Basic Electronics

Project Report
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Aim: To design a narrow bandpass filter to meet the specific requirements.

Values assigned:

The values of frequencies assigned according to my roll number is as follows:

1. f_1 => E_4 = 329.63 Hz
2. f_2 => F_4 = 349.23 Hz
3. f_3 => G_4 = 392 Hz
4. f_4 => A_4 = 440 Hz
5. f_5 => B_4 = 493.88 Hz
6. f_6 => C_5 = 523.25 Hz
7. f_7 => D_5 = 587.33 Hz

Expected output:

For a sinusoidal ac input voltage of 1 V:

- the output should be (close to) 1 V at the frequency f4, and
- the output should be less than 0.75 V at frequencies f3 and f5

Files:

The input and output audio (.wav) files are in "audio" folder. The Bandpass filter and the circuit to generate input audio file is in "circuits" folder. The circuits are in ".asc" format.

Circuit for generating input audio:

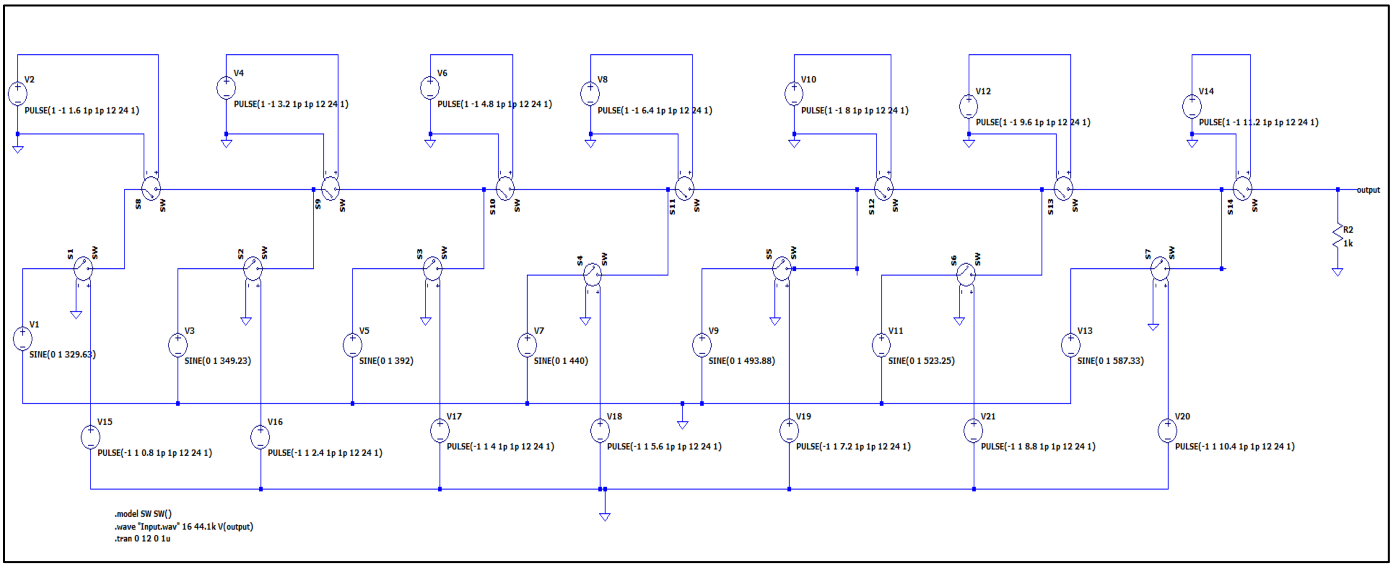


Figure 1

Block Diagram of the Filter Circuit:

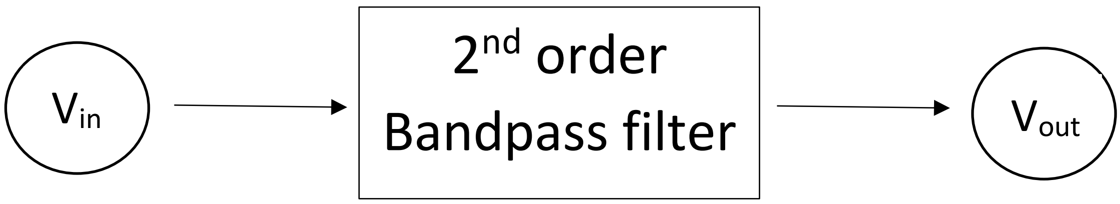


Figure 2

Bandpass Filter Circuit:

