Name: Shazim Chaudhary   31

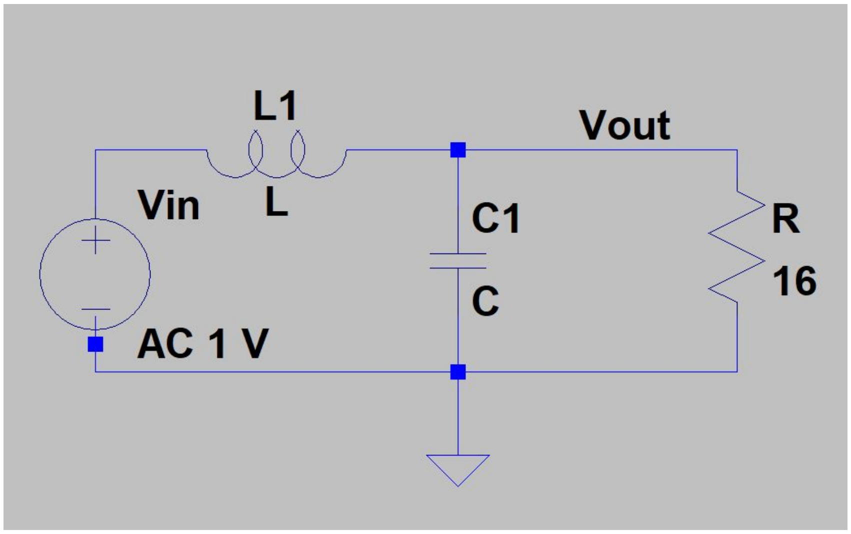
RUID: 171002730

PEE II Design Project - 332:222 - Spring 2018

Design Type A

1. Transfer Functions: $H(s) = \frac{V_{out}}{V_{in}}$

Low Pass Filter (Woofer) :



KCL at Vout:

$$\frac{V_{out} - V_{in}}{L_1 s} + \frac{V_{out}}{R} + V_{out} C_1 s = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{L_1 s} / \left[\frac{1}{L_1 s} + \frac{1}{R} + C_1 s \right]$$

$$H(s) = \frac{1}{L_1 s}\left[\frac{R L_1 s}{R + L1s + C1L1s^2 R} \right]$$

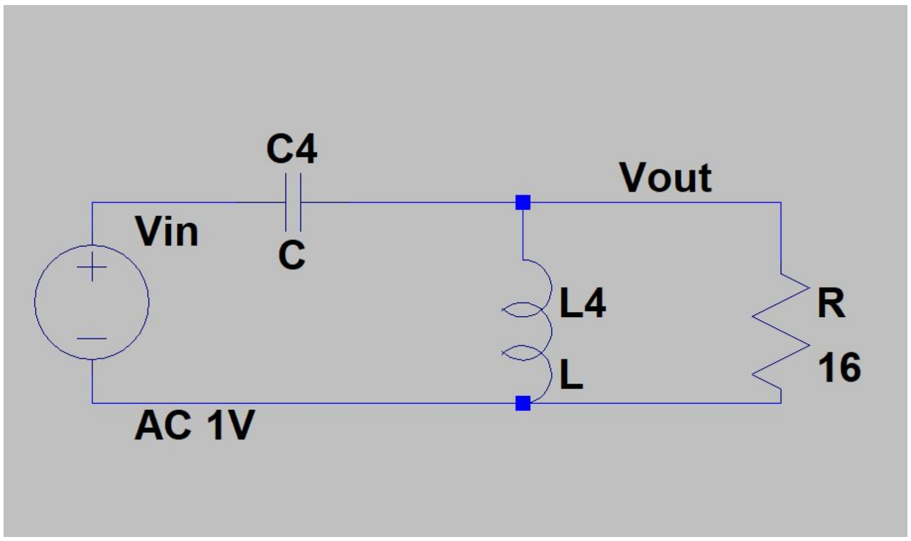
$$H(s) = \frac{R}{R + L1s + C1L1s^2 R}$$

$$H(s) = \frac{1/(L1C1)}{s^2 + s/(RC1) + 1/(L1C1)}$$

$$H(s) = \frac{\omega_0{}^2}{s^2 + 2\alpha s + \omega_0{}^2}$$

where $\omega_0{}^2 = 1/(L1C1)$, $R = 16\ \Omega$, & $\alpha = 1/(2RC1)$

High Pass Filter (Tweeter):



KCL at Vout:

$$\frac{(Vout - Vin)}{1/C4s} - \frac{(0 - Vout)}{L4s} - \frac{(0 - Vout)}{R} = 0$$

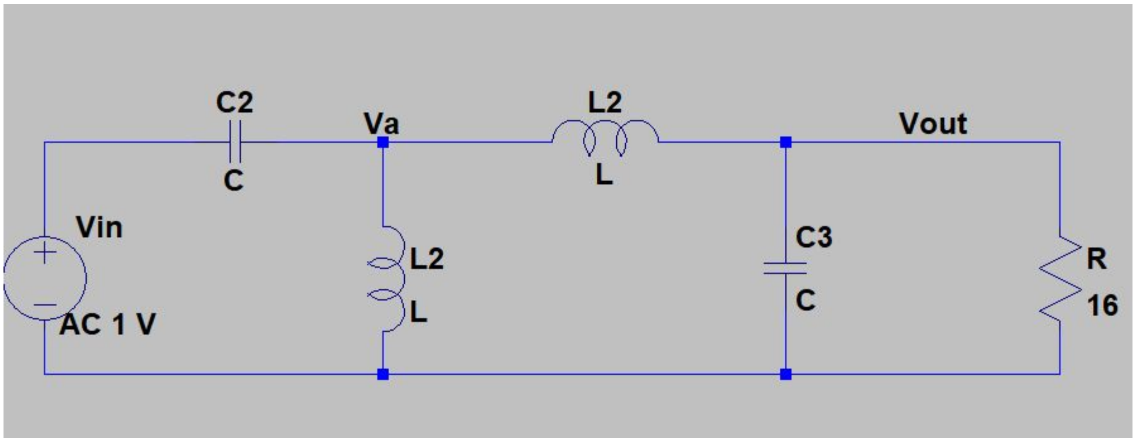
$$C4s * Vout - C4s * Vin + \frac{Vout}{L4s} + \frac{Vout}{R} = 0$$

$$\frac{Vout}{Vin} = \frac{C4s}{[C4s + 1/L4s + 1/R]}$$

$$H(s) = \frac{s^2}{s^2 + s/(RC4) + 1/(L4C4)} = \frac{s^2}{s^2 + 2\alpha s + \omega_0{}^2}$$

where $\omega_0{}^2 = 1/(L4C4)$, $R = 16\ \Omega$, & $\alpha = 1/(2RC4)$

Band Pass Filter (Mid-Range):



