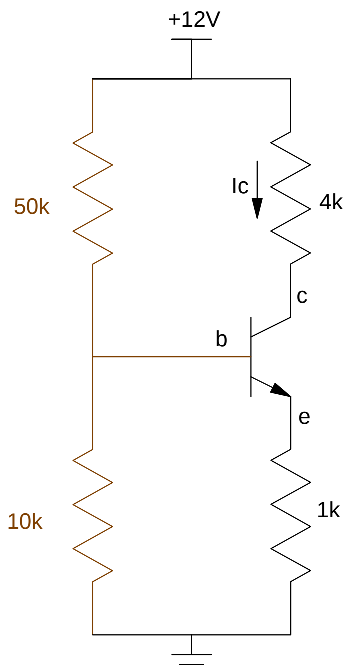
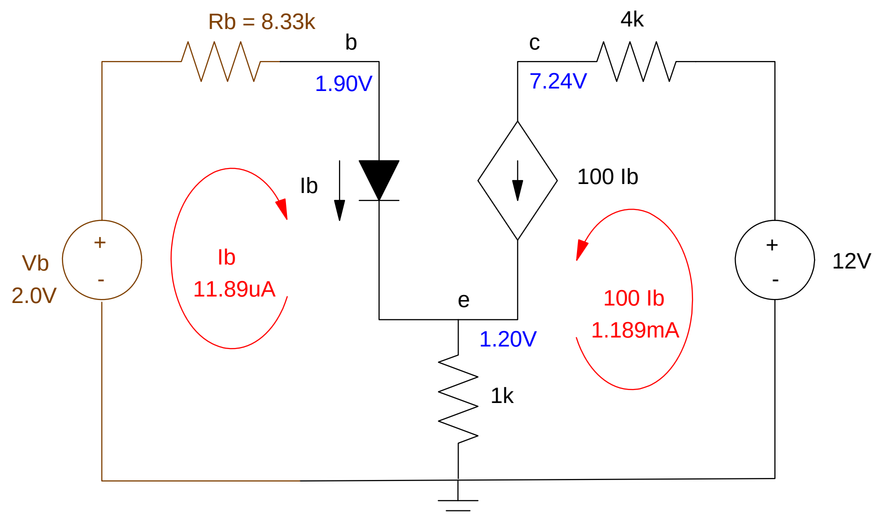
ECE 321 - Homework #3

Filters & 2-Port Models. Due Monday, April 24th, 2017

1) Determine the Q-point for the following circuit (shown on the left). Assume β=100





First, redraw the circuit using the Thevening equivalent of the 50k and 10k resistor (shown in brown).

$$V_{th} = V_{bb} = \left(\frac{10k}{10k+50k}\right) 12V = 2.00V$$

$$R_{th} = R_b = 10k || 50k = 8.33k$$

Next, find Ib:

$$-10V + 8.33k \cdot I_b + 0.7V + 1k(I_b + 100I_b) = 0$$

$$I_b = \left(\frac{2V-0.7V}{8.33k+(101)1k}\right) = 11.89\mu A$$

Ic is 100Ib

$$\boxed{I_c = 100I_b = 1.189mA}$$

This gives

$$V_e = 1k(I_b + I_c) = 1.20V$$

$$V_c = 12 - 4k \cdot I_c = 7.24V$$

$$\boxed{V_{ce} = V_c - V_e = 6.043V}$$

2) Find R1, R2, and Re so that

- The Q-point is stabilized for variations in β, and
- Vce = 6V

Well, what are the odds that random values of resistors would result in a Q-point that is 6.00V?

Step 1: Find Rb. To stabilize the Q-point

$$(1+\beta)R_e >> R_b$$

$$101k >> R_b$$

Let

$$R_b = 10k$$

Step 2: Find Vb.

