MMI401 Lab 3

Passive Variable Filters
Loudspeaker Crossovers

In this lab you are going to simulate some common passive filters and plot their frequency responses with a variety of potentiometer (knob) settings. Watch the tutorial video on how to do this - it's not that bad and the resulting plots look really good. In fact, I need them for the updated version of my book so I will select the best looking plots and import your files (you save each plot in a file, I will need those files). I'll also put your name somewhere in the Forward for this help.

Circuit 1: Variable Low Shelving Filter

Use the circuit on Page 90 of the book. Design a Variable Low Shelving Filter to have the following specifications using the 6 design equations:

- +/- 12dB of boost/cut (use -12dB/20 in equation 2. in the book)
- break frequency (fb) = 200Hz
- no resistor values lower than 100 ohms or higher than 1M
- no capacitor values lower than 22pF or higher than 100uF

Because you get to arbitrarily choose the first few component values, you may have to go back and change your choices if your component values are outside the limits.

For this simulation, use the calculated values rather than the nearest standard values on the Wiki.

- Simulate and analyze the filter capturing plots for the following potentiometer percentages:

1,5,10,20,30,40,50,60,70,80,90,95,99

If you want, take even more than that, say in 1% increments between 90 and 99% (the design calls for a log pot, and now you can see why).

- use the A or B bar to show that your break frequency is correct
- use the C-D bars to show that your overall boost/cut range is +/-12dB (about 24 dB total)

Submit your design equations and Schematic and Frequency Response plots (screen captures or WMF files you have imported into Word) for your Lab Report. Make sure you describe and label your figures so the TA gives you full credit.

Circuit 2: Variable High Shelving Filter

Use the circuit on Page 91 of the book. Design a Variable Low Shelving Filter to have the following specifications using the 6 design equations:

- +/- 12dB of boost/cut (use -12dB/20 in equation 2. in the book)
- break frequency (fb) = 6kHz
- no resistor values lower than 100 ohms or higher than 1M
- no capacitor values lower than 22pF or higher than 100uF

Because you get to arbitrarily choose the first few component values, you may have to go back and change your choices if your component values are outside the limits.

For this simulation, use the calculated values rather than the nearest standard values on the Wiki.

- Simulate and analyze the filter capturing plots for the following potentiometer percentages:

1,5,10,20,30,40,50,60,70,80,90,95,99

If you want, take even more than that, say in 1% increments between 90 and 99% (the design calls for a log pot, and now you can see why).

- use the A or B bar to show that your break frequency is correct
- use the C-D bars to show that your overall boost/cut range is +/-12dB (about 24 dB total)

Submit your design equations and Schematic and Frequency Response plots (screen captures or WMF files you have imported into Word) for your Lab Report. Make sure you describe and label your figures so the TA gives you full credit.

Circuit 3: 2-Way Loudspeaker Crossover

Loudspeaker crossovers are one of the applications of Passive EQ circuits still in very widespread use. I would guess something like 95% of loudspeakers use passive crossovers to split the low frequencies (for the woofer) and mid and high frequencies for the midrange driver and tweeters. When choosing the crossover frequency points, you sometimes use the piston frequency calculation for spherical radiation. We'll get to it in (way) more detail in MMI501, but here is a brief excerpt:

Lord Kelvin discovered that a piston radiates spherical waves if the wavelength of the emitted sound is greater than the circumference of the piston. Mathematically for omni-directional radiation,

$$\lambda \geq 2\pi a$$
$$\lambda = \text{ wavelength of frequency emitted} \qquad [1.7]$$
$$a = \text{ piston-radius of driver}$$

The frequency whose wavelength just satisfies [1.7] is called the **piston frequency**. Frequencies at or below the piston frequency will radiate omni-directionally from the piston-head surface. Equation [1.5] can be rewritten for the piston frequency as

$$f_{piston} = \frac{c}{2\pi a}$$
$$where$$
$$c = \text{the velocity of sound} \qquad [1.8]$$

For example, a 12" driver has a piston frequency of about 458 Hz. Below 458 Hz, the piston will radiate spherically. Above the piston frequency, the radiation pattern begins to deviate from spherical.

NOTE: a shortcut when dealing with metric and english units is to use c = 345 m/s (metric) and convert the speaker diameter to a piston radius. An easy approximation is that the piston radius in cm is the same as the diameter in inches. So, a 12" woofer would have a piston radius of 12cm.