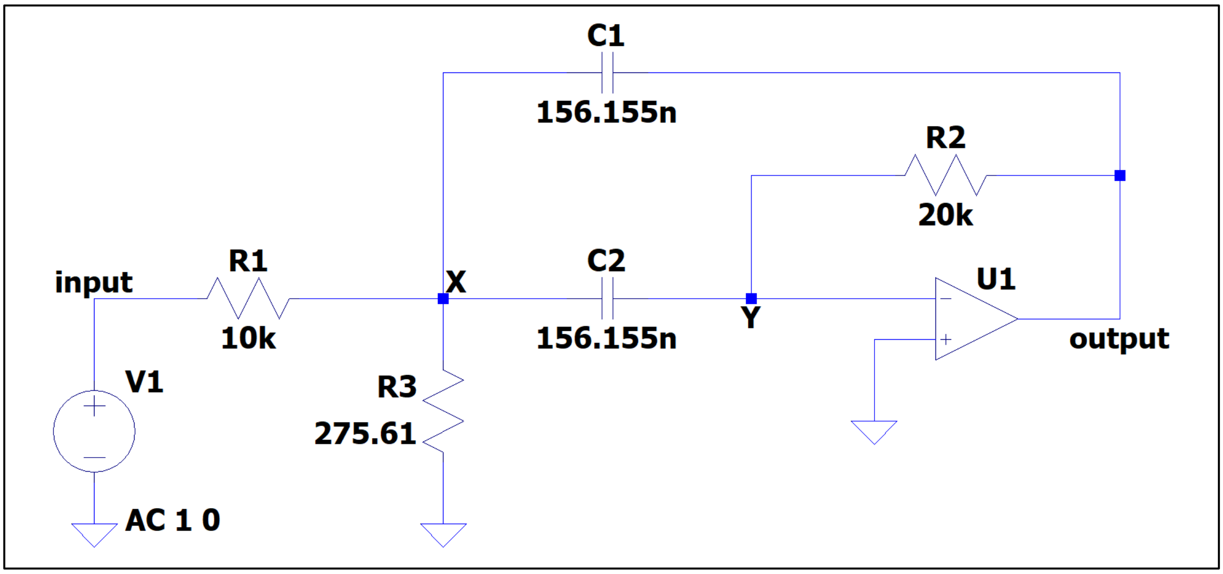


Figure 3

Derivation of transfer function:

Consider the Filter as shown in the Figure 3:
Here,

- R1 = 10k ohms.
- R2 = 20k ohms.
- R3 = 275.61 ohms.
- C1 = 156.155 x 10^{-9} F.
- C2 = 156.155 x 10^{-9} F.

This is a Multiple Feedback Bandpass Filter. The transfer function of the filter is of the form

$$H(s) = -H_o \frac{\frac{\omega_o}{Q} s}{s^2 + \frac{\omega_o}{Q} s + \omega_o^2}$$

Where ω_o is the peak frequency, H_o is the gain at ω_o and Q is the quality factor of the circuit.
The filter in figure 3 has three resistors R1, R2 and R3 and two capacitors C1 and C2 along with an opamp.

Here, $V_Y = 0$ as $V_+ = V_- = 0$.

<u>We will use nodal analysis to derive the equation.</u>
<u>Consider node Y:</u>

Using KCL, we can write:

$$\frac{V_Y - V_X}{\frac{1}{sC_2}} + \frac{V_Y - V_{out}}{R_2} = 0$$

By substituting, $V_Y = 0$ we get

$$-sC_2V_X + \frac{-V_{out}}{R_2} = 0$$

Thus,

$$V_X = \frac{-V_{out}}{R_2C_2s}$$

<u>Now, consider node X:</u>
Using KCL, we can write:

$$\frac{V_X - V_{in}}{R_1} + \frac{V_X}{R_3} + \frac{V_X - V_Y}{\frac{1}{sC_2}} + \frac{V_X - V_{out}}{\frac{1}{sC_1}} = 0$$

By substituting, $V_Y = 0$ and rearranging the terms, we get:

$$V_X\left(\frac{1}{R_1} + \frac{1}{R_3} + sC_1 + sC_2\right) - sC_1V_{out} = \frac{V_{in}}{R_1}$$

By substituting the value of V_X, we get:

$$\frac{-V_{out}}{R_2C_2s}\left(\frac{1}{R_1} + \frac{1}{R_3} + sC_1 + sC_2 + C_1C_2R_2s^2\right) = \frac{V_{in}}{R_1}$$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{\frac{-R_2C_2s}{R_1}}{\frac{R_1 + R_3}{R_1R_3} + (C_1 + C_2)s + C_1C_2R_2s^2}$$

By dividing the numerator and denominator by $C_1C_2R_2$, we get:

$$\frac{V_{out}}{V_{in}} = \frac{\frac{-s}{R_1C_1}}{\frac{R_1 + R_3}{R_1R_2R_3C_1C_2} + \frac{(C_1 + C_2)s}{C_1C_2R_2} + s^2}$$

Hence the transfer function of the filter is given by

$$H(s) = \frac{\frac{-1}{R_1C_1}s}{s^2 + \frac{\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}{R_2}s + \frac{R_1/R_3 + 1}{R_1R_2C_1C_2}}$$

To design the filter, we can assume $C_1 = C_2 = C$ to make the calculations simpler.