For Vce = 6V,

$$I_c = \frac{12V-6V}{4k+(1.01)1k} = 1.198mA$$

$$I_b = \frac{I_c}{\beta} = 11.98\mu A$$

$$V_b = I_b R_b + 0.7 + (I_b + I_c)R_e$$

$$V_b = 2.029V$$

Step 3: Find R1 and R2

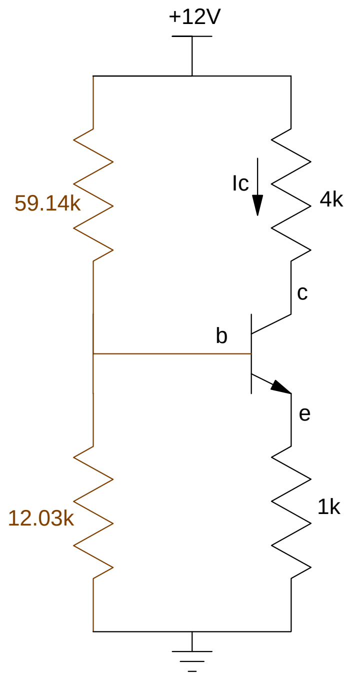
$$\left(\frac{R_2}{R_1+R_2}\right)12V = 2.029V$$

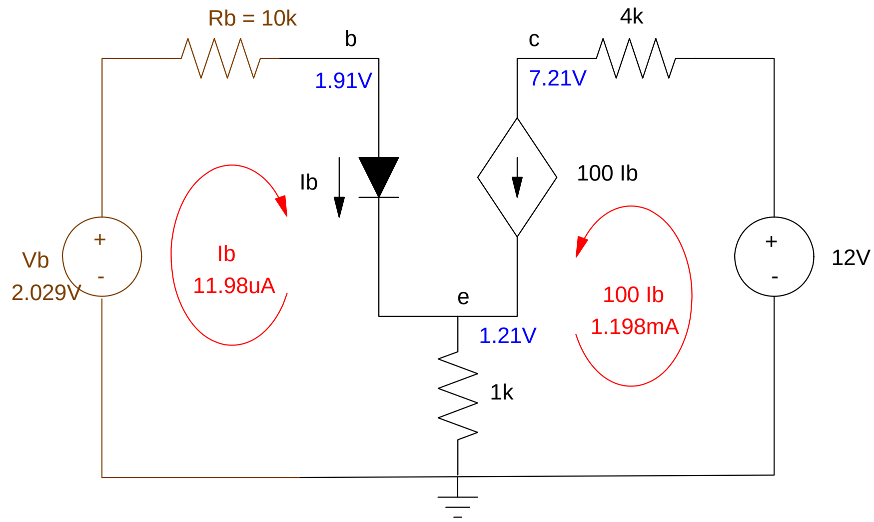
$$\left(\frac{R_1 R_2}{R_1+R_2}\right) = 10k$$

$$R_1 = \left(\frac{12V}{2.029V}\right)10k$$

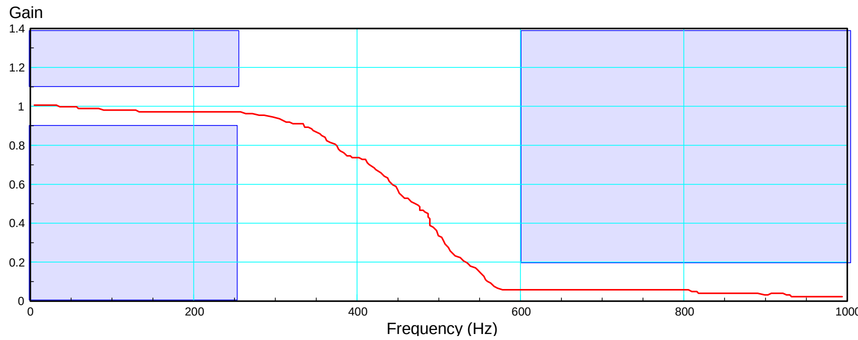
$$R_1 = 59.14k\Omega$$

$$R_2 = 12.03k\Omega$$


+12V
59.14k
Ic
4k
c
b
e
12.03k
1k


Rb = 10k
b
1.91V
c
7.21V
4k
Ib
100 Ib
+
-
Vb
2.029V
Ib
11.98uA
e
1.21V
100 Ib
1.198mA
1k
12V

Design a filter for your push-pull amlifier



3) Requirements:

- Input: +/- 10V analog signal, 100Hz to 1kHz, capable of 20mA (i.e. a LM833 op-amp)
- Output: +/- 10V analog signal capable of 20mA (i.e. another LM833 op-amp)
- Relationship: Specify how the input and output relate. For a low-pass filter, for example, this might be
  - 0.9 < Gain < 1.1 for frequencies below 250 Hz
  - Gain < 0.2 for frequencies above 600 Hz

Let's go with this set of requirements.

