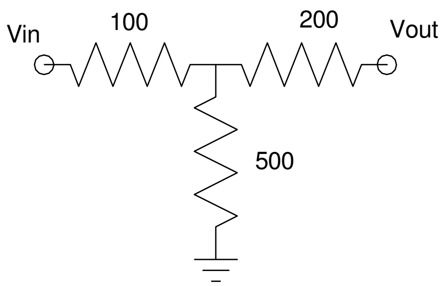
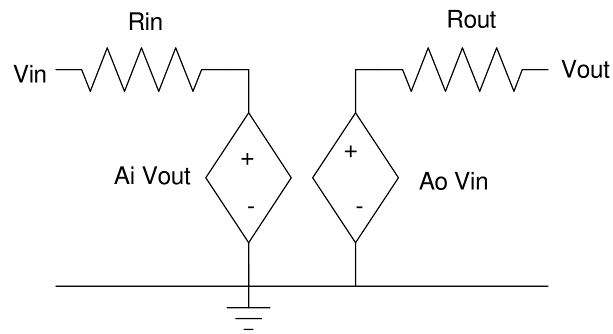
ECE 321 - Homework #4

2-Port Models, DC Bias for Transistors, Common Emitter Amplifier. Due Monday, April 23rd, 2018

2-Port Model

1) Find the 2-port model for the following circuit





Rin: Set Vout = 0V, measure the resistance at Vin

$$R_{in} = 100 + 200||500$$

$$R_{in} = 242\Omega$$

Ain: Set Vout = 1V, measure Vin

$$A_i = \left(\frac{500}{500+200}\right) \cdot 1V$$

$$A_i = 0.7143$$

Rout: Set Vin = 0. Measure the resistance at the output

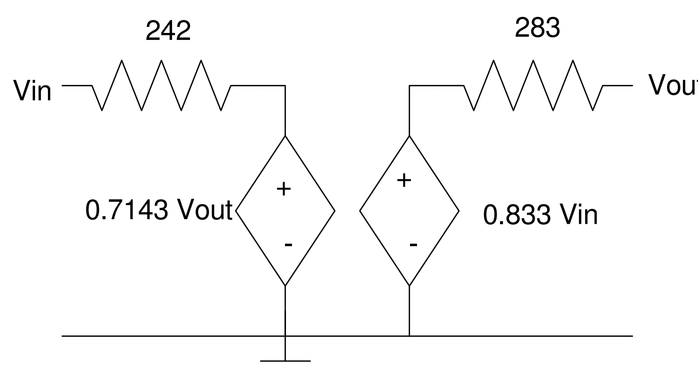
$$R_{out} = 200 + 100||500$$

$$R_{out} = 283\Omega$$

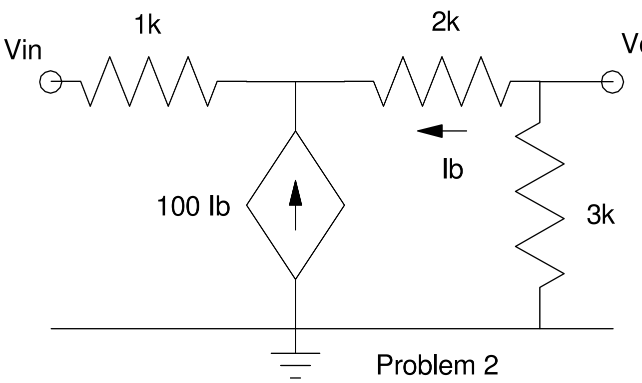
Ao: Set Vin = 1V, measure Vout

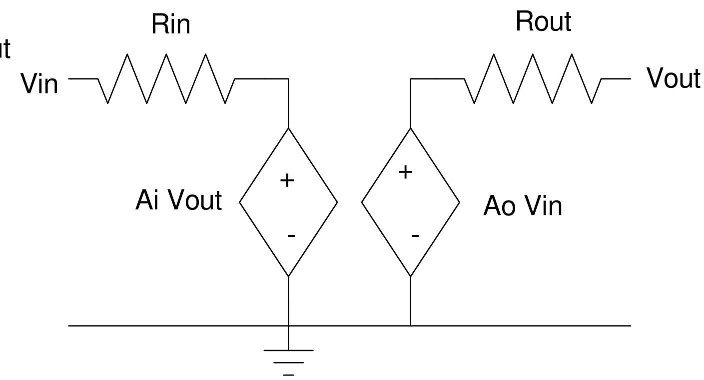
$$A_o = \left(\frac{500}{500+100}\right) \cdot 1V$$

$$A_o = 0.833$$

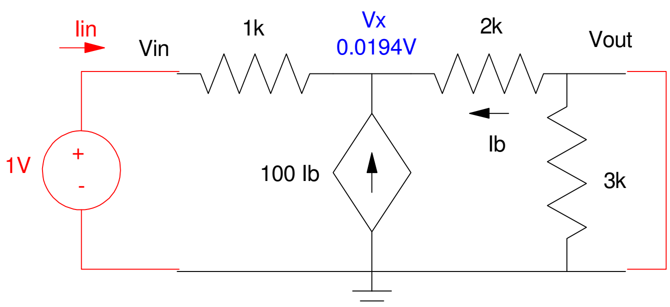


2) Find the 2-port model for the following circuit





Rin: Set Vout = 0V, measure the resistance at the input. Since this isn't obvious, apply a 1V test voltage at Vin and compute Iin:



Writing the voltage node equation at Vx

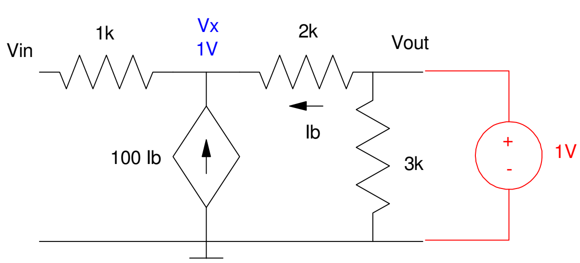
$$\left(\frac{V_x-1}{1k}\right)+\left(\frac{V_x}{2k}\right)+100\left(\frac{V_x}{2k}\right)=0$$

$$V_x = 0.0194V$$

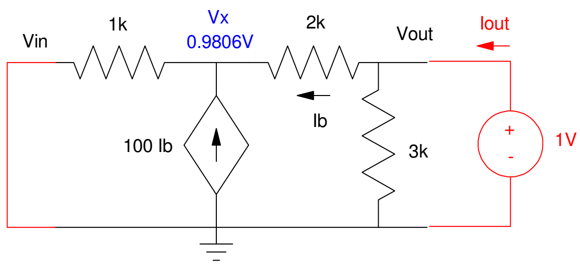
$$I_{in}=\left(\frac{1-V_x}{1000}\right)=980\mu A$$

$$R_{in}=\frac{V_{in}}{I_{in}}=\frac{1V}{980\mu A}=1020\Omega$$

Ai: Apply 1V at Vout, compute Vin: This works out ot Vx = 1V (Ib = 100Ib = 0). Ai = 1.



Rout: Short Vin, measure the resistance at Vout. Since this isn't obvious, add a 1V test voltage at the output and computer Iout



Solve for Vx:

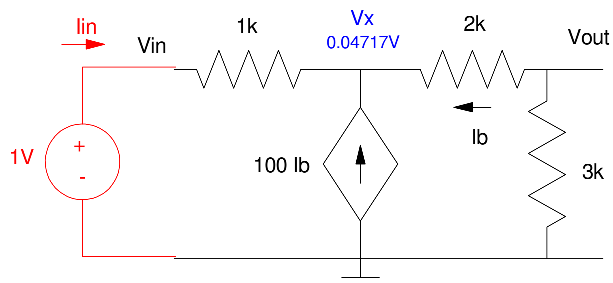
$$\left(\frac{V_x}{1k}\right) + \left(\frac{V_x - 1}{2k}\right) + 100\left(\frac{V_x - 1}{2k}\right) = 0$$

$$V_x = 0.9806V$$

$$I_{out} = \frac{1}{3k} + \left(\frac{1 - 0.9806}{2k}\right) = 343\mu A$$

$$R_{out} = \frac{1V}{343\mu A} = 2915\Omega$$

Ao: Apply 1V at the input, find the output voltage

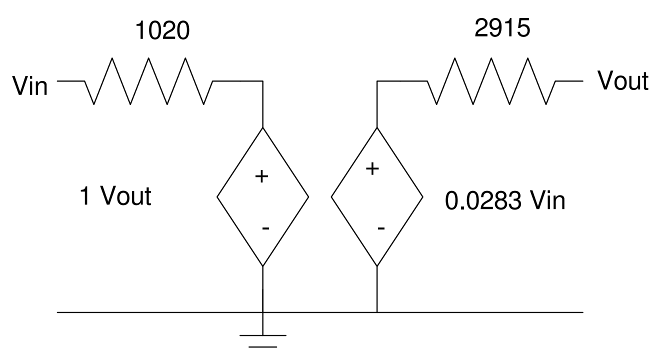


Solve for Vx

$$\left(\frac{V_x}{5k}\right) + 100\left(\frac{V_x}{5k}\right) + \left(\frac{V_x - 1}{1k}\right) = 0$$

