ECE 321 - Final - Name ____________________

Spring 2020. Due Wednesday, May 13th at midnight

alculators, internet, Matlab, circuit lab, tarot cards permitted. Just not someone else.

Please sign pledge if able (i.e. you did not work with anyone else)

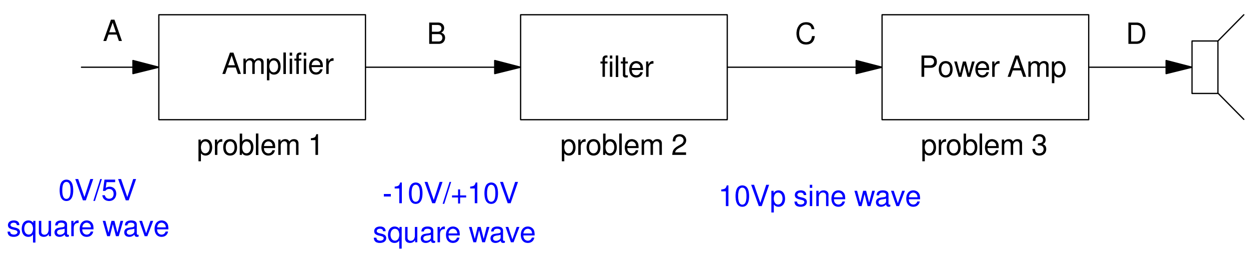
No aid given, received, or observer: ______________________________

Background: With a microprocessor, it is fairly easy to generate a square wave. Using an H-bridge, you can then drive a speaker (ECE 320 problem). This results in a harsh sounding electronic piano due to the harmonics of a square wave.

One way to produce a cleaner sounding electronic piano is to

- Amplify the resulting sine wave to -10V to +10V,
- Filter the square wave to remove the harmonics (leaving a clean sine wave), and then
- Drive a speaker using a power amplifier (push-pull amplifier).

This final exam goes through each part of this design.



Problem 1) Amplifier: Design a circuit to convert a 0V / 5V square wave into a -10V / +10V square wave

Input (X): 220Hz to 440Hz square wave

- 0V / 5V
- Capable of driving 10mA

Output (Y): 220Hz to 440 Hz square wave

- -10V to +10V
- Capable of driving 10mA

Relationship:

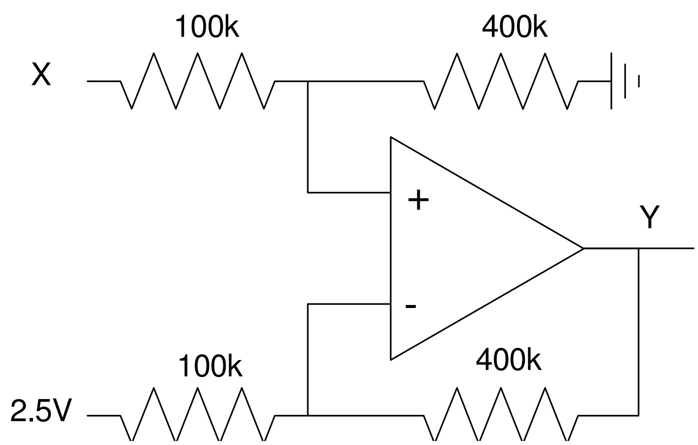
- Y = 4X - 10

Rewrite this as

$$Y = 4(X - 2.5)$$

Implement with an instrumentation amplifier

$$Y = \left(\frac{R_1}{R_2}\right)(A - B)$$



Problem 2) Filter. A square wave has odd harmonics. A sine wave has no harmonics. One way to turn a square wave into a sine wave is to filter out the harmonics.

Design a filter to meet the following requirements

Input (X): 220Hz to 440Hz square wave (i.e. problem #1)

