

# ECE-205 Lab 10

## Lowpass, Highpass, and Bandpass Filters

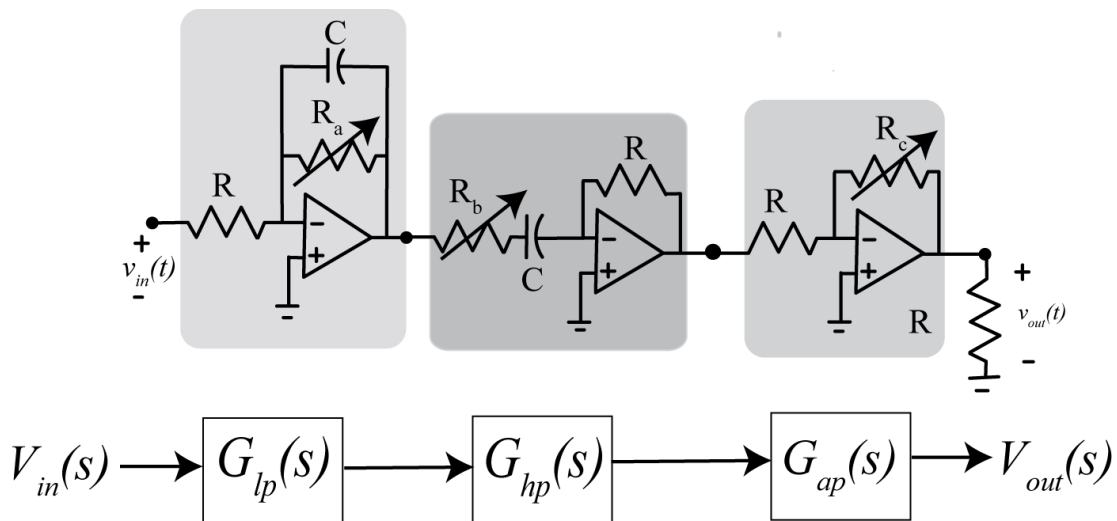
### Overview

In this lab you will build a simple lowpass filter, a simple highpass filter, an all pass (gain) amplifier, and then put them together to construct a simple bandpass filter. The filters we are building are actually very simple, and we are being very inefficient with our use of op amps. However, we are again going to build the final circuit in stages and construct the magnitude portion of the Bode plot for each part and then put them together. Finally, for the battery pack, the red is positive, the green is negative, and the black is ground.

### PART 1 : System Overview

Our bandpass filter has three parts, shown in the different shaded regions in Figure 1. The equivalent block diagram is shown below the circuit, so you can match elements of the block diagram with the circuit subsystems. The first subsystem is the lowpass filter, the second subsystem is the highpass filter, and the last subsystem is an all pass filter which just adjusts the gain of the system. As with most of the circuits in this class, this design has not been optimized and is very inefficient, but should be fairly easy to build. All of the resistors are either 1 kΩ resistors, or are variable resistors. The capacitors are 1 μf capacitor. We will be utilizing TL072 chips, which include two op amps on each chip. We will build and debug this circuit in stages, so do not start building yet!

It is a good idea to disconnect the power from your circuit while you are building it. Note that it may take some time for the screen to update when you change the variable resistor values. Be patient, and you will be rewarded. If you are impatient you will have to go back and redo parts of the lab!



**Figure 1.** Bandpass filter consisting of a lowpass filter, a highpass filter, and an all pass (gain) filter.

## PART 2: Lowpass Filter

1) Build the lowpass, shown in Figure 2. We have included a load resistor for measuring the output. The input to this circuit should be the signal generator, and the output should be the voltage across the load resistor. Set the input to a 10 Hz sine wave with an amplitude of 1 volt (peak to peak value of 2.0 volts) and 0 volt offset. Start the oscilloscope and set the input on channel 1 to **A1-Diff** and use this to measure the input signal (never trust a signal generator) and the input on channel 2 to **A2-Diff**, and use this to measure the voltage drop across the load resistor. Set channel 1 to **500 mv/div** and channel 2 to **250 mv/div**. Set the **Time/Div** to 20.00 ms/Div and the **Mode** to **Y-T**. The coupling should be set to **AC** for both channels. Adjust the variable resistor so the output has an amplitude of approximately 0.3 volts (0.6 volts peak to peak).