$$V_x = 0.04717V$$

$$V_{out} = \left(\frac{3k}{3k + 2k}\right) V_x = 0.0283V$$



Q-Point Design

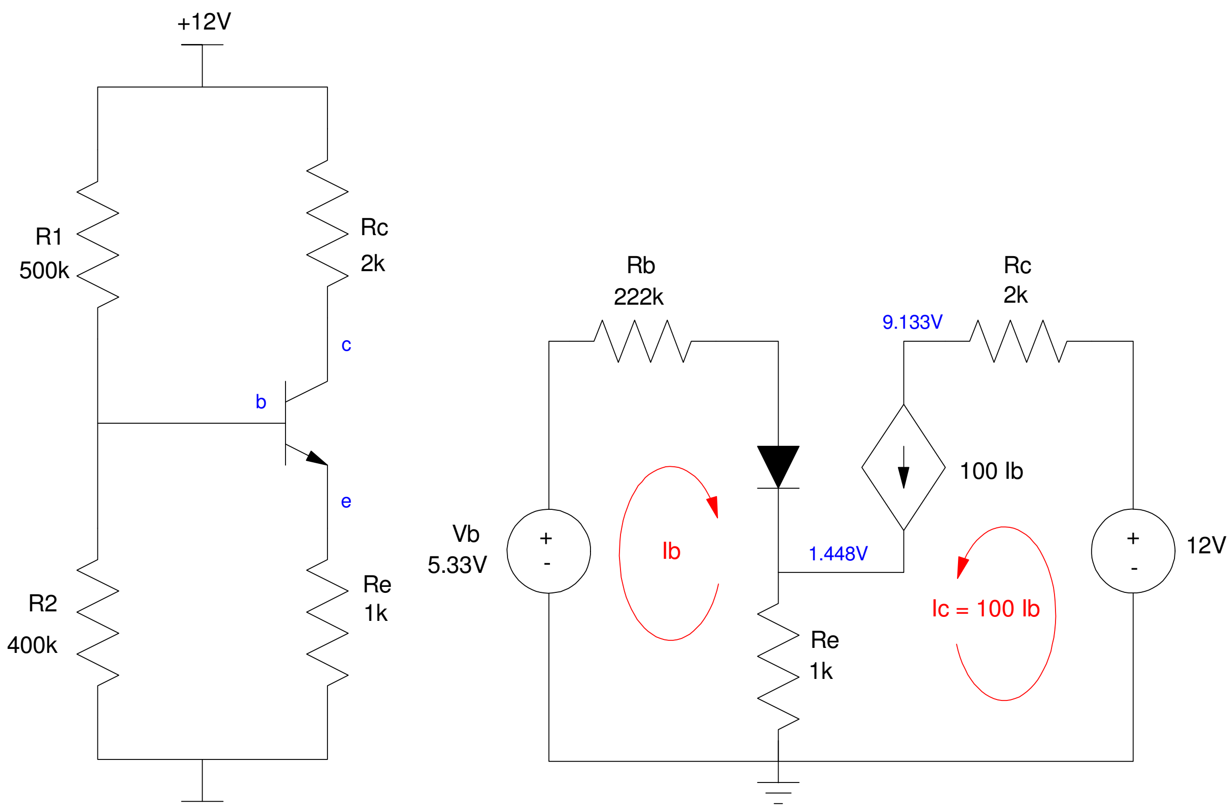
3) Determine the Q-point for the following circuit. Assume ideal silicon transistor with

