MMI401 Lab 7

Switches and Filters

The first part of this lab is to learn to use the built-in switches in Circuit Maker. CM supports several families under the Switches group in part placement. You will be using the Toggle switches for this lab. The Push Button switches are slight variations and do the same thing. The two types of toggle switches you will use are:

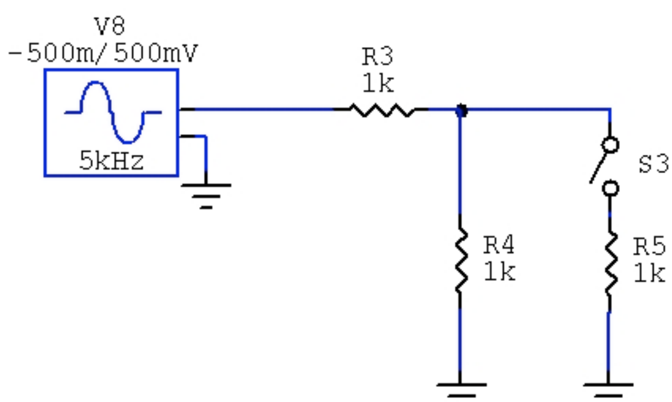
SPST: Single Pole Single Throw, this switch either opens or closes a single circuit branch. In the open circuit state, no signal flows. When you place the switch it is in the open position. You can run an analysis, then click on one of the poles (the circle) to close the switch and run a new analysis. Try this with a simple voltage divider first.

SPDT: Single Pole Double Throw, this switch allows you to choose a signal path. You can take an output and route it to two different locations or you can take an input and connect it to a choice of two sources.

DPDT: Double Pole Double Throw, this is two SPDT switches in the same package. It lets you route two separate sources to destinations or the other way around. This is the “Hard Bypass” switch found on high-end stomp boxes. It is not available in CM but we can simulate it with two SPDT switches.

SPST Voltage Divider

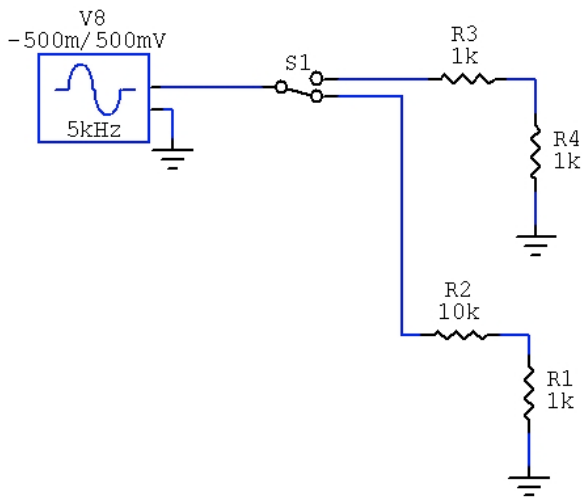
Create the Circuit shown here. The switch will be used to alter the voltage division because it will throw a resistor in parallel with R2.



With the switch open, you should get a voltage division of 0.5 or -6dB. Verify with CM. Then, throw the switch by clicking on a pole (or the switch itself). Now run the simulation. What is your attenuation in dB? Use the voltage divider equation to prove your result. *You do not have to submit your proof but it will help you later on your final project and possibly the last exam too!* ***Save the circuit for later.***

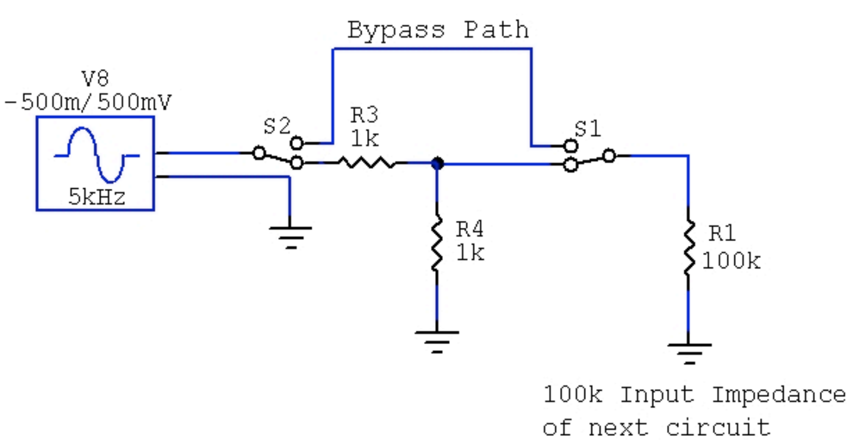
SPDT Chooser

Create this simple circuit; it uses a SPDT switch to route the source to either of two voltage divider circuits. Play with the switch and probe the outputs of the dividers; make sure you can see the switch behavior working properly. You could also reverse the switch and connect the source to both voltage dividers at once, then use the switch to choose the output to use. ***Save the circuit for later.***

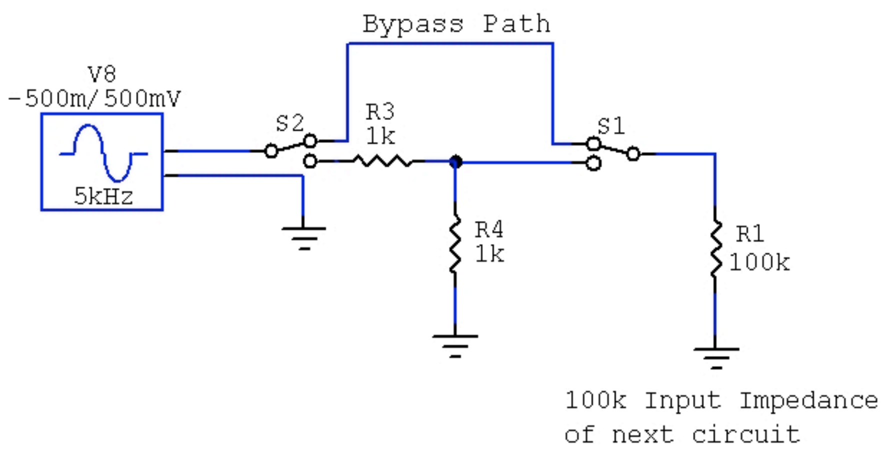


DPDT Hard Bypass

User two SPDT switches to create a simulated DPDT switch; in order to simulate properly, you must throw ***both*** switches. Implement this simple circuit and verify that the bypass path works. These are simple circuits but you need to get the switching down. ***Save the circuit for later.*** This is the switch with the divider engaged (effect mode):