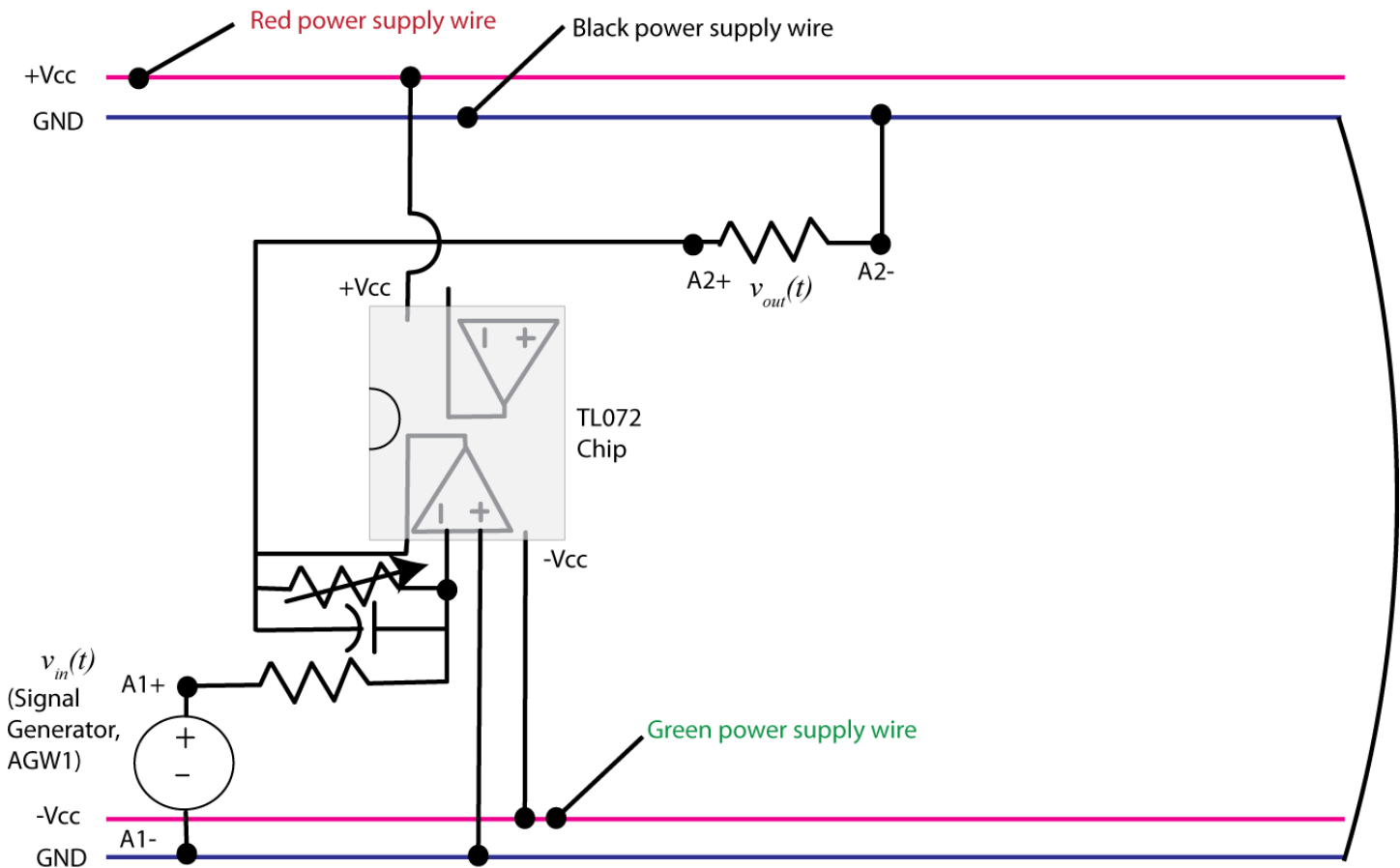


Figure 2. Prefilter (gain) circuit.

The transfer function for this lowpass filter can be shown to be

$$G_{lp}(s) = \frac{-K_{low}\omega_{low}}{s + \omega_{low}}$$

where  $K_{low} = \frac{R_a}{R}$  and  $\omega_{low} = \frac{1}{R_a C}$

2) We will now construct the magnitude portion of the Bode plot for this subsystem, just as we did in Lab 9.

a) For input frequencies of 100, 200, 400, 600, 700, 800, 1000, 1500, 2000, 2500, and 3000 Hz, measure the amplitude of the output signal (assuming the input remains at a 1.0 volt amplitude). Note that as your input frequency increases, you will need to decrease the Time/Div setting. Try and keep the second channel to 250 mV/Div. Enter your data into the program **process\_data\_low.m**. In this file, each row corresponds to a frequency. The three entries in the row are the frequency (measure in Hz), the amplitude of the input signal (measured in volts), and the amplitude of the output signal (measured in volts).