- $\beta = 100$
- $|V_{be}| = 0.7V$
- $\min(|V_{ce}|) = 0.2V$

First, redraw the circuit using the Thevenin equivalent for R1, R2, and a 12V source

$$R_{th} = R_b = 400k||500k = 222k$$

$$V_{th} = V_b = \left(\frac{400k}{400k+500k}\right) 12V = 5.333V$$



Next, solve for Ib. Writing the loop equation around Ib

$$-5.33 + 222k \cdot I_b + 0.7 + 1k \cdot (I_b + 100 I_b) = 0$$

$$I_b = \left(\frac{5.33-0.7}{222k+101 \cdot 1k}\right) = 14.33\mu A$$

$$I_c = 100 I_b = 1.433mA$$

The Q-point is then

$$V_c = 12 - 2000 \cdot I_c = 9.133V$$

$$V_e = 1000 \cdot (I_b + I_c) = 1.448V$$

$$V_{ce} = 7.686V$$

4) Change this circuit so that the Q-point is

- Vce = 6V, and
- Stabilized for variations in β

Start with Vce = 6V. This means

$$12V = 2000 \cdot I_c + 6V + 1000 \cdot (I_b + I_c)$$

$$I_c = 1.993mA$$

$$I_b = 19.93\mu A$$

To stabilize the Q-point

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

$$101k >> R_b$$

Let Rb = 10k. Vb is then

$$V_b = 10k \cdot I_b + 0.7 + 1k \cdot (I_b + I_c)$$

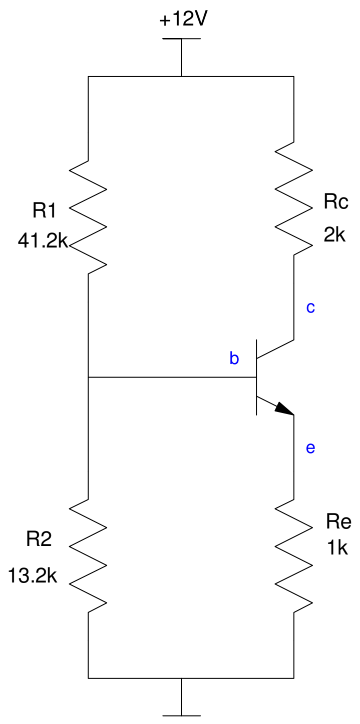
$$V_b = 2.913V$$

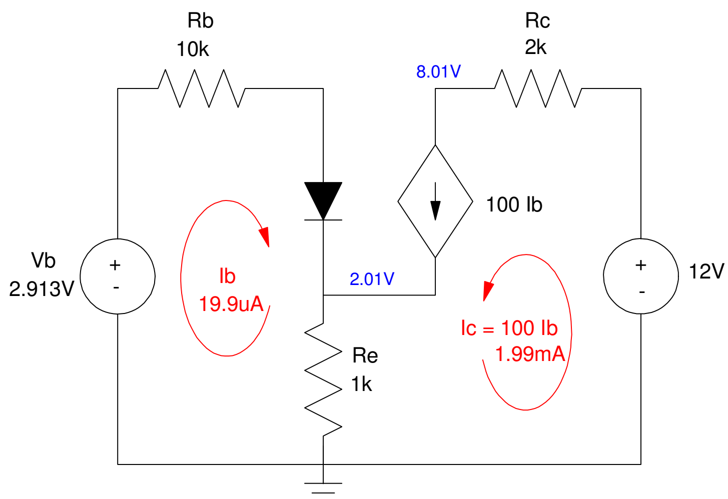
Solving for R1 and R2

$$R_1 = \left(\frac{12V}{2.913V}\right) 10k = 41.2k\Omega$$

$$R_1 || R_2 = 10k$$

$$R_2 = 13.21k$$

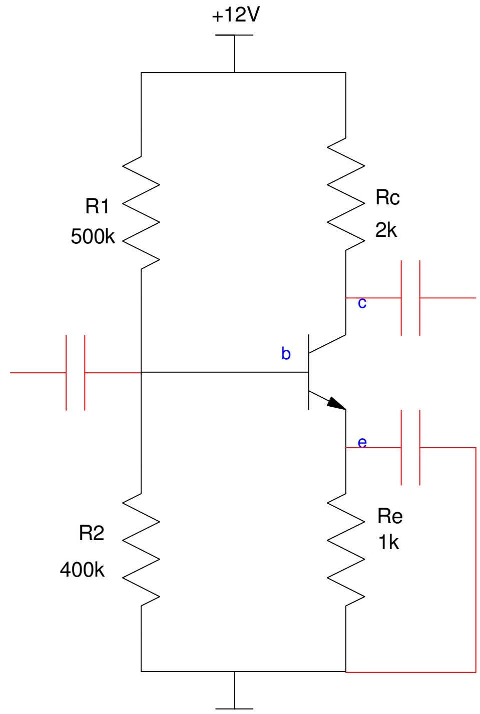


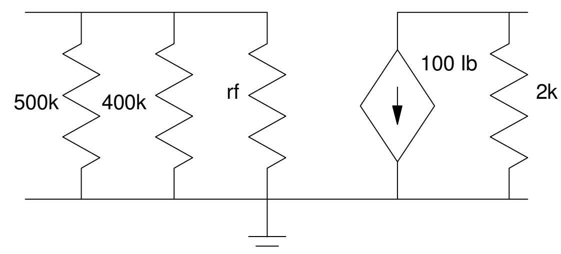


Common Emitter

5) Determine the 2-port model for the following common emitter amplifier

Redraw the AC (small signal) model:





rf comes from the DC operating point (problem #3: Ib = 14.33uA)

$$r_f = \left(\frac{0.052}{I_b}\right) = \left(\frac{0.052}{14.33\mu A}\right) = 3629\Omega$$

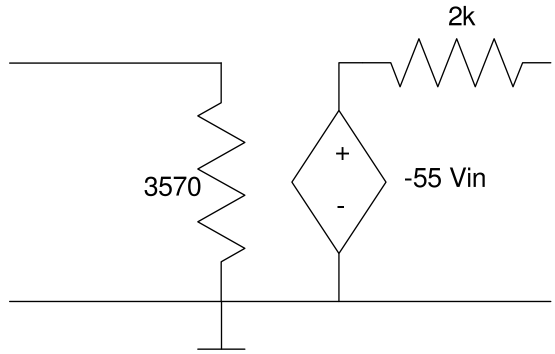
Then:

$$R_{in} = 400k||500k||r_f = 3570\Omega$$

$$A_i = 0$$

$$R_{out} = 2k\Omega$$

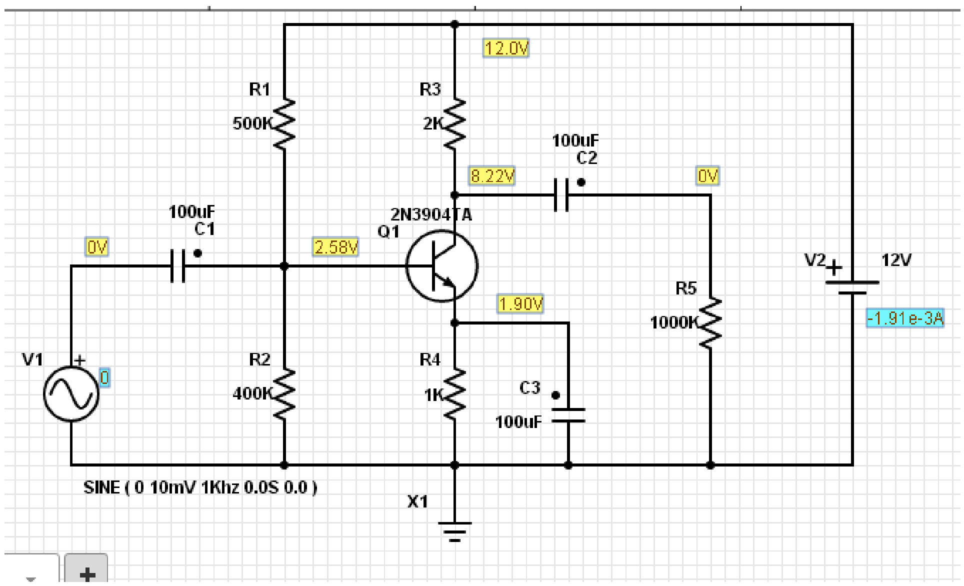
$$A_o = -\frac{\beta \cdot R_c}{r_f} = -55.12$$



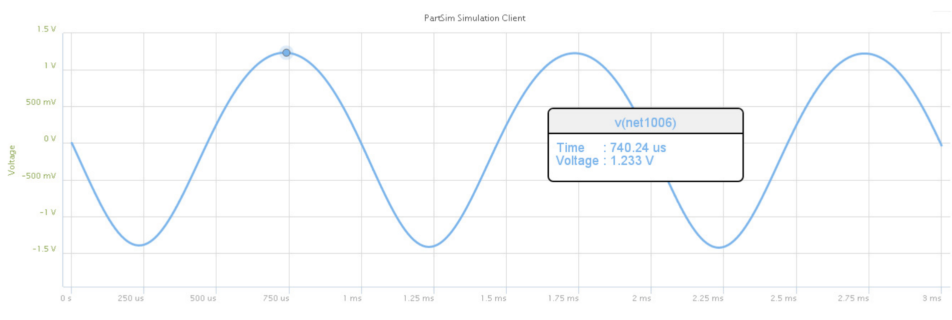
6) Check your analysis in PartSim

DC Operating Point (Problem 3)