4) Matlab Analysis:

- Give the transfer function for a filter which meets your requirements
- Plot the gain vs. frequency for your filter along with the requirements.

i) The number of poles you need is

$$\left(\frac{250Hz}{600Hz}\right)^n < \left(\frac{0.2}{1.0}\right)$$

$$n > 1.838$$

Let n = 3

Assume a 3rd order Chebychev filter with a corner at 250Hz. For a corner at 1Hz,

$$G(s) = \left(\frac{1}{(s+0.85)(s+1.21\angle\pm 69.5^0}\right)$$

Change this to 250Hz (1570 rad/sec)

- $0.85 \Rightarrow 0.85 \cdot 1570 = 1334$
- $1.21 \Rightarrow 1.21 \cdot 1570 = 1899$

so

$$G(s) = \left(\frac{(1334)(1899)(1899)}{(s+1334)(s+1899\angle\pm 69.5^0}\right)$$

In Matlab, check if this meets the requiremetns:

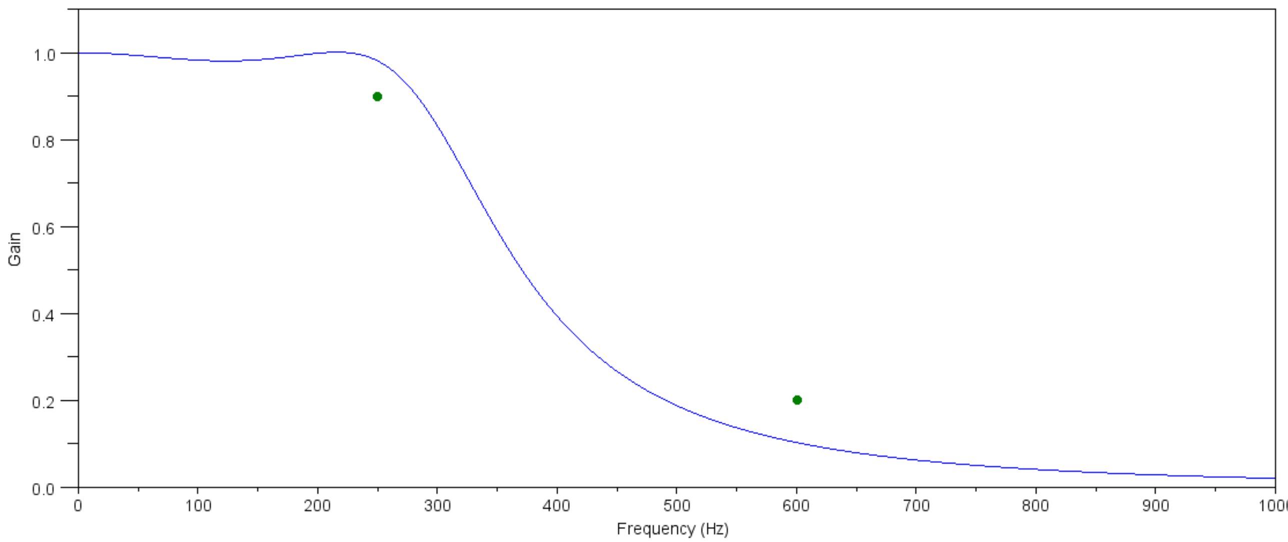
Input the poles, scaled to 250Hz (1570 rad/sec)

```
-->p1 = 0.85*1570;
-->p2 = 1.21*exp(j*69.5*%pi/180) * 1570;
-->p3 = conj(p2);
```

Plot the gain vs. frequency, scaled so that the DC gain is one:

```
-->f = [0:0.1:1000]';
-->w = 2*%pi*f;
-->s = j*w;
-->G = 1570^3 ./ ( (s+p1) .* (s+p2) .* (s+p3) );
-->G = G / G(1);

-->plot(f,abs(G),[250,600],[0.9,0.2],'.');
-->xlabel('Frequency (Hz)');
-->ylabel('Gain');
```



Well, that's pretty sweet: this meets the specs right off the bat. If it didn't, adjust the corner left and right so that the gain is more than 0.9 at 250Hz and less than 0.2 at 600 Hz.

