ECE 321 - Homework #4

2-Port Models. CE Amplifiers (DC and AC). Due Monday, December 7th

CE Amplifiers (DC Analysis)

1) Determine the Q-point for the following circuits. Assume 3904 NPN transistors

- $\beta = 200$
- $|Vbe| = 0.7V$

Converting R1 and R2 to their Thevenin equivalent (Vb and Rb)

$$V_b = \left(\frac{300k}{300k+600k}\right) 12V = 4.00V$$

$$R_b = 300k || 600k = 200k$$

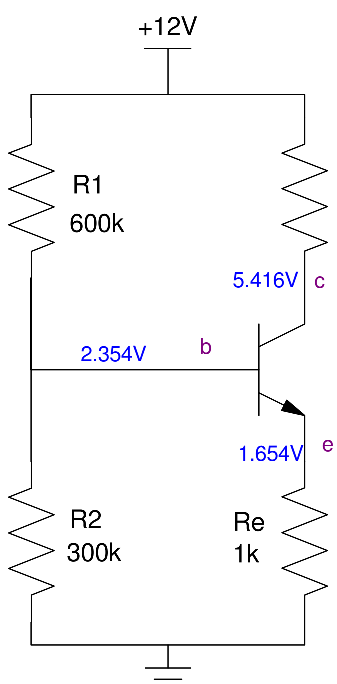
This gives the circuit to the right. Computing Ib

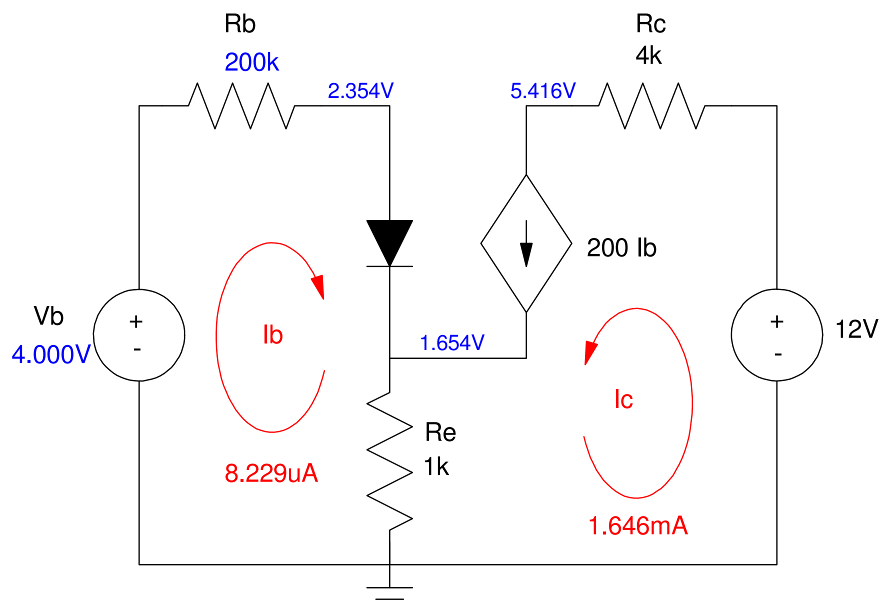
$$V_b = I_b R_b + 0.7 + R_e(I_b + 200 I_b)$$

$$I_b = \left(\frac{4.000V - 0.7V}{200k + (201)1k}\right) = 8.229\mu A$$

$$I_c = 200 I_b = 1.646mA$$

$$V_{ce} = V_c - V_e = 3.762V$$





2) Modify this circuit so that

- Vce = 6.0V, and
- The Q-point is stabilized for variations in β

To stabilize the Q-point

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

$$201k >> R_b$$

Let Rb = 20k (10x smaller).