b) In the Matlab command window type **data = process\_data\_low;**

c) Now we will fit the data to our model using the program **model\_low.m**. The arguments to this file are the data array from part b, the estimated amplitude of the gain, and the estimated value of the cutoff frequency. In the Matlab command window type **model\_low( data, 0.3, 500\*2\*pi);** You should get results similar to that shown in Figure 3. Click on the Datatip icon (just below Desktop) so identify points on the graph. Once you have identified the maximum value, you may have to use a right click and create a new data tip (it usually helps if you right click when you are on a current datatip). You can fine tune your datatip locations by using the cursor keys on your keyboard. Your data points should be from the peak value to a value 3 dB lower. Include this graph in your memo. Be sure your graph has two datatip points.

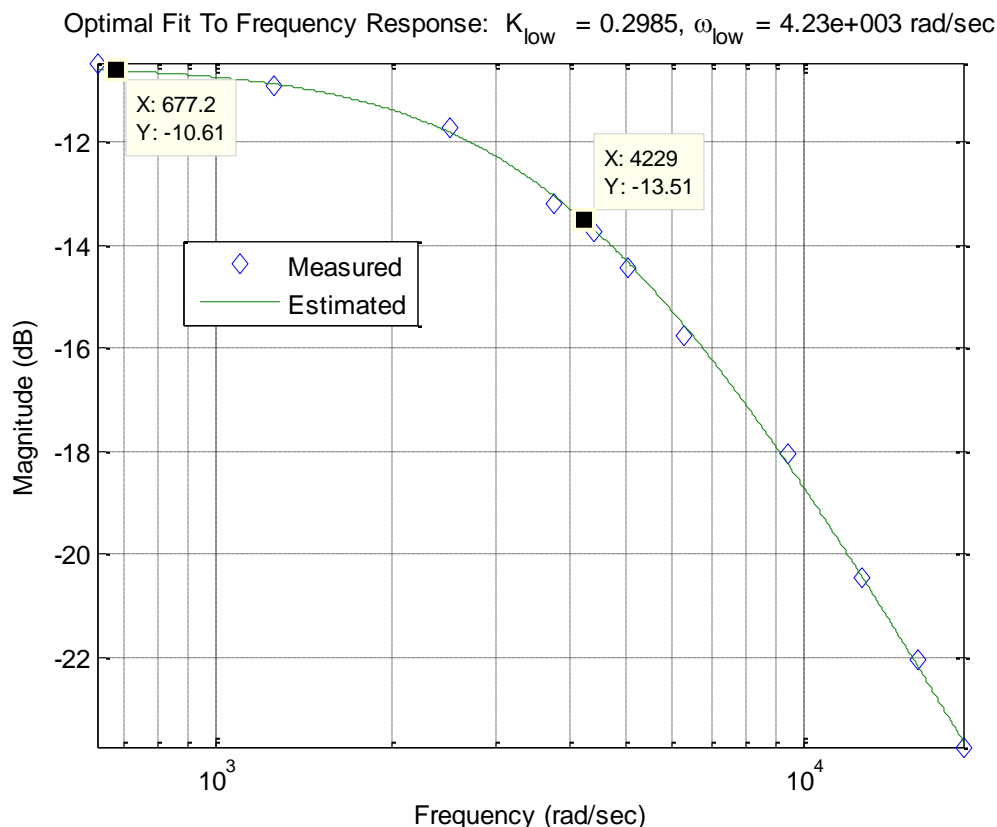


Figure 3. The lowpass filter with a bandwidth of approximately 4230 rad/sec (673 Hz).

### PART 3: Highpass Filter

3) Now build the highpass filter as shown in Figure 4. We have again included a load resistor to measure the output voltage. Do not connect the two subsystems yet. Adjust the variable resistor so for an input signal (sine wave) at 1000 Hz with an amplitude of 1.0 volts (2.0 volts peak to peak) the output signal has an amplitude of 0.4 volts (amplitude 0.8 volts peak to peak).