KCL at Va:

$$\frac{Va}{L2s} + \frac{Va - Vin}{1/C2s} - \frac{Vout - Va}{L3s} = 0$$

KCL at Vout:

$$\frac{Vout}{R} + \frac{Vout}{1/C3s} + \frac{Vout - Va}{L3s} = 0$$

Using MATLAB to solve for H(s) = Vout/Vin:

```
syms Vin Va Vout C2 C3 L2 L3 R s
eq1 = Va/(L2*s) + (Va-Vin)*C2*s + (Va - Vout)/(L3*s) == 0;
eq2 = (Vout-Va)/(L3*s) + Vout*C3*s + Vout/R == 0;

eqns = [eq1, eq2];
sol = solve(eqns, [Vin, Vout]);

H(s) = sol.Vout/sol.Vin;
```

H(s) =

$$\frac{\frac{s^2}{L_3C_3}}{\left(s^4 + s^3\left(\frac{1}{16C_3}\right) + s^2\left(\frac{1}{L_2C_2} + \frac{1}{L_3C_2} + \frac{1}{L_3C_3}\right) + \frac{s}{16C_2C_3}\left(\frac{1}{L_2} + \frac{1}{L_3}\right) + \frac{1}{L_3C_3L_2C_2}\right)}$$

2. Design Type A: Lower Crossover Frequency: 125 Hz,

Upper Crossover Frequency: 2500 Hz

Condition - **Critically Damped**, therefore:

$\alpha^2 = \omega_0{}^2$

Low Pass Filter Design:

$$H(s) = \frac{\omega_0{}^2}{s^2 + 2\alpha s + \omega_0{}^2} = \frac{1/(L1C1)}{s^2 + s/(RC1) + 1/(L1C1)}$$

Condition - **Critically Damped**, therefore:

$\alpha^2 = \omega_0{}^2$

Lower Crossover frequency, **fc = 125 Hz,** therefore:

$\omega_0 = 2\pi f_c = 250\pi \ rad/s$

$\alpha = \omega_0 = 250\pi \ rad/s$

According to **H(s)**:

$\alpha = 1/(2RC1), \ where \ R = 16 \ \Omega$, therefore:

$C_1 = 1/(32\alpha), \ where \ \alpha = 250\pi$

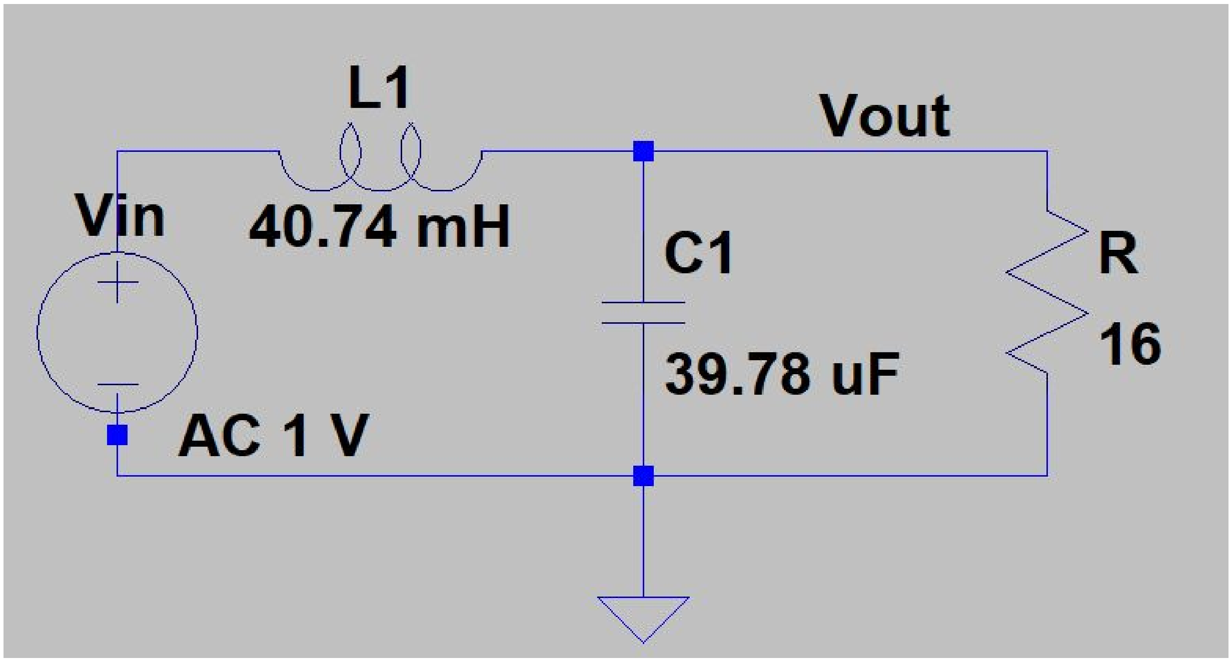
$C_1 = 39.78 \ \mu F$

$\omega_0{}^2 = 1/(L1C1)$

$L_1 = 1/(\omega_0{}^2 C1), \ where \ C1 = 39.78 \ \mu F \ \& \ \omega_0 = 250\pi \ rad/s$

$L_1 = 40.74 \ mH$

Final Low-Pass Filter (Woofer) Design:



High Pass Filter Design:

$$H(s) = \frac{s^2}{s^2 + s/(RC4) + 1/(L4C4)} = \frac{s^2}{s^2 + 2\alpha s + \omega_0^{\,2}}$$

