

ECE 320 - Homework #9

2-Port Models, CE, CB, CC Amplifiers, Multistage Amplifier

CE Amplifiers (AC Analysis)

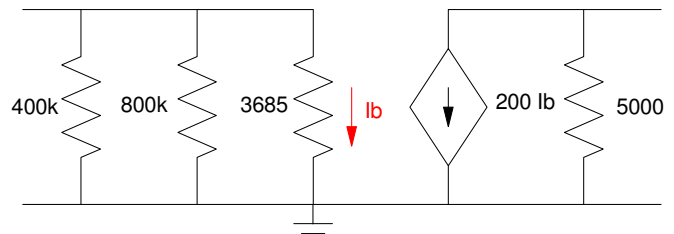
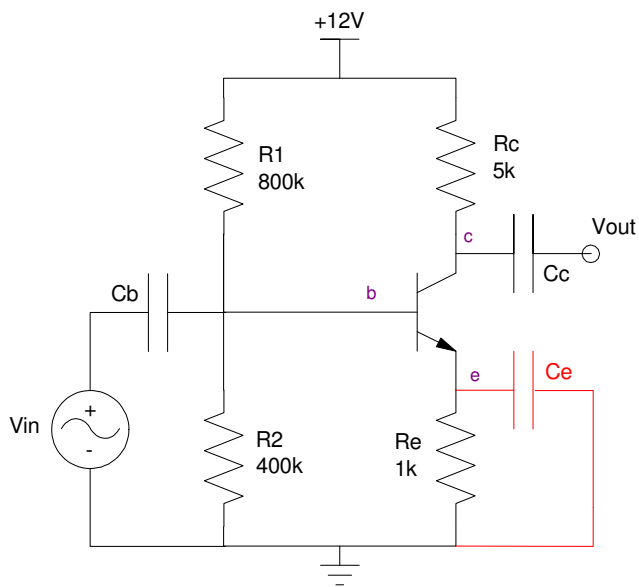
1) Draw the small signal model for the CE amplifier (below)

- Determine the resulting 2-port model

From homework #8

$$I_b = 7.056\mu A$$

$$r_f = \left(\frac{0.026}{I_b} \right) = 3685\Omega$$



This gives

$$R_{in} = 400k || 800k || 3685 = 3635\Omega$$

$$A_{in} = 0$$

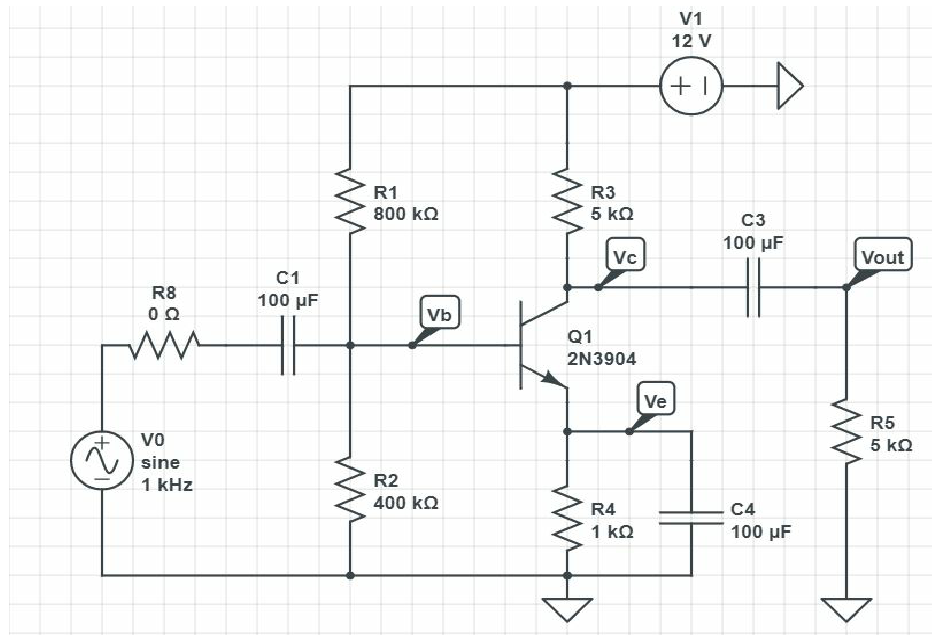
$$R_{out} = 5000\Omega$$

$$A_{out} = -\left(\frac{200 \cdot 5000}{3685} \right) = -271.4$$

Problem 2

2) Check your answers for problem #6 in CircuitLab

- R_{in} : If you add a resistor in series with V_s equal to R_{in} , the output drops by half
- R_{out} : If you load V_{out} with a resistor equal to R_{out} , the output drops by half
- A_o : Apply a 1mV, 1kHz sine wave at V_{in} . The output should be $A_o \cdot V_{in}$



V_0 , R_8 , and R_5 are added so you can run some tests to find the 2-port parameters.

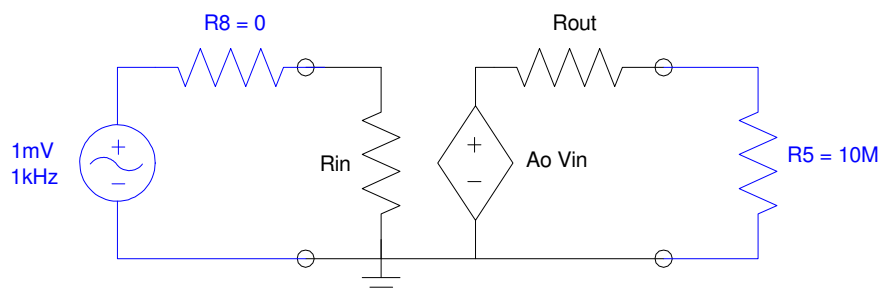
Ao: Set

- $V_0 = 1\text{mV @ } 1\text{kHz}$
- $R_8 = 0$
- $R_5 = 10\text{M}$

Run a time domain simulation and measure the peak at V_{out}

- $V_{out} = 257.9\text{mV peak}$

The 2-port model is then



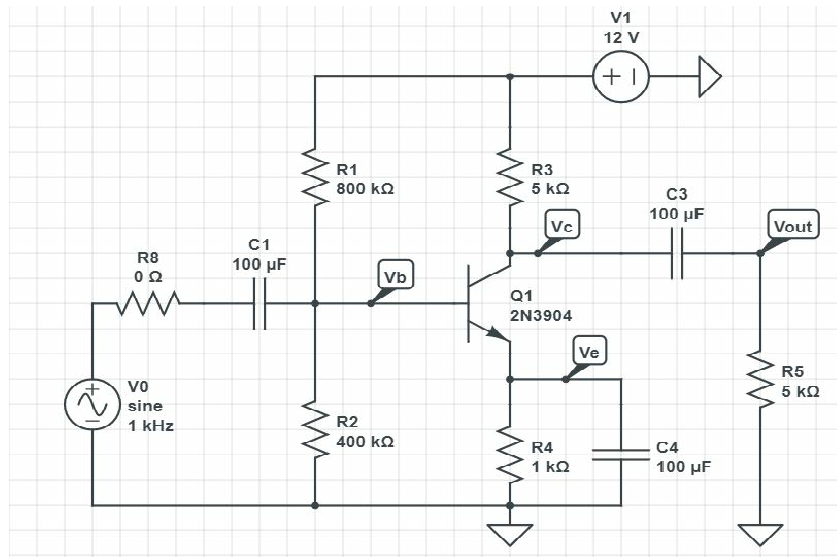
$$A_o = 257.9 \text{ (actually } -257.9\text{)}$$