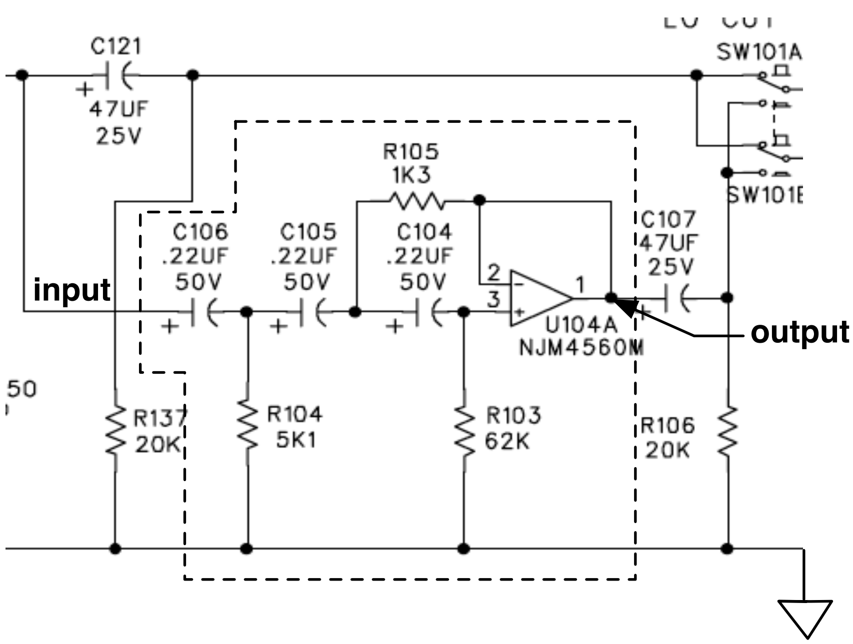


Here is the same circuit in Bypass mode:



1. Filter Sleuth

Examine the HPF in the Mackie 1604 VLZ Schematics. You will be simulating the circuit in the dotted line box. The other parts are the dry path and a DPDT switch lets you choose the HPF or not. This is the switch at the top of the mixing board channel that says Lo Cut.



Simulate this circuit in CM using the LF351 Op-Amp. What is the cutoff frequency? Is this a Butterworth response? (Hint - place the analyzer in Manual mode and use the nudge buttons to zoom way in. Do you see a resonant hump? What is the exact -3dB Frequency? **Submit** your plots and proof in your report.

A client has asked you to alter this filter to “go all the way down to 20Hz.” So you get my book and go hunting for the circuit - eventually you find it. Use the design equations to calculate the component values. Are these the same values in the Mackie Circuit? Why or why not? (Hint: read the book)

Redesign this HPF to have a cutoff frequency of 20.0Hz and a Butterworth Q. You have several options. Change only 3 component values. Simulate in CM and **submit** your calculations and CM plots to prove your design works.

2. Filter Designer

Design an active 2nd Order LPF (page 162) with the following:

Ao = 1
Q = 10
wc = 1000Hz (wc = 3dB center frequency)

You must arbitrarily select C1; I used 0.1uF in my version but you can use what ever you want.

Submit your design calculations and CM simulation results showing the proper -3dB frequency. To prove your Q is correct, you need to measure its peak value in dB from CM. Then, use this equation to see how close you are:

$$|peak| = \frac{Q^2}{\sqrt{Q^2 - 0.25}}$$

$$peak_{dB} = 20\log(|peak|)$$

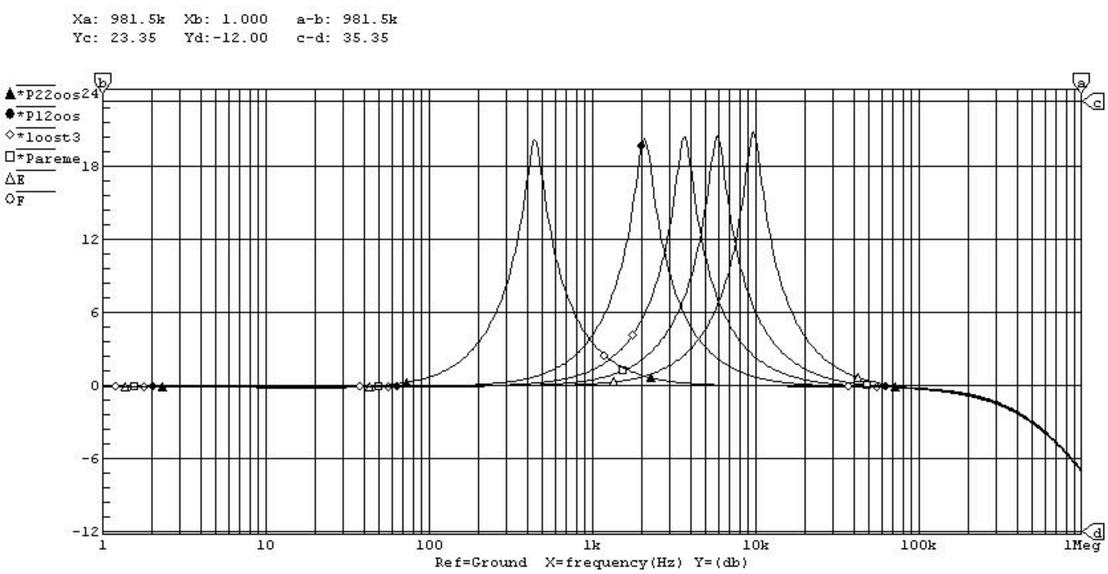
3. Parametric Module

You will need to use this parametric EQ Module for your final project. Use the Parametric EQ on page 176 of the book. It will just barely fit into Circuit Maker Student version. Design as follows:

fh = 10kHz
C1 = 500pF
Calculate the value for the two R1s in the circuit (look at it!)

