PROJECT REPORT

DESIGN AND CONSTRUCTION OF AN AMPLIFIER

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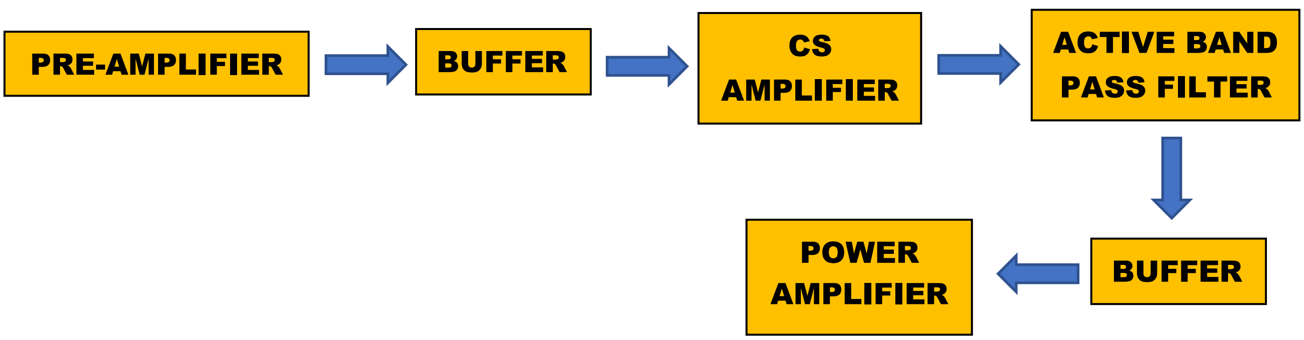
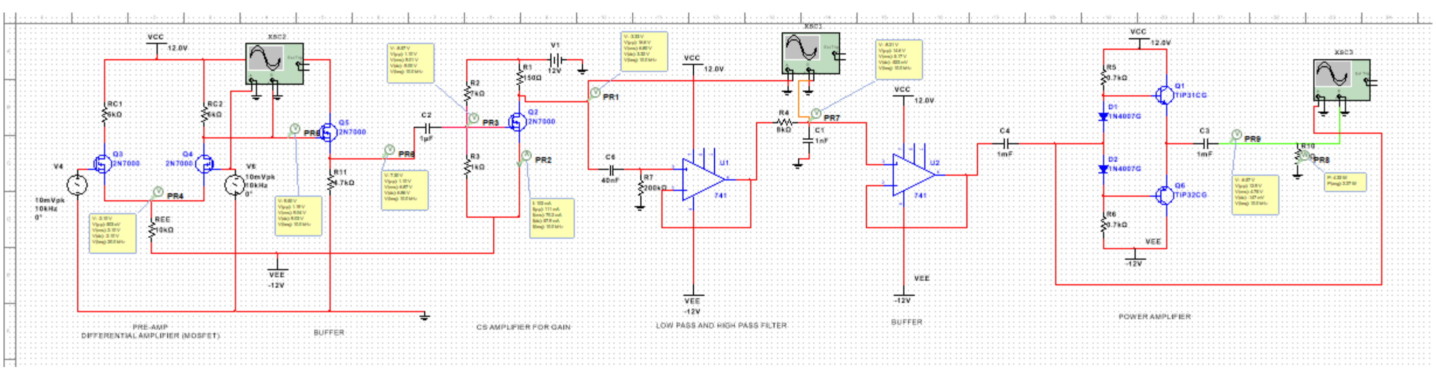
BLOCK DIAGRAM:





The full circuit for Audio Amplifier

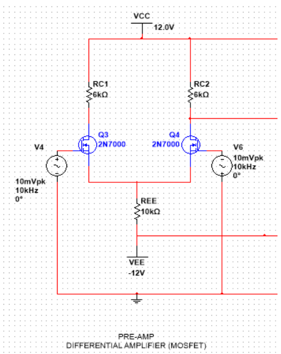
SPECIFICATIONS:

- **GAIN**: 500
- **SUPPORTED FREQUENCY RANGE**: 20Hz-20kHz
- **FINAL POWER:** 2.5 Watts

DESCRIPTION OF SUB-BLOCKS:

- **PRE-AMPLIFIER:**

CIRCUIT TOPOLOGY USED: Differential Amplifier using MOSFETs



A microphone is a transducer that converts vibrations from air molecules to electrical signals, but since the vibrations are small, the electrical signals are weak. A pre-amplifier is used to boost the low-voltage weak input coming from the microphone called a mic-level signal and to convert it into line-level so that it can be further processed for filtering and amplifying because all of the processing can be done only for strong signals because weak signals might get dominated by the stronger noise. Thus, to amplify the mic input at the initial level, we use a pre-amp and a differential amplifier design which serves the purpose of amplifying by cancelling the external noise. It takes a differential input from 2 sides as +vin and -vin. Due to the noise added, the new inputs are:

$$v_1 = v_{in} + v_{noise} \qquad\qquad v_2 = -v_{in} + v_{noise}$$

Let Outputs of Q3 and Q4 be:

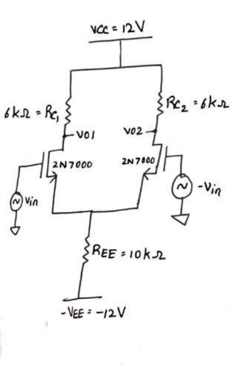
$V_{OUT1} = V_{amplified} + V_{noise\_amplified}$ $\quad V_{OUT2} = -V_{amplified} + V_{noise\_amplified}$ $\quad$ thus $\quad V_{OUT1} – V_{OUT2} = 2.V_{amplified}$

Thus, we remove the noise which is called as common mode input gain and also amplify the weak signal (differential mode input)

<u>RESISTOR VALUE CALCULATIONS:</u>

Gain expected : 60

Circuit Architecture:



Values known

$\boxed{V_{Th} = 2V}$

$K_P = \mu_n C_{ox} = 20.78\,\mu$

$W = 9.7 \times 10^{-3}$

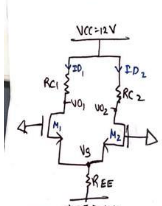
$L = 2 \times 10^{-6}$

so $k = \mu_n \cdot C_{ox} \cdot \frac{W}{L}$

$= \frac{20.78 \times 10^{-6} \times 9.7 \times 10^{-3}}{2 \times 10^{-6}}$

$\boxed{k = \mu_n \cdot C_{ox} \cdot \frac{W}{L} = 100.783 \times 10^{-3}\ A/V^2}$

Large signal model: [Differential gain calculations]



Conditions [for both mosfets]

① $V_{GS} \geq V_{TH}$ $\quad [V_G = 0]$

$0 - V_S \geq 2$ $\quad [V_{G1} = V_{G2} = V_G]$

$\boxed{V_S \leq -2V}$ — ①

② For it to amplify, it must be in saturation, so

$V_{DS} \geq V_{GS} - V_{TH}$

$V_D \geq V_G - V_{TH}$

$V_D \geq 0 - 2$

$V_D \geq -2$ [for both M_1 & M_2]

So, our output

$V_{O1} \geq -2$ & $V_{O2} \geq -2$

Here, we are using V_{O2} as our single ended output.

& we want gain ~~...~~ & input max = 10mV (peak)

~~⇒ output max = 600mV (peak)~~

gain = $\frac{V_{O2}}{V_{in}}$ ⇒ $V_{O2} = \text{gain} \cdot V_{in}$

so gain$\cdot V_{in} \geq -2$

if $V_{in} > 0$, gain $\geq \frac{-2}{V_{in}}$

gain min = $\frac{-2}{V_{in}}$

V_{in} max = 10mV, so

gain min = 200

If $V_{in} < 0$, thus

gain $\leq \frac{-2}{V_{in}}$

gain max = $\frac{-2}{V_{in}}$

V_{in} min = -10mV, so.

$\boxed{\text{gain max} = 200}$ — ③

As we want final gain ≥ 600, we need to use a CS amplifier after pre-amp.

③ Small signal model valid only when: $V_{in} \leq 2V_{ov}$

$V_{ov} = V_{GS} - V_{TH} = 0 - V_S - 2 = -V_S - 2$

So,

$V_{in} \leq 2(-V_S - 2)$

⇒ $\boxed{V_S \leq \frac{-V_{in}}{2} - 2}$

$-5mV \leq \frac{V_{in}}{2} \leq 5mV$

$-5mV \leq \frac{-V_{in}}{2} \leq 5mV$ ⇒ $\boxed{V_S \leq -1.995V}$ ②

Now from large signal model:

$$gm = K \cdot (V_{GS} - V_T)$$

$$gm = 100.783 \times 10^{-3} \times (0 - V_S - 2)$$

$$gm = 100.783 \times 10^{-3} \times 0.1$$

$$\Rightarrow \boxed{gm = 10.0783\ mS}$$

From ① & ②, $V_S \le -2$,

so, let $\boxed{V_S = -2.1}$ ④

$$I_{D_1} + I_{D_2} = \frac{V_S - (-V_{EE})}{R_{EE}}$$

$$\cancel{2} \times \frac{1}{\cancel{2}} \times \mu_n C_{ox} \frac{W}{L} (V_G - V_S - V_{TH})^2 = \frac{-2.1 + 12}{R_{EE}}$$

$$K \cdot (0 - (-2.1) - 2)^2 = \frac{9.9}{R_{EE}}$$

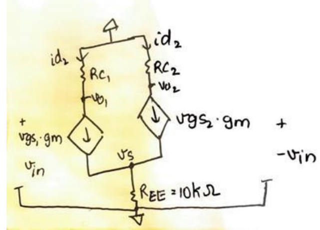
$$= gm \cdot (0 + 2.1 - 2) = \frac{9.9}{R_{EE}}$$