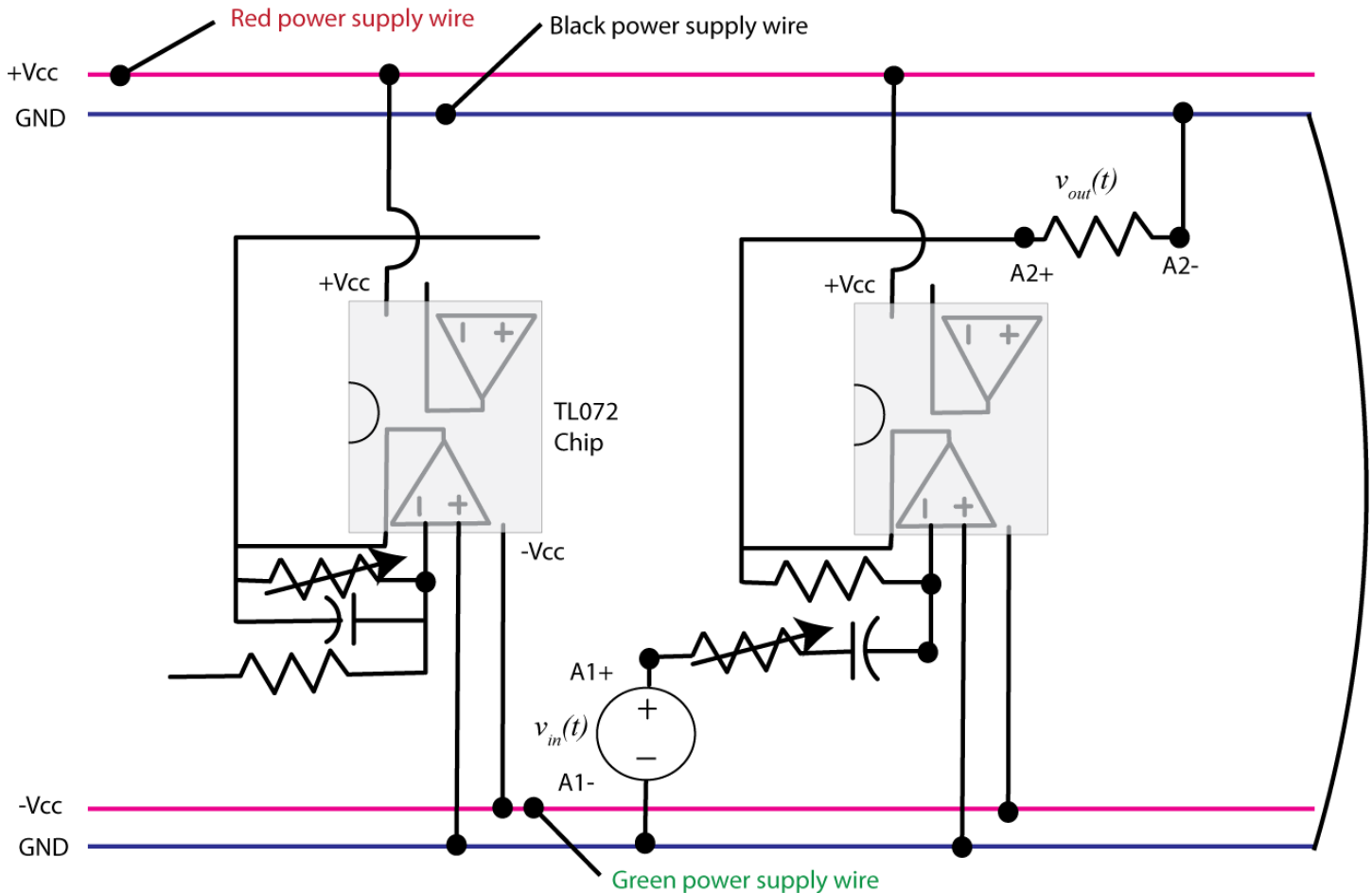


Figure 4. Lowpass and highpass subsystems.

The transfer function for this subsystem can be shown to be

$$G_{hp}(s) = \frac{-K_{high}s}{s + \omega_{high}}$$

where  $K_{high} = \frac{R}{R_b}$  and  $\omega_{high} = \frac{1}{R_b C}$

4) Now we will construct the magnitude of the Bode plot for this highpass filter.

- a) For input frequencies of 10, 25, 50, 75, 100, 200, 300, 400, 500, 750, and 1000 Hz, measure the amplitude of the output signal (assuming the input remains at a 1.0 volt amplitude).
- b) Copy the program **process\_data\_low.m** onto a new file **process\_data\_high.m**, and enter your data into this new file. Do not just reuse your previous file.
- c) In the Matlab command window type **data = process\_data\_high;**
- d) Copy the program **model\_low.m** to a new program **model\_high.m**. Modify this new program so it tries to fit the new transfer function for the highpass filter. The arguments to this file are the data array from part c, the estimated amplitude of the gain, and the estimated value of the cutoff frequency.
- e) In the Matlab command window type **model\_high( data, 0.3, 100\*2\*pi);** You should get results similar to that shown in Figure 5. Click on the Datatip icon (just below Desktop) so identify points on the graph. Once you have identified the maximum value, you may have to use a right click and create a new data tip(it usually helps if you right click when you are on a current datatip). You can fine tune your datatip locations by using the cursor keys on your keyboard. Your data points should be from the peak value to a value 3 dB lower. Include this graph in your memo. Be sure your graph has two datatip points.