For the Q-point to be Vce = 6.00V

$$12V-(R_c+R_e)I_c-R_e\left(\frac{I_c}{\beta}\right) = 6.00V$$

$$I_c = 1.199mA$$

$$I_b = 5.994\mu A$$

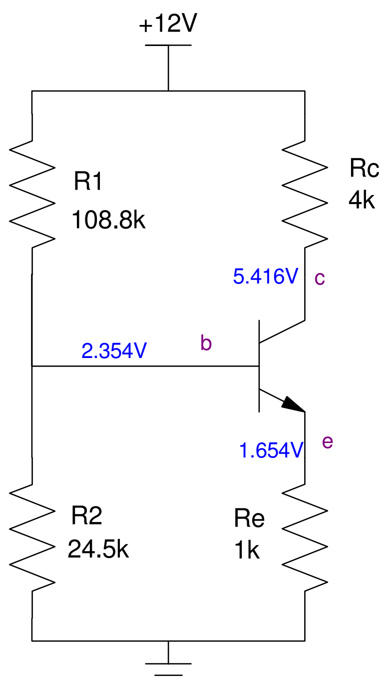
$$V_b = R_cI_c + 0.7 + R_e(I_b+I_c) = 2.025V$$

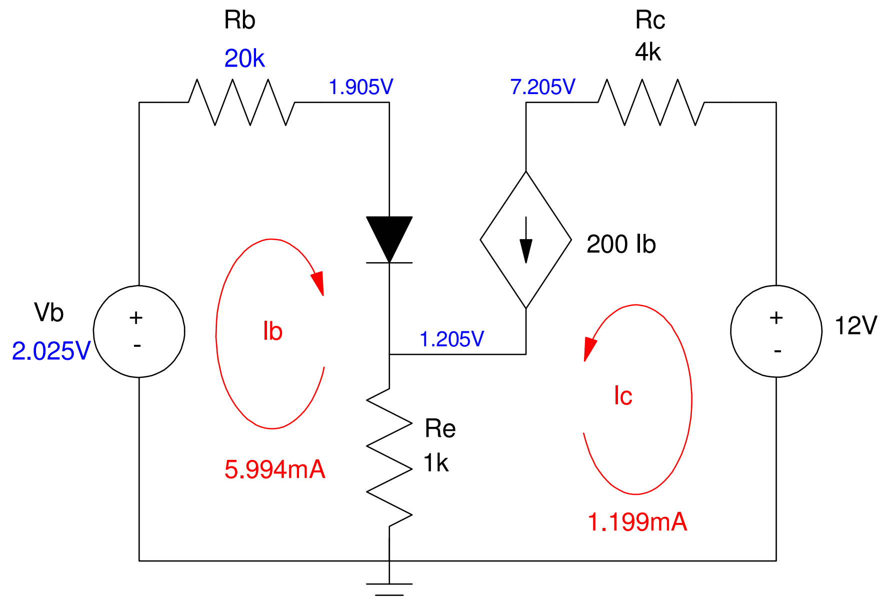
Converting back to R1 and R2

$$R_1 = \left(\frac{12V}{2.025V}\right)20k = 108.8k$$

$$R_1||R_2 = 20k$$

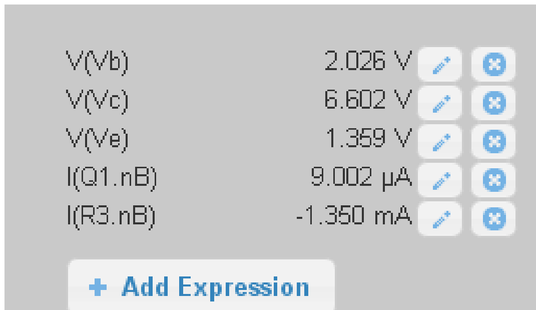
$$R_2 = 24.5k$$

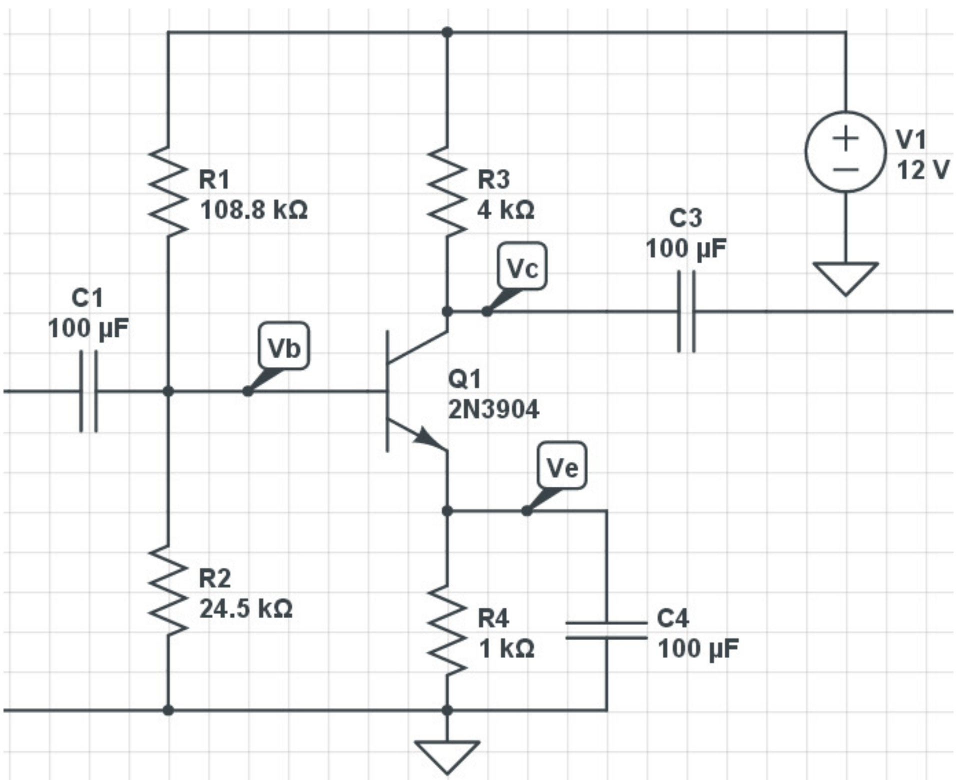




3) Check you answers in CircuitLab