$$= 10.0783 \times 10^{-3} \times 0.1 = \frac{9.9}{R_{EE}}$$

$$\Rightarrow R_{EE} = 9.823\ k\Omega$$

$$\boxed{R_{EE} \approx 10\ k\Omega} \quad ⑤$$

Small signal model



v_g

$$\frac{v_{o_2} - 0}{R_{C_2}} = -id_2$$

$$v_{o_2} = -v_{gs_2} \cdot gm \cdot R_{C_2} \quad ⑥$$

$$\boxed{v_{gs_2} = v_{g_2} - v_s = v_{in} - v_s}$$

$$id_1 + id_2 = \frac{v_S}{R_{EE}}$$

$$gm \cdot (v_{gs_1} + v_{gs_2}) = \frac{v_s}{R_{EE}}$$

$v_{g_1} = -v_{g_2}$, so

$$gm \cdot (v_{g_1} - v_s + v_{g_2} - v_s) = \frac{v_s}{R_{EE}}$$

$$gm\,(-2v_s) - \frac{v_s}{R_{EE}} = 0 \Rightarrow \boxed{v_s = 0} \quad ⑦$$

so, from ⑥ & ⑦, we get

$$v_{o_2} = (-v_{g_2})\, gm \cdot R_{C_2}$$

$$v_{o_2} = v_{in} \cdot gm \cdot R_{C_2}$$

$$\frac{v_{o_2}}{v_{in}} = \boxed{A_v = gm \cdot R_{C_2}}$$

now, required gain = 60

$$60 = 10.0783 \times 10^{-3}\, R_{C_2}$$

$$R_{C_2} = 5.95\ k\Omega$$

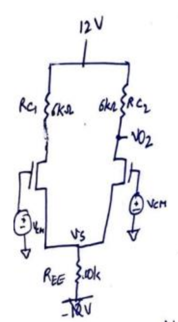
$$R_{C_2} \approx 6\ k\Omega$$

similarly doing for R_{C_1}, we get finally

$$\boxed{\begin{aligned} R_{EE} &= 10\ k\Omega \\ R_{C_1} = R_{C_2} &= 6\ k\Omega \end{aligned}}$$

CMRR (COMMON MODE REJECTION RATIO:

Common mode gain:



$$V_{O_2} = V_{DD} - I_D R_C$$

$$I_D = \frac{V_S - (-V_{DD})}{10 \times 10^3} \times \frac{1}{2}$$

(as $V_1 = V_2 = V_{CM}$), then

$$V_{O_2} = 12 - \frac{1}{\cancel{2}} \times \frac{1}{10\cancel{{}^3}} \times (-2.1 + 12)\, \cancel{6} \times 10^{\cancel{3}}$$

$$V_{O_2} = 12 - \frac{(9.9)}{10} \times 3$$

$$V_{O_2} = 12 - 2.97$$

$$V_{O_2} = 9.03$$

So, $CMRR = \frac{A_d}{A_{CM}} = \frac{gm \cdot R_{C_2}}{\left(V_{DD} - \frac{V_S + V_{DD}}{2 \times R_{EE}} \cdot R_{C_2}\right) / V_{CM}} = \left(\frac{gm \cdot R_{C_2} \cdot V_{CM}}{9.03}\right) = \boxed{6.7 \cdot V_{CM} = CMRR}$

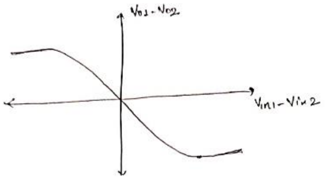
As we see from the equation, we want the common mode rejection ratio to be high so that it rejects most of the common mode gain. Now, from The given equations and values, we can see that for a high CMRR, we must have an R_{EE} value such that the denominator is positive and so, a high R_{EE} would work.

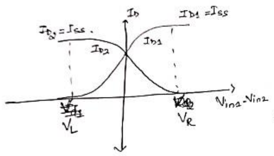
INPUT & OUTPUT SWINGS:

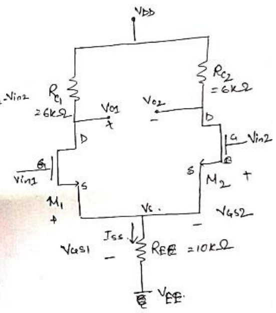
INPUT AND OUTPUT SWING

Input swing :-

for the differential amplifier, the input - output characteristics are as follows:-







We know

$V_S = -2.1V$

$V_{EE} = -12V$

$$I_{SS} = \frac{V_S - V_{EE}}{R_{EE}}$$

$$= \frac{-2.1V + 12V}{10K\Omega}$$

$$= \frac{9.9}{10K} A$$

$$= 0.99 mA$$

the allowed input range → [V_L to V_R] [after that both the mosfet get out of saturation region]

$V_{in1} - V_{in2}$

$V_{in1} - V_{in2}$ @ V_R is when

$I_{d1} = I_{SS}$

$I_{d2} = 0$

$V_S = V_{in1} - V_{GS1}$

$V_S = V_{in2} - V_{GS2}$

$V_{in1} - V_{GS1} = V_{in2} - V_{GS2}$

$V_{in1} - V_{in2} = V_{GS1} - V_{GS2}$

$V_{in2} = -V_{in1}$

$\therefore \; 2V_{in} = V_{GS1} - V_{GS2}$

$\therefore$ when $I_{d2} = 0$ $\quad V_{GS2} = V_{th}$

$$I_{d1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS1} - V_{th})^2$$

$$V_{GS1} = \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}(W/L)}} + V_{th}.$$

$$\therefore \; \boxed{2V_{in} = \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}(W/L)}}}$$

$$V_{in} = \frac{1}{2}\sqrt{\frac{2 \times 0.99 \times 10^{-3}}{100.783 \times 10^{-3}}}.$$

$$V_{in} = \frac{1}{2} \times 0.14.$$

$$V_{in} = 0.07 V.$$

$$V_{in} = 70mV$$

Max input signal should have a peak of 70mV

Beyond that the mosfet goes out of saturation region [ie they go to cut off region]

for output swing

$V_{output\ swing} = V_{o1} - V_{o2}$

as $V_{in2} = -V_{in1}$

$\therefore \; V_{o2} = -V_{o1}$

$V_{od} = V_{o1} - V_{o2}$

$= 2V_o$

$V_{o1} = V_{DD} - I_{D1}R_{DD}$

$V_{o2} = V_{DD} - I_{D2}R_{DD}$

$V_{o1} - V_{o2} = -R_D(I_{D1} - I_{D2})$

$$V_{in1} - V_{in2} = V_{GS1} - V_{GS2}$$

$$= \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}(\frac{W}{L})}} + \cancel{V_{th}} - \sqrt{\frac{2I_{D2}}{\mu_n C_{ox}(\frac{W}{L})}} - \cancel{V_{th}}$$

$$= \sqrt{\frac{2}{\mu_n C_{ox}(\frac{W}{L})}}\left[\sqrt{I_{D1}} - \sqrt{I_{D2}}\right]$$

$$(V_{in1} - V_{in2})^2 = \frac{2}{\mu_n C_{ox}(\frac{W}{L})}\left[\underbrace{I_{D1} + I_{D2}}_{I_{SS}.} - 2\sqrt{I_{D1}I_{D2}}\right]$$

$$(V_{in1} - V_{in2})^2 = \frac{2}{\mu_n C_{ox}(\frac{W}{L})}\left[I_{SS} - 2\sqrt{I_{D1}I_{D2}}\right]$$

$$2\sqrt{I_{D1}I_{D2}} = -\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})^2 + I_{SS}$$

$$4I_{D1}I_{D2} = \left[I_{SS} - \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})^2\right]^2$$

$$(I_{D1} + I_{D2})^2 - (I_{D1} - I_{D2})^2 = \left[I_{SS} - \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})^2\right]^2$$

$$\cancel{I_{SS}^2} - (I_{D1} - I_{D2})^2 = \cancel{I_{SS}^2} - 2\cdot\frac{1}{2}\mu_n C_{ox}\frac{W}{L} \times I_{SS}(V_{in1} - V_{in2})^2 + (V_{in1} - V_{in2})^4 \frac{1}{4}\left(\mu_n C_{ox}\frac{W}{L}\right)^2$$

$$(I_{D1} - I_{D2})^2 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})^2 - (V_{in1} - V_{in2})^4 \frac{1}{4}\left(\mu_n C_{ox}\frac{W}{L}\right)^2$$

$$(I_{D1} - I_{D2})^2 = \frac{1}{4}\left[\mu_n C_{ox}\frac{W}{L}\right]^2 (V_{in1} - V_{in2})^2 \left[\frac{4I_{SS}}{\mu_n C_{ox}(\frac{W}{L})} - (V_{in1} - V_{in2})^2\right]$$

$$I_{D1} - I_{D2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}(\frac{W}{L})} - (V_{in1} - V_{in2})^2}$$

max. input swing ⇐ $V_{in1} - V_{in2} = 2V_{in} = 2 \times 0.07 = 0.14V.$

$$I_{D1} - I_{D2} = \frac{1}{2} \times 100.783 \times 10^{-3} \times 0.14\sqrt{\frac{4 \times 0.99 \times 10^{-3}}{100 \times 10^{-3}} - (0.14)^2}$$

$$= \frac{1}{2} \times 100.783 \times 10^{-3} \times 0.14 \times 0.14.$$

$$= 0.987 \times 10^{-3} A$$

max current swing ⇐ $I_{D1} - I_{D2} = 0.987 mA$

Output swing.

$$2V_o = |-R_D(I_{D1} - I_{D2})|$$

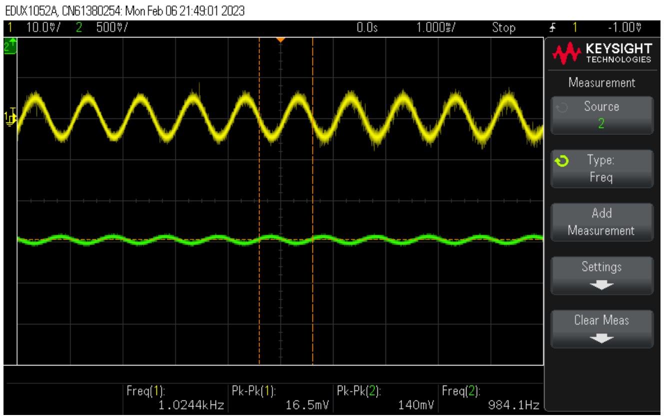
$$V_o = |-6 \times 10^{3} \times 0.987 \times 10^{-3}|$$

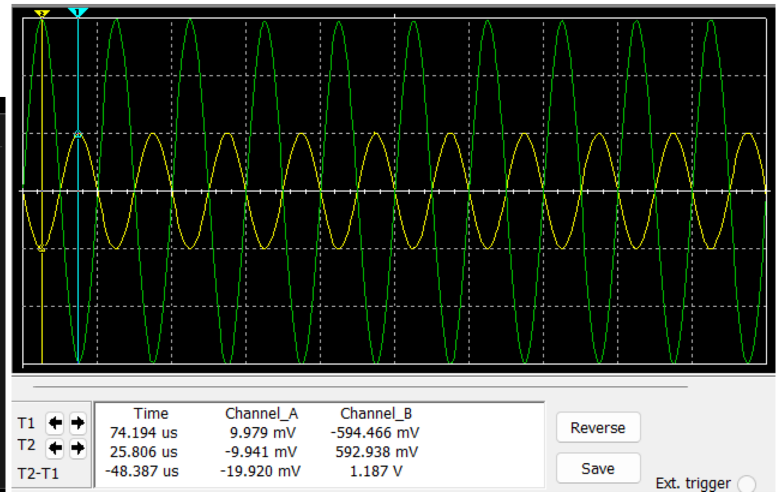
$$V_o = \frac{5.922}{2}$$

$$V_o = 4.96V$$

Max output swing we can get = 4.96V

RESULTS:



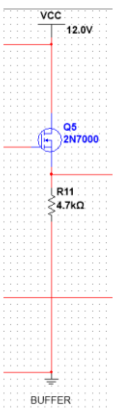


HARDWARE RESULTS

MULTISIM RESULTS

- **BUFFER:**

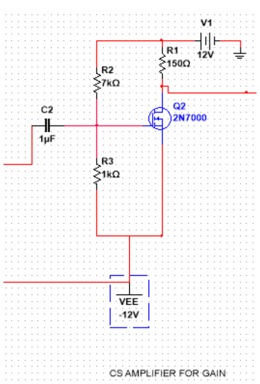
CIRCUIT TOPOLOGY USED: (Source Follower)



A buffer is basically used for impedance matching. The output impedance of a pre-amp must be matched with the input impedance of the CS-amplifier. So, when we use a buffer between pre-amp and CS-amp, the output impedance of pre-amp becomes infinite and the input impedance of CS-amp is also infinite. Thus, we use a source follower as a buffer which is built using a MOSFET here

- **COMON SOURCE (CS) -AMPLIFIER:**

CIRCUIT TOPOLOGY USED:



We use a CS-amplifier to provide the rest of the gain required. We provided a gain of 60 in pre-amp and so here, we are aiming for a gain of 17. We provided only 60 gain in pre-amp because if we give high gain here, then input for CS-amplifier will become very high and we will not be able to do small signal analysis for that.

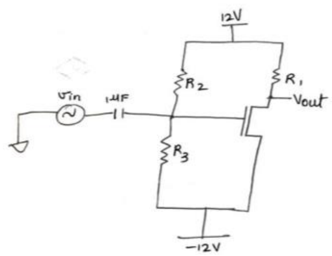
The condition to do small signal analysis is:

$$v_{in} \leq 2 * v_{overdrive}$$

<u>RESISTOR VALUE CALCULATIONS:</u>

Gain Expected: 17

Circuit Architechture:



R2 & R3 are used to give the required biasing

$V_{TH} = 2V$

$K = 100.783 \times 10^{-3}$

$V_S = -12$

-12V

Conditions:

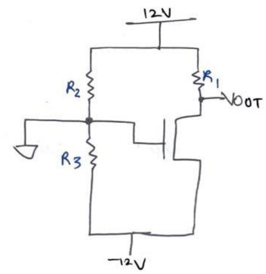
$V_{GS} \geq V_{TH}$

$V_G - V_S \geq 2$

$V_G \geq 2 + V_S$

$\boxed{V_G \geq -10}$ — ①

Large Signal model



② Condition for Saturation:

$V_{DS} \geq V_{GS} - V_{TH}$

$V_D \geq V_G - 2$

$V_G \leq V_D + 2$

now, as gain = 17, & max input we can get = 10m × 60 = 600mV, so

$V_G \leq$

$V_D = gain \cdot v_{in}$

so, $V_D \leq 10.2V$, so

$\boxed{V_G \leq 12.2V}$ — ②

From ① & ②,

$-10 \leq V_G \leq 12.2V.$

Let $V_G = -9V$. so,

$$\frac{12 - V_G}{R_2} = \frac{V_G + 12}{R_3}$$

Let $R_2 = 1k\Omega$, then

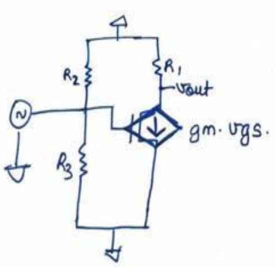
$7R_3 = R_2$

$\Rightarrow \boxed{\begin{array}{l} R_2 = 7k\Omega \\ R_3 = 1k\Omega \end{array}}$ $\boxed{V_G = -9V}$

so, we want 17 gain,

$\boxed{17 = -gm \cdot R_1}$ —③

Small Signal



$v_{out} = -gm \cdot v_{gs} \cdot R_1$

$v_S = 0$, so

$v_{out} = -gm \cdot v_g \cdot R_1$

$v_{out} = -gm \cdot v_{in} \cdot R_1$

$\frac{v_{out}}{v_{in}} = \boxed{A_V = -gm \cdot R_1}$

$gm = k \cdot (V_{GS} - V_{TH})$

$= 100.783 \times 10^{-3} \times (-9 + 12 - 2)$

$\boxed{gm = 100.783\, mS}$ — ④

From ③ & ④,

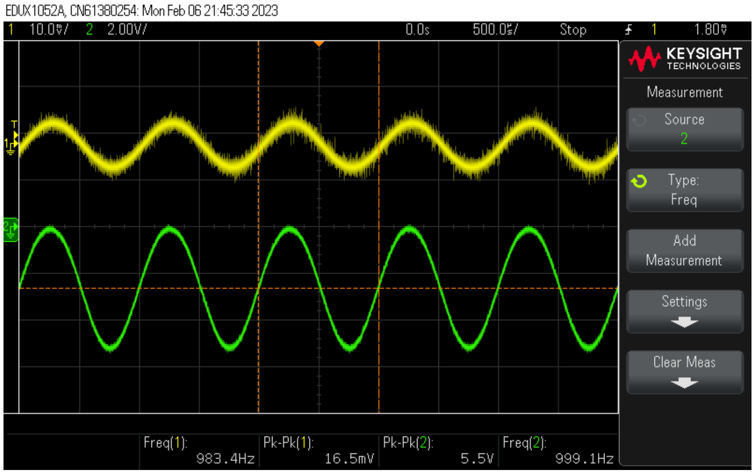
$17 = -gm \cdot R_1.$

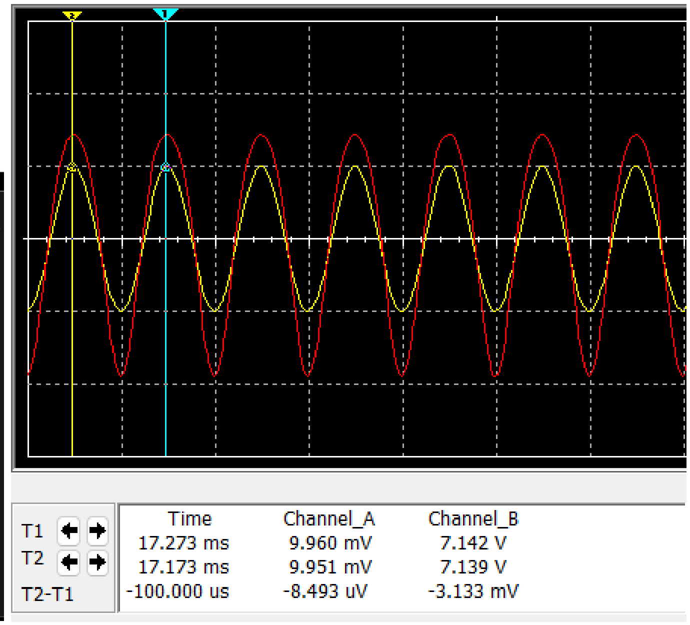
$-17 = -100.783 \cdot R_1$

$\Rightarrow |R_1| = 168.6$

$\boxed{R_1 \approx 170\Omega}$

so, $\boxed{\begin{array}{l} R_1 = 170\Omega \\ R_2 = 7k\Omega \\ R_3 = 1k\Omega \end{array}}$





HARDWARE RESULTS MULTISIM RESULTS

- **FILTER:**

For the next block we built a filter to filter out high frequency noise and tune our signal according to our requirements. We built a band pass filter that allows frequency in the range of 20Hz and 20kHz to pass without attenuation and it attenuates the other frequency. To build this band pass filter we need to build a low pass filter with a cut-off frequency 20kHz and a high pass filter with a cut-off frequency of 20Hz. To decide the values for low pass and high pass filters we do the following calculation.