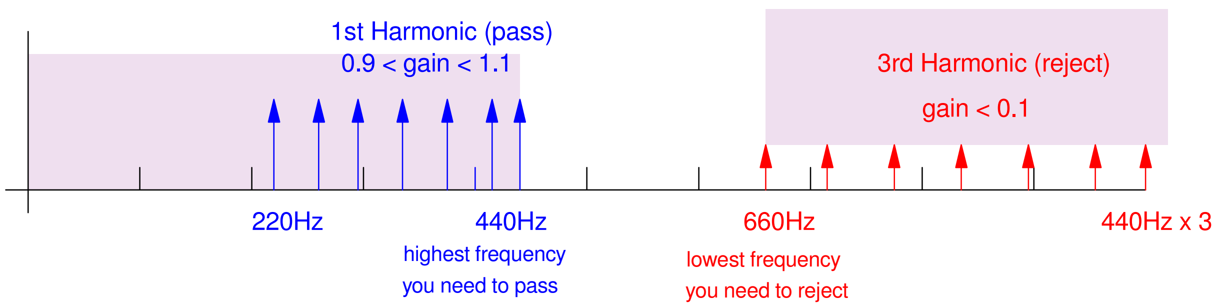
- -10V to +10V
- Capable of driving up to 10mA

Output (Y): 220Hz to 440Hz sine wave

- Capable of driving up to 10mA

Relationship:

- 0.9 < gain < 1.1   0 < frequency < 440Hz
- 0.1 < gain   frequency > 660Hz



The number of poles you need are

$$\left(\frac{440}{660}\right)^n < 0.1$$

$$n > 5.68$$

Let N = 6

Assume a Chebuchev filter. For a corner at 1 rad/sec

$$G(s) = \left(\frac{-}{(s+0.4722\angle\pm36.10^0)(s+0.8100\angle\pm69.83^0)(s+1.0436\angle\pm84.38^0)}\right)$$

For a corner at 440Hz (2764 rad/sec)

$$G(s) = \left(\frac{-}{(s+1305\angle\pm36.10^0)(s+2239\angle\pm69.83^0)(s+2885\angle\pm84.38^0)}\right)$$

Design this in three stages

Stage 1:

$$G(s) = \left(\frac{k \cdot 1305^2}{\left(s + 1305 \angle \pm 36.10^0\right)} \right)$$

$$\left(\frac{1}{RC}\right) = 1305$$

R = 100k, C = 7.66nF

$$3 - k = 2\cos(36.10^0)$$

$$k = 1.384$$

R1 = 100k, R2 = 38.4k

Stage 2:

$$G(s) = \left(\frac{k \cdot 2239^2}{\left(s + 2239 \angle \pm 69.83^0\right)} \right)$$

$$\left(\frac{1}{RC}\right) = 2239$$

R = 100k, C = 4.466nF

$$3 - k = 2\cos(69.83^0)$$

$$k = 2.310$$

R1 = 100k, R2 = 131.0k

Stage 3:

$$G(s) = \left(\frac{k \cdot 2885^2}{\left(s + 2885 \angle \pm 84.38^0\right)} \right)$$

