may be present.

Circuit stability:

Circuit stability in electronics refers to the ability of a circuit to maintain its operating characteristics over time and in response to various changes in the environment or operating conditions. A stable circuit will continue to operate correctly and produce the expected results, even in the presence of changes in temperature, power supply voltage, or other variables. In contrast, an unstable circuit may produce unpredictable or undesirable results, such as oscillations or changes in gain or frequency response.

CMRR (Common mode rejection ratio):

CMRR stands for Common Mode Rejection Ratio. It's a measure of the differential amplifier's ability to reject common mode signals, which are signals that are present on both inputs of the amplifier with the same amplitude and phase.

On calculating, for the given differential amplifier, CMRR comes out to be ≈ 70772.7273

Slew rate:

The Slew Rate is a term used in electronics that refers to the rate of change of the output voltage of an amplifier. It's a measure of how fast an amplifier can change its output voltage in response to a change in input. The Slew Rate is usually specified in volts per microsecond (V/μs) and it's a key performance parameter of an amplifier, especially for high-frequency applications.