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

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

LOW PASS FILTER:

$$f_c = 20kHz$$

$$RC = \frac{1}{2\pi \times 20k}$$

$$RC = 7.96 \times 10^{-6}$$

$$R = 8k\Omega \quad C = 1nF$$

HIGH PASS FILTER:

$$f_c = 20Hz$$

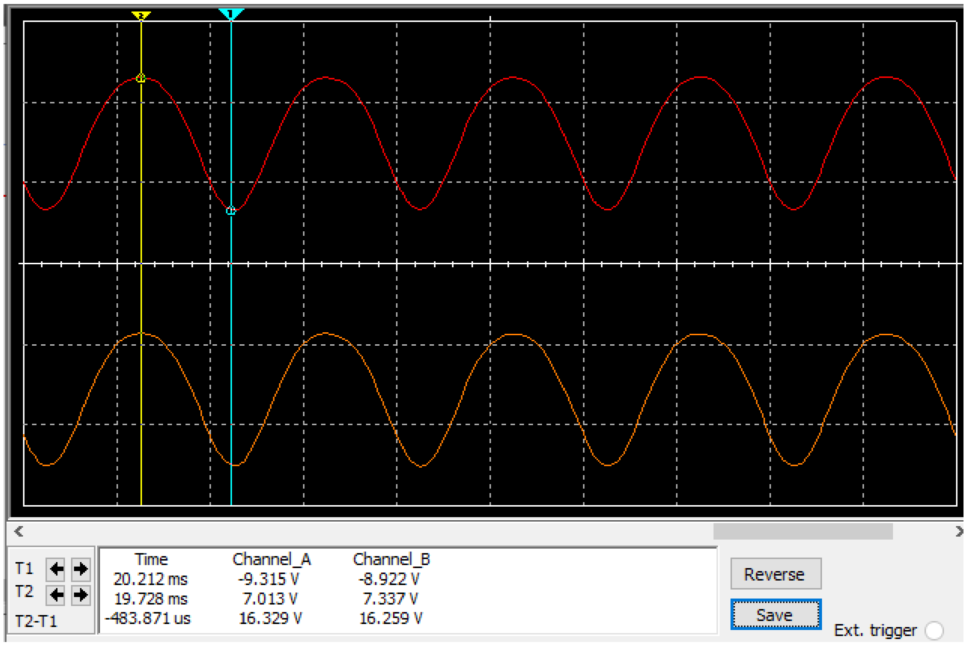
$$RC = \frac{1}{2\pi \times 20}$$

$$RC = 7.96 \times 10^{-3}$$

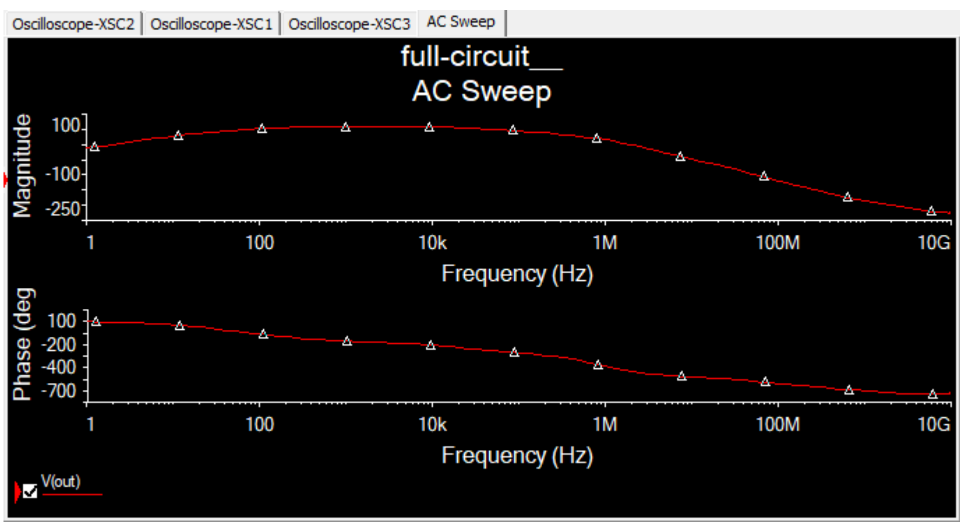
$$R = 200k\Omega \quad C = 40nF$$

We use the above calculated values of resistor and capacitor to build the low pass filter. We also use a opamp buffer to connect the high pass filter with low pass filter as opamp provides an infinite input impedance. We again use this opamp buffer to connect the output from the low pass filter to the next stage, i.e., Power Amplifier, for impedance matching.