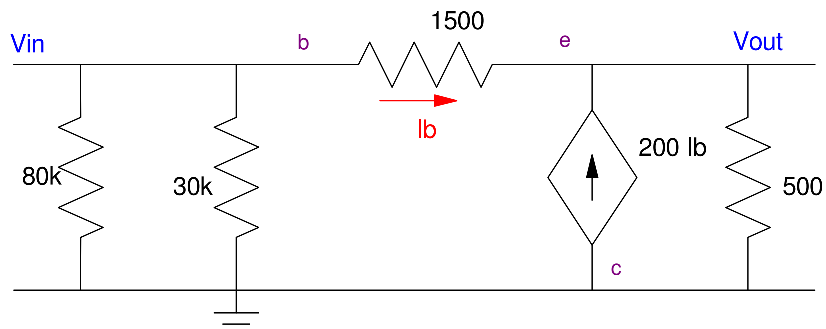
	Calculations	Simulation
Vb	1.905 V	2.206 V
Vc	7.205 V	6.602 V
Ve	1.205 V	1.359 V
Vce	6.000V	5.243 V
Ib	5.994 uA	9.002 uA
Ic / Ib (beta)	200	145





2-Port Models

4) Determine the 2-port model for the following circuit



Rin:

- Short Vout
- Measure the resistance at the input

$$R_{in} = 80k||30k||1500 = 1403\Omega$$

Ai:

- Apply 1V at the output
- Compute Vin

$$V_{in} = \left(\frac{30k||80k}{30k||80k+1500}\right) = 0.9357$$

Rout:

- Short Vin
- Apply 1V at Vout
- Compute the current

$$I = \left(\frac{1V}{1500\Omega}\right) + 200\left(\frac{1V}{1500\Omega}\right) + \left(\frac{1V}{500\Omega}\right)$$

$$I = 136.0mA$$

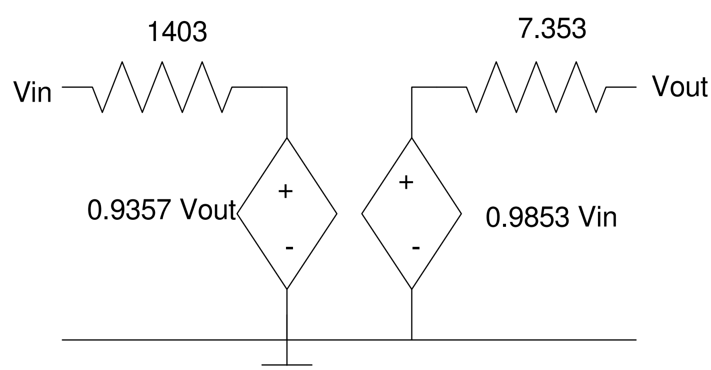
$$R_{out} = \frac{1V}{136mA} = 7.353\Omega$$

Ao:

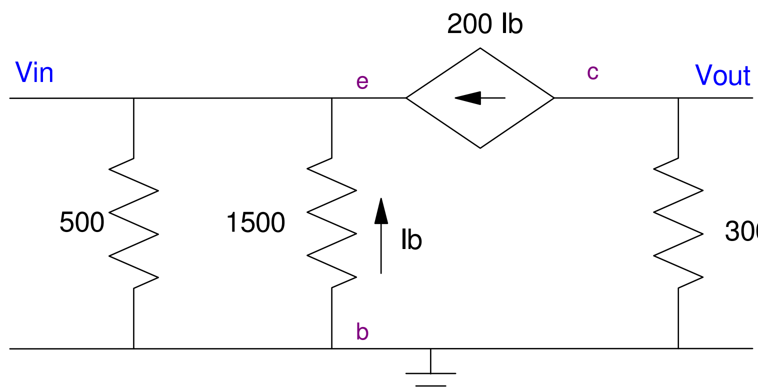
- Apply 1V at the input
- Compute Vout

$$\left(\frac{V_{out}-1}{1500}\right) + 200\left(\frac{V_{out}-1}{1500}\right) + \left(\frac{V_{out}}{500}\right) = 0$$

$$V_{out} = A_o = 0.9853V$$



5) Determine the 2-port model for the following circuit



Rin:

- Short Vout
- Apply 1V at Vin
- Compute I

$$I = \left(\frac{1V}{500\Omega}\right) + \left(\frac{1V}{1500\Omega}\right) + 200\left(\frac{1V}{1500\Omega}\right)$$

$$I = 136mA$$

$$R_{in} = \frac{1V}{136mA} = 7.35\Omega$$

Ai:

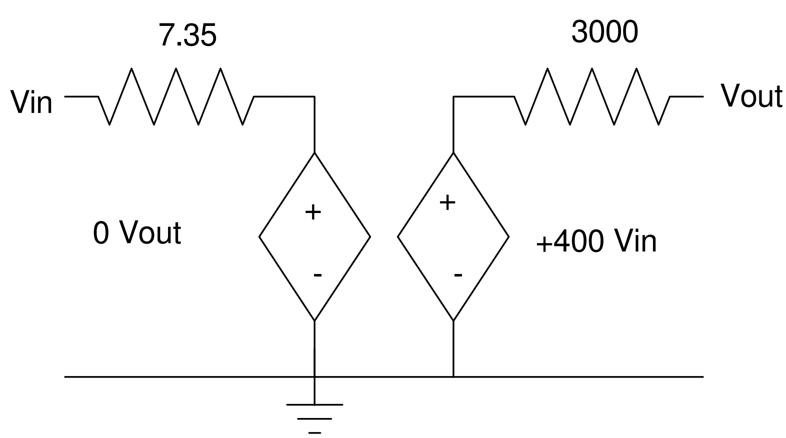
- Apply 1V to Vout
- Compute Vin

$$V_{in} = A_i = 0$$

Rout:

- Short Vin
- Compute Rout

$$R_{out} = 3000$$



Aout:

- Connect 1V to Vin
- Compute Vout

$$I_b = -\frac{1V}{1500\Omega} = -666.7\mu A$$

$$-200I_b = 133.3mA$$

$$V_{out} = 3000\Omega \cdot 133.3mA$$

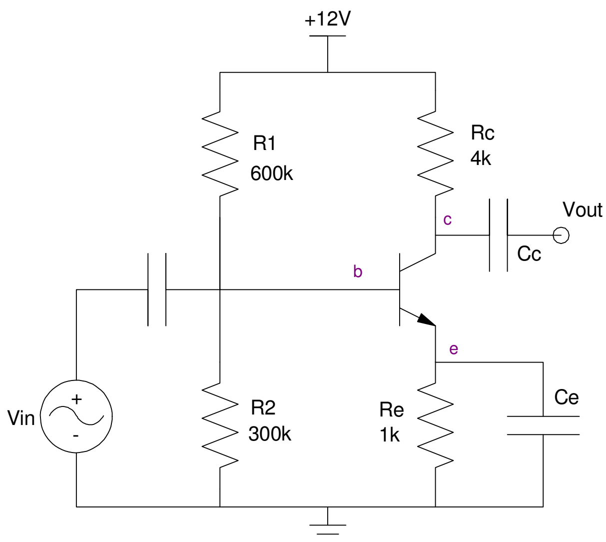
$$V_{out} = +400$$

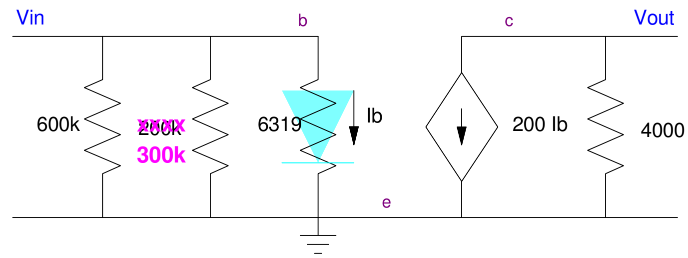
CE Amplifiers (AC Analysis)

6) Draw the small signal model for the CE amplifier used in problem #1

$$I_b = 8.228\mu A$$

$$r_f \approx \frac{0.052V}{I_b} = 6319\Omega$$





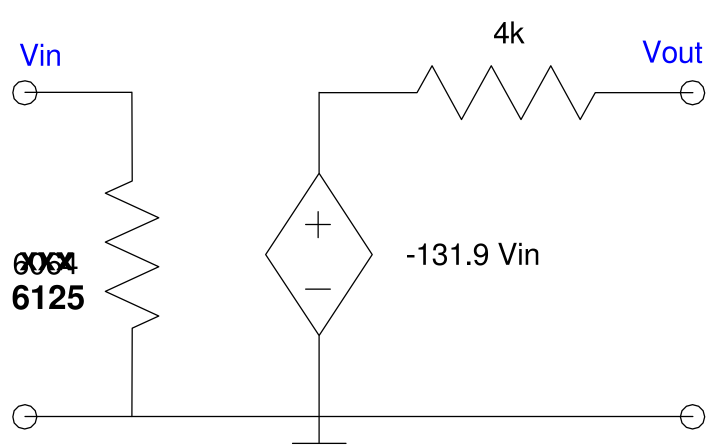
Determine the resulting 2-port model. By inspection

$$R_{in} = 600k||300k||6319 = 6125\Omega$$

$$A_{in} = 0$$

$$R_{out} = 4k\Omega$$

$$A_{out} = -\left(\frac{200 \cdot 4000}{6064}\right) = -131.9$$



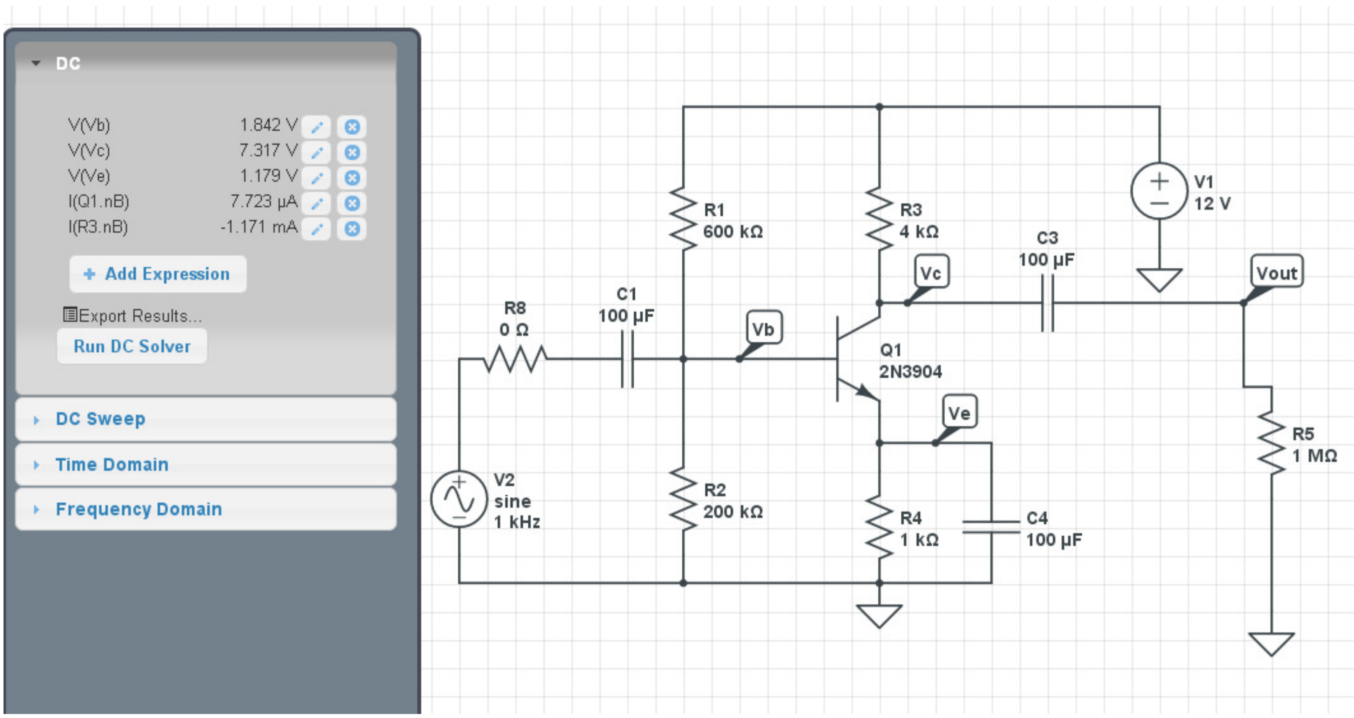
7) Check your answers for problem #6 (and #1) in CircuitLab

- Rin: If you add a resistor in series with Vs equal to Rin, the output drops by half
- Rout: If you load Vout with a resistor equal to Rout, the output drops by half
- Ao: Apply a 1mV, 1kHz sine wave at Vin. The output should be Ao*Vin

DC Analysis:

Ib = 7.723uA (vs. 8.828uA calculated)

Ic / Ib = 151.6 (vs. 200 calculated)



AC Analysis (2-port model)

Ao:

- V2 = 1mV, 1kHz sine wave
- R8 = 0 Ohms
- R5 = 1M (large)
- Measure Vout = 170.8mVp sine wave: Ao = 170.8 (vs. 253 calculated)
- Not surprising since CircuitLab assumes a gain of 151 for a 3904 transistor

Rout:

- V2 = 1mV, 1kHz sine wave
- R8 = 0 Ohms
- R5 = 4000 Ohms
- Measure Vout = 88.08mVp sine wave:

$$88.08mV = \left(\frac{R_{out}}{R_{out}+4000}\right)170.8mV$$

$$R_{out} = \left(\frac{88.08mV}{170.8mV-88.08mV}\right)4000 = 4259\Omega$$

Rin:

- V2 = 1mV, 1kHz sine wave
- R8 = 3095 Ohms
- R5 = 1M Ohms
- Measure Vout = 88.7mVp sine wave:

$$R_{in} = \left(\frac{88.7mV}{170.8mV - 88.7mV}\right)3095 = 3344\Omega$$

Note: Since CircuitLab uses Ib = 7.723uA (vs. 8.828uA calculated)

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

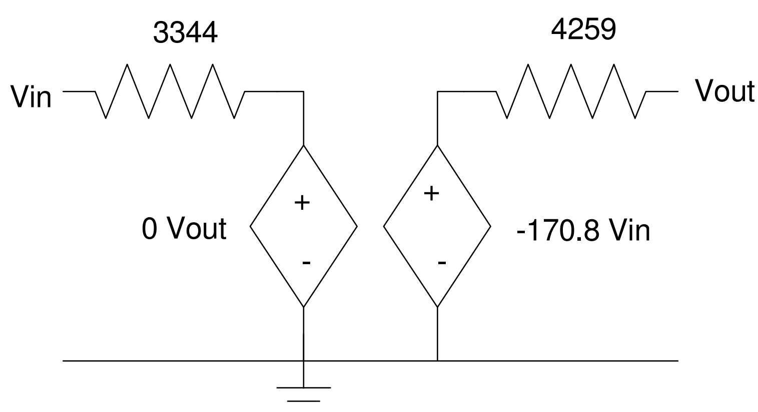
$$170.8 = \frac{151.6 \cdot 4000}{r_f}$$

$$r_f = 3550\Omega$$

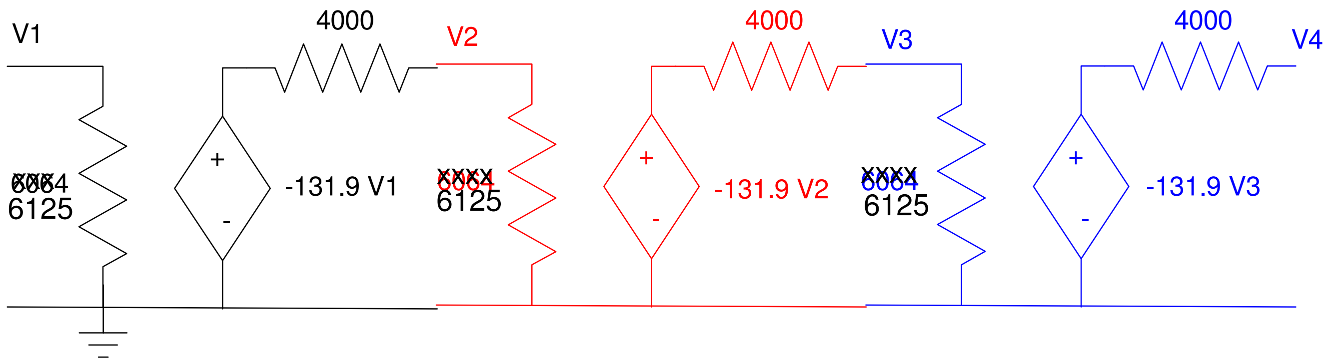
$$r_f = \frac{nV_T}{I_b} = \frac{nV_T}{7.723\mu A}$$

$$nV_T = 0.0274$$

This is what CircuitLab uses (lecture notes assume nV_T = 0.052)



8) Determine the 2-port model for cascading three of these CE amplifers (CE : CE : CE)



By inspection

- Rin = 6125
- Ai = 0
- Rout = 4000

Ao you have to work for.

