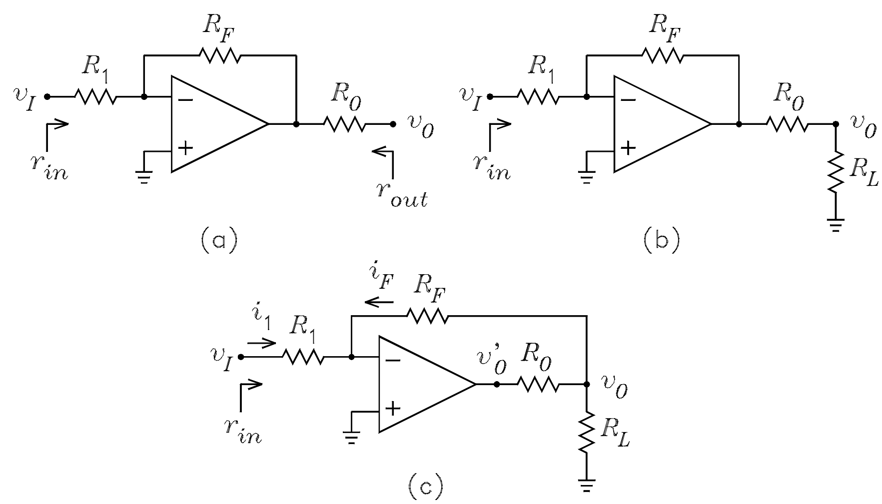
ECE3040 – Assignment 9

1. The figures show inverting amplifier circuits.

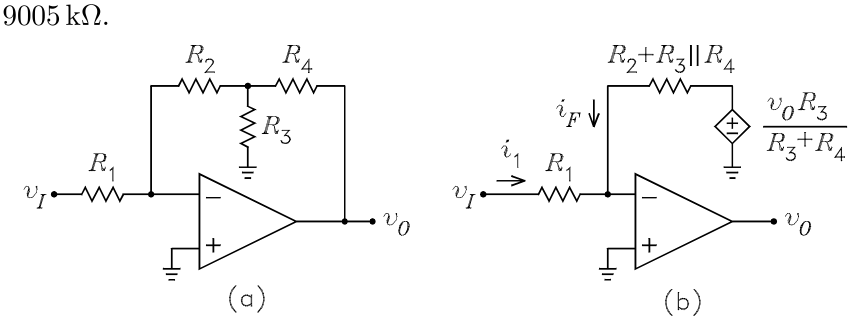
   (a) For the circuit of Fig. (a), specify R_1, R_F, and R_O for a voltage gain of -50, an input resistance of $2\,\text{k}\Omega$, and an output resistance of $1\,\text{k}\Omega$. If the op amp clips at a peak output voltage of $12\,\text{V}$, specify the maximum peak input voltage if the op amp is not to be driven into clipping. Answers: $R_1 = 2\,\text{k}\Omega$, $R_F = 100\,\text{k}\Omega$, $R_O = 1\,\text{k}\Omega$, and $\left|v_{I(peak)}\right| = 0.24\,\text{V}$.

   (b) Fig. (b) shows the circuit of Fig. (a) with a load resistor connected to the output. Calculate the new voltage gain if $R_L = 1\,\text{k}\Omega$. What is the maximum peak output voltage if the op amp is not to clip? Answers: $v_O/v_I = -25$ and $\left|v_{O(peak)}\right| = 6\,\text{V}$.

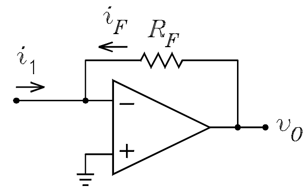
   (c) Repeat part (b) if the circuit is modified as shown in Fig. (c). Answers: $v_O/v_I = -50$ and $\left|v_{O(peak)}\right| = 5.97\,\text{V}$. Hint, use voltage division to solve for $\left|v_{O(peak)}\right|$ in terms of $\left|v'_{O(peak)}\right|$.



2. Fig. (a) shows an inverting amplifier with a T feedback network. Fig. (b) shows the amplifier with a Thévenin equivalent made looking into the feedback network from the input. The amplifier is to be designed for an input resistance of $1\,\text{k}\Omega$ and a voltage gain of -1000. If $R_2 = R_4$ and $R_3 = 100\,\Omega$, specify the value of R_2 and R_4. Answers: $R_1 = 1\,\text{k}\Omega$ and $R_2 = R_4 = 9.9005\,\text{k}\Omega$.