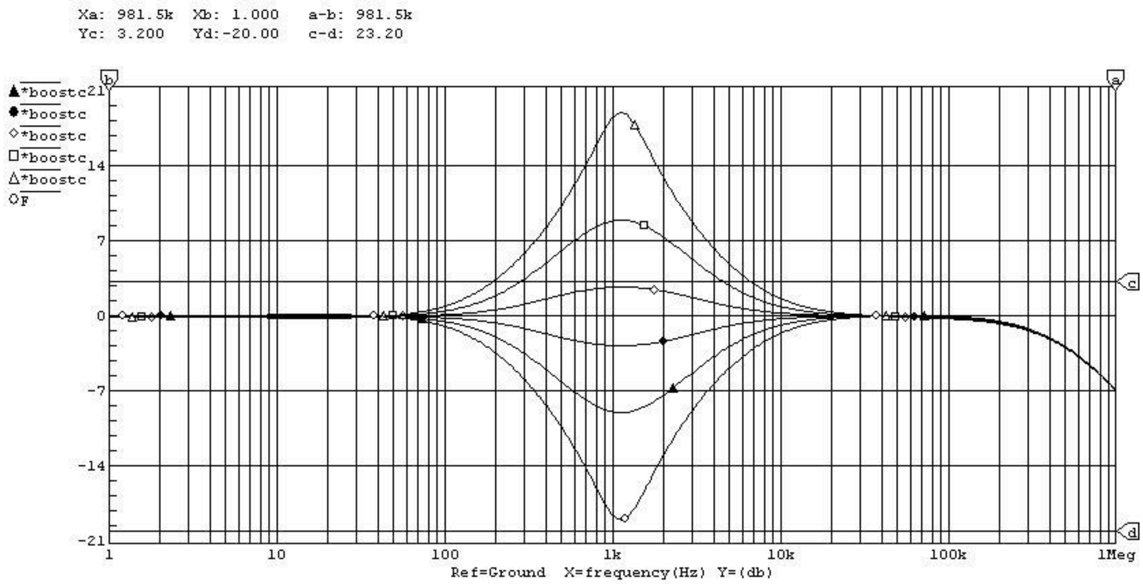
Next, simulate and do waveform captures. You need to document the following:

1. Prove the Fc control works by setting the Q to a maximum, Boost to Maximum, then sweep the pair of pots (they are dual ganged) that control frequency. You must adjust both of them identically. Use 1%, 25%, 50%, 75% and 99% to produce 5 different frequency plots and use the save/recall to plot them all together.For the boost version you will get this, and you can verify the upper limit is 10kHz here:



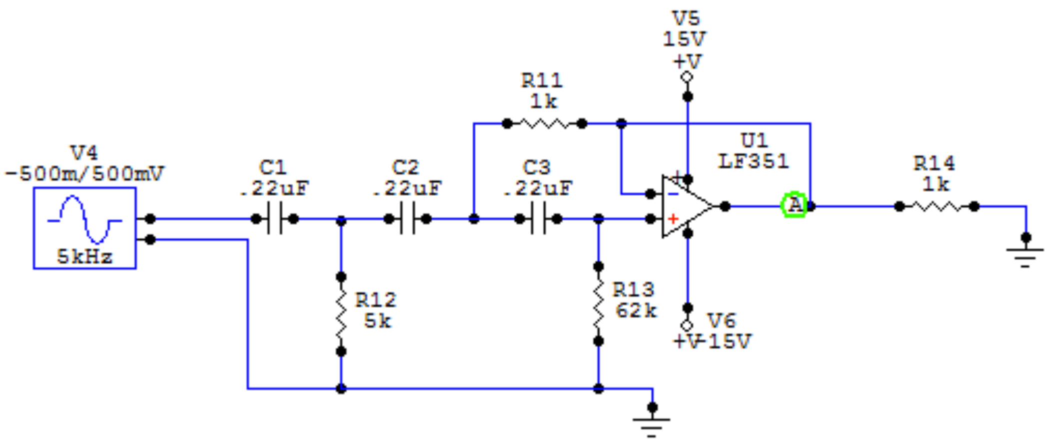
Now, adjust the boost/cut for maximum **cut** and plot 5 of those. Plot the boost and cut responses all on one graph (I have half of that done above) and **submit** in your report. Use CM to show how close you got to the theoretical frequency range of about 4.5 octaves and **submit** this as well.