$$\left(\frac{1}{RC}\right) = 2885$$

R = 100k, C = 3.466nF

$$3 - k = 2\cos(84.38^0)$$

$$k = 2.804$$

R1 = 100k, R2 = 180.4k

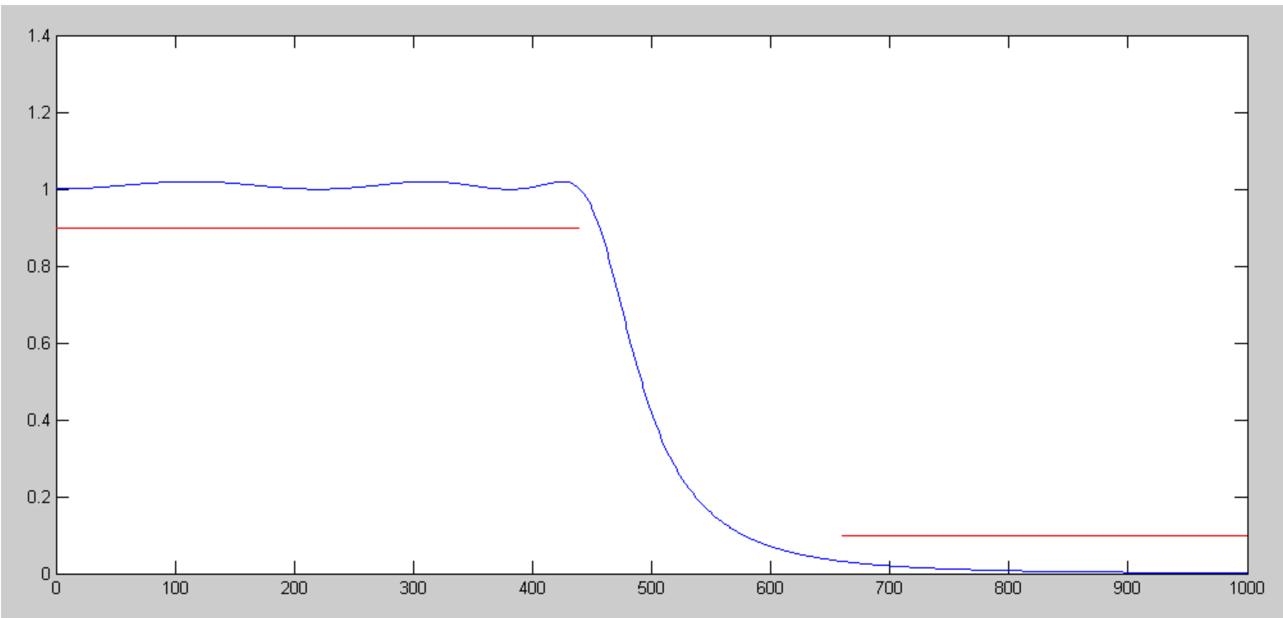
Checking this design in Matlab

```
p1 = 1305 * exp(j*36.1*pi/180);
p2 = conj(p1);
p3 = 2239*exp(j*69.83*pi/180);
p4 = conj(p3);
p5 = 2885*exp(j*84.38*pi/180);
p6 = conj(p5);
num = p1 * p2 * p3 * p4 * p5 * p6

num = abs(num)

num =  7.1059e+019

f = [0:1000]';
w = 2*pi*f;
s = j*w;
G = num ./ ( (s+p1).*(s+p2).*(s+p3).*(s+p4).*(s+p5).*(s+p6) );
plot(f,abs(G))
plot(f,abs(G),'b',[0,440],[0.9,0.9],'r')
plot(f,abs(G),'b',[0,440],[0.9,0.9],'r',[660,1000],[0.1,0.1],'r')
```



Problem 3) Power Amplifier. Design a circuit to take the output of the filter and drive an 8-Ohm speaker

Input (X) (problem #2)

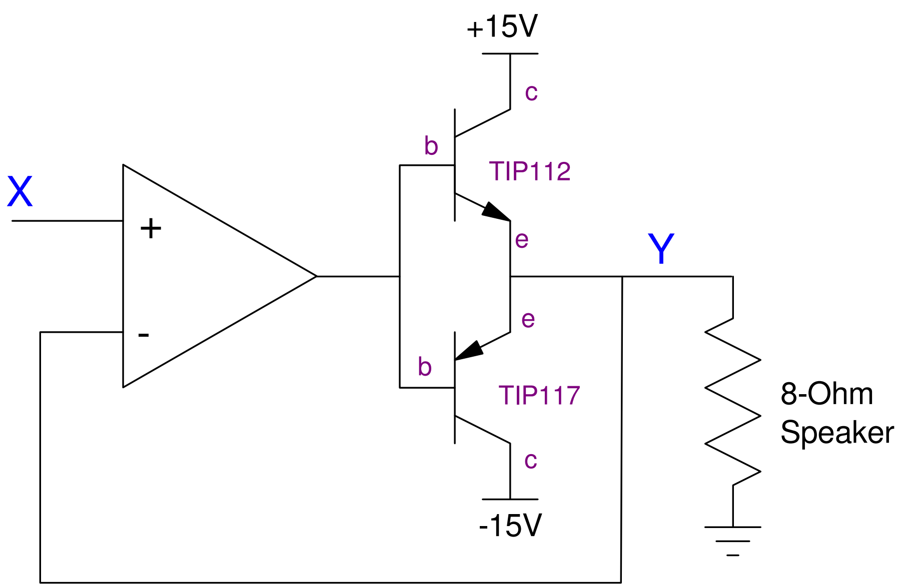
- -10V to +10V sine wave
- 220Hz to 440Hz
- Capable of driving 10mA

Output (Y): 8-Ohm speaker

Relationship:

- Y = X
- +/- 100mV

This is just a push-pull amplifier



Problem 4) CircuitLab Simulation.

Verify your design using CircuitLab.