Net:

$$G(s) = \left(\frac{1334 \cdot 1899^2}{(s+1334)\left(s+1899\angle 69.5^0\right)(s+1899\angle -69.5^0)} \right)$$

5) Analysis: R and C Calculations. Give the schematic along with calculations for R and C for a circuit to implement the transfer function you found in problem #3.

For the circuit below

$$\left(\frac{1}{RC}\right) = 1344$$

Let R = 10k

C = 74.4nF

$$\left(\frac{1}{RC}\right) = 1899$$

Let R = 100k

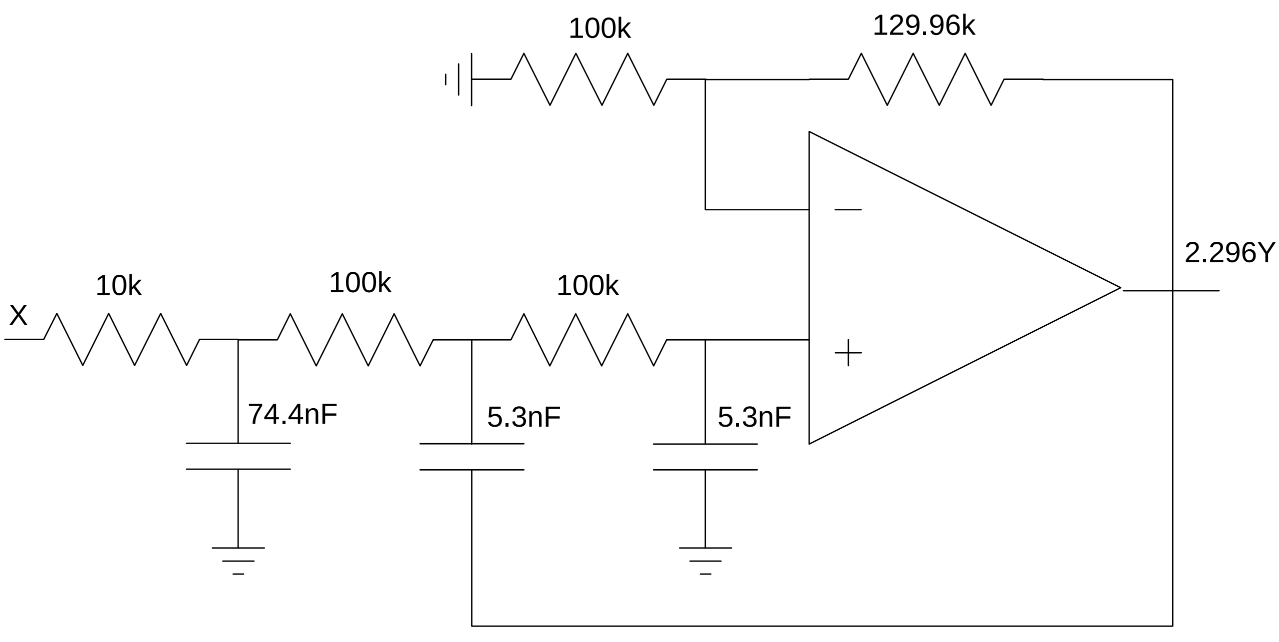
$$C = 5.3nF$$

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

$$k = 2.2996$$

Let R1 = 100k

R2 = 129.96k

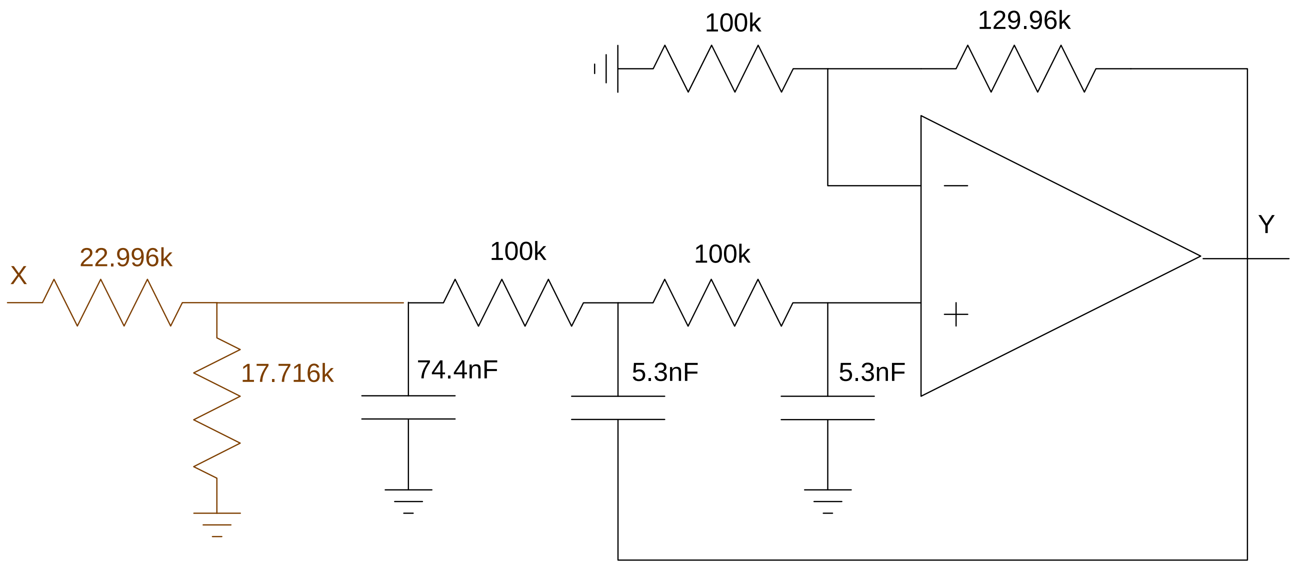