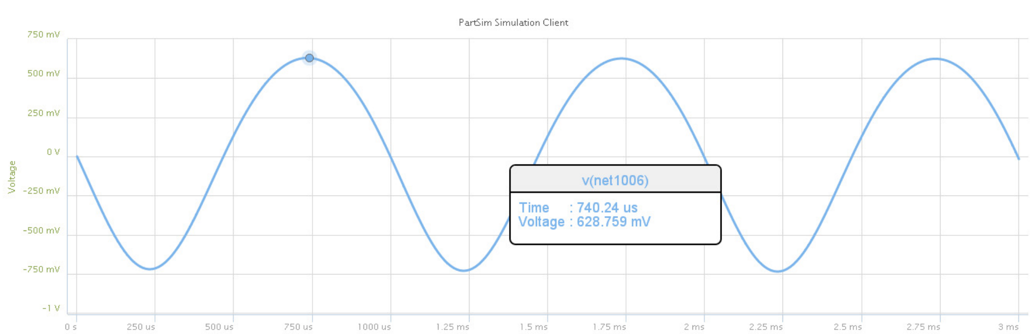
	Analysis (problem 3)	Simulation Run - DC Bias
Vce	7.68V	6.32V
Ic	1.43mA	1.91mA



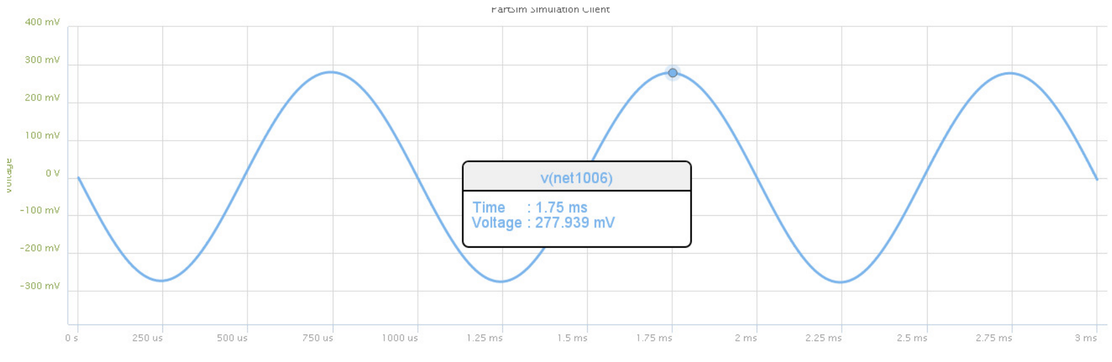
AC Operating Point (1M load): Ao = -123.3 (vs. -55 computed)



AC Operating Point: 2k Load. Gain = -62.6 (half of what it was for a 1M load. The output impedance is 2k)



AC Operating Point with a 3570 Ohm resistor added in series with Vin:



The output voltage drops from

- 628mV when Rin = 0
- 277mV when Rin = 3570

This means

$$\left(\frac{R_{in}}{R_{in}+3570}\right) = \left(\frac{277mV}{628mV}\right)$$

$$R_{in} = 2817\Omega$$

Lab (over)

Lab

7a) Specify the overall requirements for a circuit which incorporates the hardware built in previous homework assignments. For example:

- Input: +/- 1V AC signal capable of driving 1mA (i.e. a cell phone)
- Output: 8 Ohm Speaker
- Relationship:
  - 9 < gain < 11 for frequencies less than 200Hz
  - gain < 1 for frequencies above 600Hz

7b) Specify how this design is split into three secions and the requirements for each section. For example:

Secion 1: Amplfier

- Input: +/- 1V AC signal capable of driving 1mA (i.e. a cell phone)
- Output: +/- 10V AC signal capable of driving 1kOhm
- Relationship: y = 10x (+/- 10%)

Section 2: Filter

- Input: +/- 10V AC signal capable of driving 1kOhm
- Output: +/- 10V AC signal capable of driving 1kOhm
- Relationship:
  - 9 < gain < 11 for frequencies less than 200Hz
  - gain < 1 for frequencies above 600Hz

Section 3: Push-Pull Amplifier

- Input: +/- 10V AC signal capable of driving 1kOhm
- Output: 8 Ohm speaker
- Relationship: y = x (+/- 10%)

(next week - homework #5): Assembler your three circuits together and collect data to validate

- Each section works separately
- The entire circuit works together