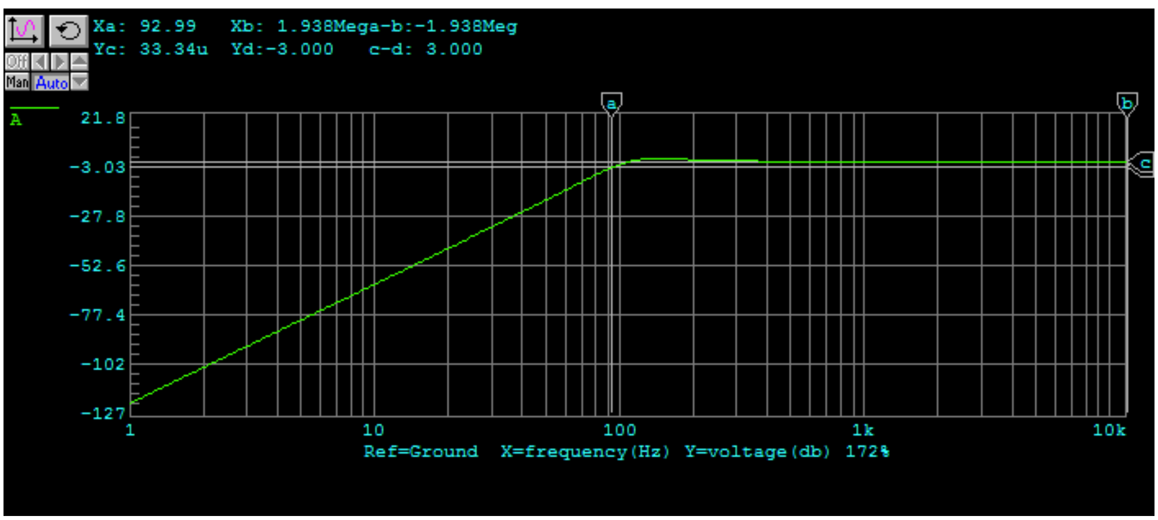
2. Next, verify the boost/cut works by fixing the Frequency pots (adjust to get close to 1kHz because that is in the center of the plot) and the Q (adjust to a medium value). Now, create a family of boost/cut curves by adjusting the boost/cut control the same way; at 50% there will be no boost/cut so use the following: 1%, 20%, 40%, 60%, 80%, 99% -- you will get 6 curves altogether. Here's my composite plot. **Submit** yours in your report.



3. Lastly, verify that the Q control works by holding the Boost at maximum and the frequency around 1kHz. Then, vary the Q control and take the plots for each with the Q pot at 1%, 20%, 40%, 60%, 80%, 99% -- you will get 6 curves altogether. **Submit** you plots in your report.

Circuit 1:

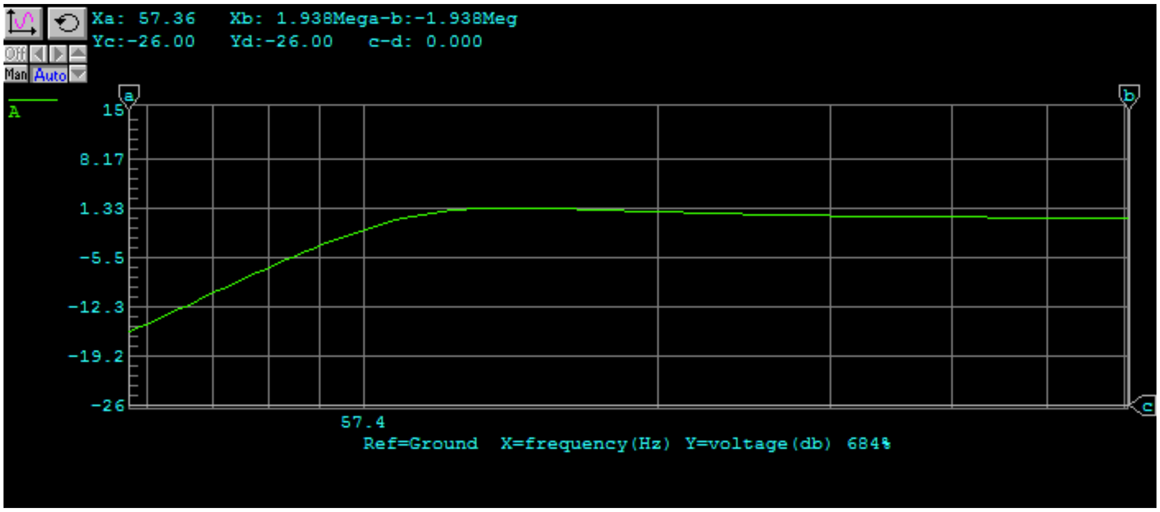




- A cutoff frequency of 93Hz is shown by marker 'a'.

$$f_c = \frac{.71808}{2\pi R_{12} C_1} = \frac{.71808}{2\pi(5k\Omega)(.22uF)} = 104Hz$$

- 104Hz *would* be the cutoff frequency if this filter had a Butterworth resonance



- Upon further inspection we can confirm that this HPF does not quite have a Butterworth response because there is a slight Q hump.

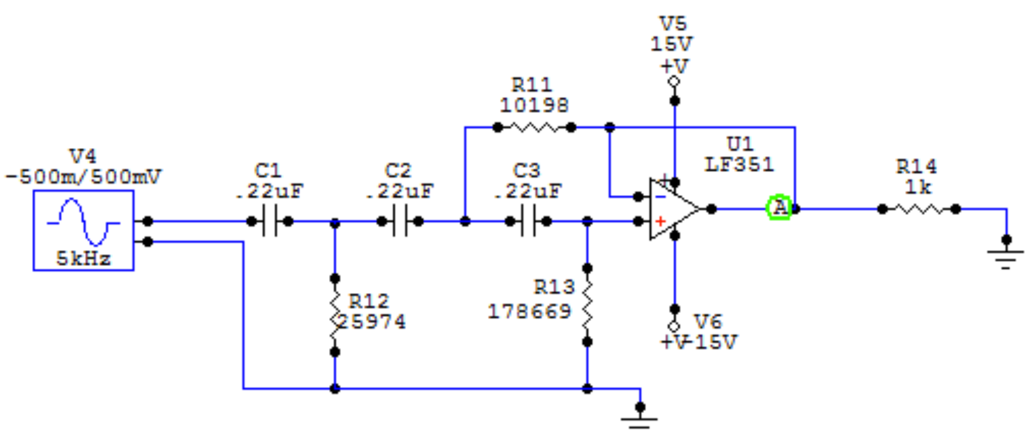
- Design equations for a 3rd order HPF with cutoff frequency of 20Hz and Butterworth Q:

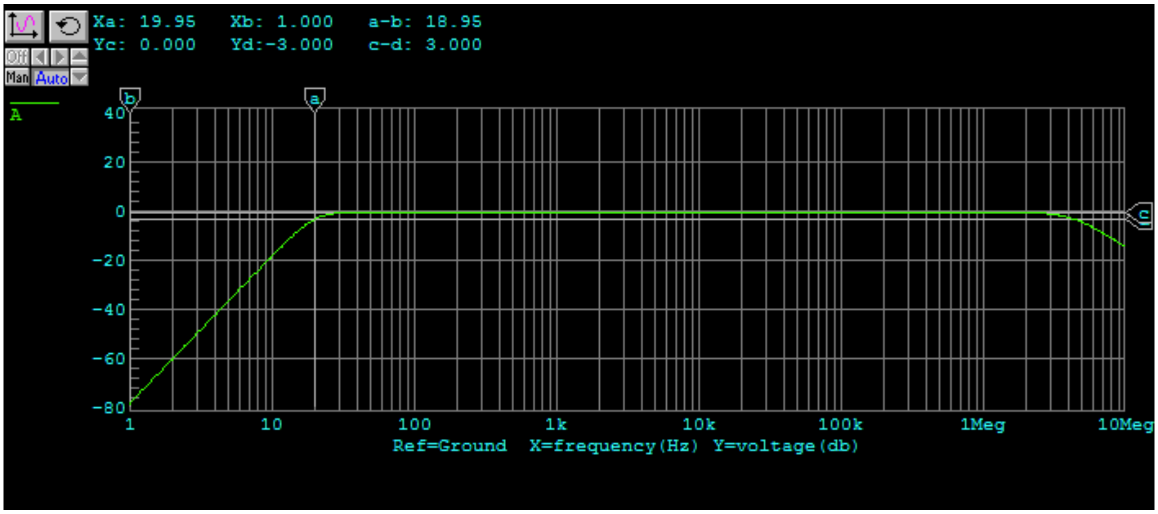
$$f_c = 20Hz$$

$$R_{11} = \frac{.28194}{2\pi f_c C} = \frac{.28194}{2\pi(20Hz)(.22uF)} = 10198\Omega$$

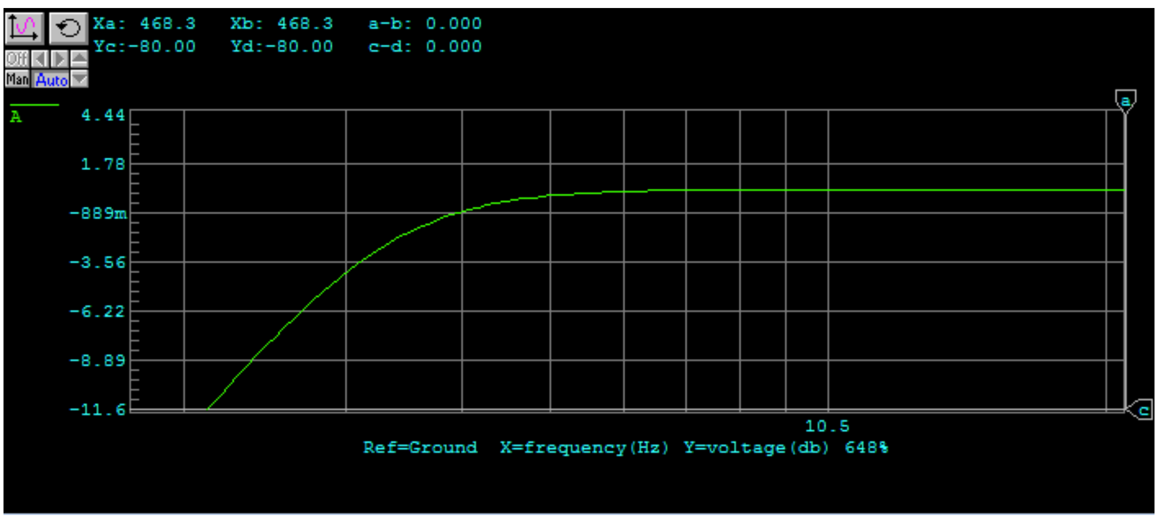
$$R_{12} = \frac{.71808}{2\pi f_c C} = \frac{.71808}{2\pi(20Hz)(.22uF)} = 25974\Omega$$

$$R_{13} = \frac{4.93949}{2\pi f_c C} = \frac{4.93949}{2\pi(20Hz)(.22uF)} = 178669\Omega$$





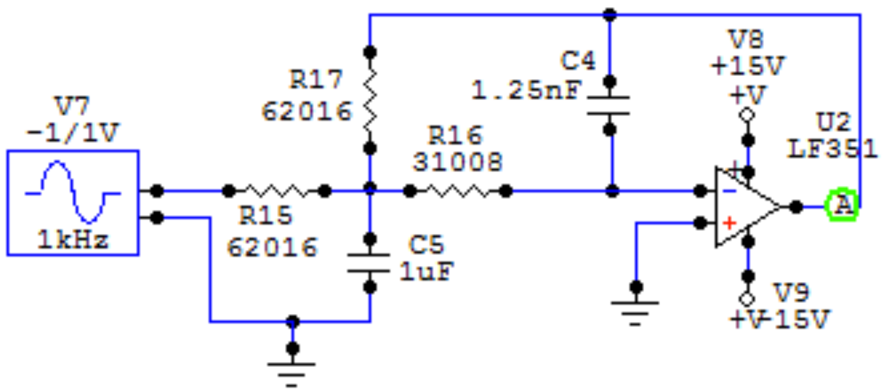
- A cutoff frequency of 20Hz is shown by marker ‘a’.



- And we can see now that the HPF frequency response graph does not show a resonant hump. It is indeed a Butterworth filter.

