ECE 321 - Homework #4

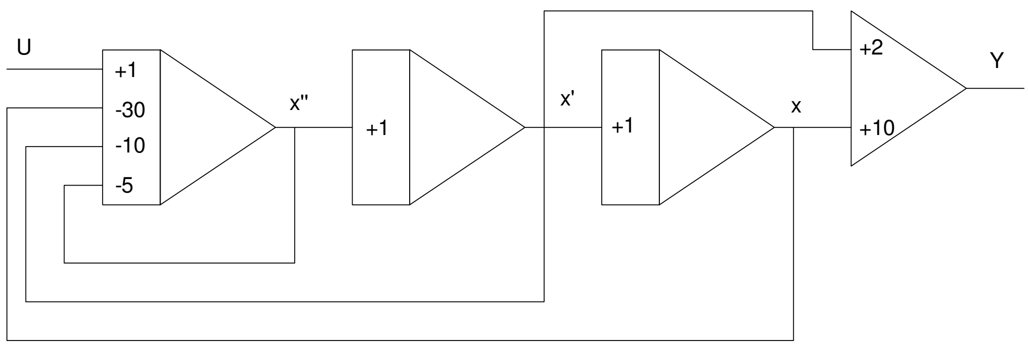
Butterworth & Chebychev filters, Analog Computers. Due Monday, April 24th
Please email to jacob.glower@ndsu.edu, or submit as a hard copy, or submit on BlackBoard

Analog Computers

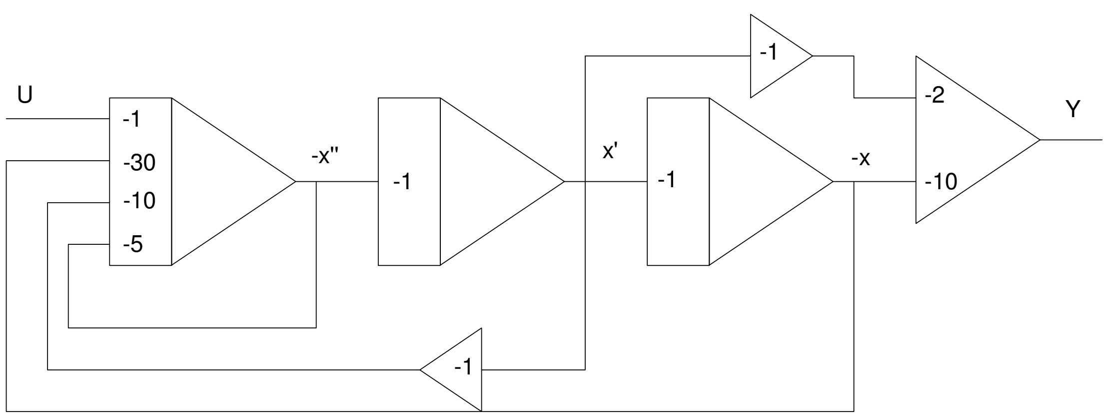
1) Design an analog computer to implement