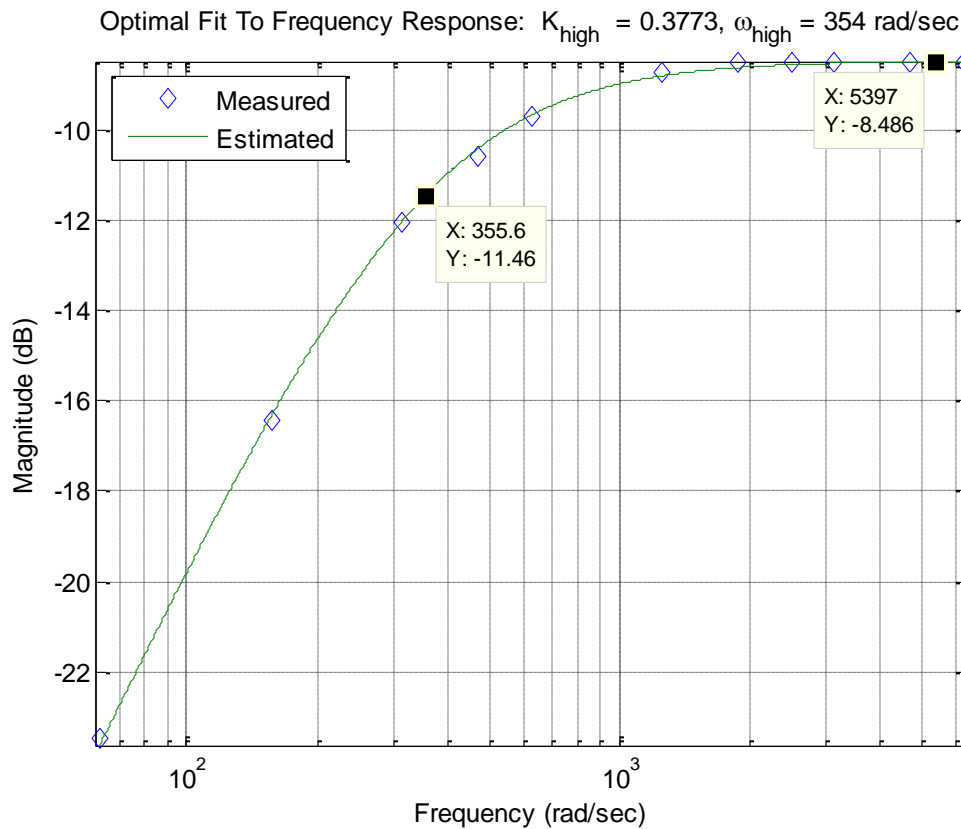


Figure 5: Highpass filter with a cutoff frequency of approximately 354 (56 Hz).

## PART 4: Allpass Filter

5) Construct the gain subsystem, as shown in Figure 6. Adjust the variable resistor so that for an input sine wave with a 1 volt amplitude at 500 Hz, the output has a 1 volt amplitude (or as close to this as you can get it).