- Adjust the gain of the amplifier (problem #1) so that the output is a +10V to -10V sine wave
- Verify the output of the resulting amplifier (problem 1) at 220Hz and 440Hz
- Verify the output of the filter (problem 2) at 220Hz and 440Hz
- Verify the output of push-pull amplifier (problem #3) at 220Hz and 440Hz

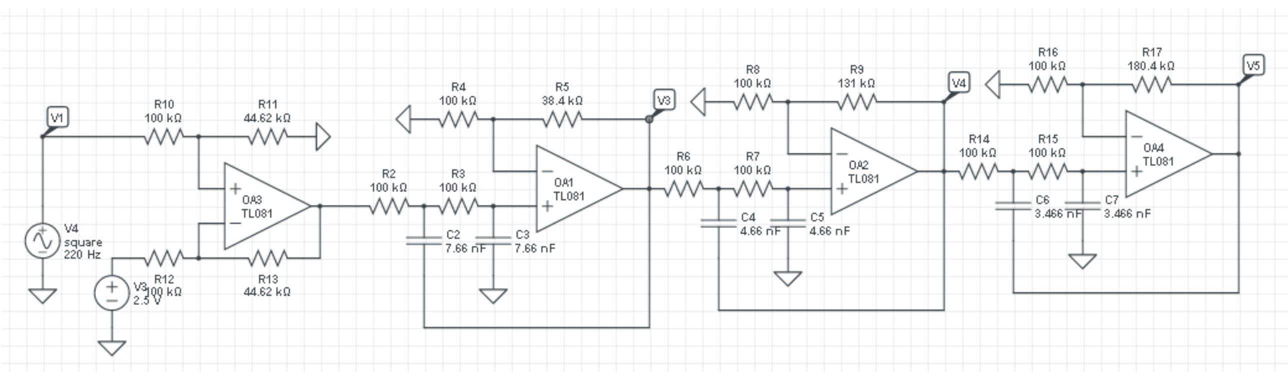
The low-pass filter has a DC gain of

$$k = k_1 \; k_2 \; k_3 = 1.384 \cdot 2.310 \cdot 2.804$$

$$k = 8.965$$

We only want a gain of 4.000, so change the insrumentation amplifier to have a gain of