3. The figure shows a current to voltage converter. The circuit is to be designed to convert an input current of $-50\,\mu\text{A}$ into an output voltage of $+4\,\text{V}$.

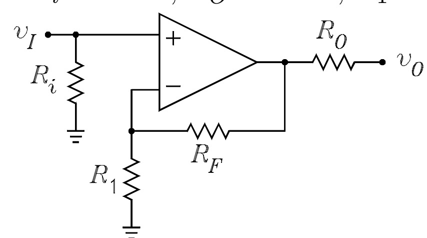


(a) Calculate the required value of R_F. Answer: $R_F = 80\,\mathrm{k}\Omega$.

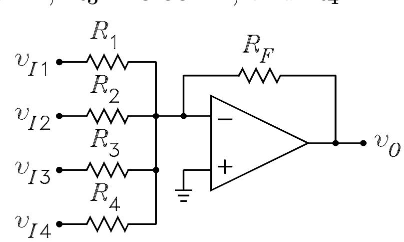
(b) If the op amp clips at a peak output voltage of 12 V, calculate the maximum peak input current. Answer: $i_{1(peak)} = 150\,\mu\mathrm{A}$.

(c) The circuit is driven from an amplifier which can be modeled by a voltage-controlled voltage source with an open-circuit voltage gain of 10 and an output resistance of $2\,\mathrm{k}\Omega$. Calculate the overall voltage gain of the two circuits in combination. Answer: $v_O/v_I = -400$.

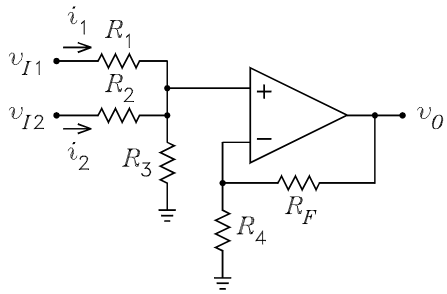
4. The figure shows a non-inverting amplifier. The circuit is to be designed for an input resistance of $10\,\mathrm{k}\Omega$, and output resistance of $100\,\Omega$, and an open-circuit voltage gain of 20. When the peak output voltage is 10 V, the current through R_F and R_1 is to be 0.2 mA. Specify the resistors in the circuit. Answers: $R_i = 10\,\mathrm{k}\Omega$, $R_O = 100\,\Omega$, $R_1 = 2.5\,\mathrm{k}\Omega$, and $R_F = 47.5\,\mathrm{k}\Omega$.



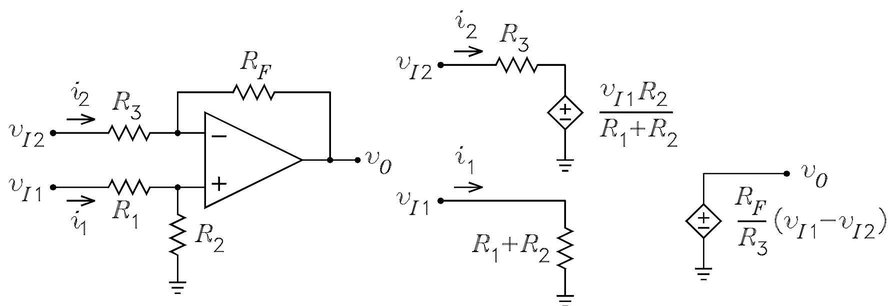
5. The figure shows a 4 input inverting summer. The circuit is to be designed for an output voltage given by $v_O = -(2v_{I1} + 4v_{I2} + 6v_{I3} + 8v_{I4})$. When the peak output voltage is 10 V, the current through R_F is to be 0.5 mA. Specify the resistors in the circuit. Answers: $R_F = 20\,\mathrm{k}\Omega$, $R_1 = 10\,\mathrm{k}\Omega$, $R_2 = 5\,\mathrm{k}\Omega$, $R_3 = 3.33\,\mathrm{k}\Omega$, and $R_4 = 2.5\,\mathrm{k}\Omega$.