Let us consider $C_1 = C_2 = C$.
The transfer function is now given by:

$$H(s) = \frac{\frac{-1}{R_1C}s}{s^2 + \frac{2}{R_2C}s + \frac{R_1/R_3 + 1}{R_1R_2C^2}}$$

Comparing with $H(s) = -H_o \frac{\frac{\omega_o}{Q}s}{s^2+\frac{\omega_o}{Q}s+\omega_o^2}$, we now get the following equations:

$$\omega_o = \frac{1}{C}\sqrt{\left(\frac{\frac{R_1}{R_3}+1}{R_1 R_2}\right)} \qquad Q = \frac{1}{2}\sqrt{\left(\frac{R_1}{R_3}+1\right)\left(\frac{R_2}{R_1}\right)} \qquad H(\omega_o) = H_o = -\frac{R_2}{2R_1}$$

Thus, one can now choose values of R_1, R_2 and R_3 as per Q and H_o and ω_o value to get the desired bandpass filter.

Choosing R_1 = 10k ohms, we get R_2 = 20k ohms (from $H_o = -\frac{R_2}{2R_1}$).

Substituting the values in $Q = \frac{1}{2}\sqrt{\left(\frac{R_1}{R_3}+1\right)\left(\frac{R_2}{R_1}\right)}$, we get R_3 as 275.61 ohms where Q is 4.3188 (Q = f_o/Bandwidth).

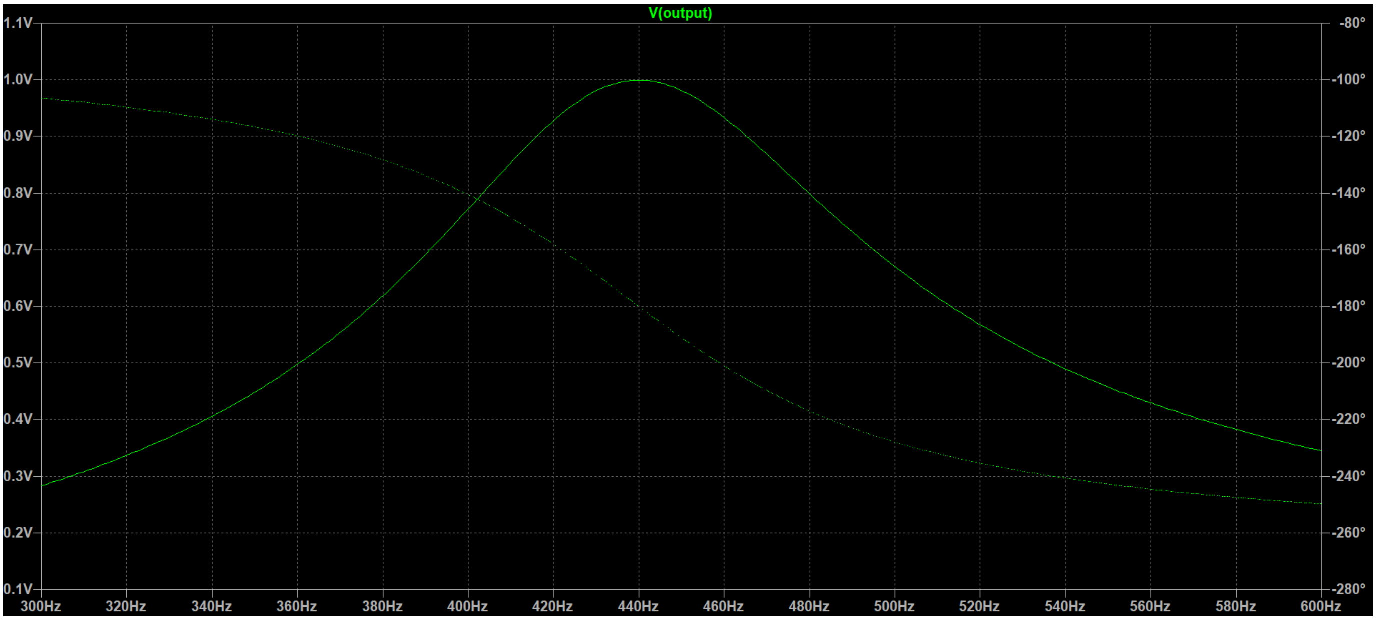
Substituting the value in $\omega_o = \frac{1}{C}\sqrt{\left(\frac{\frac{R_1}{R_3}+1}{R_1 R_2}\right)}$, we get C = 156.155 nF.

Substituting the values of resistors and capacitors, the transfer function of the bandpass filter is:

$$H(\omega j) = \frac{-640.389\omega j}{-\omega^2 + 640.389\omega j + 7644872.23}$$

Results:

1. Frequency and phase response of the bandpass filter:



2. Input and output audio plots: