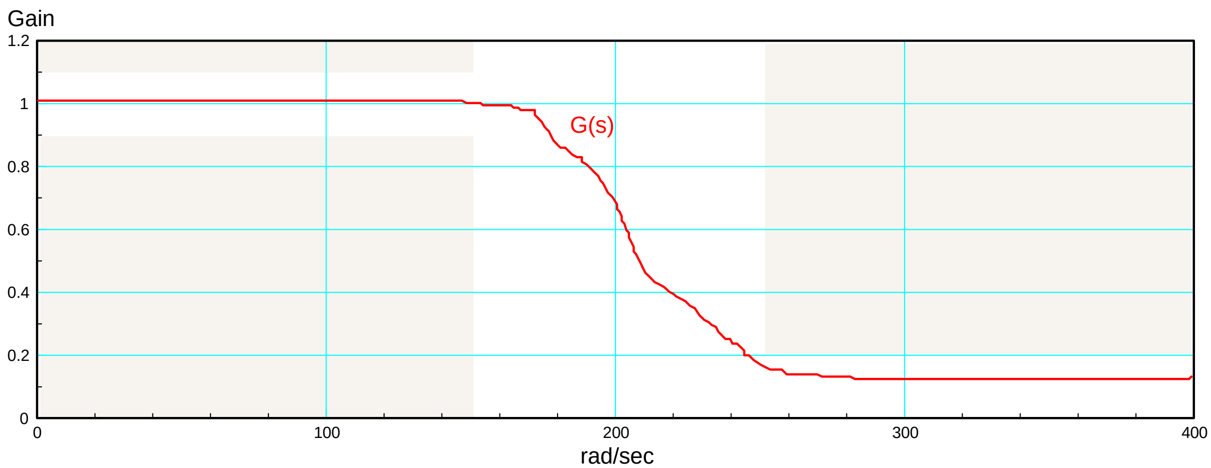
ECE 321 - Solution to Homework #4

Filters, Common Emitter Amplifiers. Due Monday, April 29th

Filters



1) Design a filter to meet the following requirements

- Input: -10V to +10V analog voltage, capable of 10mA, 0 - 1kHz
- Output: -10V to +10V analog votlage, capable of 10mA
- Relationship:

$$|G(s)| = \begin{cases} 0.9 < |G| < 1.1 & 0 < \omega < 150 \ \frac{rad}{sec} \\ |G| < 0.1 & \omega > 250 \ \frac{rad}{sec} \end{cases}$$

First, determine how many poles you need

$$\left(\frac{150Hz}{250Hz}\right)^n < 0.1$$

$$n > 4.50$$

Let n = 5

Assume a Chebychev filter. From the lecture notes, this is of the form

$$G(s) = \left(\frac{a}{(s+0.48)\left(s+0.76\angle\pm 59.3^0\right)\left(s+1.06\angle\pm 82^0\right)}\right)$$

Adjust the corner until it meets the requirements

- The gain is more than 0.9 at 150 rad/sec
- The gain is less than 0.1 at 250 rad/sec

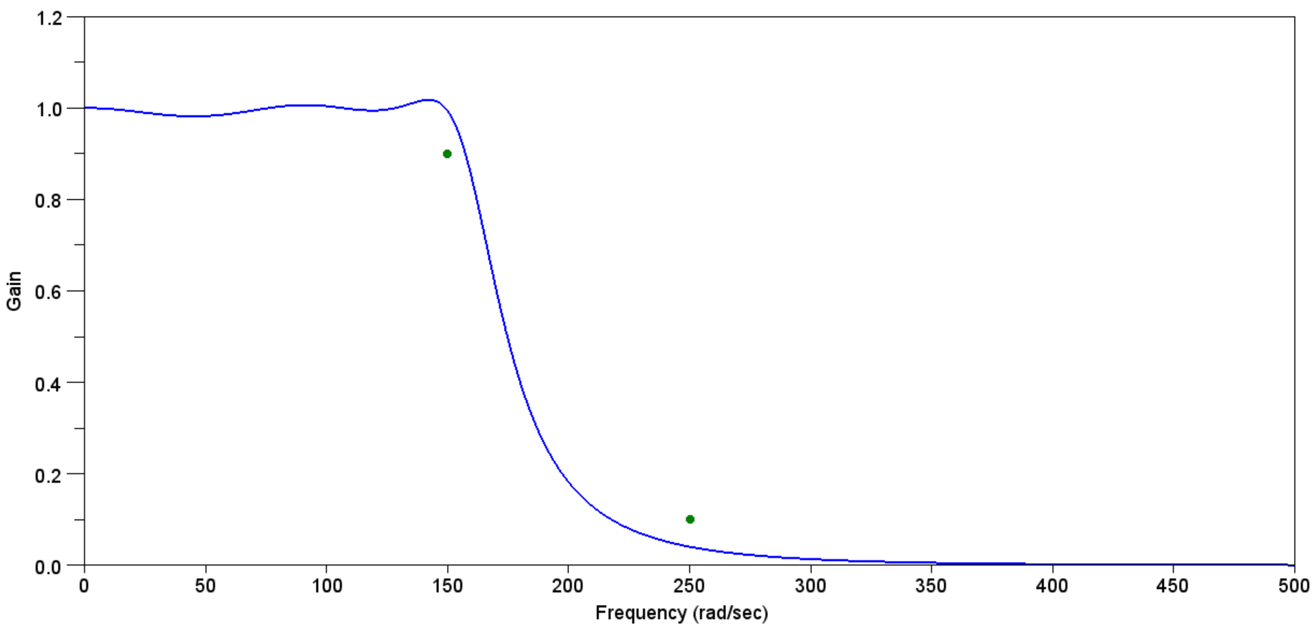
Guess the corner is 150 rad/sec

```
w = [0:500]';
```

```
s = j*w;

p1 = 0.48*150;
p2 = 0.76*150 * exp(j*59.3*pi/180);
p3 = conj(p2);
p4 = 1.06*150 * exp(j*82*pi/180);
p5 = conj(p4);

a = abs(p1)*abs(p2)*abs(p3)*abs(p4)*abs(p5)

    2.366D+10

Gs = a ./ ( (s+p1).*(s+p2).*(s+p3).*(s+p4).*(s+p5) );
plot(w,abs(Gs),[150,250],[0.9,0.1],'.');
xlabel('Frequency (rad/sec)');
ylabel('Gain');
```

This meets the design specs so I can stop (the corners don't need to be adjusted)

$$G(s) = \left(\frac{2.366e10}{(s+0.72)\left(s+114\angle\pm59.3^0\right)\left(s+159\angle\pm82^0\right)} \right)$$



2) Design an op-amp circuit to implement the filter from problem #1

Treat this as three separate (cascaded) filters:

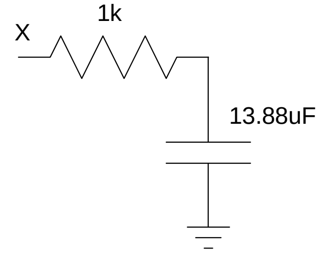
$$G(s) = \left(\frac{72}{s+72}\right)\left(\frac{114^2}{s+114\angle\pm59.3^0}\right)\left(\frac{159^2}{s+159\angle\pm82^0}\right)$$