MULTISIM RESULTS:



Red waveform denotes the signal given as an input the filter block and Blue waveform denotes the output signal from the filter block

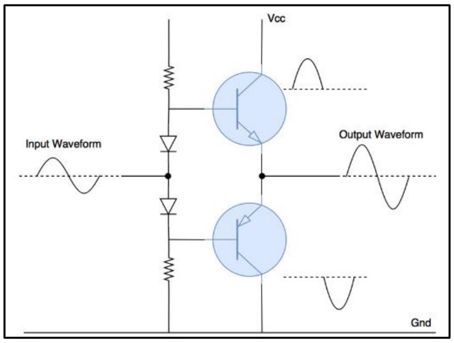


Frequency Response of the filter block

- **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 in 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 differential amplifier and CS amplifier and is sent as input to the power amplifier.

For this power amplifier, we use the AB type topology as shown below.



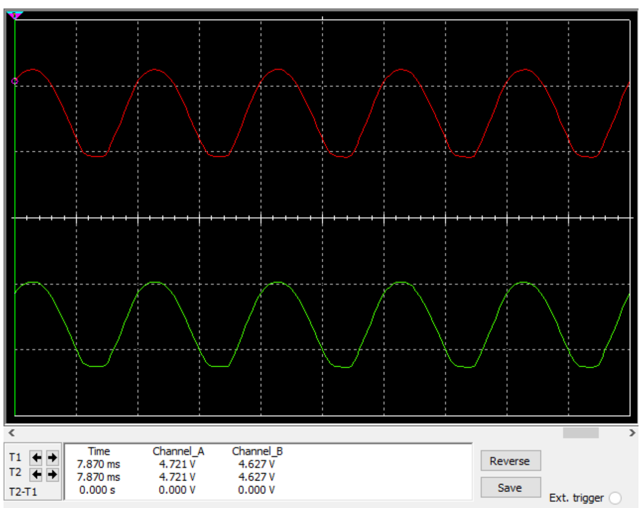
This class of amplifier is a combination of Class A and Class B amplifiers. This class of power amplifier is efficient (unlike class A) and reduces the problem of distortion of the signal at the crossover region (as seen in class B amplifier).

For this topology, we use two transistors, one npn type and other pnp type. Two forward biased diodes are connected in series to control the variation of V_{BE} (emitter-base voltage).

The resistors are connected in series with each diode. This type of circuit operates even for small power inputs. Because the class A amplifier operated for small current outputs and Class B operates for high current outputs. This is achieved by pre-biasing the two transistors in the output stage of the amplifier circuit (by use of diodes). For high input currents one of the two transistors is switched on and the other is off (for positive input cycle npn transistor is on and for negative input cycle pnp is switched on). Ans for the low input signal both the transistors are on due to pre-biasing of the transistor.

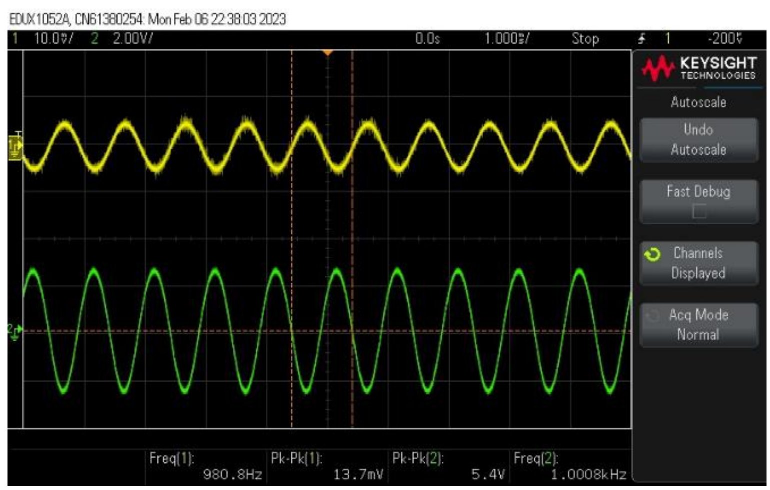
We feed the output from the filter block to this power amplifier after passing it through a coupling capacitor to remove any dc biasing if any. The output of this power amplifier is applied to the speaker which has a input impedance of approximately 10ohms. The average power obtained at the output load is approximately 2.5W which is enough to drive the speaker.

MULTISIM RESULTS:



Red waveform is the output from the filter (input given to the power amplifier) and the green waveform is the final output from the power amplifier across the speaker load

HARDWARE RESULTS:



Yellow waveform is the input signal given (10mVpp) to this audio amplifier and the green waveform is the output signal received from the power amplifier across the speaker.