Rin: Set

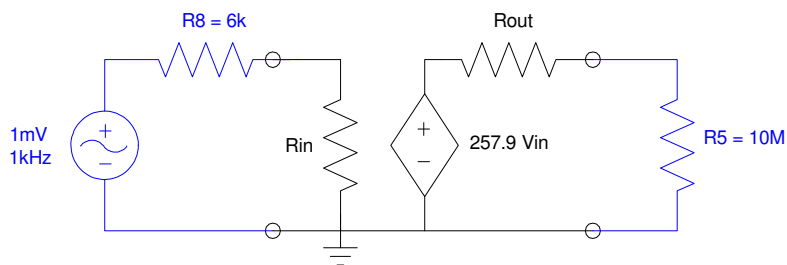
- $R8 = 6000$
- $R5 = 10M$

Measure Vout:

- $V_{out} = 98.81mV$



This tells you Rin. It's easier to see with the 2-port model:



$$V_{out} = 98.81mV = 257.9 \cdot \left(\frac{R_{in}}{R_{in} + 6k} \right) \cdot 1mV$$

Solving for Rin

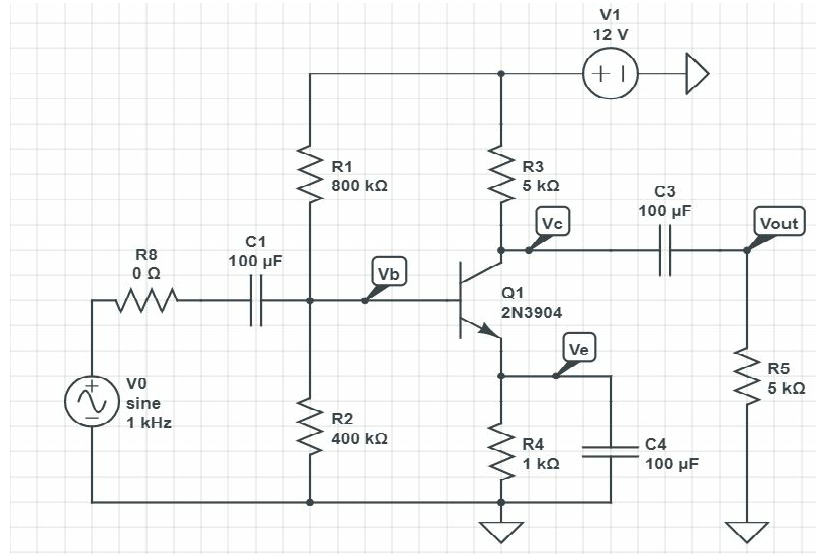
$$R_{in} = \left(\frac{98.81mV}{257.9mV - 98.81mV} \right) 6000\Omega = 3727\Omega$$

Rout: Set

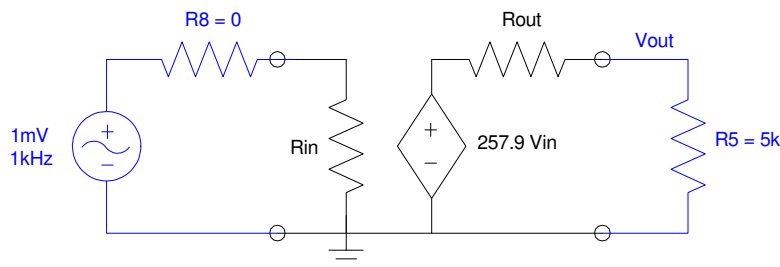
- $R8 = 0$
- $R5 = 5000$

Measure Vout:

- $V_{out} = 134.6\text{mV}$



This tells you R_{out} . The 2-port model is now:



V_{out} is

$$V_{out} = 134.6\text{mV} = \left(\frac{5k}{5k + R_{out}} \right) \cdot 257.9 \cdot 1\text{mV}$$

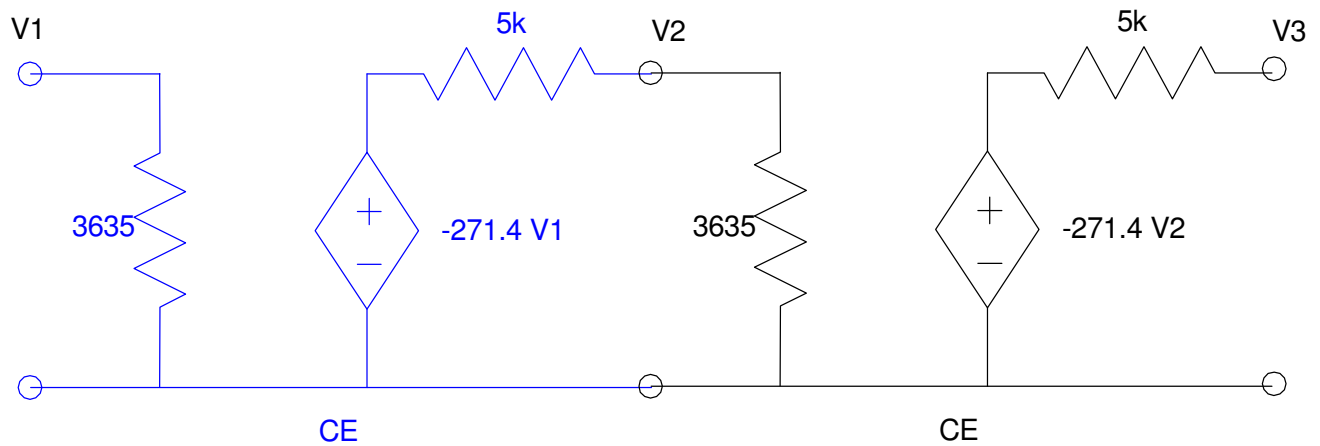
Solving for R_{out} :

$$R_{out} = \left(\frac{257.9\text{mV} - 134.6\text{mV}}{134.6\text{mV}} \right) 5000\Omega = 4580\Omega$$