$$Y = \left(\frac{2s+10}{s^3+5s^2+10s+30}\right)X$$

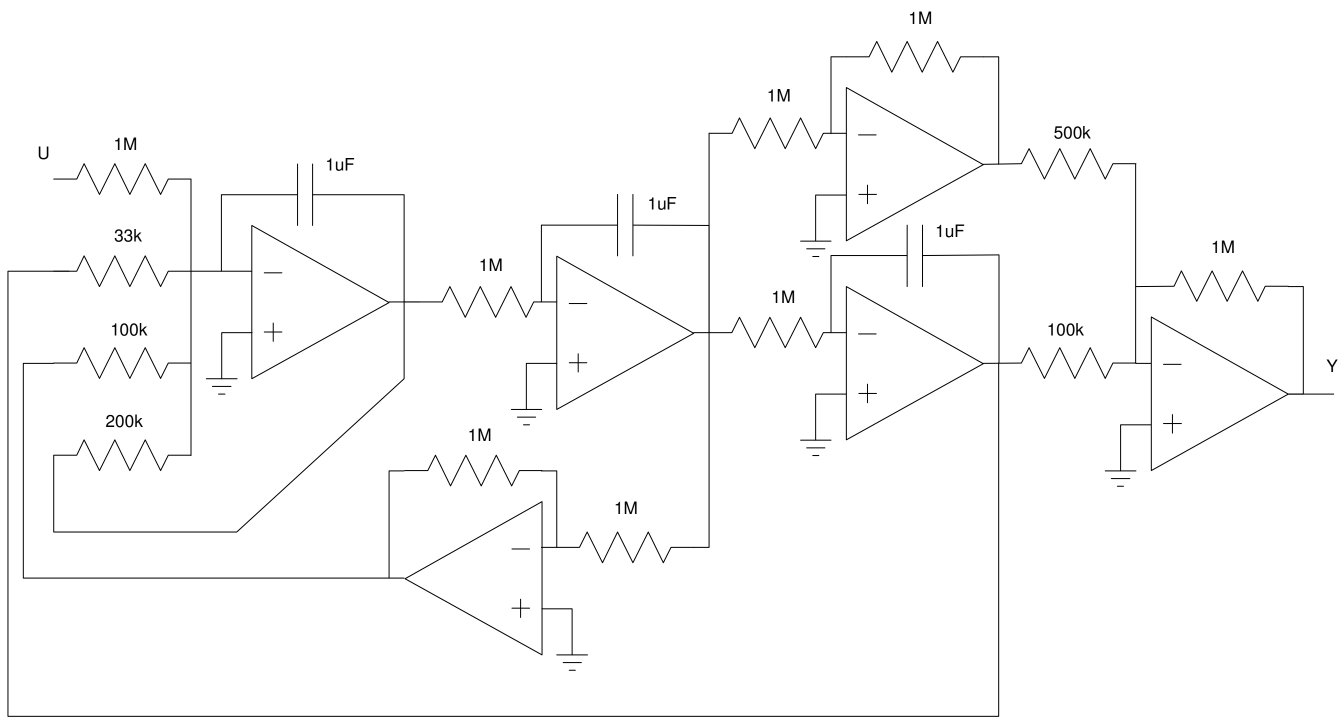
Step 1: Draw an analog computer circuit



Step 2: Adjust the gains so that they are all negative. Add an inverter if needed.



Replace each amplifier with its op-amp equivalent


U
1M
1uF
33k
100k
200k
1M
1uF
1M
1M
1M
1uF
1M
500k
1M
100k
Y
1M
1M

Butterworth and Chebychev Filters

2) Specify the requirements for a filter. For example:

Subwoofer

- Pass frequencies below 250Hz
  - $0.9 < \text{gain} < 1.1$ for $f > 250$Hz
- Reject frequencies above 500Hz
  - $\text{gain} < 0.2$ for $f > 500$Hz

3) Filter Design. Give the transfer function for filter which meets your requirements.

- Plot the gain vs. frequency of your filter.

Assume a 3rd-order Chebychev filter. If the corner is 1 rad/sec, then

$$G(s) = \left(\frac{k}{(s+0.85)\left(s+1.21\angle\pm 69.5^0\right)} \right)$$

Adjust the corner until you meet the requirements

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>> p1 = 0.85;
>> p2 = 1.21 * exp(j*69.5*pi/180);
>> p3 = conj(p2);

>> A = 1600;
>> G = 1 ./ ( (s + A*p1) .* (s + A*p2) .* (s + A*p3) );
>> G = G / max(abs(G));
>> plot(f,abs(G),'b',[250,250,500],[1.1,0.9,0.2],'r+')

