BEE 233 Circuits
Fall 2015
Lab 3: Opamp circuits: Notes on the prelab

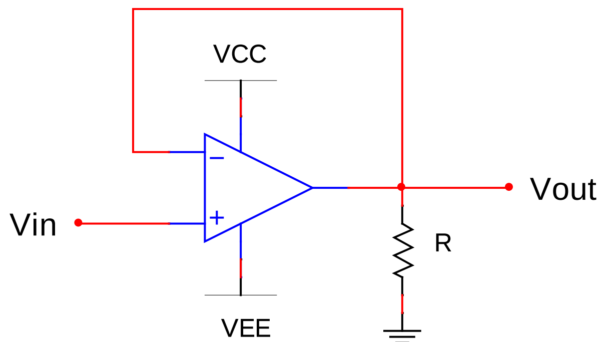
6 Pre-lab

6.1 Recording specified opamp parameters for analysis and design

Requires downloading manufacturer's datasheet.

Ri = 0.8 MΩ min to 2.5 MΩ typical
Zo = 1.0 Ω at 1.0 KHz, Av = 10.0
Av = 25 V/mV min to 160 V/mV typical
Slew rate = 0.5 V/μS

6.2 Analysis of simple opamp voltage follower circuit



For the circuit in figure 1 with R = 5.1 KΩ, VCC = +12 V, VEE = –12 V, and the parameter values in section 6.1, answer the following questions:

1. What is the voltage gain of the circuit at low frequency?

   Because we assume the opamp is being operated under conditions where the voltage across the inputs to the opamp will always be zero, this circuit will produce unity gain.

   $$Vin = Vout$$

   $$\frac{Vout}{Vin} = 1$$

2. If Vin is a square wave with an amplitude of 2.5 Vpp from –1.25 V to +1.25 V, how long will the output signal take to reach the final value after each input transition?

   The slew rate is given as 0.5 V/μS from the datasheet. For ΔVin = 2.5 V and Av = 1 (unity gain), Δt = 2.5/0.5 = 5 μS.

3. Assume Vin is a sine wave = 3 Vpp. Derive an equation for the maximum rate of change of the output voltage |dVout/dt| as function of the input amplitude and frequency. From this equation and the opamp slew rate, determine the input frequency at which the slew rate of the opamp begins to limit its ability to act as a voltage follower?

Let $Vin = Vout = A\cos(\omega t)$

$$\frac{dVout}{dt} = -A\omega\sin(\omega t)$$

Then $\max\left|\frac{dVout}{dt}\right| = A\omega$ occurs where $\sin(\omega t)$ = −1 or +1.

Since $\frac{dVout}{dt} < Slew\ rate,\ A\omega < 0.5\ \mathrm{V/\mu S}$.

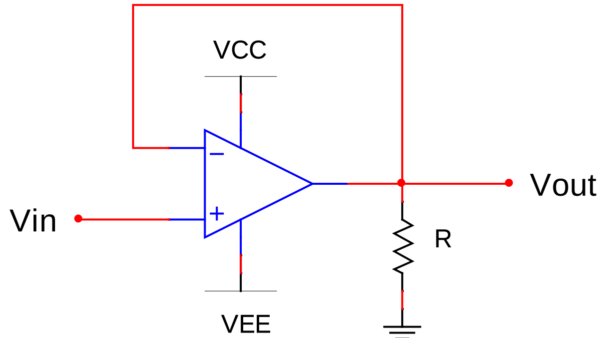
Amplitude is given as 3 Vpp, meaning A = 1.5 V, therefore:

$$(1.5\ V)\omega < 0.5\ \mathrm{V/\mu S}$$

$$\omega < 0.333\ radians/\mathrm{\mu S}$$

$$\mathrm{f} = \frac{\omega}{2\pi} = 53\ \mathrm{KHz}$$

4. Assume small-signal inputs to avoid slew-rate limitations and that the opamp is not ideal, i.e., it has a finite open-loop gain A_V. Analyze the circuit in Figure 1 to derive an equation for the circuit gain Vout/Vin as a function of A_V. At what value of A_V does Vout/Vin equal 0.5?



$$Vout = Av(Vin - Vout)$$

$$Vout = Av\ Vin - Av\ Vout$$

$$Vout(1 + Av) = Av\ Vin$$

$$\frac{Vout}{Vin} = \frac{Av}{1 + Av}$$

Let $\frac{Vout}{Vin} = 0.5$. Then

$$\frac{Vout}{Vin} = \frac{Av}{1 + Av} = 0.5$$

$$0.5 + 0.5\,Av = Av$$

$$0.5 = 0.5\,Av$$

$$Av = 1$$

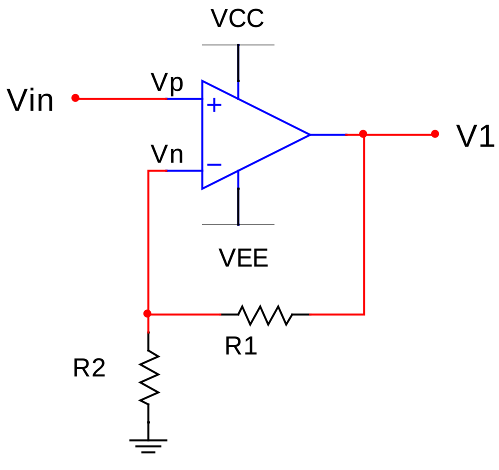
5. Using the opamp specifications (plot of opamp gain A_V as function of frequency) and the result in item 4 above, at what frequency do you expect Vout/Vin = 0.5?

   From the manufacturers' datasheets, the opamp gain should fall to unity at 1 MHz.

6.3 Analysis of the gain circuit in Figure 2

Use the techniques in the text and what you've learned about opamp circuits, analyze the gain circuit in Figure 2 following this procedure:

1. What is the function of the first opamp stage? Find the voltage gain V1/Vin of this stage?



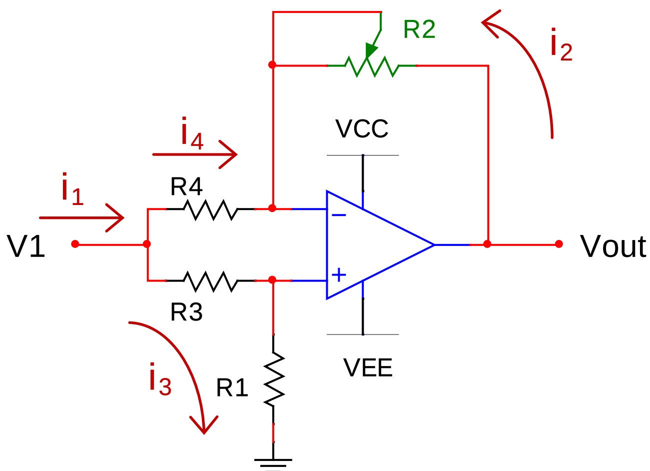
R1 = 20 KΩ, R2 = 1 KΩ. Assume Vp = Vn.

$$Vn = Vin = \left(\frac{R2}{R1 + R2}\right) V1$$

$$Av1 = \frac{V1}{Vin} = \frac{R1 + R2}{R2} = \frac{20 + 1}{1} = 21$$

The first stage is a non-inverting amplifier with a gain = 21.

2. What is the function of the second opamp stage? Find the voltage gain Vout/V1 of this stage as a function of the variable resistance R2.



$$i1 = i3 + i4$$

$$i4 = -i2$$

$$V1 = i3(R1 + R3)$$

$$V1 = i4\ R4 + Vn$$

$$V1 = i4\ R4 + i3\ R1$$

From these two equations for V1:

$$i3(R1 + R3) = i4\ R4 + i3\ R1$$

$$i3\ R1 + i3\ R3 = i4\ R4 + i3\ R1$$

$$i3\ R3 = i4\ R4$$

Since R3 = R4:

$$i3 = i4$$

$$V1 = i4(R1 + R3)$$

Separately:

$$Vout = i2\ R2 - i4\ R4 + V1$$

$$Vout = i2\ R2 - i4\ R4 + i4(R1 + R3)$$

$$Vout = i4(R1 - \ R2 + R3 - R4)$$

Again, since R3 = R4:

$$Vout = i4(R1 - \ R2)$$

$$Av2 = \frac{Vout}{V1} = \frac{i4(R1 - \ R2)}{i4(R1 + R3)} = \frac{R1 - R2}{R1 + R3} = 0.5 - \frac{R2}{10.2\ K}$$

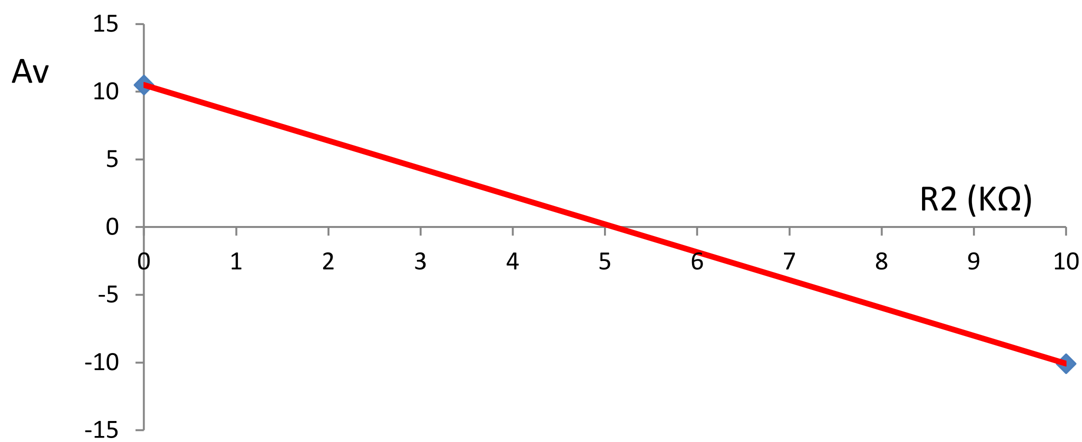
For R1 and R3 = 5.1 KΩ and 0 ≤ R2 ≤ 10 KΩ:

$$Av2 = 0.5 - \frac{R2}{10.2\ K}$$

$$-0.48\ \leq Av2\ \leq +0.5$$

3. With the results from items 1 and 2 above, what is the overall voltage gain Vout/Vin of this circuit as a function of R2? Plot the gain as function of R2. Use the linear scale for the gain.

$$Av = (Av1)(Av2) = (21)\left(0.5 - \frac{R2}{10.2\ K}\right) = \ 10.5 - \frac{R2}{485.7}$$



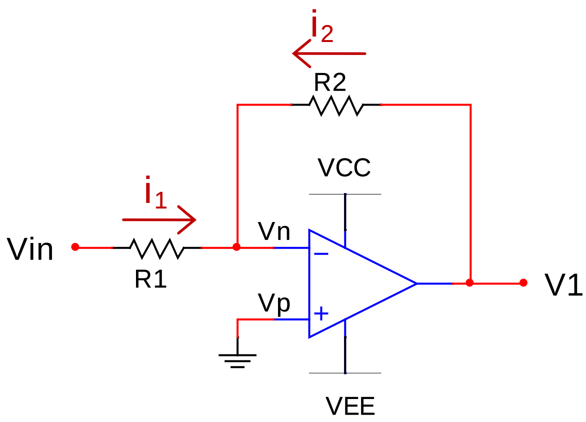
4. You should now be able to see what is interesting about this circuit. Explain its feature in one sentence.

It provides adjustable inverting or non-inverting gain.

6.4 Design of another gain circuit

Re-design the circuit in Figure 2 so that the new overall gain has the opposite sign, i.e. if the circuit in Figure 2 has a gain G, the new circuit has gain –G over the entire range of the resistor R2. Use as few components as possible and keep the design simple.