If you want the gain to be one, change the 10k resistor so that

- The Thevenin resistance is 10k
- The Thevenin voltage is X / 2.296

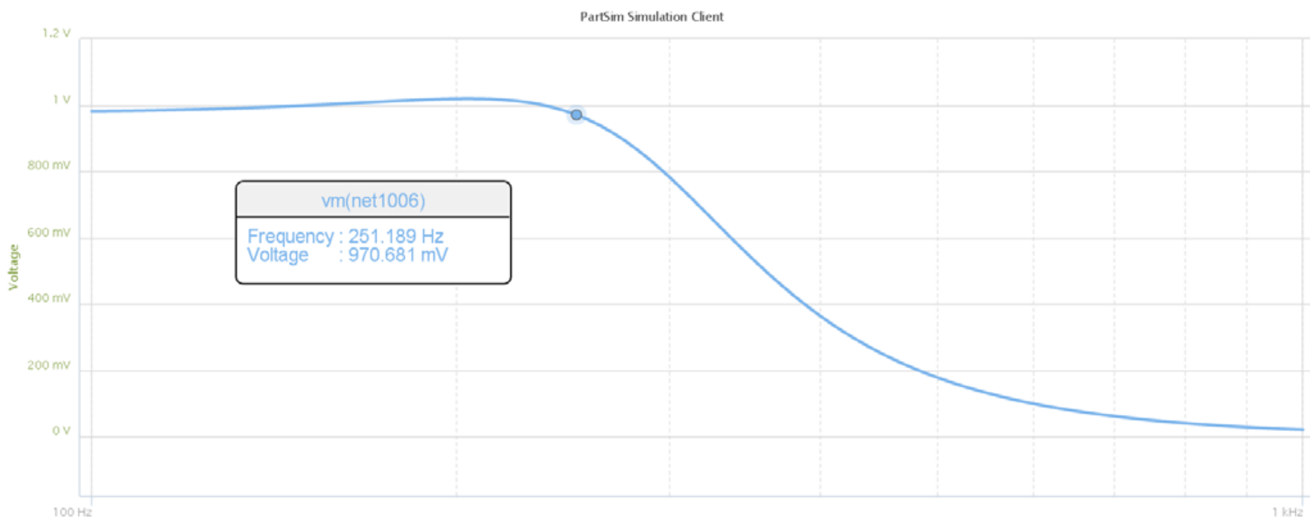
Rb = 22.96k

Ra = 17.716k



6) Test: Simulate your circuit in PartSim. Check the simulated gain at

- The two endpoints
- The corners, and
- A few other points



Frequency (Hz)	Gain (Matlab)	Gain (PartSim)	Gain (Lab)
100 Hz	1.000	0.9814	-
250 Hz	0.998	0.9768	-
400 Hz	0.400	0.3670	-
600 Hz	0.104	0.0968	-
1000 Hz	0.021	0.0199	-

7) Validation (Lab): Build your filter. Measure the gain at several frequencies to see if it agrees with your analysis