Upper Crossover Frequency: **fc = 2500 Hz**

$\omega_0 = \alpha = 5000\pi \; rad/s$

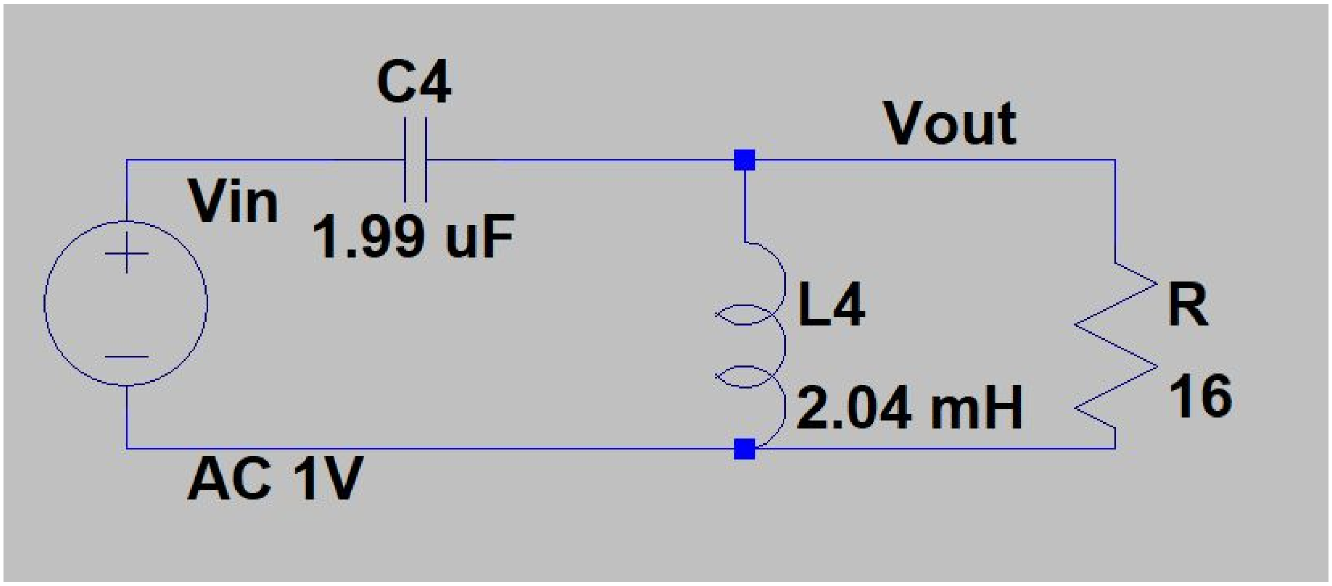
$2\alpha = 1/(16C_4)$

$C_4 = 1/(32\alpha) = 1.99 \; \mu F$

$\omega_0^{\,2} = 1/(L_4C_4)$

$L_4 = 1/(\omega_0^{\,2}C_4) = 2.04 \; mH$

Final High-Pass Filter (Tweeter) Design:



Band-Pass Filter Design:

- Since the band-pass filter is essentially the low pass filter cascaded with the high pass filter, we can use the corresponding inductor and capacitor values to approximate an accurate simulation of the band-pass filter with the desired frequency output. Therefore, we can set the bandpass components to the following:

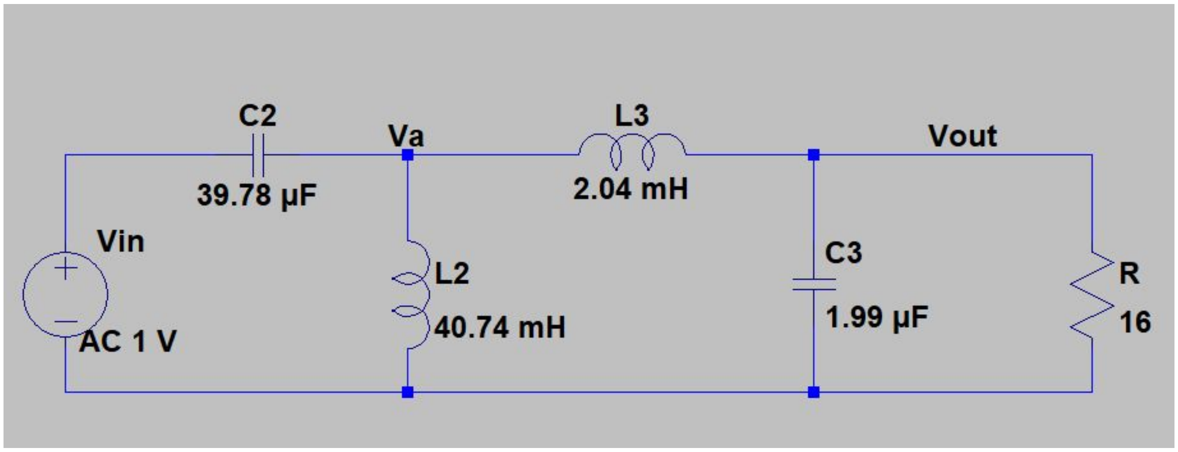
$C_2 = C_1 = 39.78\ \mu F$

$L_2 = L_1 = 40.74\ mH$

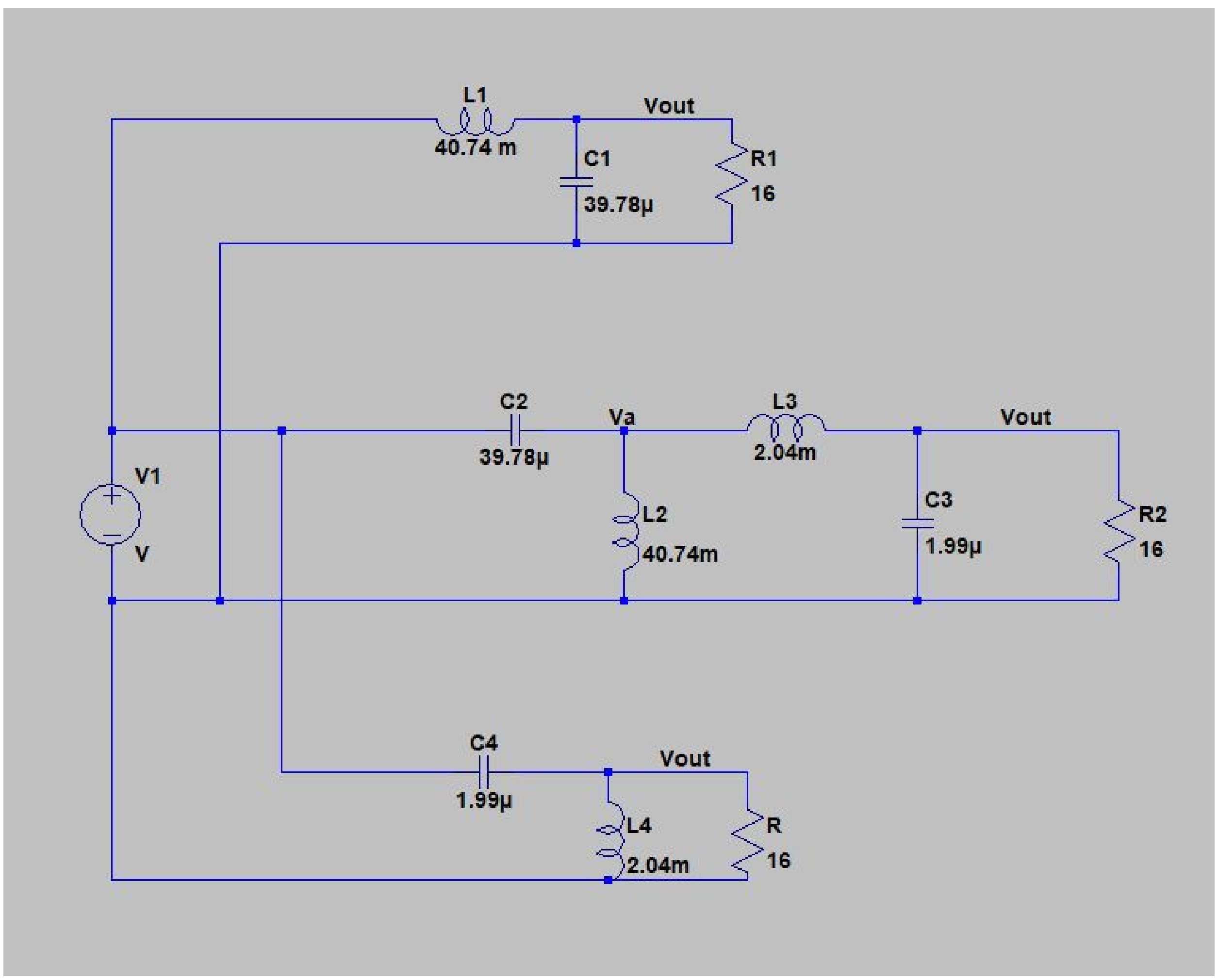
$C_3 = C_4 = 1.99\ \mu F$

$L_3 = L_4 = 2.04\ mH$

Final Band-Pass Filter (Mid-range) Design:

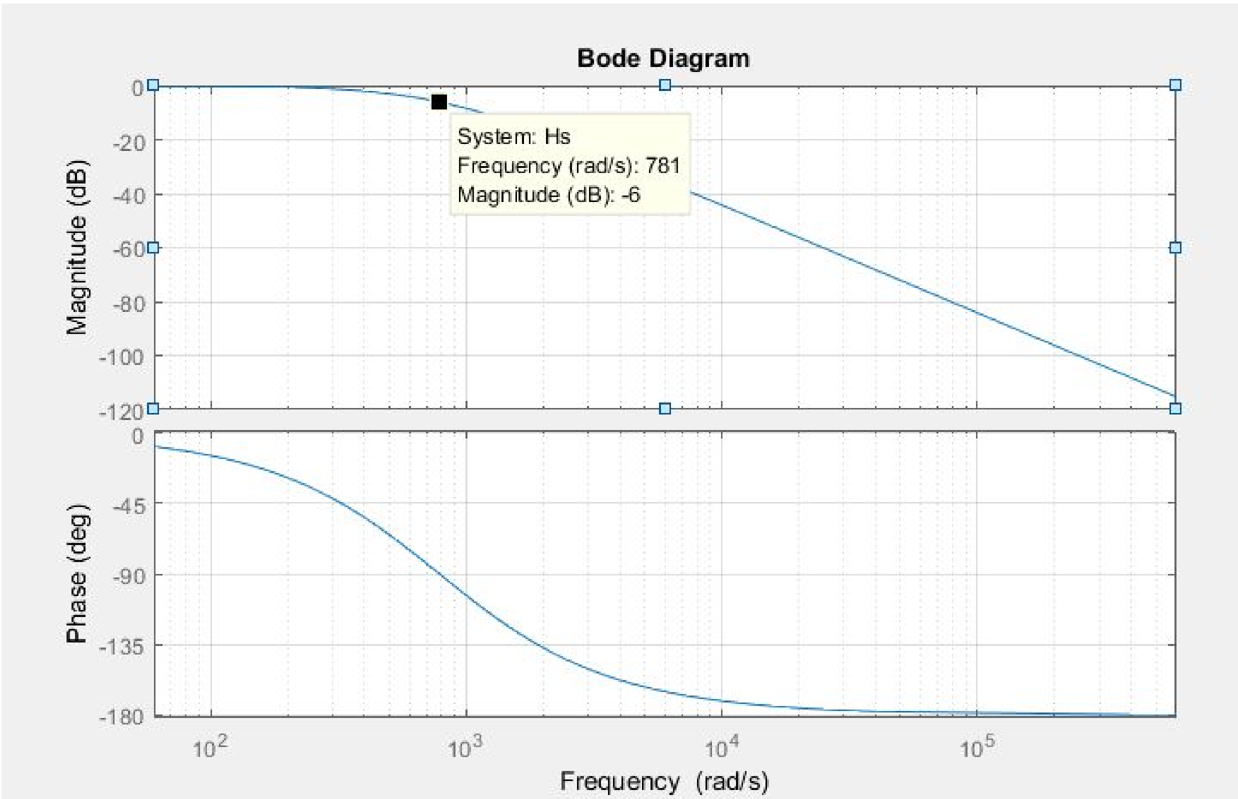


FINAL FULL SPEAKER DESIGN:



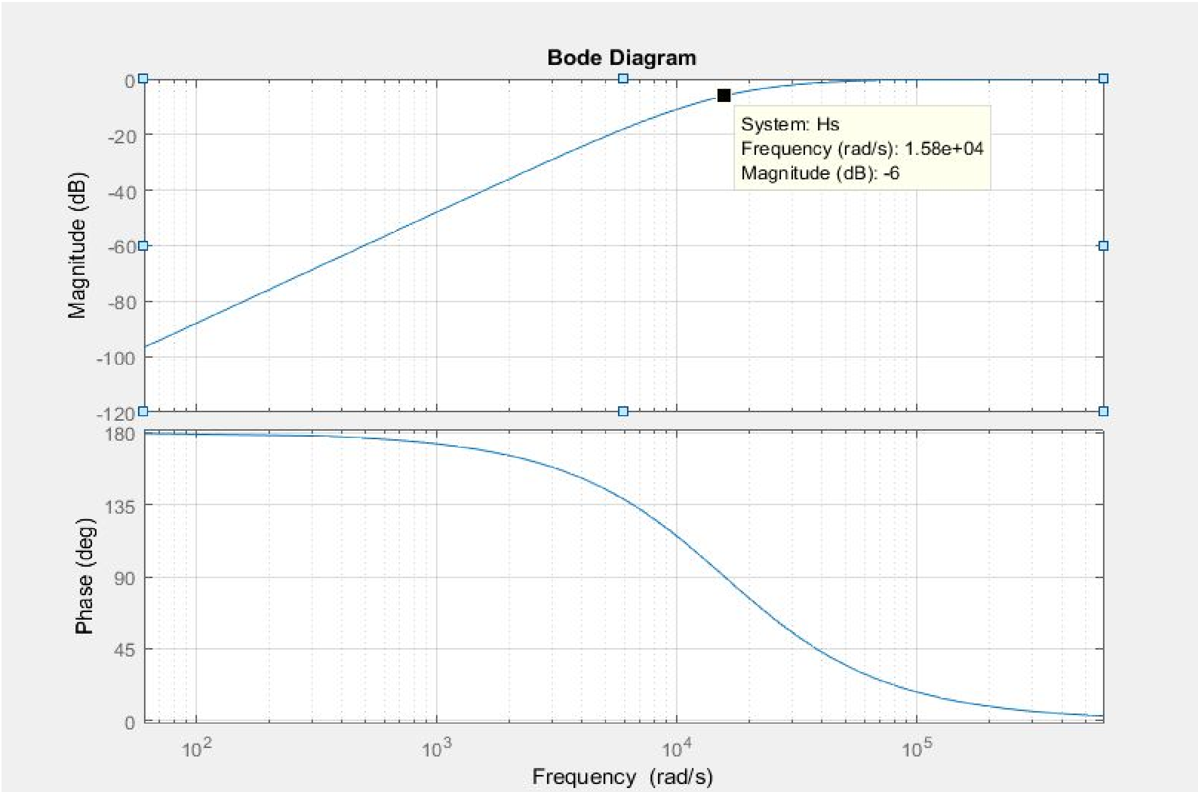
3. MATLAB Bode Plots using tf() and bode().

Low-Pass Filter (Woofer) Bode Plot:



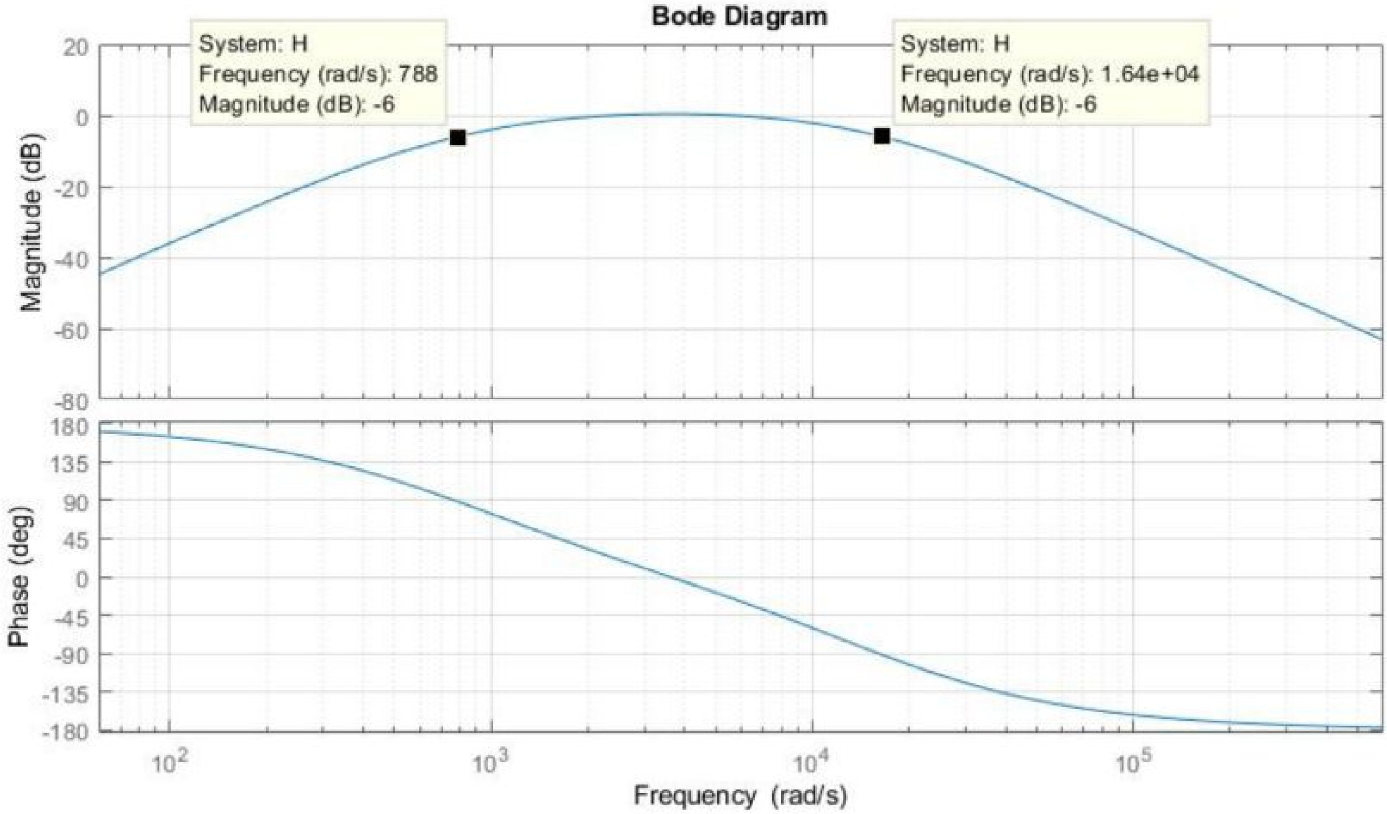
As indicated by the highlighted point on the magnitude Bode plot, the -6dB frequency came out to be 781 rad/s which is approximately equal to 785 (~250pi) - 4. This is well with in the provided lower cutoff frequency and therefore the component values found are accurate enough. The phase plot accurately displays the phase change of the low pass filter going from 0 to 180 degrees over the increments of frequency.