	R_{in}	A_o	R_{out}
Calculated	3,685	-271.4	5,000
Simulated	3,727	-257.9	4,580

Problem 3) Determine the 2-port model for cascading two CE amplifiers

Use the 2-port models



By inspection

$$R_{in} = 3635$$

$$A_{in} = 0$$

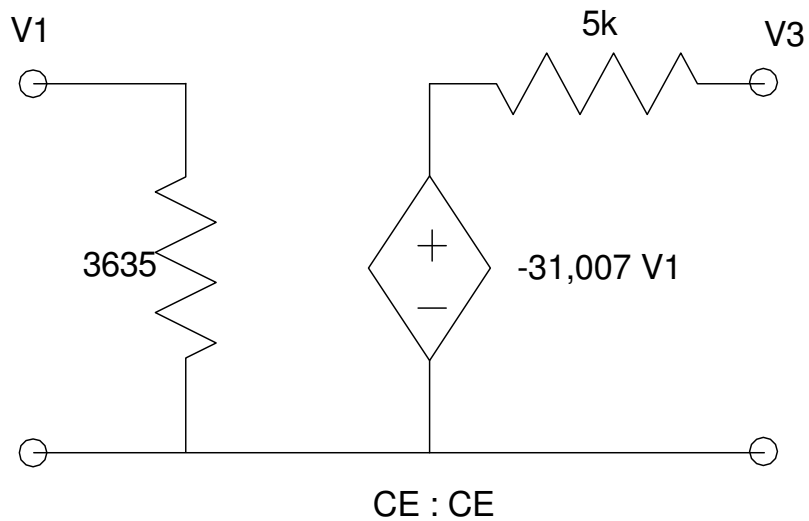
$$R_{out} = 5000$$

As you need to work for. Set $V_1 = 1V$

$$V_2 = \left(\frac{3635}{3635+5000} \right) (-271.4V) = -114.2V$$

$$V_3 = -271.4 \cdot V_2 = 31,007V$$

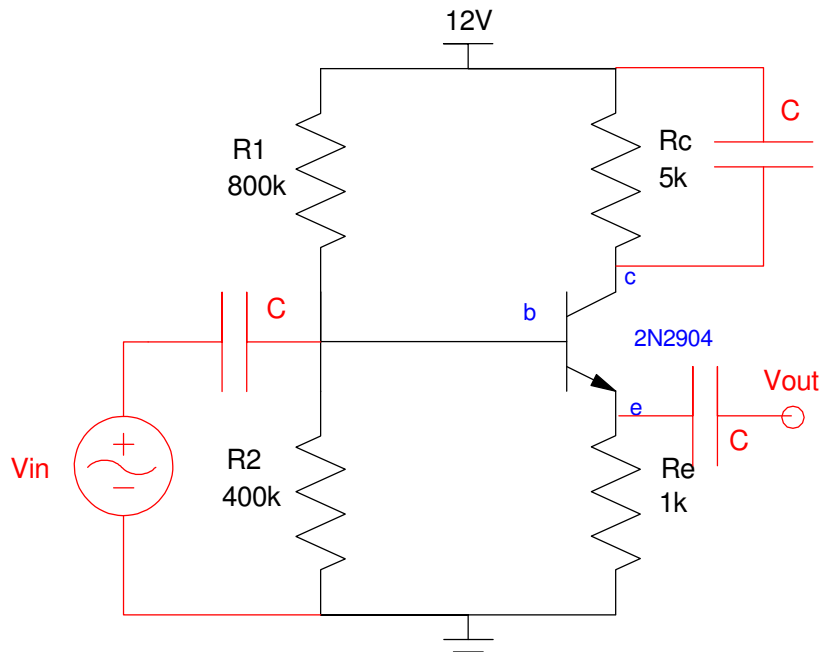
resulting in the 2-port model being



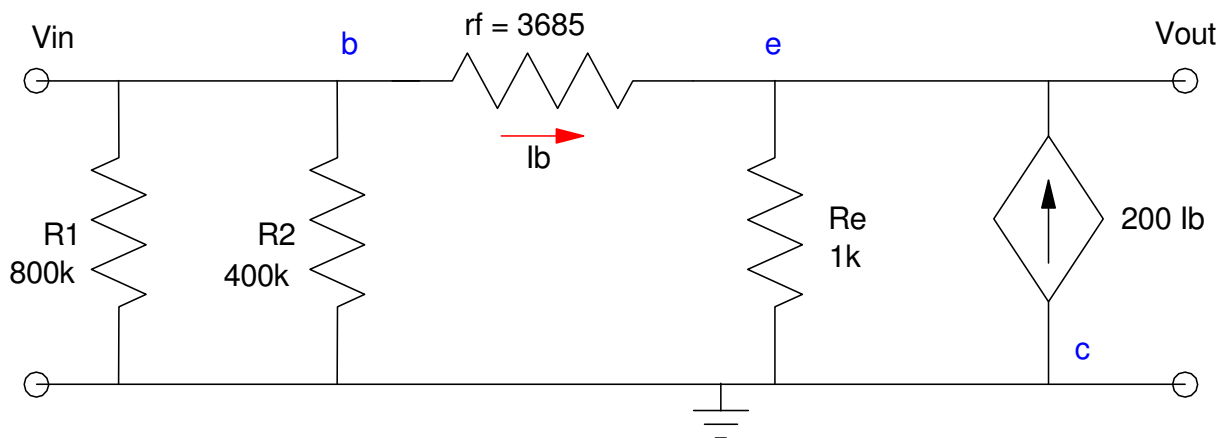
Problem 4) CC Amplifiers (AC Analysis)

Draw the small signal model for the CC amplifier (below)

- Determine the resulting 2-port model



The small signal model is



Now, find the 2-port parameters

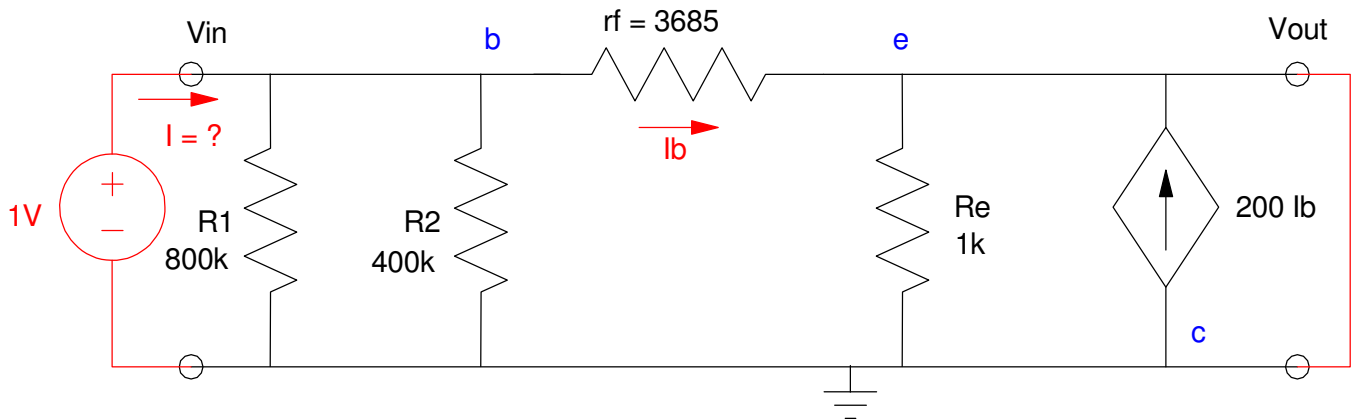
R_{in}

- Short V_{out}
- Apply 1V to V_{in}
- Measure the current draw

$$I = \left(\frac{1V}{R_1} \right) + \left(\frac{1V}{R_2} \right) + \left(\frac{1V}{r_f} \right)$$