One way to choose a crossover frequency (or upper limit on the speaker) is to use this value or a value an octave above it (or so, there are many variations). Let's use the "octave above the piston frequency" to design a crossover. For a 12" woofer that would be 916Hz.

Use the circuit on page 101 of the book but ignore the midrange mart (Cm and Lm); we are designing a 2-way crossover for a loudspeaker with just a woofer and tweeter. For this design:

Woofer:
- Diameter = 12”
- Impedance = 8 ohms

Tweeter:
- Diameter doesn’t matter - we are forced to cross it over at the same frequency as the woofer.
- Impedance = 8 ohms

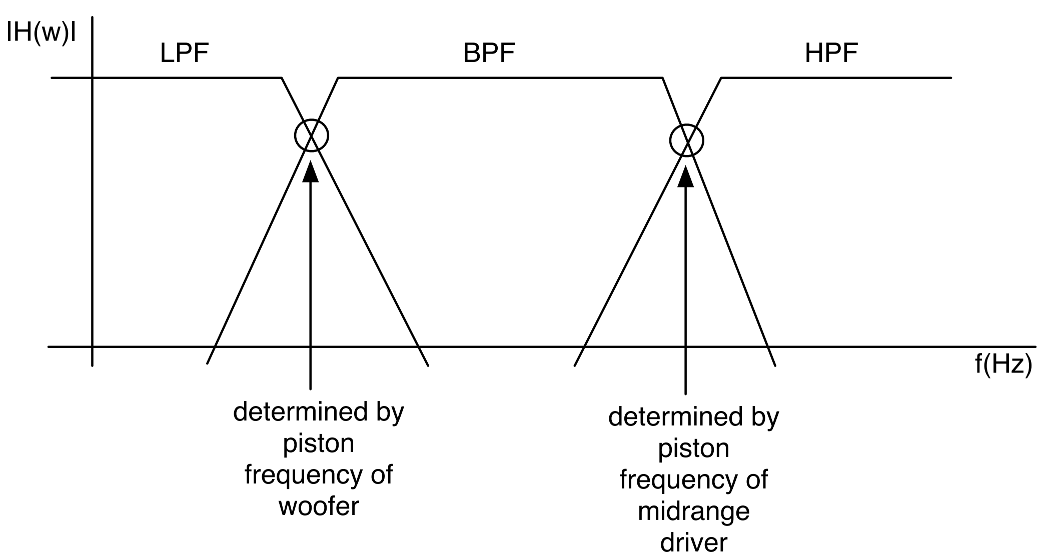
- no capacitor values lower than 22pF or higher than 100uF
- no inductor values lower than 100uH or higher than 500mH

Use the “octave above the piston frequency” rule to design the 2-way crossover. Simulate the crossover in Circuit Maker. Plot both the LPF and HPF together to show the crossover points at -3dB cross correctly.

Submit your design equations and screen-shots of the Schematic and AC Analysis to show your design works properly.

Circuit 4: 3-Way Loudspeaker Crossover

A 3-way crossover adds a bandpass filter to send only mid frequencies to the midrange driver (a speaker or sometimes a horn). In the 3-way crossover, you can use the “octave above the piston frequency” to calculate both your cutoffs:



Design a 3-Way Loudspeaker Crossover for the following speaker system:

Woofer:

- Diameter = 10”
- Impedance = 8 ohms

Midrange Driver:
- Diameter = 2.5”
- Impedance = 8 ohms

Tweeter:
- Diameter doesn’t matter - we are forced to cross it over at the same upper frequency as the midrange driver.
- Impedance = 8 ohms

- no capacitor values lower than 22pF or higher than 100uF
- no inductor values lower than 100uH or higher than 500mH

Simulate your crossover design in Circuit Maker. Plot both the LPF and HPF together to show the crossover points at -3dB cross correctly.

Submit your design equations and screen-shots of the Schematic and AC Analysis to show your design works properly.