High-Pass Filter (Tweeter) Bode Plot:



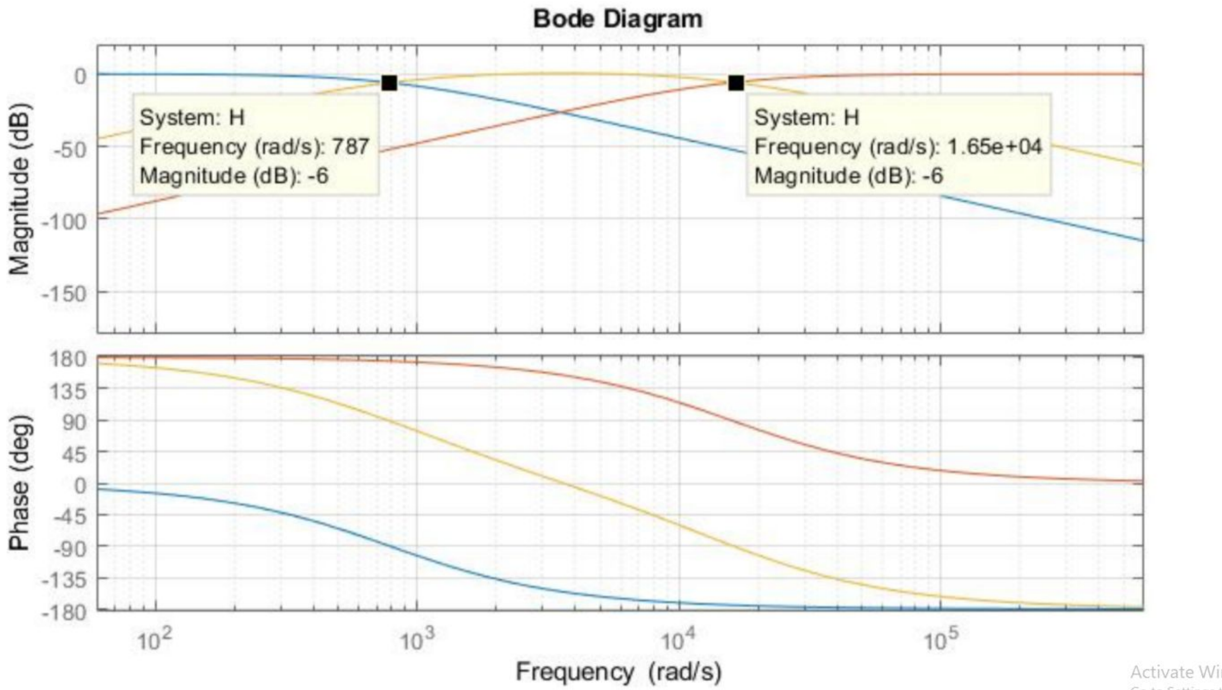
As indicated by the upper cutoff point highlighted in the magnitude plot, the -6dB frequency came out to be 1.58*10^4 rad/s which is approximately equal to the upper cutoff frequency provided in the project manual: 2500*pi rad/s. This indicates that the component values found for the high pass filter are accurate enough and simulate the tweeter close to our desired frequency output. The phase plot accurately displays the phase change (opposite to the low pass filter) going from 180 to 0 degrees over the increments of frequency.

Band-Pass Filter (Midrange) Bode Plot:



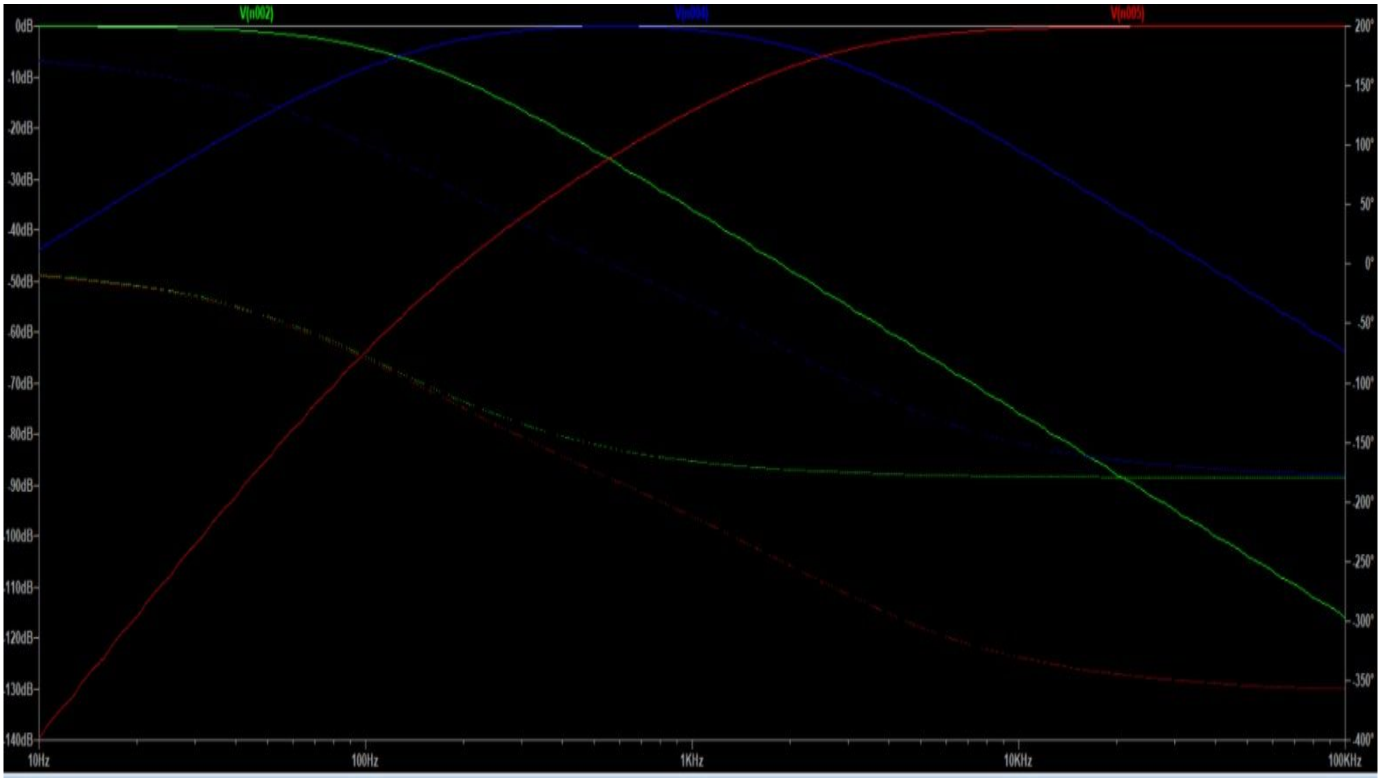
Since the bandpass filter was essentially the low pass filter (woofer) cascaded with the high pass filter (tweeter) to result in a bandpass filter (midrange) that would allow frequencies between the lower cutoff frequency and the upper cutoff frequency to pass, the highlighted points gave us the lower and upper cutoff frequencies approximately the same as those of the low pass and high pass filter. The phase plot is a combination of the phase plots of the low pass and high pass filters where the bandpass filter goes from -180 deg to 180 deg over increments of the frequency.

Full Circuit Bode Plot:



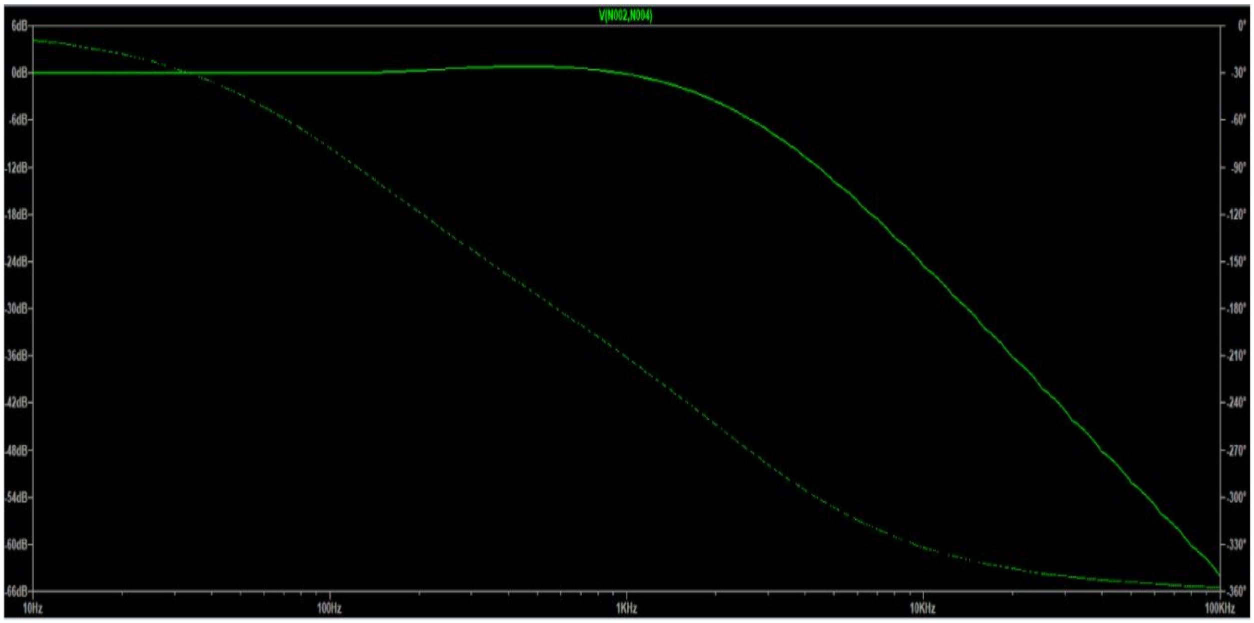
As indicated by the highlighted points, the low pass -6dB frequency and magnitude correspond with the lower bandpass -6dB frequency and magnitude, and the high pass -6dB frequency and magnitude correspond with the upper bandpass -6dB frequency and magnitude. This indicates that the full circuit design works between the 20 Hz and 20 Khz frequencies.