$$I = 275.1\mu A$$

$$R_{in} = \left(\frac{1V}{275.1\mu A} \right) = 3635\Omega$$



A_{in}

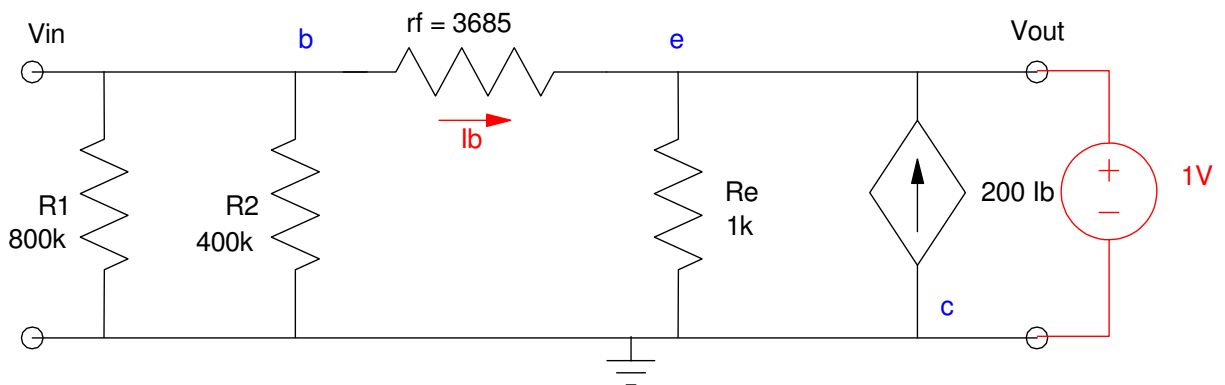
- Apply 1V to V_{out}
- Measure V_{in}

By voltage division

$$R_1 || R_2 = 266.67k\Omega$$

$$V_{in} = \left(\frac{266.67k}{266.67k + 3685} \right) 1V = 0.9864$$

$$A_{in} = 0.9864$$



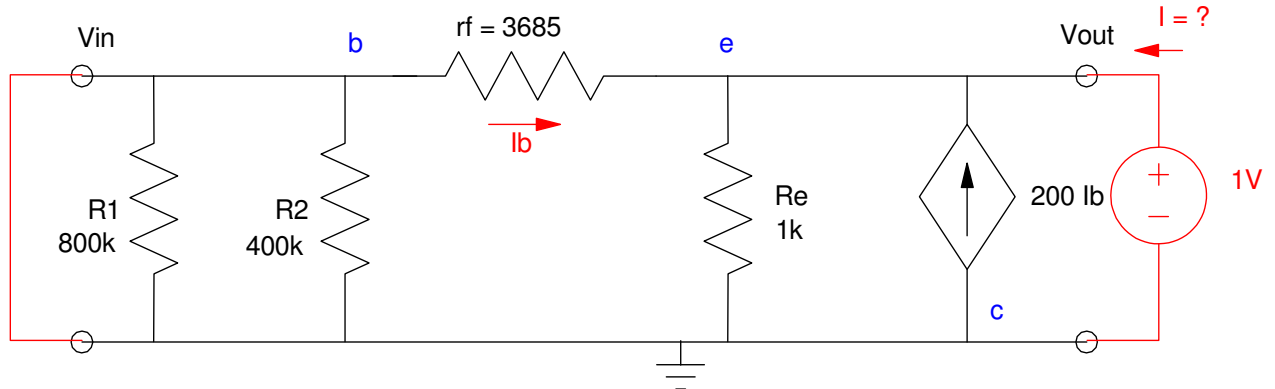
Rout

- Short Vin
- Apply 1V to Vout
- Measure the current draw

$$I = \left(\frac{1V}{r_f} \right) + \left(\frac{1V}{R_e} \right) + 200 \left(\frac{1V}{r_f} \right)$$