6. The figure shows a non-inverting summer. The gain v_O/v_+ is specified to be 50. If $R_3 = R_4 = 1\,\mathrm{k}\Omega$, specify R_1, R_2, and R_F for an output voltage given by $v_O = 5v_{I1} + 2v_{I2}$. Answers: $R_F = 49\,\mathrm{k}\Omega$, $R_1 = 8.6\,\mathrm{k}\Omega$, and $R_2 = 21.5\,\mathrm{k}\Omega$.



7. Fig. (a) shows a differential amplifier. Fig. (b) shows the equivalent circuit for the special case $R_1 = R_3$ and $R_2 = R_F$. It is desired to design the circuit so that $v_O = 10\,(v_{I1} - v_{I2})$. In addition, the input resistance seen between the two input nodes is to be $10\,\mathrm{k}\Omega$.



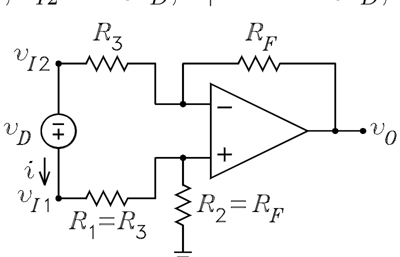
(a) (b)

(a) Specify the resistors in the circuit. Answers: $R_1 = R_3 = 5\,\mathrm{k}\Omega$, $R_2 = R_F = 50\,\mathrm{k}\Omega$.

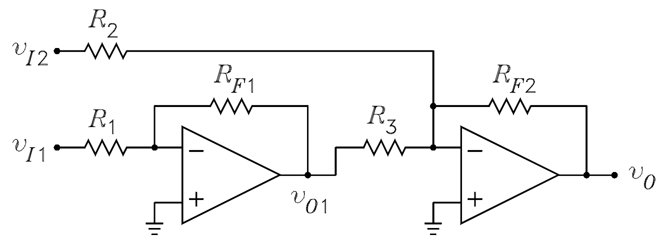
(b) For $v_{I2} = 0$, solve for the resistance seen looking into the v_{I1} input. Answer: $55\,\mathrm{k}\Omega$.

(c) For $v_{I1} = 0$, solve for the resistance seen looking into the v_{I2} input. Answer: $5\,\mathrm{k}\Omega$.

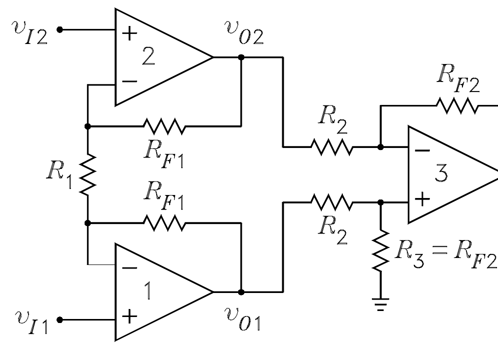
8. The figure shows a differential amplifier with a source connected between its two inputs. The circuit elements values are the same as those found in problem 7. Solve for the voltage gain v_O/v_D, v_{I1}, v_{I2}, the voltage at each op amp input, and the common-mode input voltage v_{ICM}. Answers: $v_O/v_D = 10$, $v_{I1} = 5.5v_D$, $v_{I2} = 4.5v_D$, $v_+ = v_- = 5v_D$, $v_{ICM} = v_O/2 = 5v_D$.



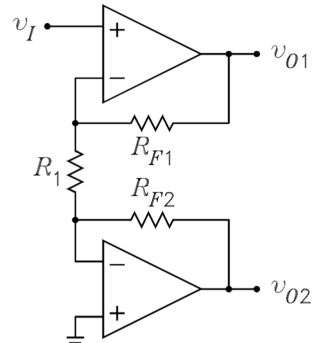
9. The figure shows a two op amp diff amp. Design the circuit for an output voltage given by $v_O = 50\,(v_{I1} - v_{I2})$. The input resistance to each input is to be $5\,\mathrm{k}\Omega$. Answers: $R_1 = R_2 = R_{F1} = R_3 = 5\,\mathrm{k}\Omega$, $R_{F2} = 250\,\mathrm{k}\Omega$.