4. Spice Bode Plots:
Full Circuit:



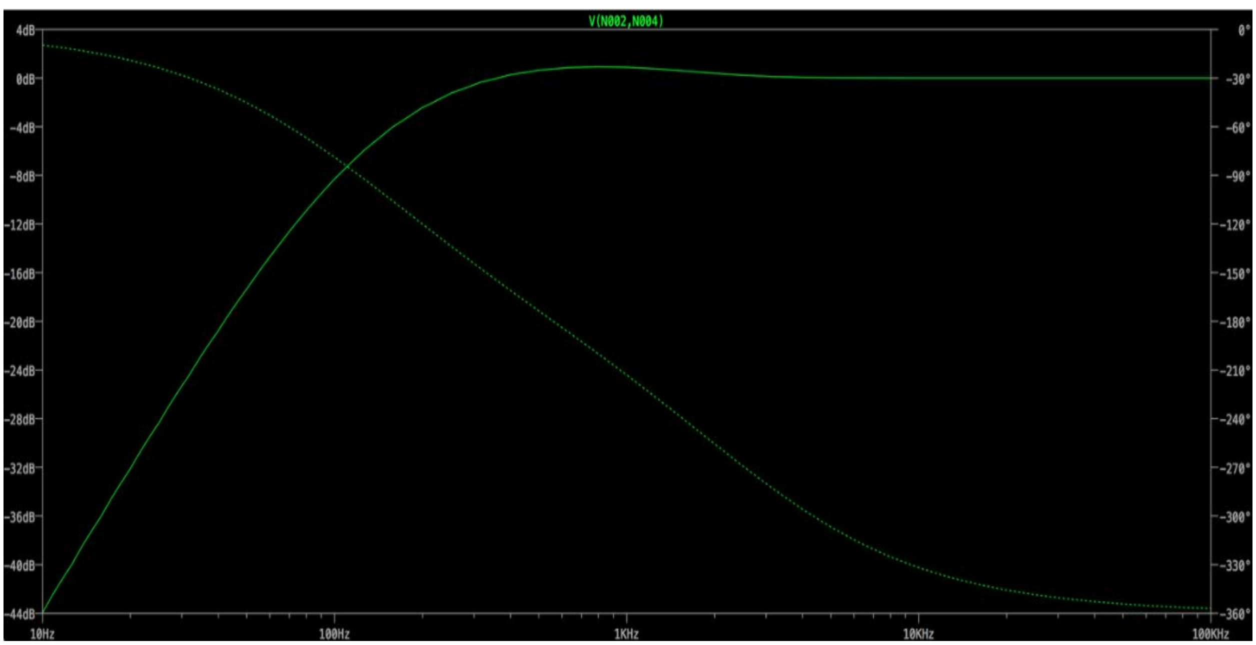
The magnitude transfer function Bode Plot looks a lot similar to the MATLAB magnitude transfer function Bode Plot and so we can conclude that our component values were found optimally and that the circuit is function as it should be.

Low Pass to Band Pass Vout:



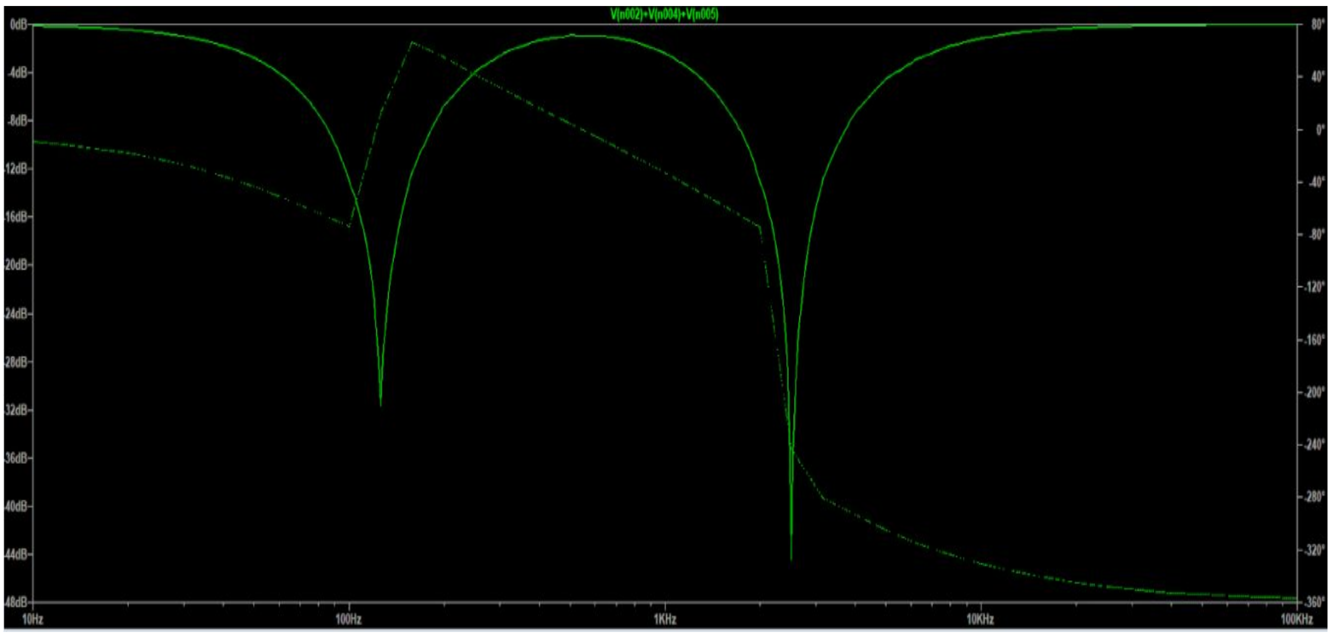
Since the upper cutoff frequency was 2500 Hz we the plot shows that the voltage between the low pass and the bandpass filter was flat from 0 Hz to 2500 Hz.

High Pass to Band Pass Vout:



Similarly, since the lower cutoff frequency was 125 Hz, the plot shows that the output voltage between the high pass and the band pass filter was flat from 125 Hz onwards.

Sum of all Vouts:



The plot shows that the three output voltages added when added together indicate that the speaker circuit is able to output from lower frequencies to the lower cutoff frequency, from the lower cutoff frequency to the upper cutoff frequency and from the upper cutoff frequency to higher frequencies. The low peaks however indicate that at those specific cutoff frequencies, the circuit is not able to output as well.