Circuit 1

$$R_2 = 10k\Omega$$
$$Ratio = 10^{\frac{-12dB}{20}}$$
$$Ratio = .251$$
$$R_1 = (ratio)(R_2)$$
$$R_1 = (.251)(10k\Omega)$$
$$R_1 = 2512\Omega$$
$$R_3 = (ratio)(R_1)$$
$$R_3 = (.251)(2512\Omega)$$
$$R_3 = 631\Omega$$

$$C_1 = \frac{1}{2\pi f_b R_1}$$

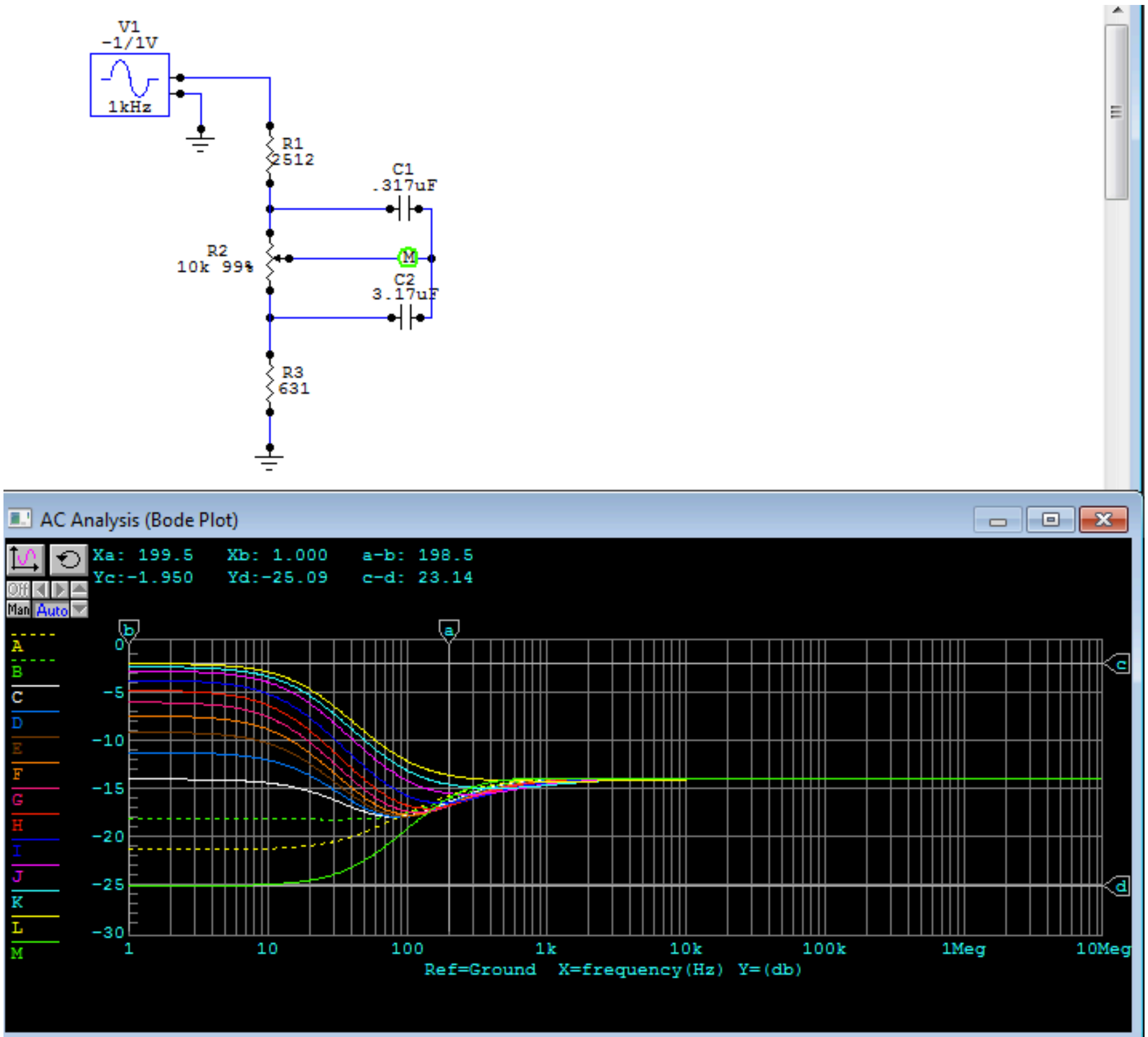
$$C_1 = \frac{1}{2\pi(200Hz)(2512\Omega)}$$

$$C_1 = .317\mu F$$

$$C_2 = 10C_1$$

$$C_2 = 3.17\mu F$$

The overall dynamic range is c-d = 23.14 which is roughly 24dB allowing for some room for calculation error. The break frequency a is 200Hz.