10. The figure shows a three op amp instrumentation amplifier. (a) Design the circuit such that $v_{O1} - v_{O2} = 10\,(v_{I1} - v_{I2})$ and $v_O = 10\,(v_{O1} - v_{O2})$. Answers: $1 + 2R_{F1}/R_1 = 10$, choose $R_1 = 2\,\text{k}\Omega$ and $R_{F1} = 9\,\text{k}\Omega$, $R_{F2}/R_2 = 10$, choose $R_{F2} = 10\,\text{k}\Omega$, and $R_2 = 1\,\text{k}\Omega$. (b) For $v_{I1} = 0.03\,\text{V}$ and $v_{I2} = 0.01\,\text{V}$, calculate v_{O1}, v_{O2}, and v_O. Answers: $v_{O1} = 0.12\,\text{V}$, $v_{O2} = -0.08\,\text{V}$, and $v_O = 2\,\text{V}$.

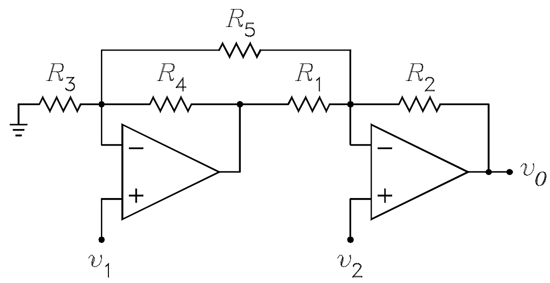


11. The figure shows a balanced output amplifier. Design the circuit so that $v_{O1} = -v_{O2} = 6v_I$. When $v_{O1} = \pm 12\,\text{V}$ and $v_{O2} = \mp 12\,\text{V}$, the current through R_{F1} and R_{F2} is not to exceed $1\,\text{mA}$. Answers: for $1\,\text{mA}$, $R_1 = 2\,\text{k}\Omega$, $R_{F1} = 10\,\text{k}\Omega$, and $R_{F2} = 12\,\text{k}\Omega$.



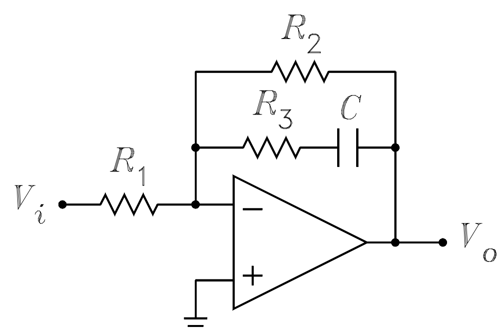
12. For the circuit shown, use superposition of v_1 and v_2 to show that v_O is given by

$$v_O = -v_1 \left[\left(1 + \frac{R_4}{R_3 \| R_5} \right) \frac{R_2}{R_1} + \frac{R_2}{R_5} \right] + v_2 \left(1 + \frac{R_2}{R_1 \| R_5} + \frac{R_4}{R_5}\,\frac{R_2}{R_1} \right)$$



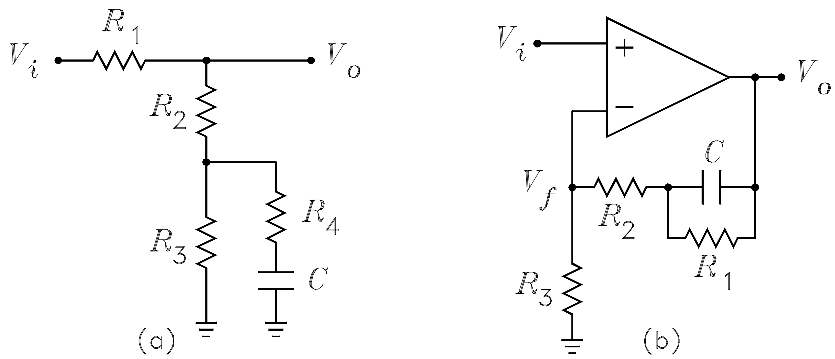
13. Solve for the transfer function for V_o/V_i for the circuit below. Sketch the Bode plot, label the break frequencies, and label the gain on the zero-slope asymptotes. Answer:

$$\frac{V_o}{V_i} = -\frac{Z_F}{R_1} = -\frac{R_2}{R_1}\,\frac{1 + R_3 Cs}{1 + (R_2 + R_3)\,Cs}$$



The circuit is to be designed as a lag-lead compensator for a motor control system. The specifications are low-frequency asymptotic gain: -2, input resistance: $10\,\mathrm{k}\Omega$, pole frequency: $1\,\mathrm{Hz}$, zero frequency: $10\,\mathrm{Hz}$. Specify the element values. Answers: $R_1 = 10\,\mathrm{k}\Omega$, $R_2 = 20\,\mathrm{k}\Omega$, $R_3 = 2222.2\,\Omega$, and $C = 7.1620\,\mu\mathrm{F}$.