Stage 1: $\left(\frac{72}{s+72}\right)$

Let R = 1k

$$\left(\frac{1}{RC}\right) = 72$$

$$C = 13.88\mu F$$



Stage 2: $\left(\frac{114^2}{s+114\angle\pm59.3^0}\right)$

Let R = 10k

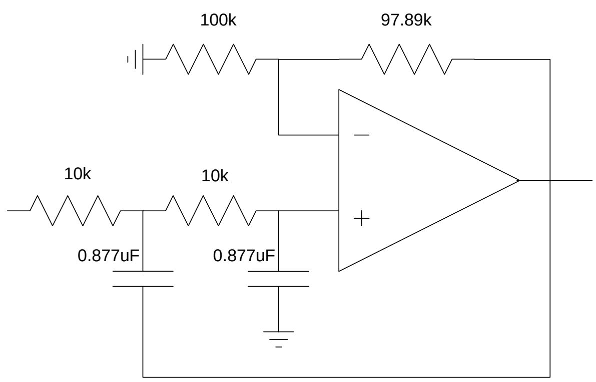
$$\left(\frac{1}{RC}\right) = 114$$

$$C = 0.877\mu F$$

$$3 - k = 2\cos(59.3^0)$$

$$k = 1.9789 = 1 + \frac{R_1}{R_2}$$

Let R2 = 100k, R1 = 97.89k



Stage 3: $\left(\frac{159^2}{s+159\angle\pm82^0}\right)$

Let R = 10k

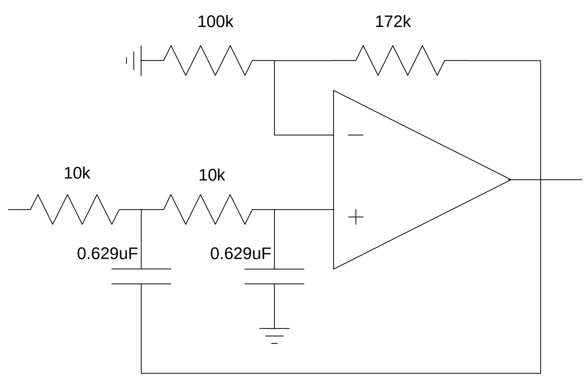
$$\left(\frac{1}{RC}\right) = 159$$

$$C = 0.629\mu F$$

$$3 - k = 2\cos(82^0)$$

$$k = 2.7217 = 1 + \frac{R_1}{R_2}$$

Let R2 = 100k, R1 = 172k