V1
-1/1V
1kHz
R1
2512
C1
.317uF
R2
10k 99%
C2
3.17uF
R3
631
AC Analysis (Bode Plot)
Xa: 199.5
Xb: 1.000
a-b: 198.5
Yc:-1.950
Yd:-25.09
c-d: 23.14
Off
Man
Auto
A
B
C
D
E
F
G
H
I
J
K
L
M
0
-5
-10
-15
-20
-25
-30
1
10
100
1k
10k
100k
1Meg
10Meg
Ref=Ground X=frequency(Hz) Y=(db)

Circuit 2

$$R_2 = 10k\Omega$$
$$R_1 = 5k\Omega$$
$$Ratio = 10^{\frac{-12dB}{20}}$$
$$Ratio = .251$$
$$R_3 = (ratio)(R_1)$$
$$R_3 = (.251)(5k\Omega)$$
$$R_3 = 1255\Omega$$

$$C_1 = \frac{1}{2\pi f_b R_1}$$

$$C_1 = \frac{1}{2\pi(6kHz)(5k\Omega)}$$

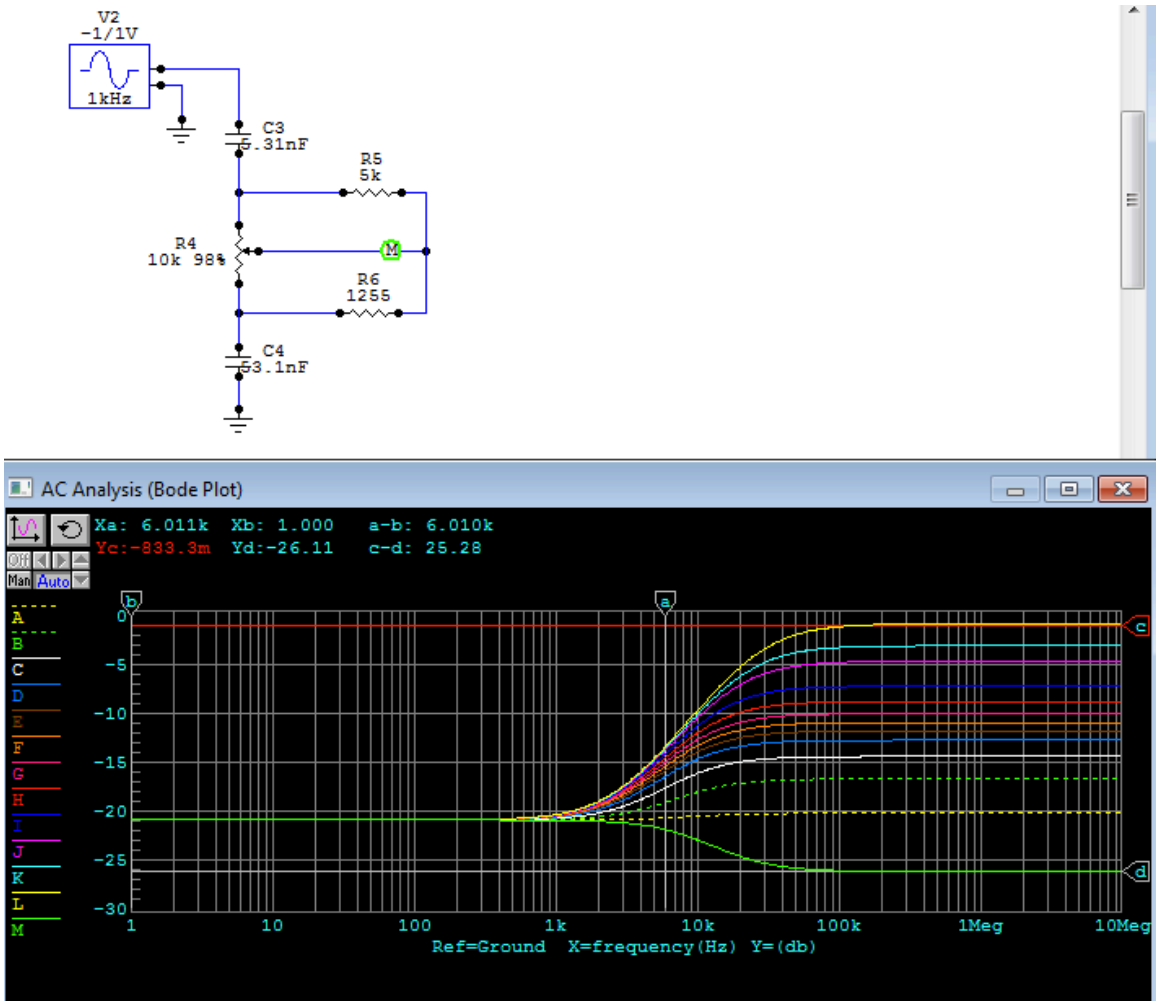
$$C_1 = 5.31nF$$

$$C_2 = 10C_1$$

$$C_2 = 10(5.31nF)$$

$$C_2 = 53.1nF$$

The overall dynamic range is c-d = 25.28 which is roughly 24dB allowing for some room for calculation error. The break frequency a is 6kHz. Due to problems in Spice, I had to use some alternate values such as 9%, 19%, 29%, and 82%.



V2
-1/1V
1kHz
C3
5.31nF
R5
5k
R4
10k 98%
M
R6
1255
C4
53.1nF
AC Analysis (Bode Plot)
Xa: 6.011k
Xb: 1.000
a-b: 6.010k
Yc:-833.3m
Yd:-26.11
c-d: 25.28
Off
Man
Auto
A
B
C
D
E
F
G
H
I
J
K
L
M
0
-5
-10
-15
-20
-25
-30
1
10
100
1k
10k
100k
1Meg
10Meg
Ref=Ground X=frequency(Hz) Y=(db)

For Circuits 3 and 4:

$$f_t = tweeter\ crossover\ frequency$$
$$f_w = woofer\ crossover\ frequency$$
$$f_L = bandpass\ low\ edge\ frequency$$
$$f_H = bandpass\ high\ edge\ frequency$$
$$R_t = DC\ resistance\ of\ tweeter$$
$$R_m = DC\ resistance\ of\ midrange\ driver$$
$$R_w = DC\ resistance\ of\ woofer$$