Circuit 2:

Specs:
A_o = 1
Q = 10
ω_c = 1000Hz (ω_c = -3dB center frequency)



- Design Equations:

$$C_5 = 1uF$$

$$K = \frac{1}{4Q^2(A_o + 1)} = \frac{1}{4(10)^2(1 + 1)} = .00125$$

$$\beta = \sqrt{\left(1 - \frac{1}{2Q^2}\right) + \sqrt{(1 - \frac{1}{2Q^2})^2 + 1}} = \sqrt{\left(1 - \frac{1}{2(10)^2}\right) + \sqrt{(1 - \frac{1}{2(10)^2})^2 + 1}} = 1.55$$

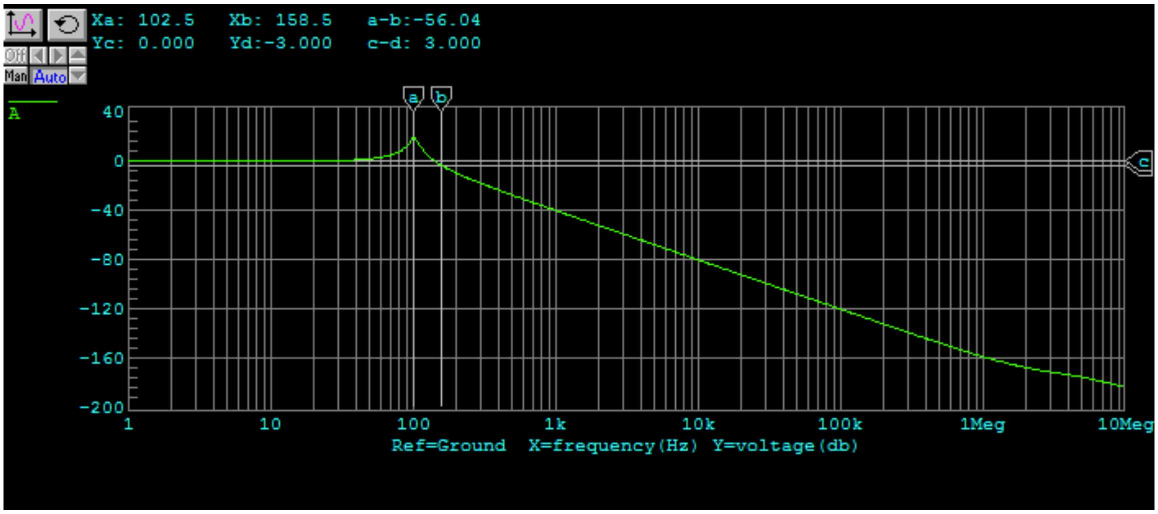
$$\omega_o = \frac{\omega_c}{\beta} = \frac{(1000Hz)}{1.55} = 645Hz$$

$$C_4 = KC_5 = (.00125)(\,1uF) = 1.25nF$$

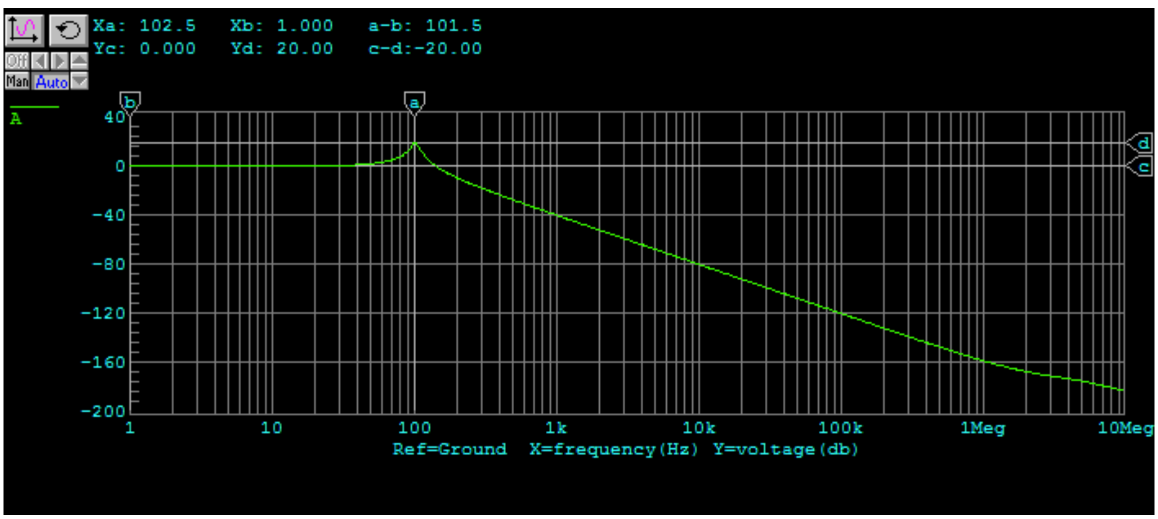
$$R_{17} = \frac{1}{2Q\omega_o C_5 K} = \frac{1}{2(10)(645Hz)(1uF)(.00125)} = 62016\Omega$$

$$R_{16} = \frac{R_{17}}{A_o + 1} = \frac{62016\Omega}{1 + 1} = 31008\Omega$$

$$R_{15} = \frac{R_{17}}{A_o} = \frac{62016\Omega}{1} = 62016\Omega$$



- The cutoff frequency ω_c of 1000Hz ($f_c = \frac{\omega_c}{2\pi} = \frac{1000Hz}{2\pi} = 159Hz$) is verified by marker 'b'. Marker 'a' shows the center frequency ω_o of 645Hz ($f_o = \frac{\omega_o}{2\pi} = \frac{645Hz}{2\pi} = 103Hz$).