Assume V1 = 1V

$$V_2 = \left(\frac{6125}{6125+4000}\right)(-131.9)V_1$$

$$V_2 = -79.79V$$

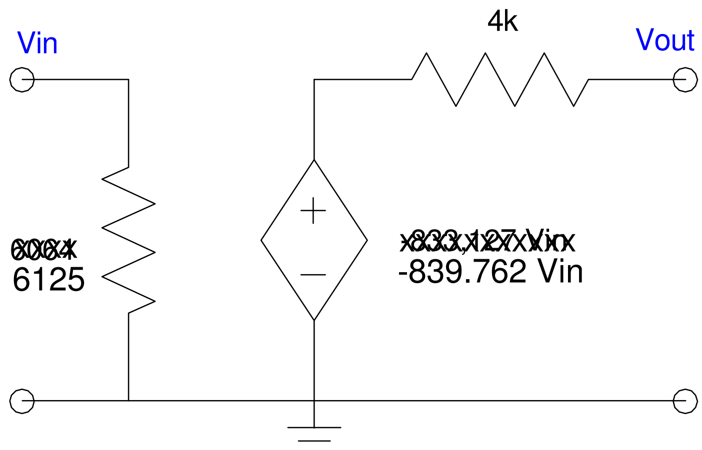
$$V_3 = \left(\frac{6125}{6125+4000}\right)(-131.9)V_2$$

$$V_3 = 6366V$$

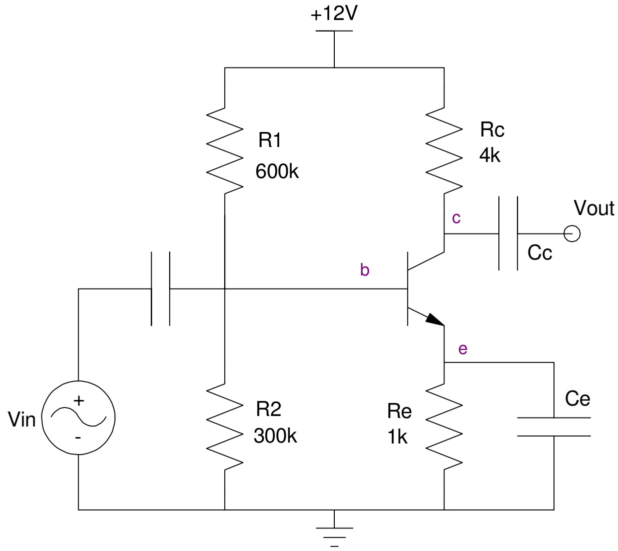
$$V_4 = -131.9V_3$$

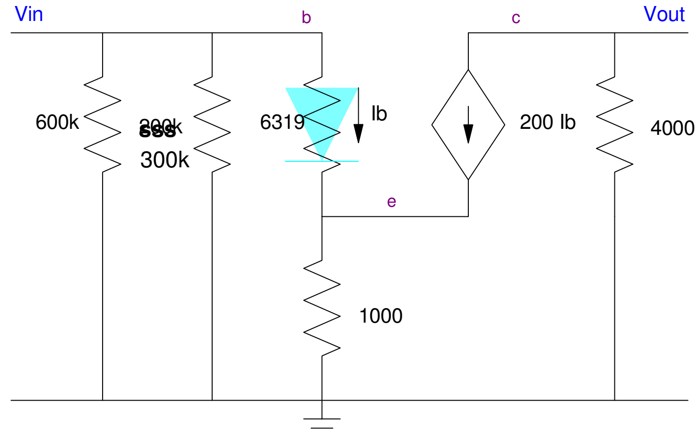
$$V_4 = -839,762$$

Ao = -839,762



9) Remove Ce. Determine the 2-port model of this CE amplifiers





Rin: The 1000 resistor looks like a 201k resistor looking infrom the left

$$R_{in} = 600k||300k||(6319 + 201k)$$

$$R_{in} = 101.8k\Omega$$

Ain: zero again

Rout: 4000 again

Ao: Vin = 1V

$$I_b = \frac{1V}{6319+201000} = 4.823\mu A$$

$$200 I_b = 964\mu A$$

$$V_{out} = -4000 \cdot 200 I_b = -3.859V$$