Circuit 3

$$f_{piston} = \frac{c}{2\pi a}$$

$$f_{piston} = \frac{345m/s}{2\pi(.12m)}$$

$$f_{piston} = 458Hz$$

$$f_{piston}(Octave\ above) = 916Hz$$

$$L_w = \frac{R_w}{2\pi f_w}$$

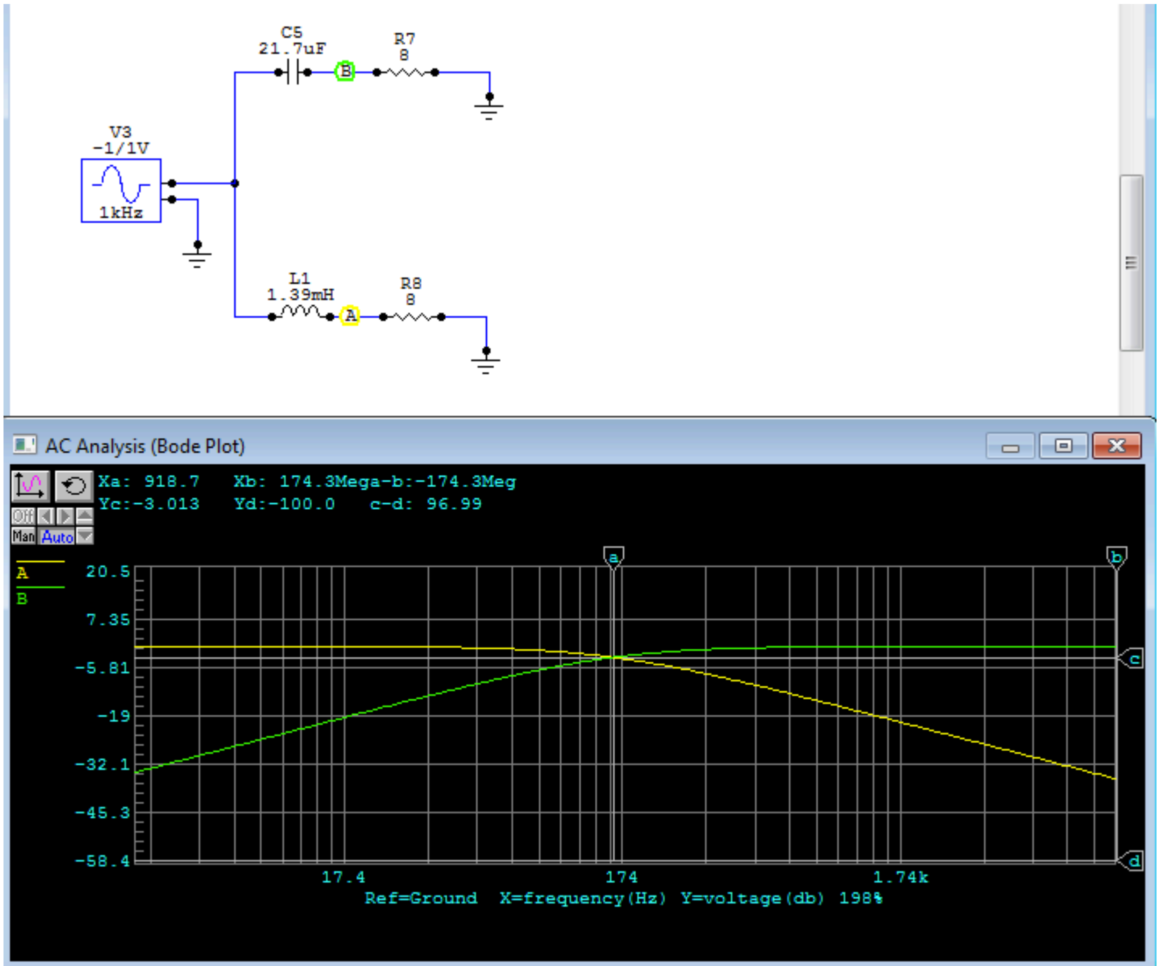
$$L_w = \frac{8\Omega}{2\pi(916Hz)}$$

$$L_w = 1.39mH$$

$$C_t = \frac{1}{2\pi f_t R_t}$$

$$C_t = \frac{1}{2\pi(916Hz)(8\Omega)}$$

$$C_t = 21.7\mu F$$



C5
21.7uF
R7
8
V3
-1/1V
1kHz
L1
1.39mH
R8
8
AC Analysis (Bode Plot)
Xa: 918.7 Xb: 174.3Mega-b:-174.3Meg
Yc:-3.013 Yd:-100.0 c-d: 96.99
20.5
7.35
-5.81
-19
-32.1
-45.3
-58.4
17.4
174
1.74k
Ref=Ground X=frequency(Hz) Y=voltage(db) 198%

Circuit 4

$$f_{piston} = \frac{c}{2\pi a}$$

$$f_{woofer/piston} = \frac{345m/s}{2\pi(.10m)}$$

$$f_{woofer/piston} = 549Hz$$

$$f_{\frac{woofer}{piston}}(Octave\ Above) = 1098Hz$$

$$f_{midrange/piston} = \frac{345m/s}{2\pi(.025m)}$$

$$f_{midrange/piston} = 2196Hz$$

$$f_{\frac{midrange}{piston}}(Octave\ Above) = 4392Hz$$

$$C_t = \frac{1}{2\pi f_t R_t}$$

$$C_t = \frac{1}{2\pi(4392Hz)(8\Omega)}$$

$$C_t = 4.53\mu F$$

$$C_m = \frac{1}{2\pi f_L R_m}$$

$$C_m = \frac{1}{2\pi(1098Hz)(8\Omega)}$$

$$C_m = 18.1\mu F$$

$$L_m = \frac{R_m}{2\pi f_H}$$

$$L_m = \frac{8\Omega}{2\pi(4392Hz)}$$

$$L_m = .290mH$$

$$L_w = \frac{R_w}{2\pi f_w}$$

$$L_w = \frac{8\Omega}{2\pi(1098Hz)}$$

$$L_w = 1.16mH$$

A shows the piston frequency for the woofer and B shows the piston frequency for the midrange driver. C shows that the filters crossover at -3dB at these frequencies. The numbers are a bit off because of rounding (A is 98 Hz off, B is 400 Hz off, C is 0.2 dB off).