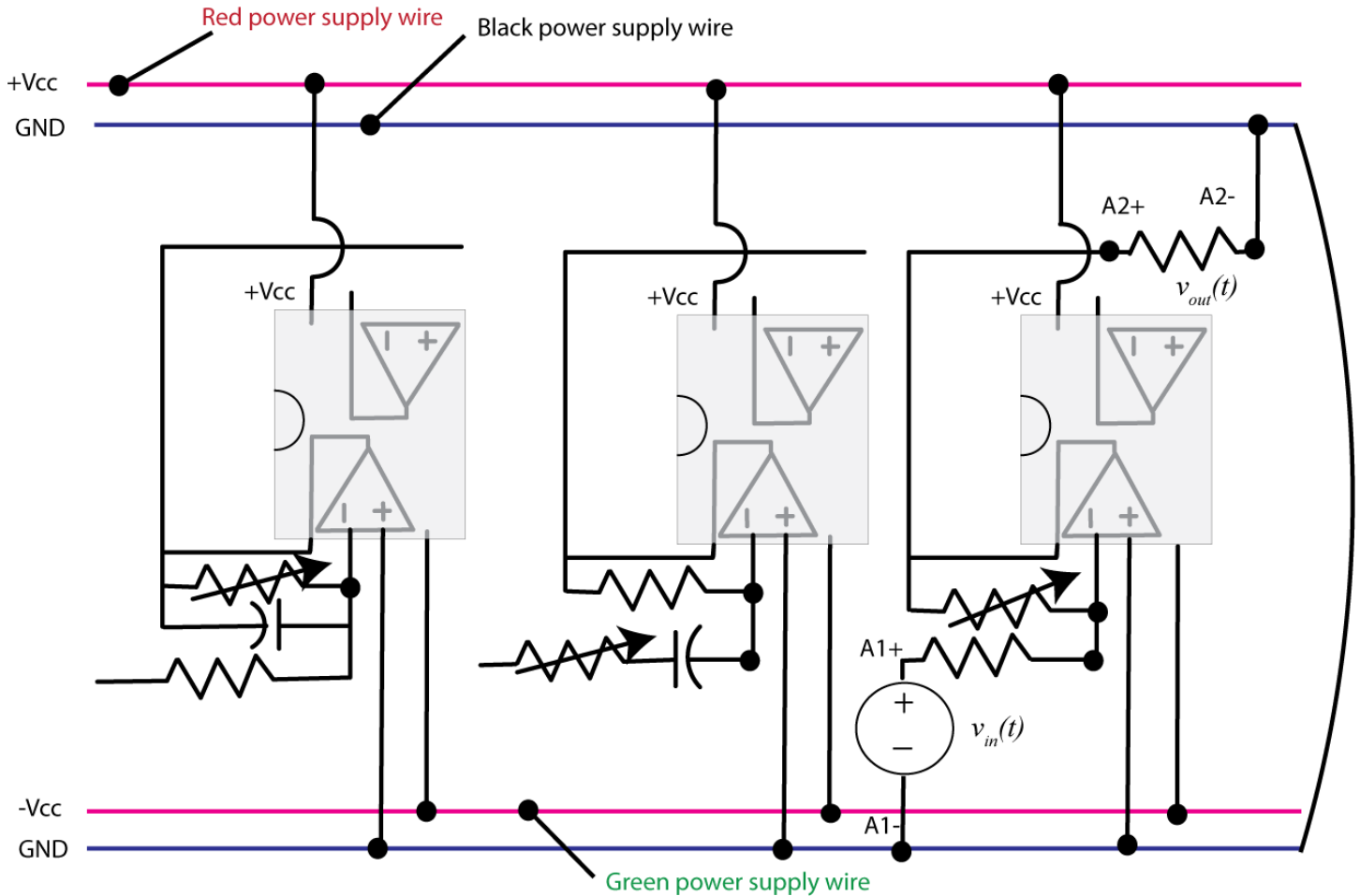


Figure 6. Lowpass, highpass, and all pass subsystems.