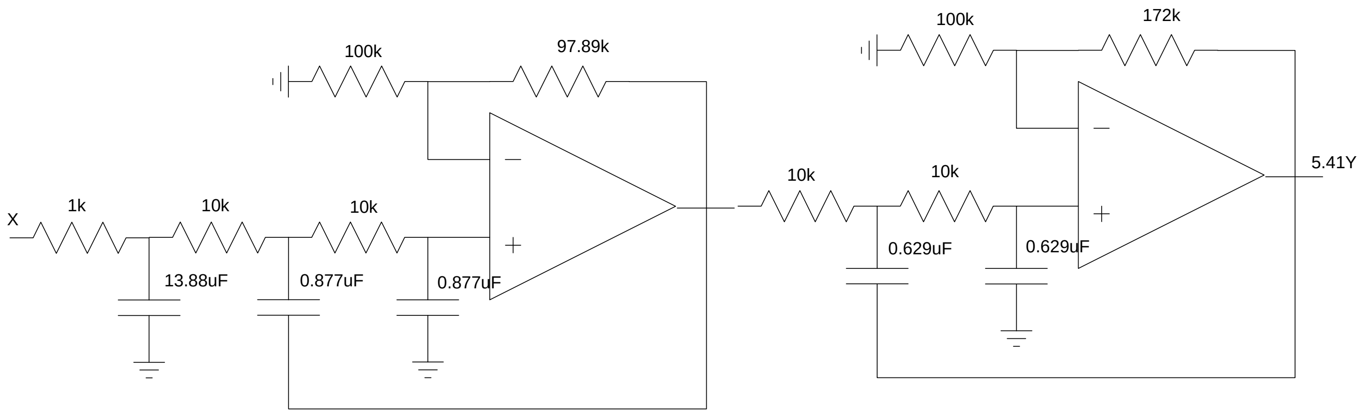


Note that the DC gain is

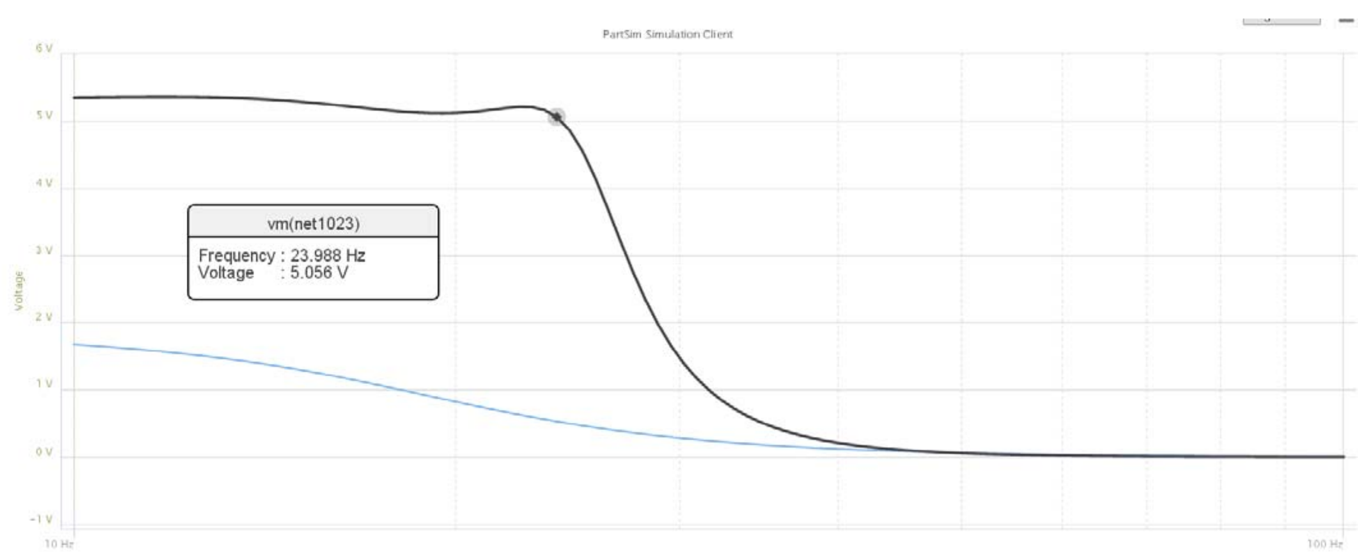
$$DC = 1 \cdot 1.9878 \cdot 2.7217 = 5.41$$

Take that into account by calling the output 5.41Y

The total circuit is then



3) Using PartSim, determine the gain vs. frequency of your filter.
   - Does the simulation result match your calculations?



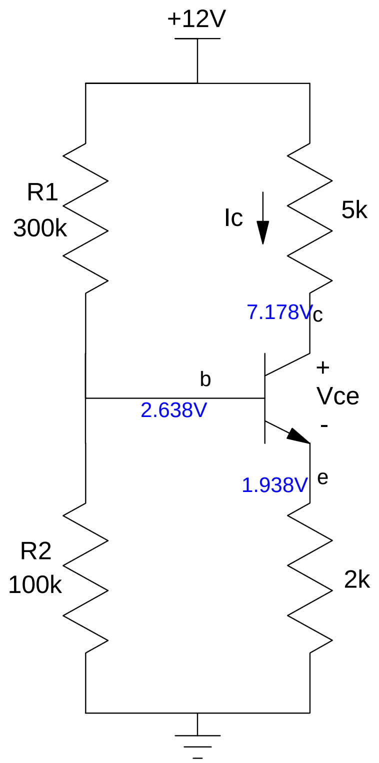
Freq	10 Hz	24Hz	40Hz	100Hz
Calculated	5.35	5.34	0.21	0.0014
Simulated	5.436	5.056	0.186	0.0014
Measured				

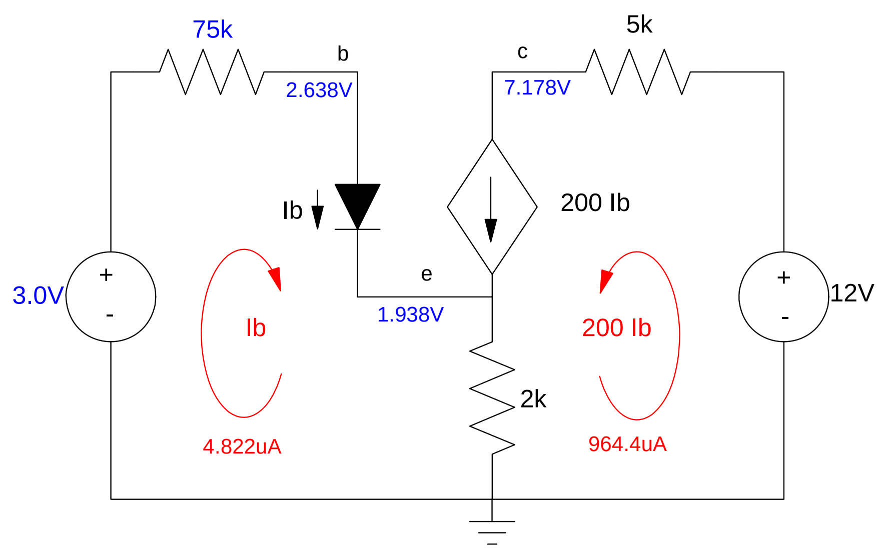
4) Build your circuit and verify it's operation (gain vs. frequency)