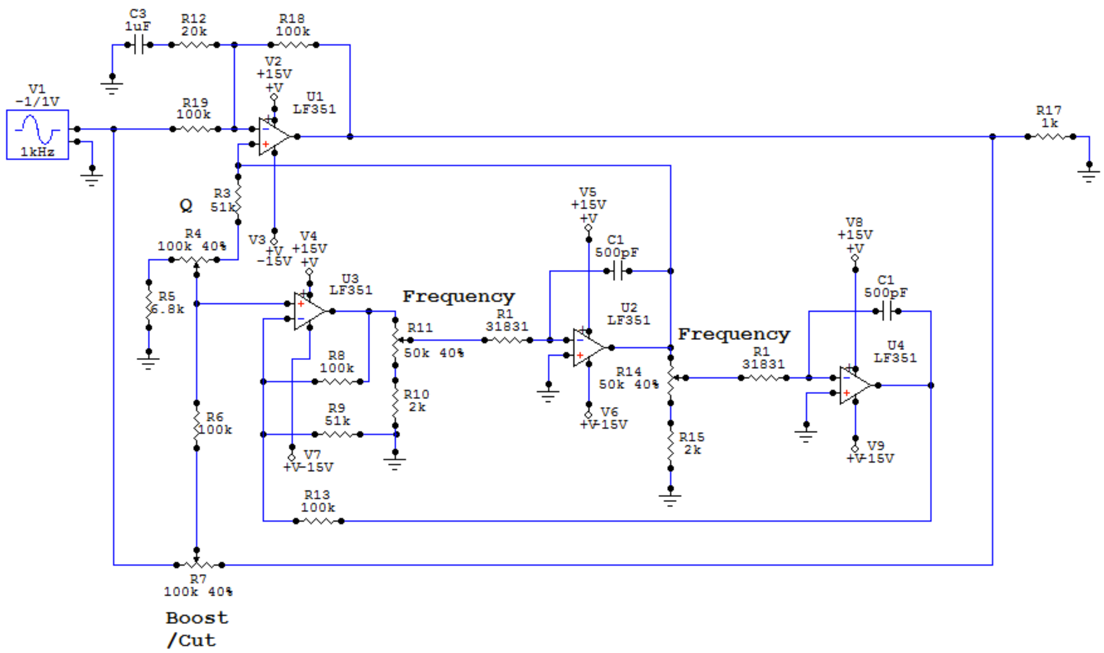
- The peak value of the Q (in decibels) of this LPF is +20dB as shown by marker 'd'.
- Verifying peak Q:

$$|peak| = \frac{Q^2}{\sqrt{Q^2 - 0.25}} = \frac{(10)^2}{\sqrt{(10)^2 - 0.25}} = 10.0125$$

$$peak_{dB} = 20\log(|peak|) = 20\log(10.0125) = +20.01dB$$

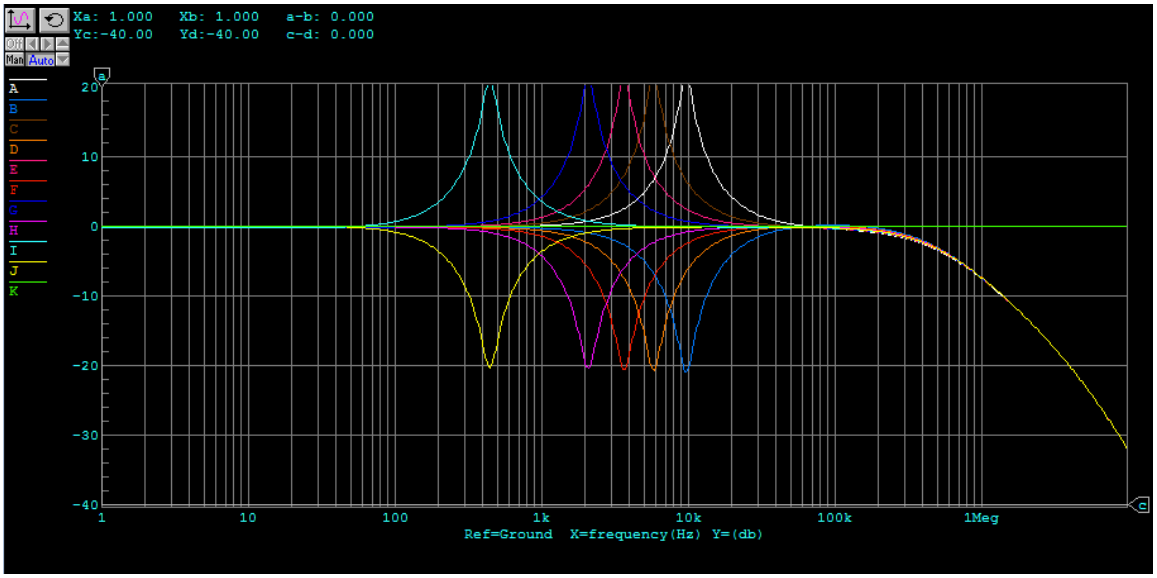
Circuit 3:

Specs:
$f_h = 10kHz$
$C_1 = 500pF$

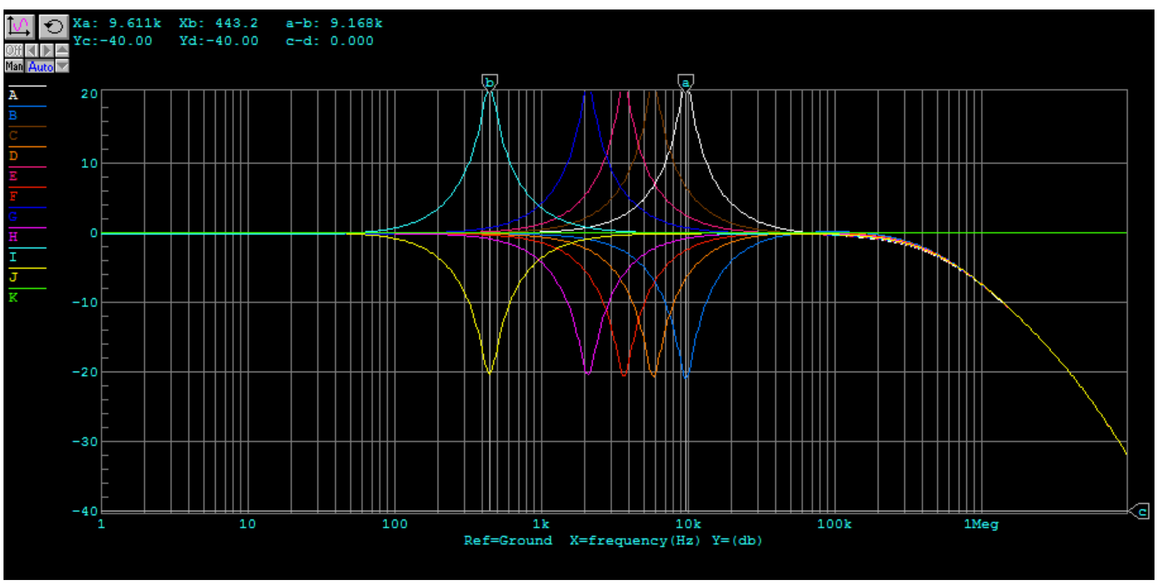


- Design Equations

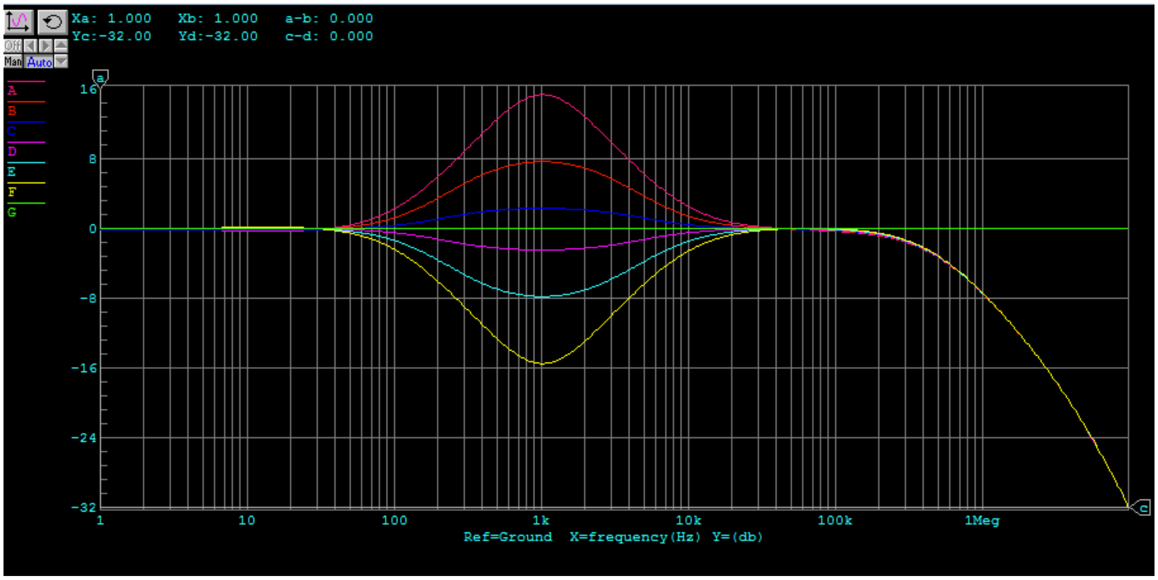
$$R_1 = \frac{1}{2\pi f_h C_1} = \frac{1}{2\pi(10kHz)(500pF)} = 31831\Omega$$



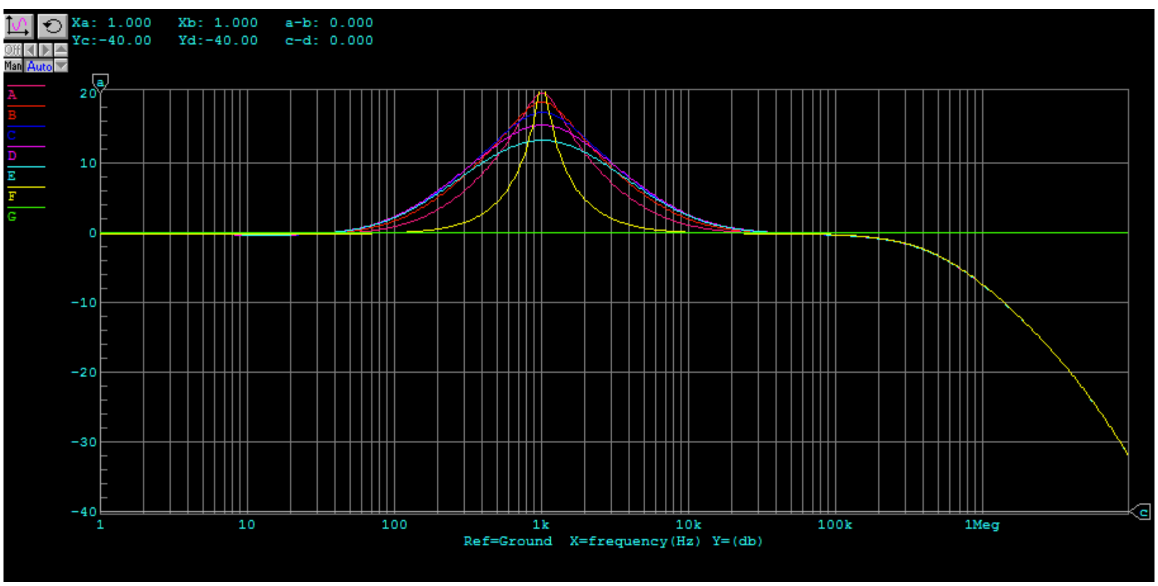
- With the Q, boost, and cut set at a maximum here we can see five plots of varying center frequencies.



- Marker ‘a’ shows the highest center frequency as about 9.6kHz and marker ‘b’ shows the lowest center frequency as about 440Hz (the A above middle C).
- 4.5 octaves above 440Hz is approximately 10kHz. The theoretical range of the parametric EQ is slightly higher than the practical range.



- With the Q and center frequency controls set at a medium value we can see the range of boosts and cuts this parametric EQ is capable of.



- Similarly, with the center frequency and boost controls set at a maximum value we can see the range of Q this parametric EQ is capable of.