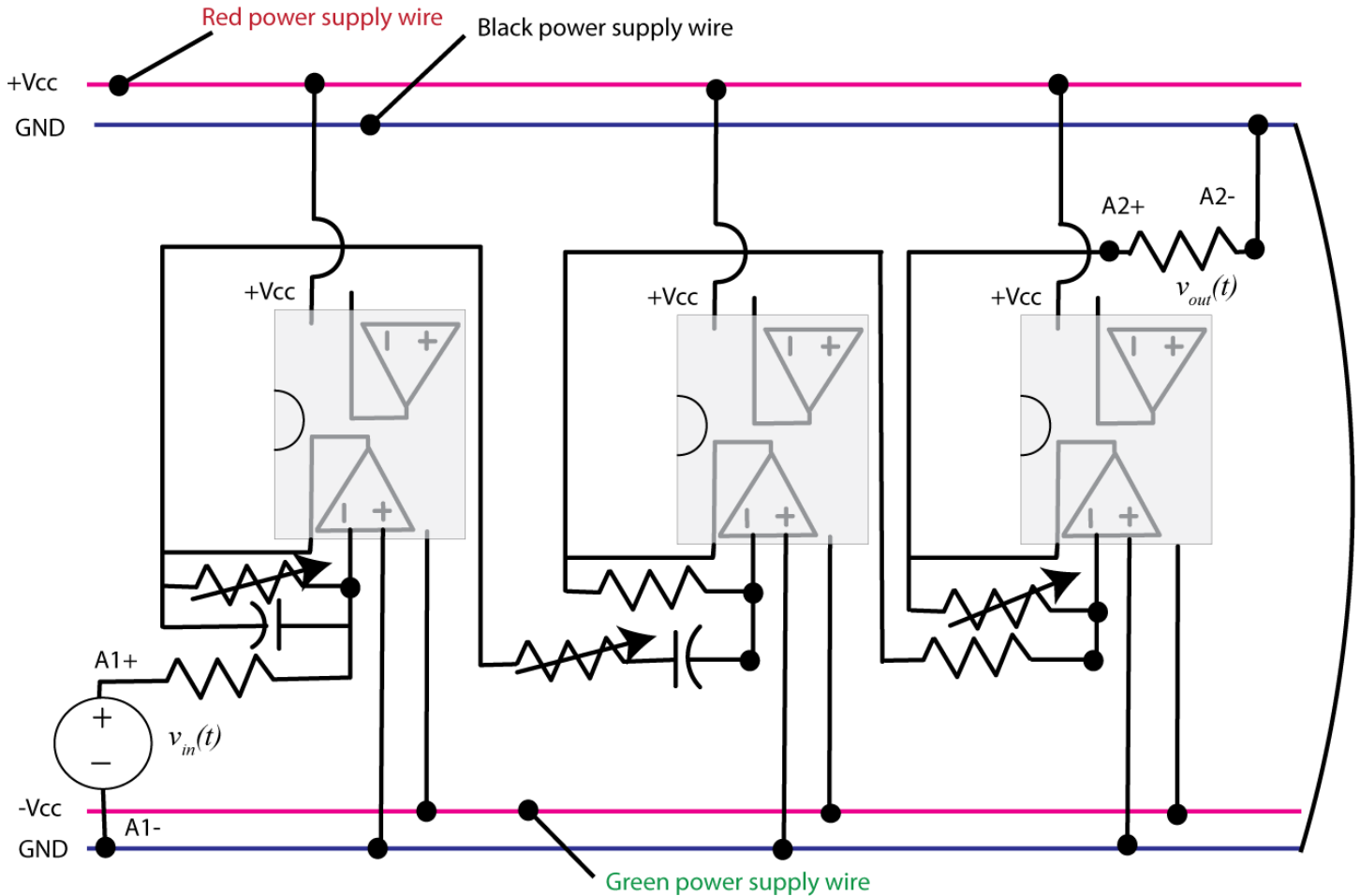
The transfer function for this subsystem can be easily shown to be

$$G_{ap}(s) = -K_{ap}$$

where  $K_{ap} = \frac{R_c}{R}$

## PART 5: Bandpass Filter

6) Connect all of the subsystems together as shown in Figure 7. Be sure to remove some of the load resistors we have been using.



**Figure 8.** The bandpass system composed of lowpass, highpass, and all pass subsystems.

The transfer function for this system is then the product of the transfer functions of the subsystems,

$$G_{bp}(s) = G_{lp}(s)G_{hp}(s)G_{ap}(s) = \left( -\frac{K_{low}\omega_{low}}{s + \omega_{low}} \right) \left( -\frac{K_{high}s}{s + \omega_{high}} \right) (-K_{ap})$$

We can simplify this as

$$G_{bp}(s) = -\frac{Ks}{s^2 + (\omega_{low} + \omega_{high})s + \omega_{low}\omega_{high}}$$

Since we are only interested in the magnitude, we can ignore the negative sign (but you will see it on the output since it will be out of phase with the input).

7) Finally we will construct the magnitude portion of the Bode plot for this simple bandpass filter.

a) For input frequencies of 10,15, 25,40, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500 and 2000 Hz, measure the amplitude of the output signal (assuming the input remains at a 1.0 volt amplitude).

b) Copy the program **process\_data\_low.m** onto a new file **process\_data\_bandpass.m**, and enter your data into this new file. Do not just reuse your previous file.