Transistor Amplifiers

5) Determine the Q-point (Vce, Ic) for the following transistor circuit. Assume

- $\beta = 200$
- $V_{be} = 0.7V$





$$R_b = R_{th} = R_1 || R_2 = 75k$$

$$V_b = V_{th} = \left(\frac{100k}{100k+300k}\right) \cdot 12V = 3.0V$$

$$I_b = \left(\frac{3V-0.7V}{75k+(201)\cdot 2k}\right) = 4.822\mu A$$

$$I_c = \beta I_b = 964.4\mu A$$

$$V_e = 2k \cdot (I_b + I_c) = 1.938V$$

$$V_c = 12V - 5k \cdot I_c = 7.178V$$

$$V_{ce} = V_c - V_e = 5.240V$$

The Q-Point is

- **Ic = 964.4uA**
- **Vce = 5.240V**

6) Determine R1 and R2 so that the Q-point is

- Vce = 6.0V

First, stabilize the Q-point

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

$$402k >> R_b$$

Let Rb = 40k

Now Find Vb.

$$I_c \approx \left(\frac{12V - V_{ce}}{R_e + R_c}\right) = \left(\frac{12-6}{2k+5k}\right) = 857.1\mu A$$

$$I_b = \frac{I_c}{\beta} = 4.286\mu A$$

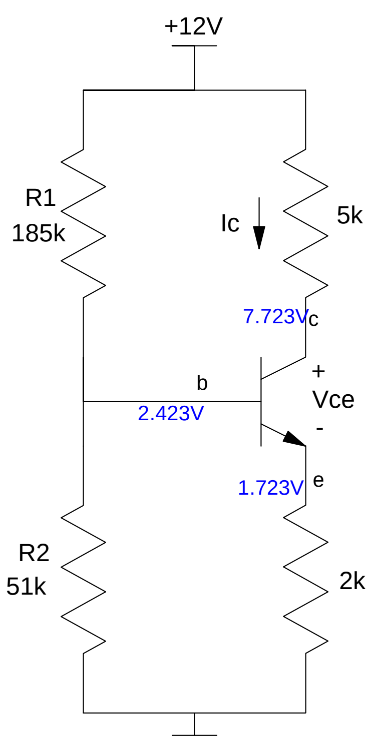
$$V_b = I_b R_b + 0.7 + R_e(I_b + I_c)$$