$$gain = \left(\frac{4}{8.965}\right) = 0.4462$$



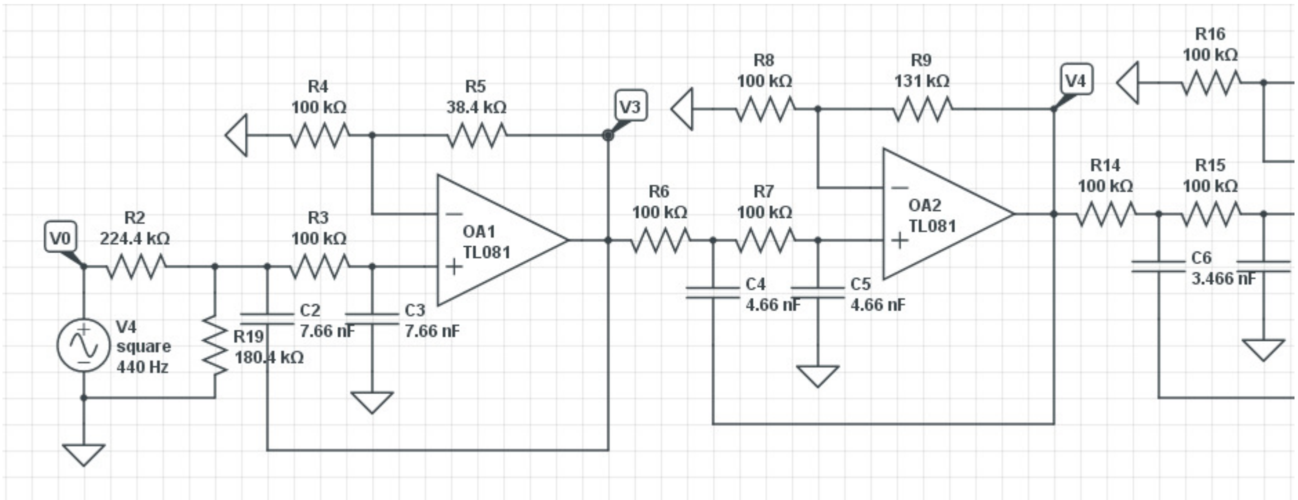
Part 1 of circuit

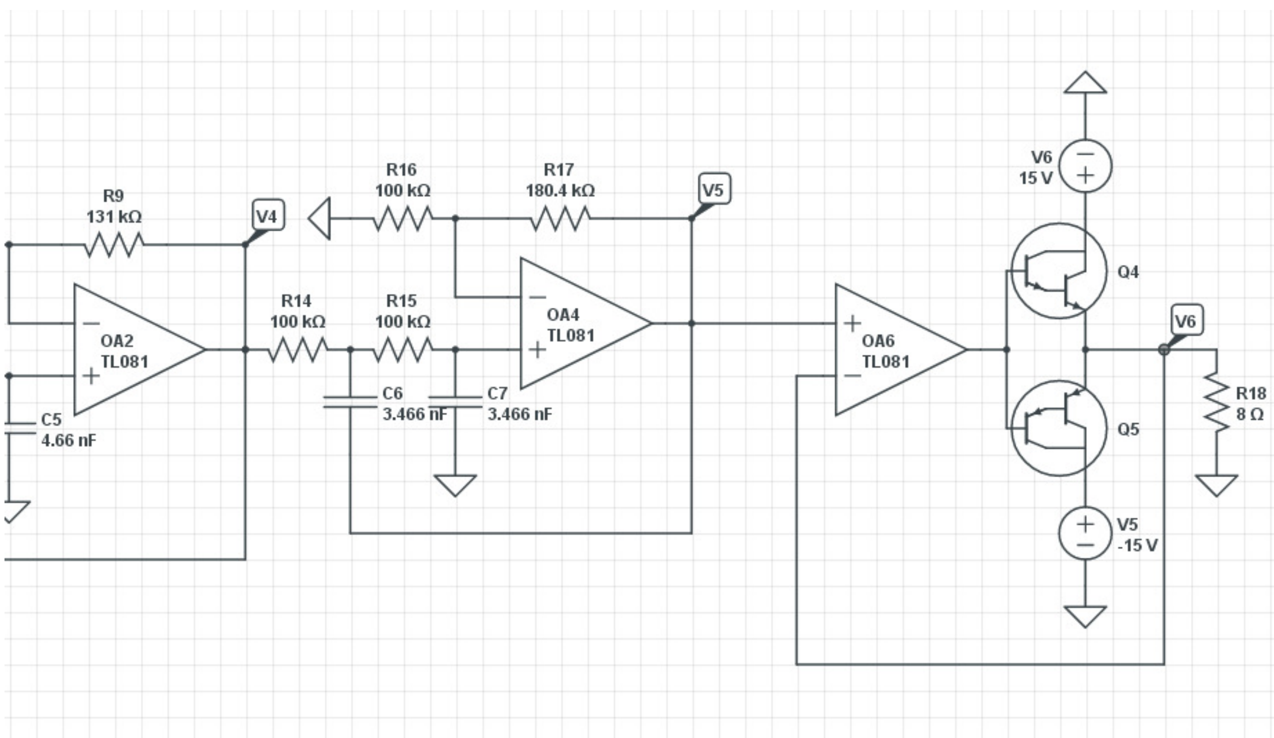
This hit the 30 component limit on my personal account - so I'll have to simulate it in two sections