c) In the Matlab command window type **data = process\_data\_bandpass;**

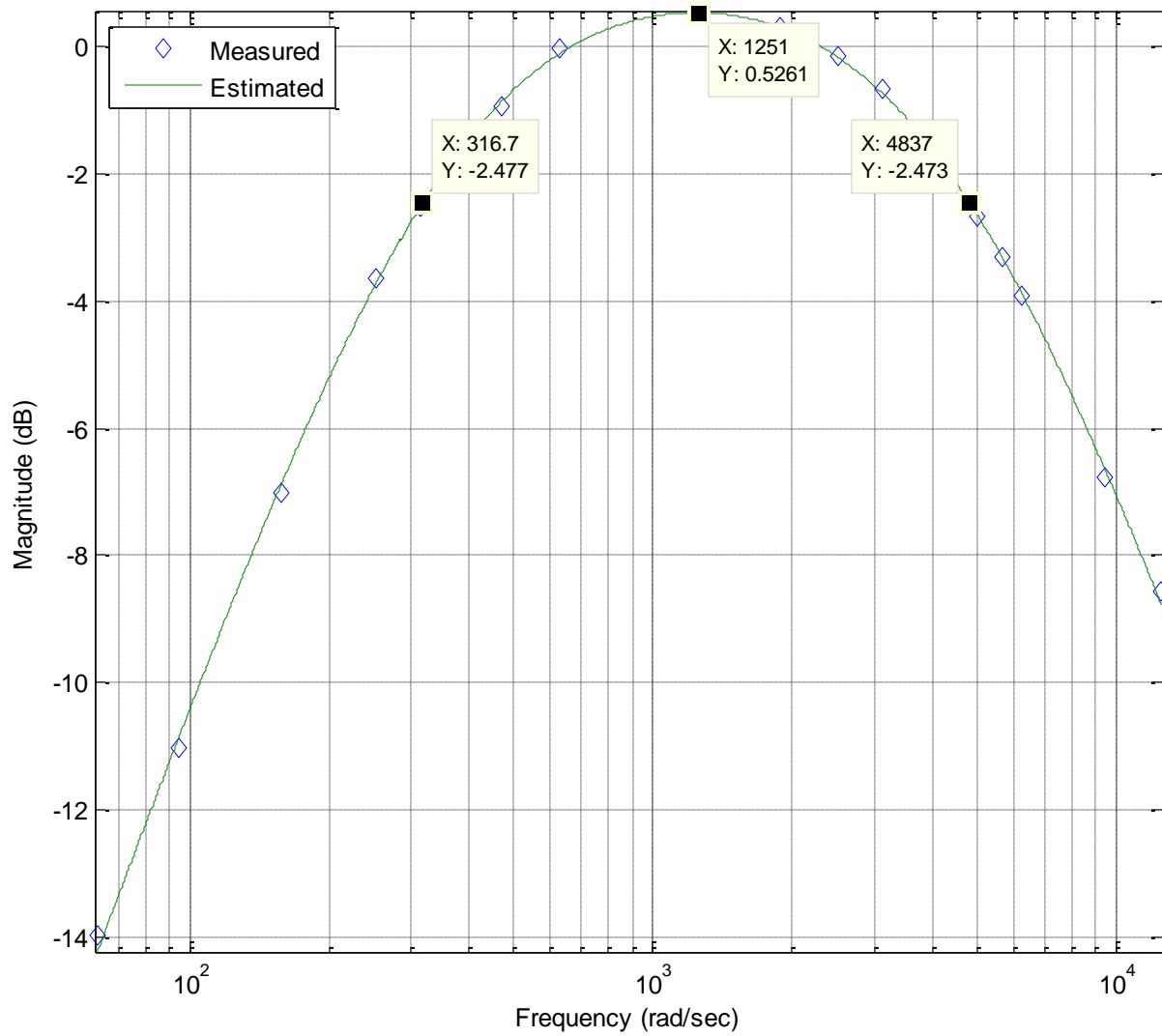
d) Copy the program **model\_low.m** to a new program **model\_bandpass.m**. Modify this new program so it tries to fit the new transfer function for the bandpassfilter. The arguments to this file are the data array from part c, the estimated amplitude of the gain, and the estimated value of the high and low cutoff frequencies..

e) In the Matlab command window type **model\_bandpass( data, 4800, 355, 4230);** You should get results similar to that shown in Figure 9. Note that your peak amplitude may be different depending on how much you could adjust the gain on the final stage. At this point we mostly are looking for the same general shape. Click on the Datatip icon (just below Desktop) so identify points on the graph. Once you have identified the maximum value, you may have to use a right click and create a new data tip (it usually helps if you right click when you are on a current datatip). You can fine tune your datatip locations by using the cursor keys on your keyboard. Your data points should be from the peak value to a value 3 dB lower on both sides. Include this graph in your memo. Be sure your graph has three datatip points. Note that in this case the program has confused the low and high frequencies, since they are symmetric there is no way to tell them apart. The Measured bandwidth of this system is then approximately  $4837-316=4521$  rad/sec or approximately 720 Hz.

**Send me the your memo in an e-mail and you are done!**



Optimal Fit To Frequency Response:  $K = 4815$ ,  $\omega_{low} = 368$  (rad/sec),  $\omega_{high} = 4.16e+003$  (rad/sec)



**Figure 9.** Bandpass filter with both low and high cutoff frequencies identified. The bandwidth of this system is approximately 4521 rad/sec.