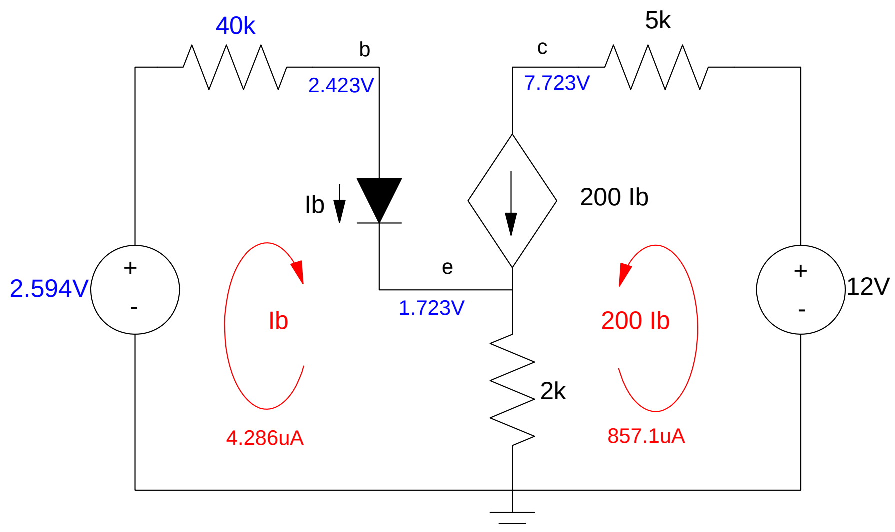
$$V_b = 2.594V$$

Now find R1 and R2

$$R_1 = \left(\frac{12V}{2.594V}\right) 40k = 185k$$

$$R_2 = 51k$$

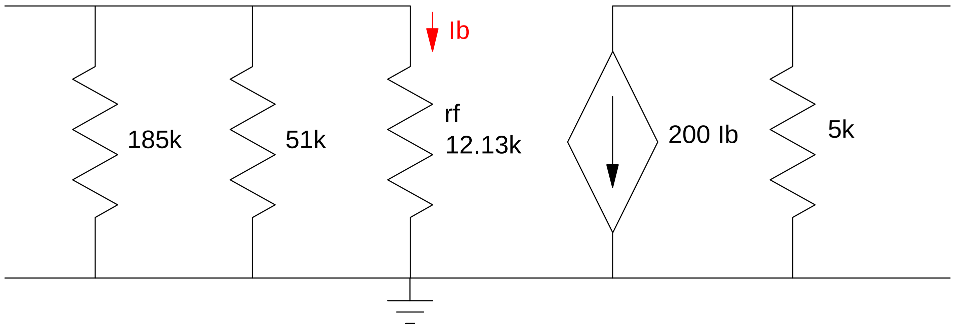




7) For your circuit of problem #6, determine the 2-port model for this transistor amplifier if set up as a Common Emitter amlifier

Redraw the circuit for a small-signal model. Replace the diode with it's Taylor's series expansion

$$r_f = \frac{0.052V}{I_b} = \frac{0.052V}{4.286\mu A} = 12.13k\Omega$$



Rin:

short Vout. Measure the resistance at the input

$$R_{in} = 185k||51k||12.13k$$

$$R_{in} = 9.31k\Omega$$

Ai = 0

Set Vout = 1V. Measure the voltage at Vin

Rout:

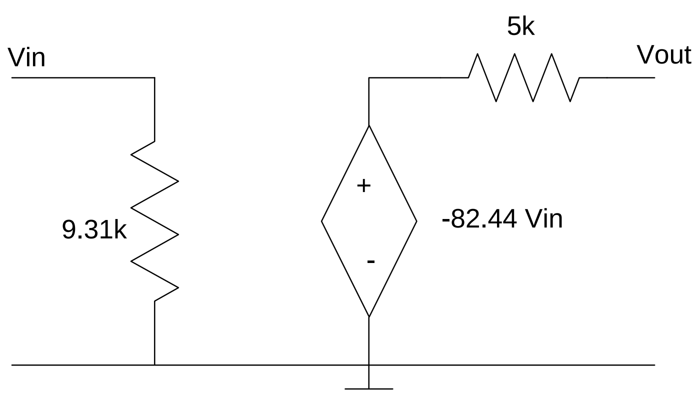
short Vin. Measure the resitance at the output

$$R_{out} = 5k$$

Ao:

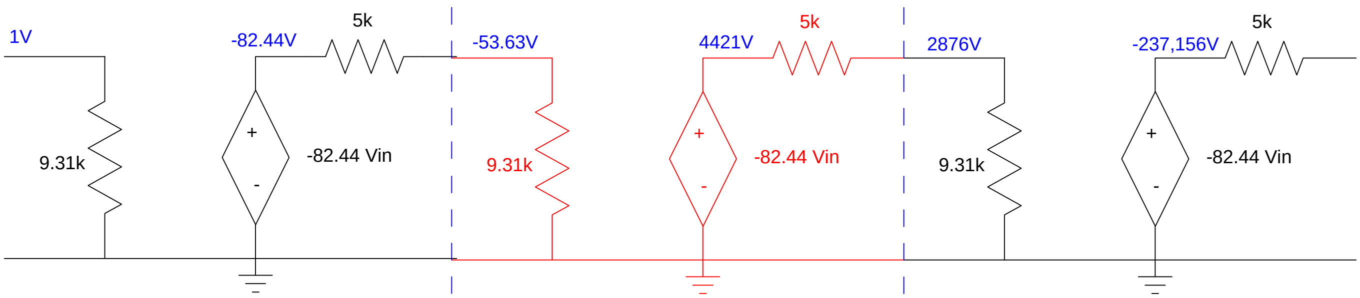
Set Vin = 1V. Measure the voltage at Vout

$$A_o = -\left(\frac{200 \cdot 5k}{12.13k}\right) = -82.44$$



8) Determine the 2-port model for three cascaded amplifiers

- Common Emitter - Common Emitter - Common Emitter



Rin:

Rin = 9.31k

Ain:

Ai = 0

Rout

Rout = 5k

Aout:

Apply 1V to Vin. Measure the votlage at Vout

Ao = -237.156