$$I = 55.55mA$$

$$R_{out} = \left(\frac{1V}{55.55mA} \right) = 18.0\Omega$$



Aout

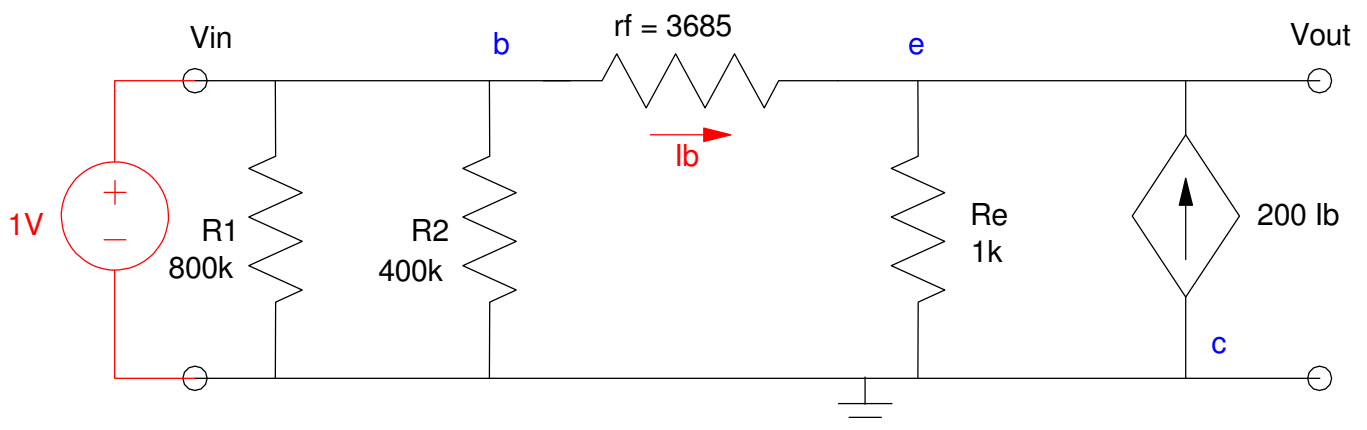
- Apply 1V to Vin
- Measure Vout

Write the voltage node equation at Vout

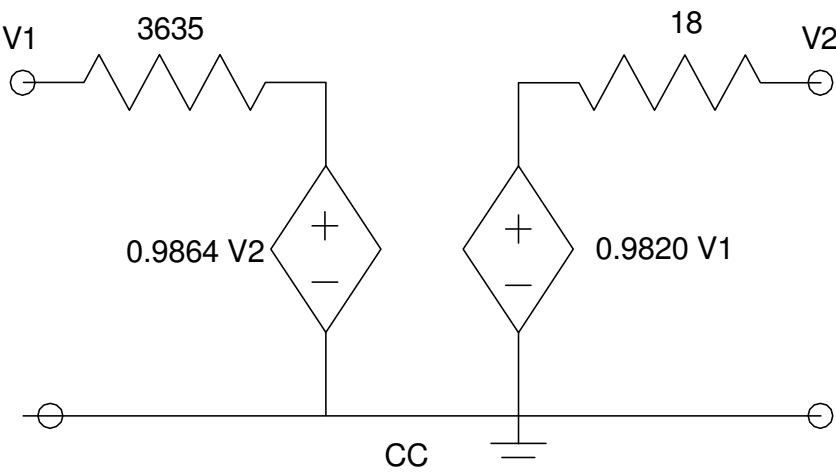
$$\left(\frac{V_{out}-1}{r_f} \right) + \left(\frac{V_{out}}{R_e} \right) + 200 \left(\frac{V_{out}-1}{r_f} \right) = 0$$

$$V_{out} = 0.9820$$

$$A_{out} = 0.9820$$



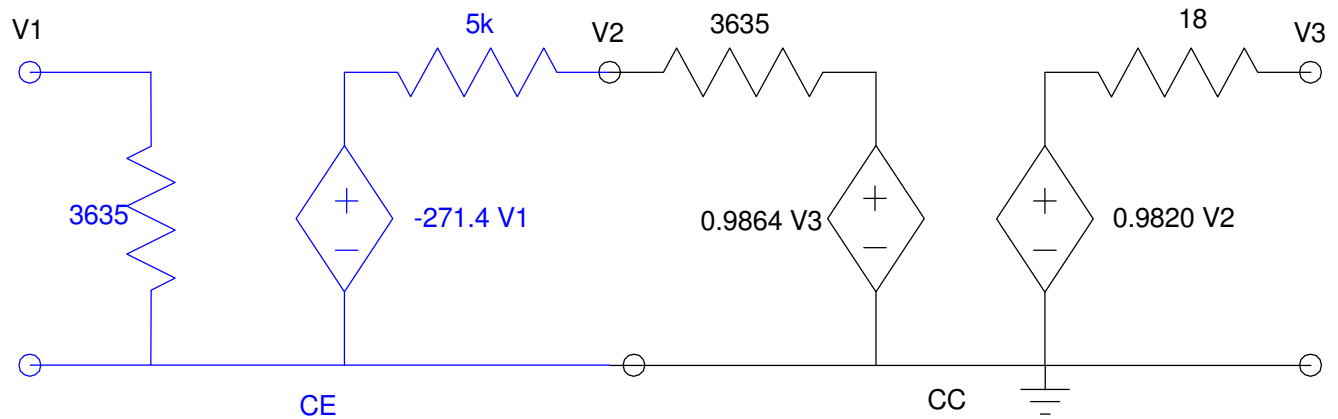
So, the 2-port model is



Problem 5: CE : CC

5) Determine the 2-port model for a CE amplifier cascaded with a CC amplifier

CE : CC



By inspection

- $R_{in} = 3625$
- $A_{in} = 0$

Rout:

- Short V1
- Apply 1V to V3
- Measure the current draw

$$V_2 = \left(\frac{5k}{5k+3635} \right) (0.9864) = 0.5712$$

$$I = \left(\frac{1V - 0.9820(0.5712)}{18} \right) = 24.40mA$$

$$R_{out} = \frac{1}{24.40mA} = 40.99\Omega$$

Aout:

- Apply 1V to V1
- Measure V3

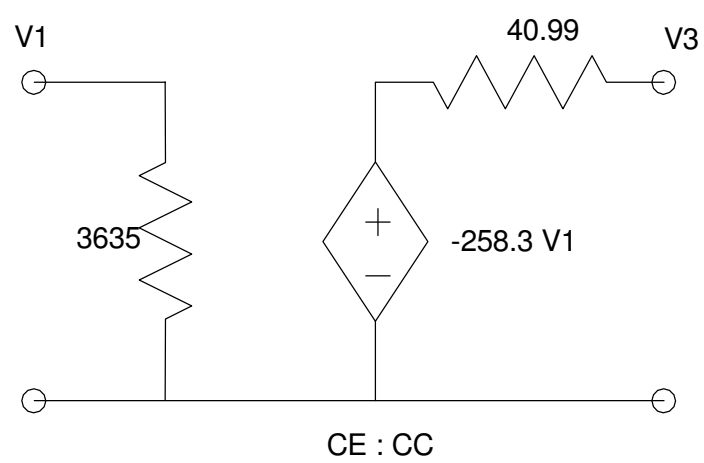
$$V_3 = 0.9820V_2$$

$$\left(\frac{V_2 - (-271.4)}{5k} \right) + \left(\frac{V_1 - 0.9864V_3}{3635} \right) = 0$$

Solving results in $V_3 = -258.3$

$$A_{out} = -258.3$$

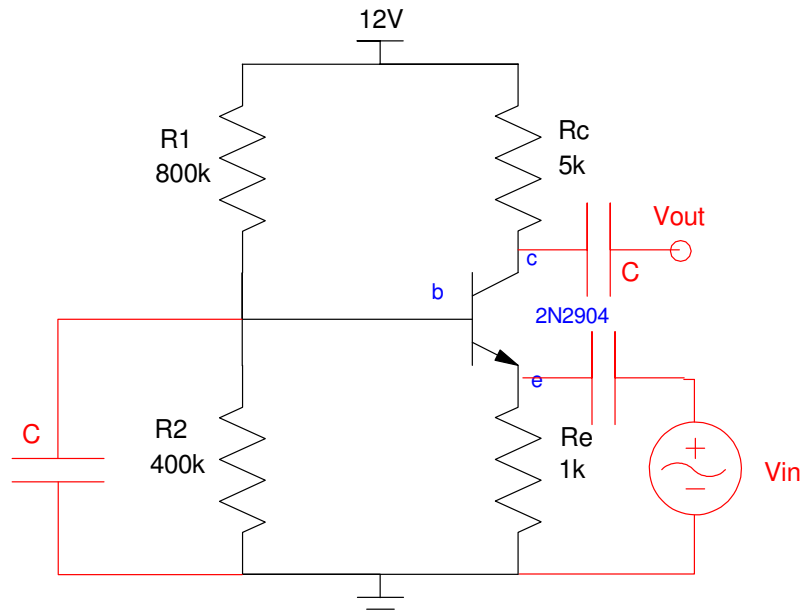
The net result is a CE : CC amplifier looks like the following:



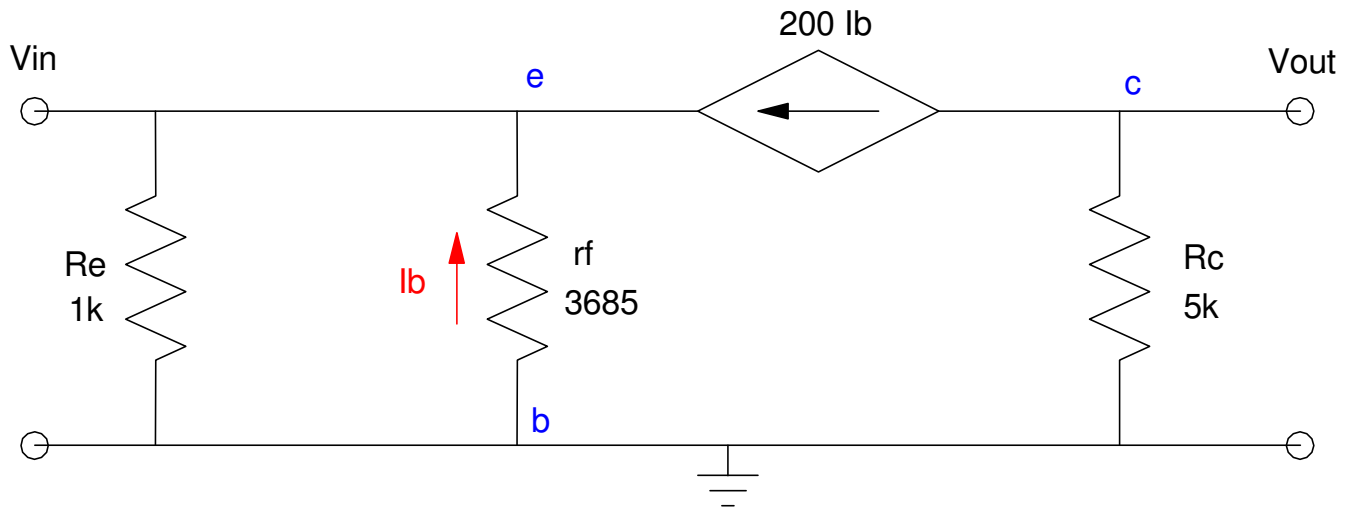
Problem 6) CB Amplifiers (AC Analysis)

6) Draw the small signal model for the CE amplifier (below)

- Determine the resulting 2-port model



Draw the small signal model

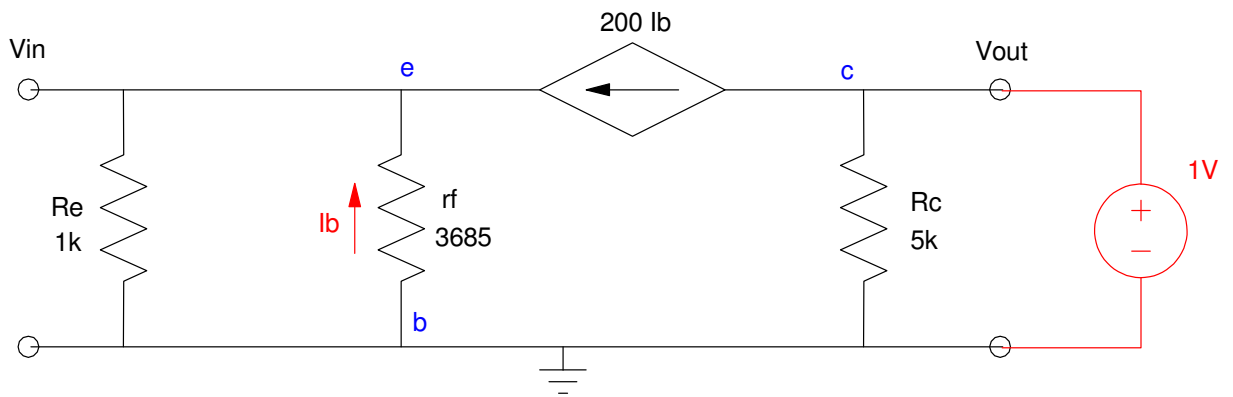


Now, find the 2-port parameters

Ain:

- Apply 1V to Vout
- Measure Vin

Vin = 0 (Ain = 0)



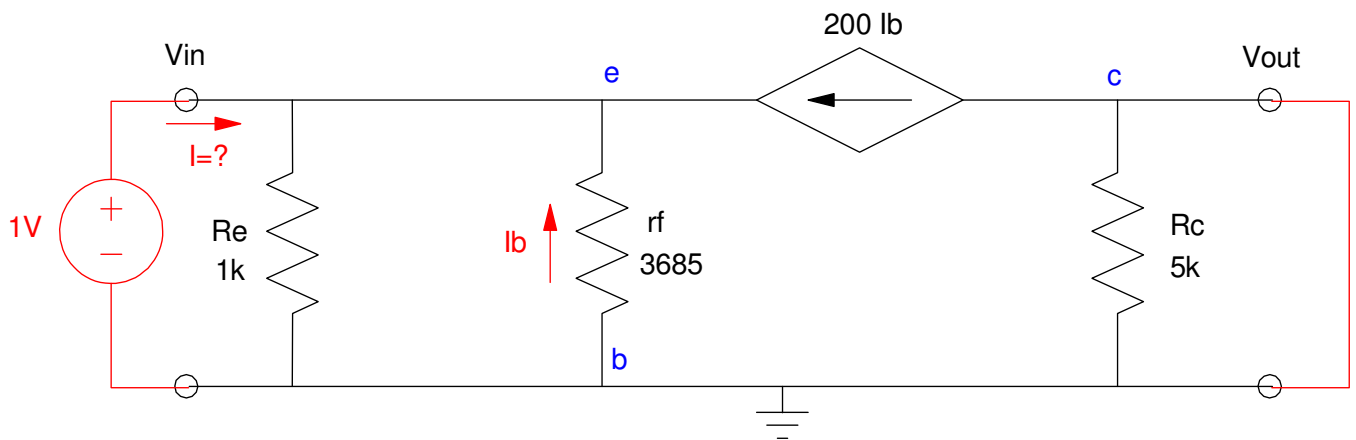
Rin:

- Short V_{out}
- Apply 1V to V_{in}
- Measure the current draw

$$I = \left(\frac{1V}{R_e} \right) + \left(\frac{1V}{r_f} \right) + 200 \left(\frac{1V}{r_f} \right)$$

$$I = 55.55mA$$

$$R_{in} = \left(\frac{1V}{55.55mA} \right) = 18.0\Omega$$



Ao:

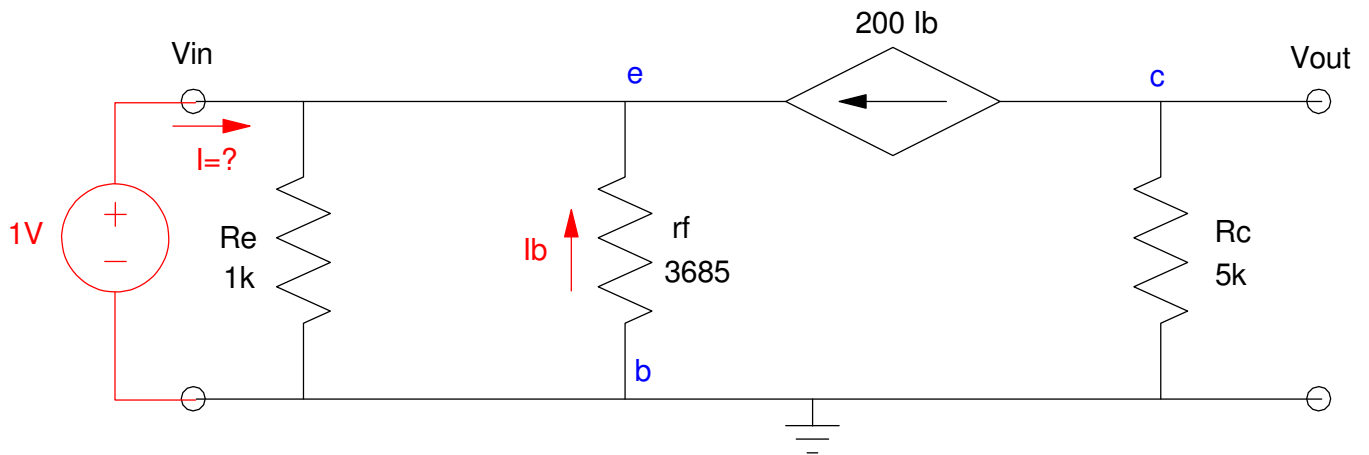
- Apply 1V to Vin
- Measure Vout

$$I_b = \left(\frac{-1}{r_f} \right)$$

$$V_{out} = -200I_b \cdot R_c$$

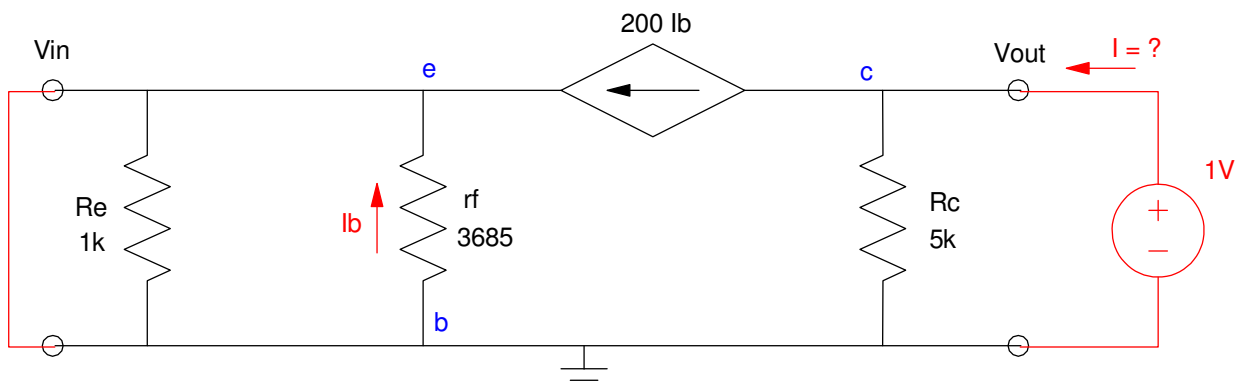
$$V_{out} = + \left(\frac{\beta R_c}{r_f} \right) = +271.4$$

$$A_o = +271.4$$

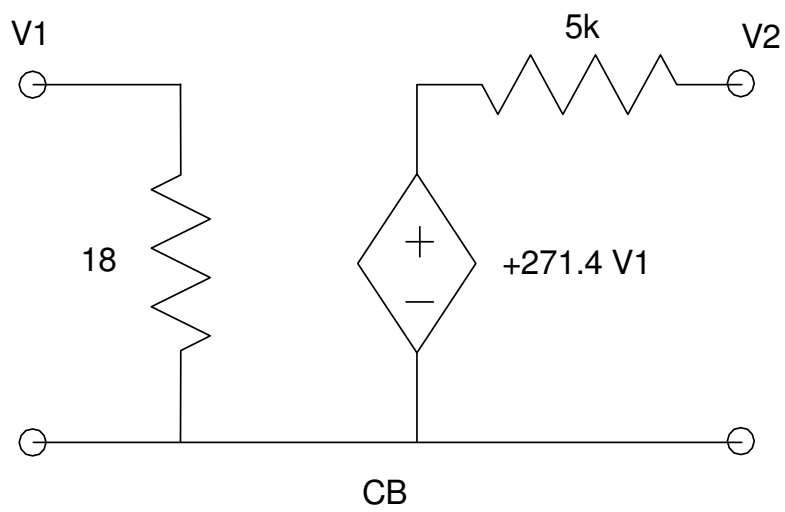


Rout:

- Short V_{in}
- By inspection, $R_{out} = 5k$



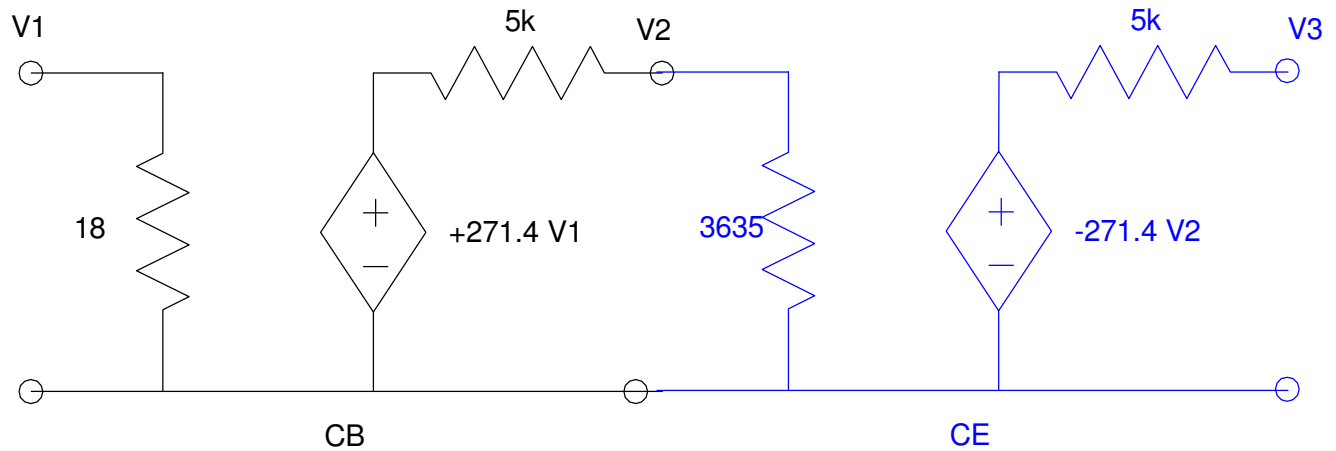
The net result is



Problem 7) CB : CE

7) Determine the 2-port model for a CB amplifier cascaded with a CE amplifier

CB : CE



By inspection

$$R_{in} = 18$$

$$A_{in} = 0$$

$$R_{out} = 5k$$

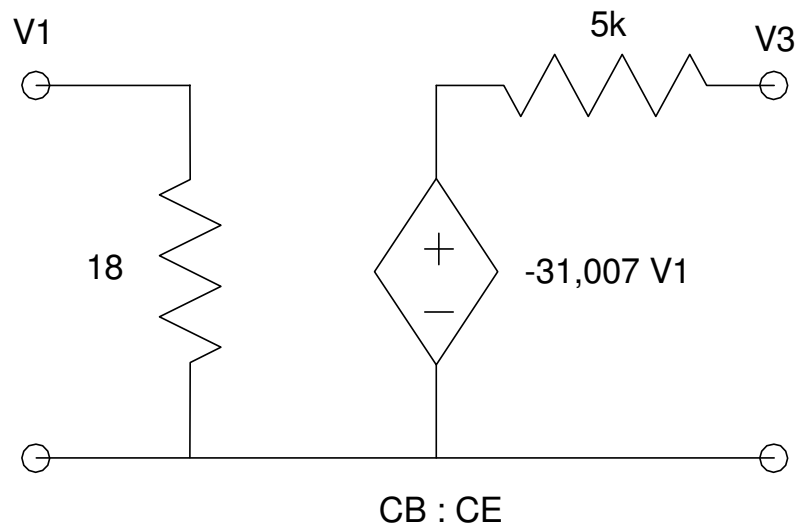
To find the gain, apply 1V to V1 and compute V3

$$V_2 = \left(\frac{3635}{3635 + 5000} \right) (271.4)$$

$$V_2 = 114.2V$$

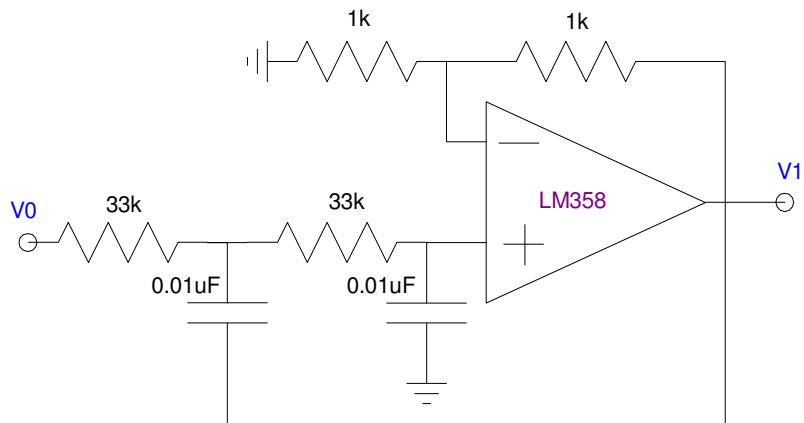
$$V_3 = -271.4V_2$$

$$V_3 = -31,007$$



Lab (Subwoofer Crossover)

8) Find the transfer function for the following low-pass filter



From the lecture notes

$$G(s) = \left(\frac{k \left(\frac{1}{RC} \right)^2}{s^2 + \left(\frac{3-k}{RC} \right) s + \left(\frac{1}{RC} \right)^2} \right)$$

k is the gain

$$k = 1 + \left(\frac{R_1}{R_2} \right) = 2$$

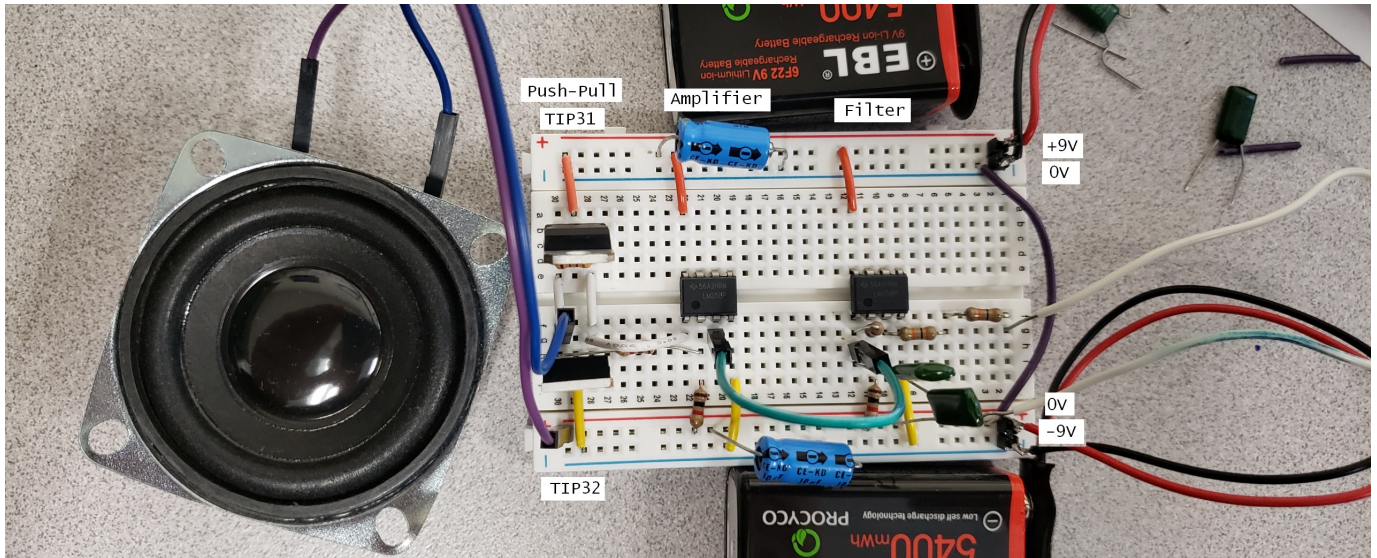
$1/RC$ is the corner frequency (482Hz)

$$\left(\frac{1}{RC} \right) = \left(\frac{1}{(33k)(0.01\mu F)} \right) = 3030$$

$$G(s) = \left(\frac{2(3030)^2}{s^2 + (3030)s + (3030)^2} \right)$$

9) Add this filter to the push-pull amplifier from homework #8 on your breadboard

- Include a photo of your breadboard circuit for full credit.



10) Apply a 1Vp sine wave at V0 and record the voltage at {V1, V2, V3} for

- V0 = 200Hz
- V0 = 2kHz

Document this with a photo of your oscilloscope readings using your FNRSI multimeter

11) Apply music to V0 using your cell phone or the audio output of your computer playing a YouTube video. Document the output using a photo of an oscilloscope trace at V3 or a YouTube recording of your subwoofer