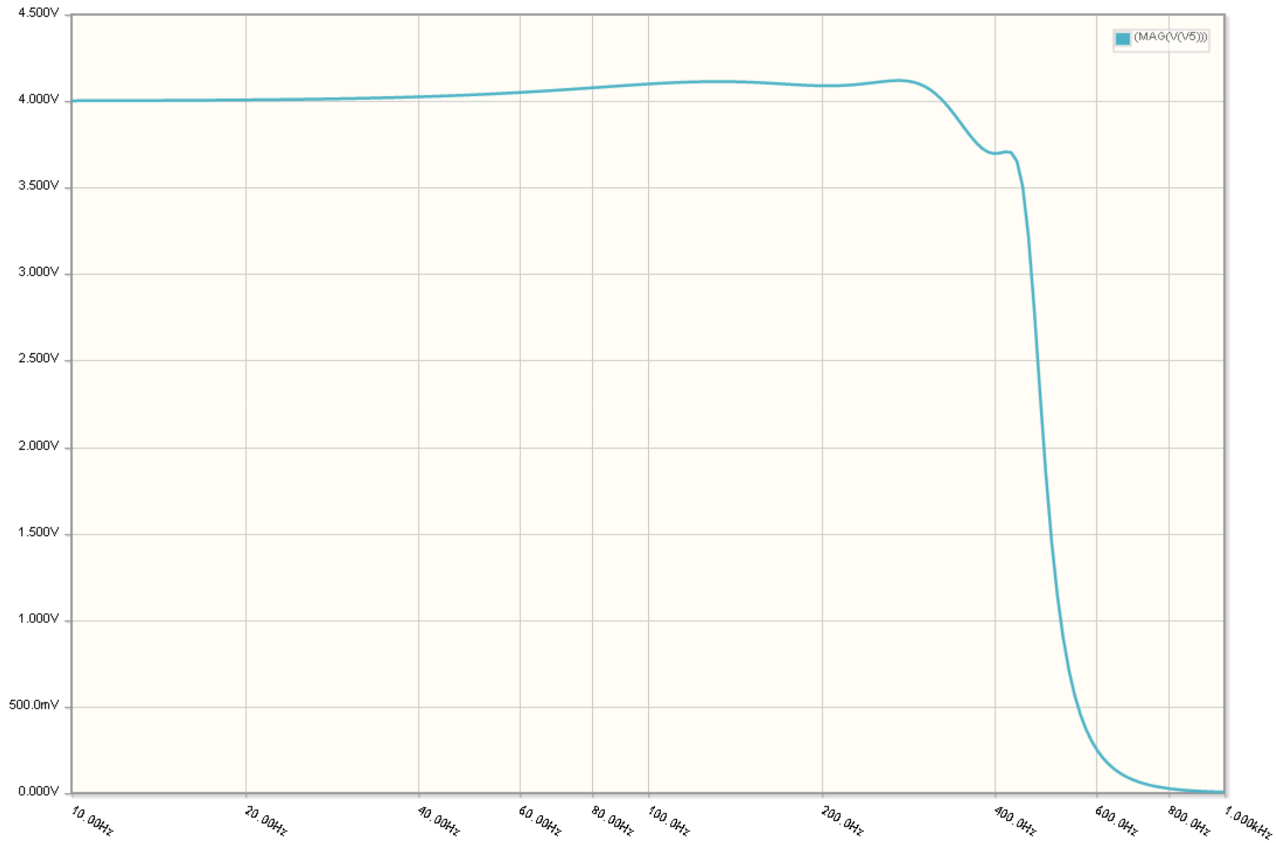
Section 2:

Replace stage 1 with its Thevenin equivalent

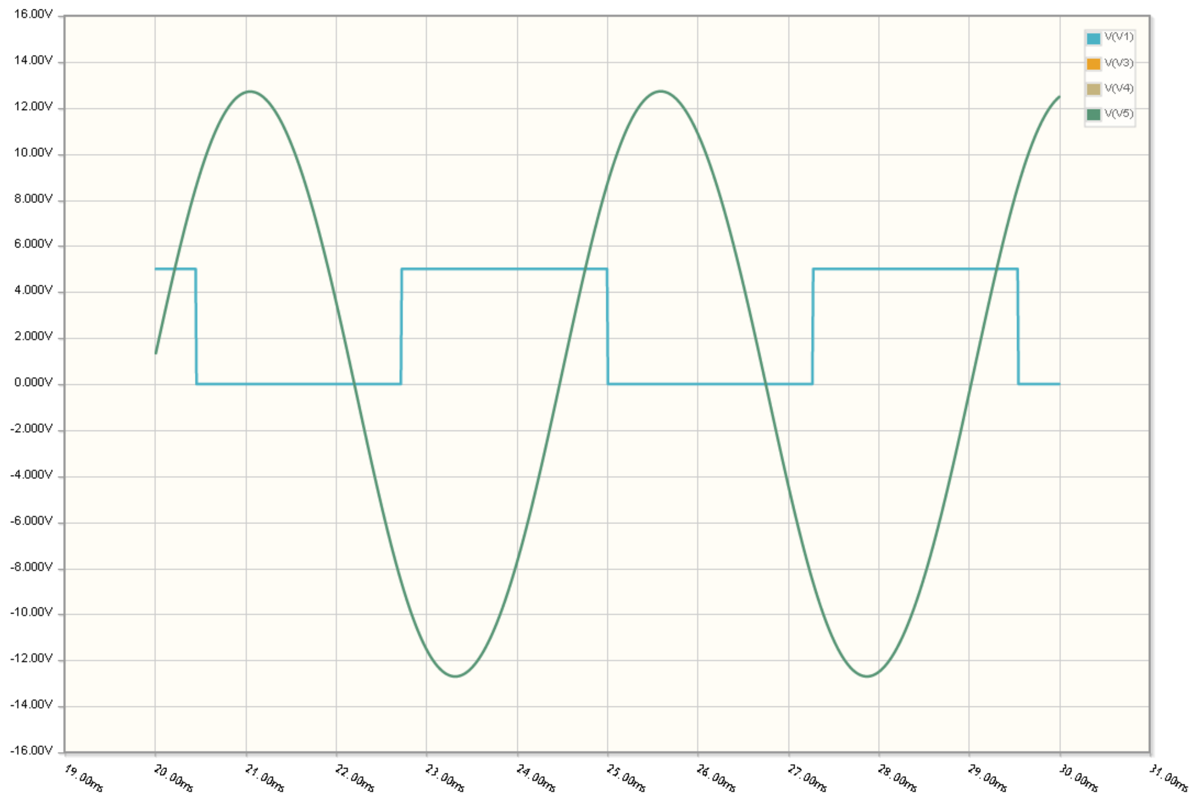
- Rth = 100k
- Vth = 0.4462 Vin



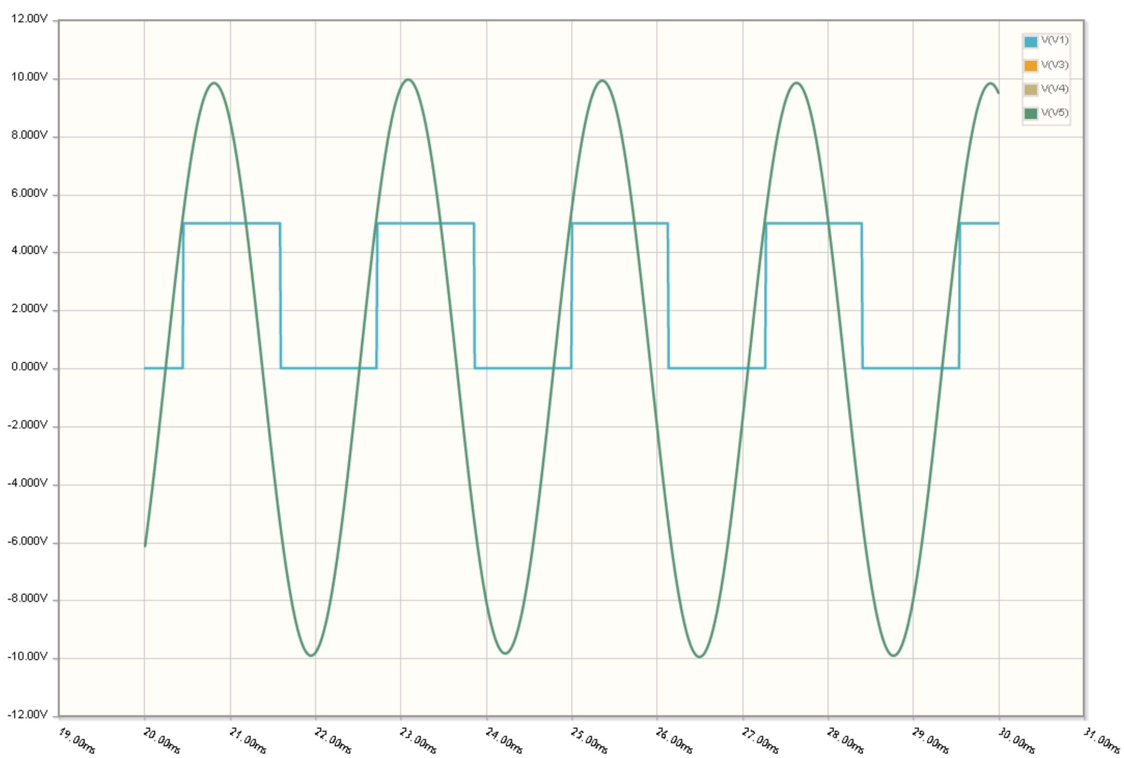




Gain vs. Frequency: The gain at 440Hz is down a little...



Response to a 220Hz squre wave input



Response to a 440 Hz squar wave input