>> A = 1500;
>> G = 1 ./ ( (s + A*p1) .* (s + A*p2) .* (s + A*p3) );
>> G = G / max(abs(G));
>> plot(f,abs(G),'b',[250,250,500],[1.1,0.9,0.2],'r+')
>> xlabel('Frequency (Hz)');
>> ylabel('Gain');
>>
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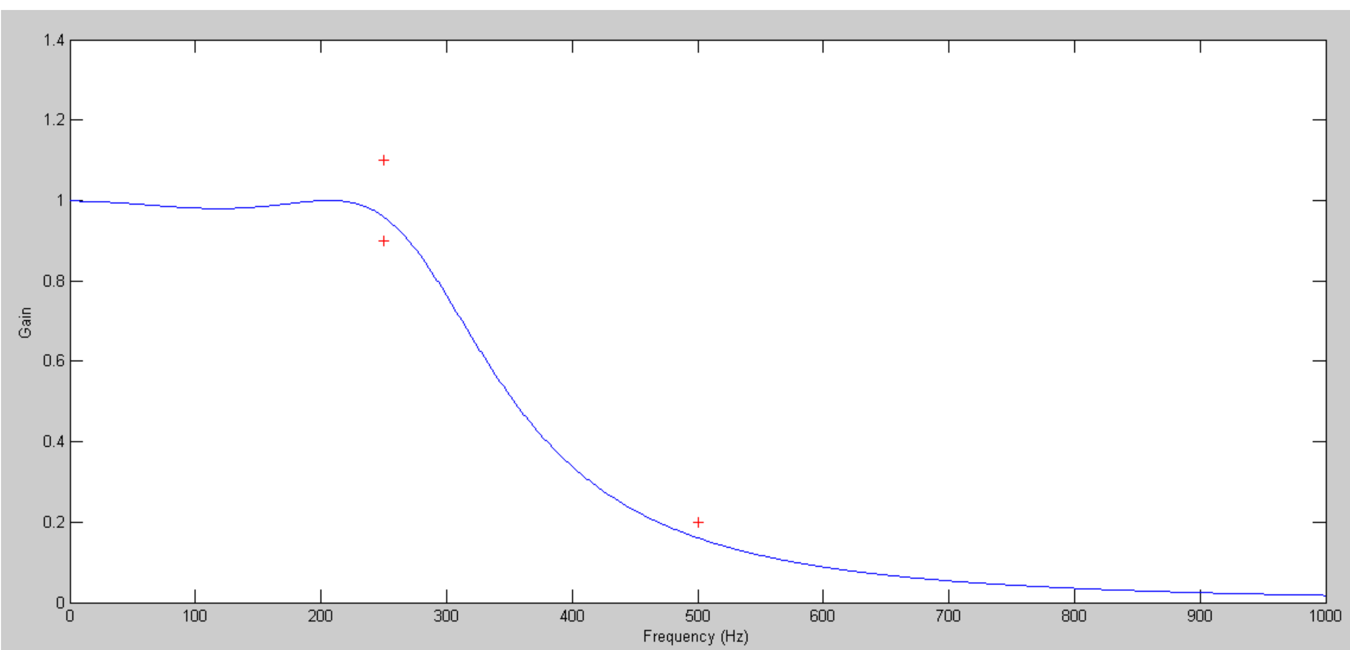


4) Simulation: Design a circuit to implement your filter. Simulate it in CircuitLab to verify it meets your requirements

- $0.9 < \text{gain} < 1.1$ in the pass-band region, and
- $\text{gain} < 0.2$ in the band-reject region

Design:

$$G(s) = \left(\frac{k}{(s+1275)\left(s+1815\angle\pm 69.5^0\right)} \right)$$

Pole = -1275:

- C = 0.1uF
- R = 7843 Ohms

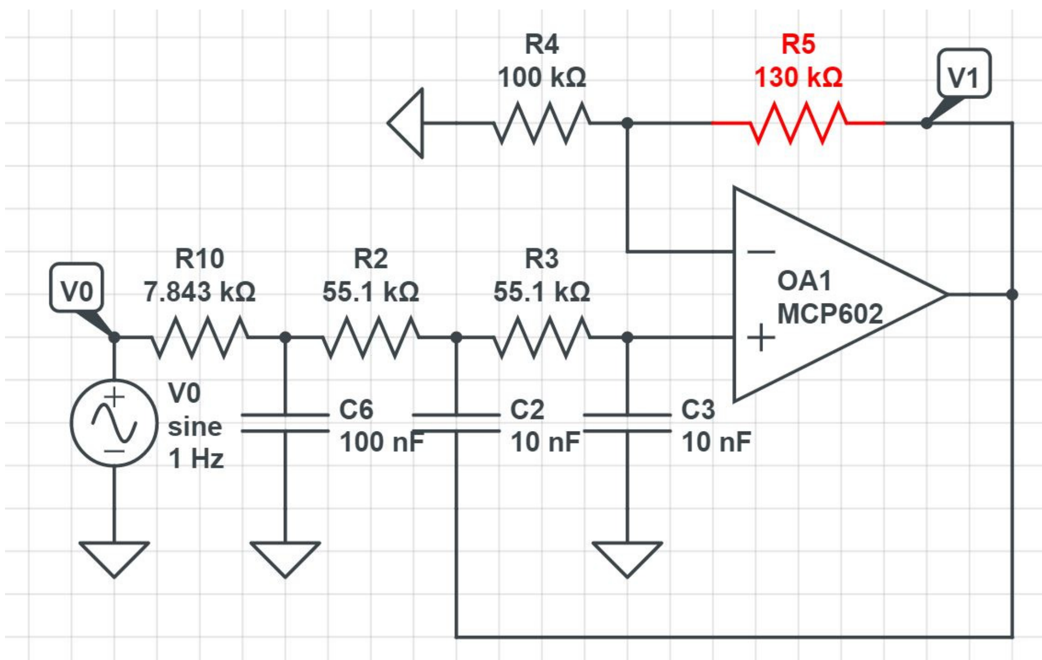
Pole = 1815 @ 69.5 degrees

- C = 0.01uF
- R = 55.1k

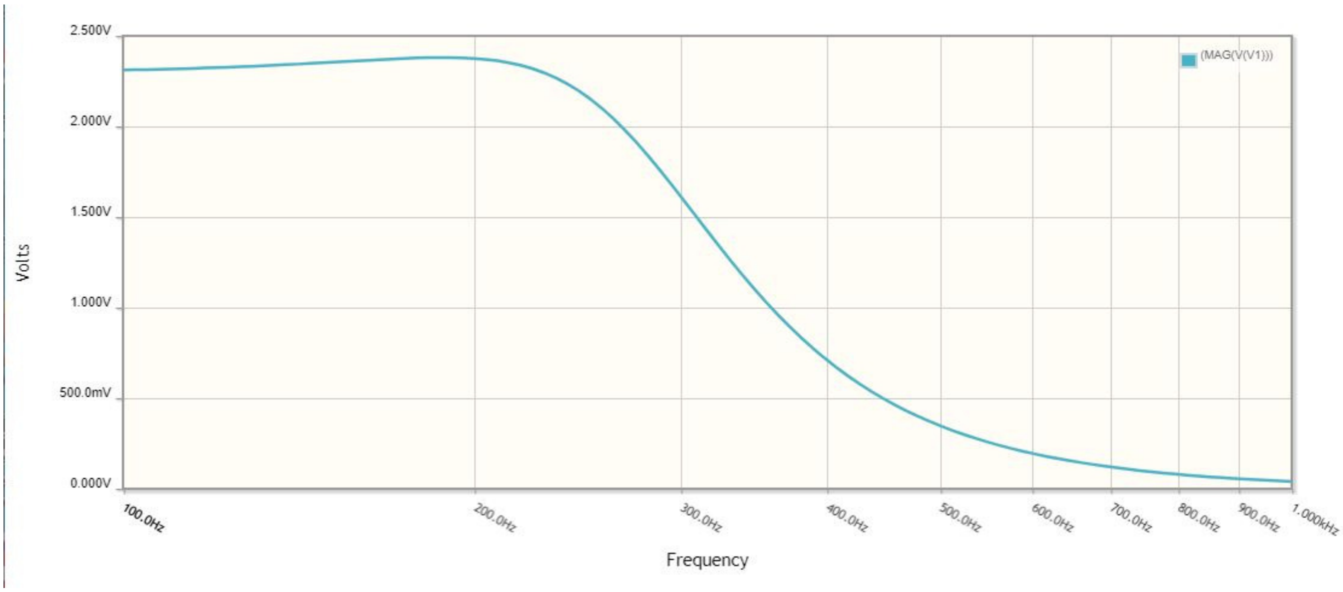
$$3 - k = 2\cos(69.5^0)$$

$$k = 2.300$$

- Ra = 100k
- Rb = 130k



From CircuitLab

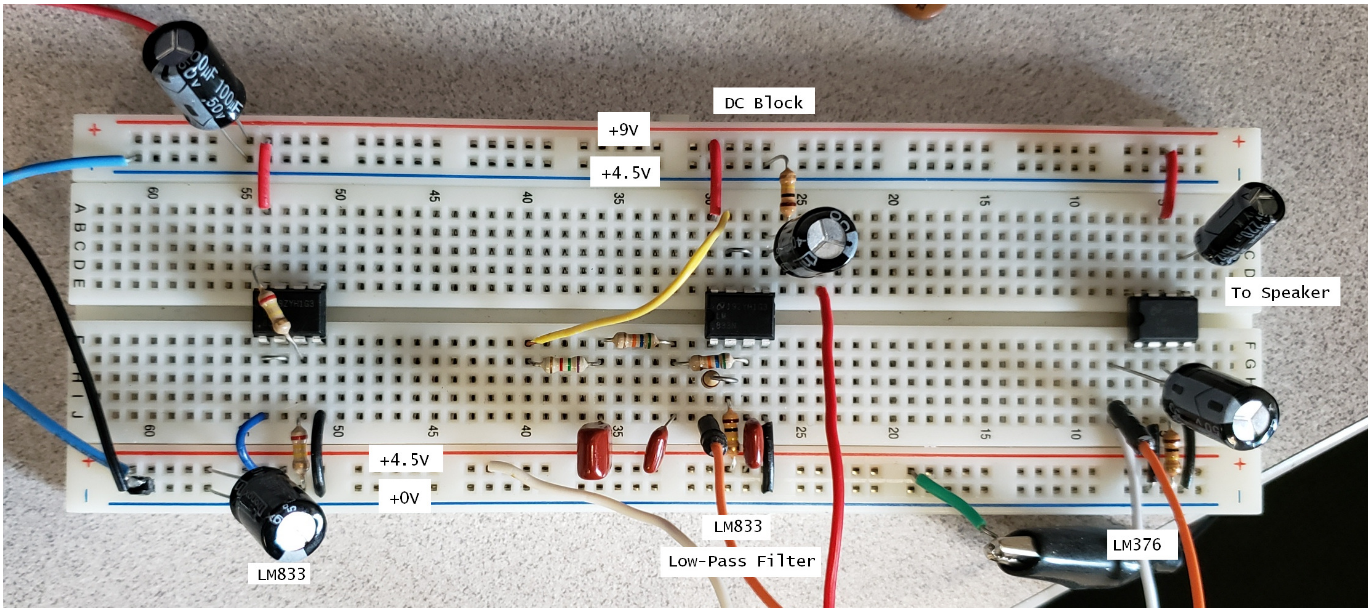


Frequency	Gain	G(s) / G(100Hz)	Meet Specs?
100Hz	2.315	1.0000	
250Hz	2.151	0.9292	yes
500Hz	0.3457	0.1497	yes

Lab:

5) Add a low-pass filter to circuit from homework #1

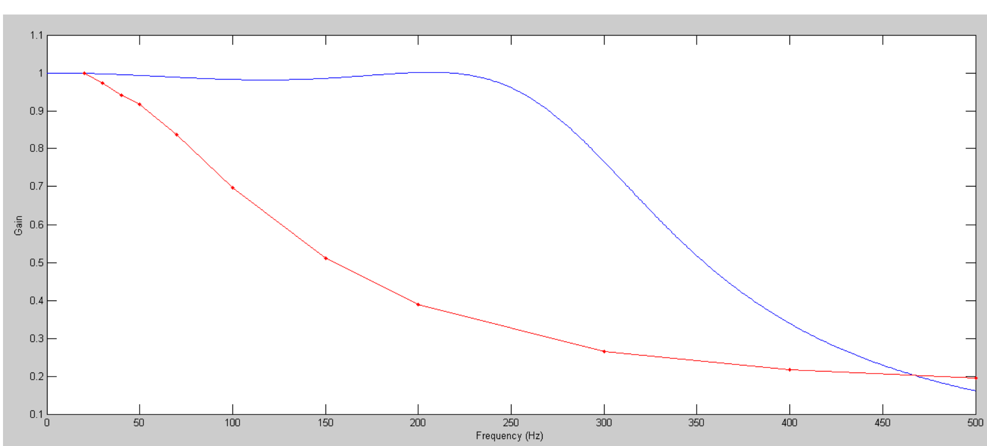
- Include a photo for full credit



6) Measure the gain at several frequencies

- Check if you do / do not meet your requirements

Frequency (Hz)	Filter Output (mV)	Filter Output (% DC)	Theory
20	337	100	99.8787
30	328	97.33	99.7341
40	317	94.07	99.5446
50	309	91.69	99.3221
70	282	83.68	98.8370
100	235	69.73	98.2529
150	172	51.04	98.5591
200	131	38.87	100.1012
300	89	26.41	76.5776
400	73	21.66	33.8873
500	66	19.58	16.1026



Does this meet the requirements?

- No
- The second capacitor is going to ground (4.5V) rather than Vout
- This results in three real poles rather than complex poles

Moving the second capacitor to the output rather than ground should fix this.

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7) Demonstrate your filter + speaker driver

- With a sine-wave input &
- With music as an input