The easiest solution is to replace the non-inverting first stage with an inverting first stage of the same gain.



$$Vn = Vp = 0$$

$$i1 = -i2$$

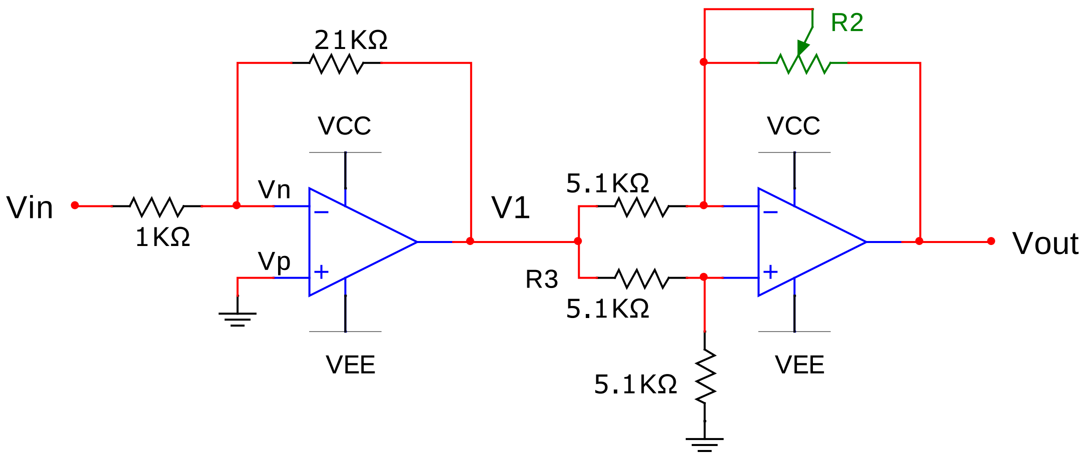
$$Vin = i1\ R1 + Vn = i1\ R1$$

$$V1 = i2\ R2 + Vn = i2\ R2 = \ -i1\ R2$$

$$Av1 = \frac{V1}{Vin} = -\frac{i1\ R2}{i1\ R1} = -\frac{R2}{R1}$$

For Av1 = –21 and R1 = 1 KΩ, R2 = 21 KΩ

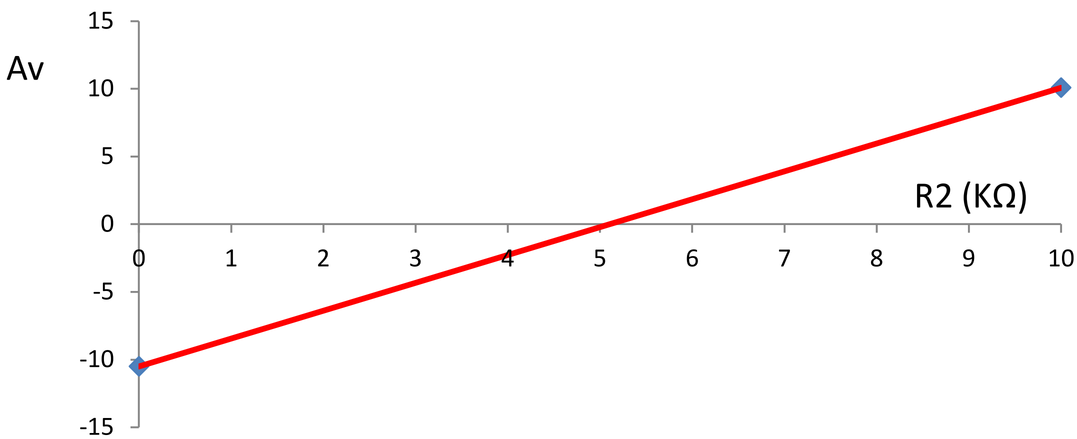
1. Show the schematic of your circuit with all components completely specified (component types and values, component part numbers, power supply values, etc.).



2. Analyze your circuit to prove that it has the gain as specified. If you find out that the magnitude of the gain somehow is not large as the gain magnitude for the circuit in Figure 2, explain why this is so.

$$Av = (Av1)(Av2) = (-21)\left(0.5 - \frac{R2}{10.2\ K}\right) = -10.5 + \frac{R2}{485.7}$$

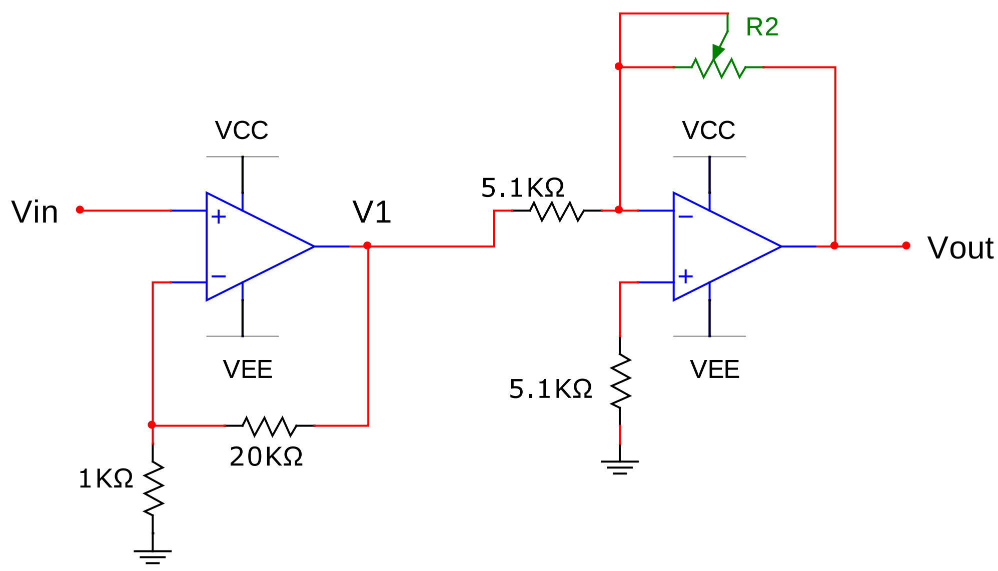
3. Plot the gain of this new circuit as a function of R2. Use the linear scale for the gain.



6.5 Open fault in circuit in Figure 2

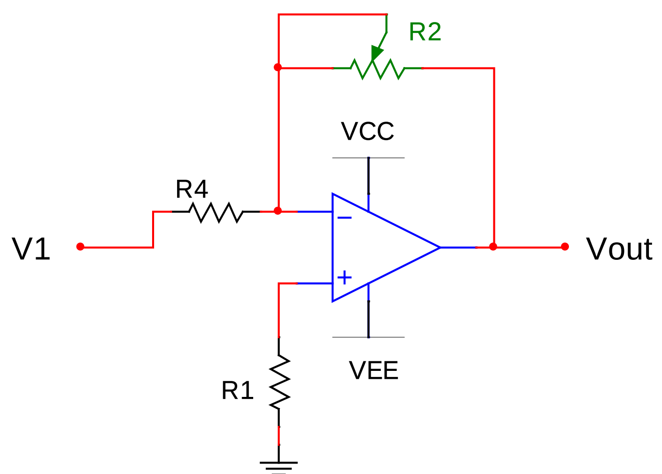
Assume that the circuit in Figure 2 has an open fault at the R3 (5.1 KΩ) resistor. The effect of this open fault is to remove R3 totally from the circuit.

1. Re-draw the circuit diagram in Figure 2, omitting the resistor R3 to simulate the effect of the open fault.



2. Analyze this new circuit to find the overall voltage gain Vout/Vin in one particular case when R2 = 8 KΩ.

Because no current flows through R1, the second stage is an inverting amp like the one analyzed in 6.4.



$$Av2 = -\frac{R2}{R4} = -\frac{8K}{5.1K} = -1.57$$

Because the first stage is unchanged, the overall gain is:

$$Av = (Av1)(Av2) = (21)(-1.57) = -32.9$$

3. Is this gain different than the gain when the circuit has no fault? The good (no fault) circuit is also called the "fault-free" circuit.

Yes, it's different. For the good circuit with R2 = 8 KΩ:

$$Av2 = 0.5 - \frac{R2}{10.2\ K} = 0.5 - \frac{8\ K}{10.2\ K} = -0.284$$

$$Av = (Av1)(Av2) = (21)(-0.284) = -5.97$$

Quite clearly, Av is different, –5.97 in the good circuit versus –32.9 in the faulty circuit.