14. Solve for V_o/V_i for the circuits below. Sketch and label the Bode magnitude plots.



Answers: (a) The transfer function is a low-pass shelving function with a dc gain of

$$K_{dc} = \frac{R_2 + R_3}{R_1 + R_2 + R_3}$$

and a high-frequency gain of

$$K_\infty = \frac{R_2 + R_3 \| R_4}{R_1 + R_2 + R_3 \| R_4}$$

The transfer function is

$$\frac{V_o}{V_i} = \frac{R_2 + R_3}{R_1 + R_2 + R_3} \frac{1 + (R_2 \| R_3 + R_4)\, Cs}{1 + [(R_1 + R_2) \| R_3 + R_4]\, Cs}$$

(b) The transfer function is a high-pass shelving function. The zero-frequency gain is

$$K_{dc} = 1 + \frac{R_1 + R_2}{R_3}$$

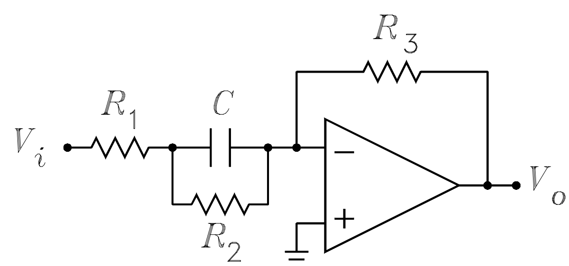
The high-frequency gain is

$$K_\infty = 1 + \frac{R_2}{R_3}$$

The transfer function is given by

$$\frac{V_o}{V_i} = \left(\frac{V_f}{V_o}\right)^{-1} = \left(1 + \frac{R_1 + R_2}{R_3}\right) \frac{1 + [(R_2 + R_3) \| R_1]\, Cs}{1 + R_1 Cs}$$

15. Solve for the voltage-gain transfer function for the circuit below Sketch and label the Bode magnitude plot.



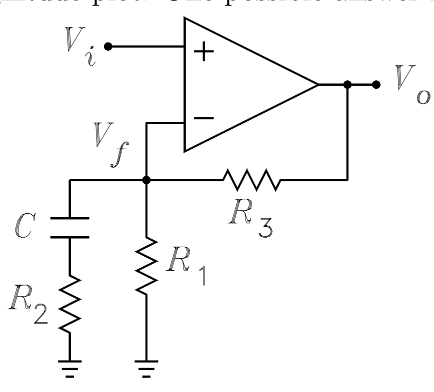
Answer:

$$\frac{V_o}{V_i} = -\frac{R_3}{Z_1} = -\frac{R_3}{R_1 + R_2} \frac{1 + R_2 Cs}{1 + (R_1 \| R_2)\, Cs}$$

16. Using a single 100 μF capacitor, design a single op amp circuit which has the voltage-gain transfer function

$$\frac{V_o}{V_i} = 10 \frac{1 + s/10}{1 + s/100}$$

Sketch and label the Bode magnitude plot. One possible answer is the circuit below.



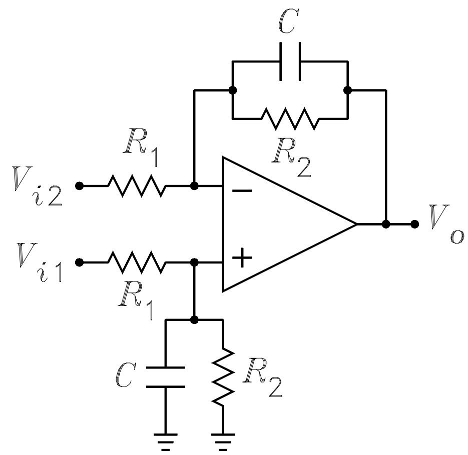
where

$$\frac{V_o}{V_i} = \left(\frac{V_f}{V_o}\right)^{-1} = \left(1 + \frac{R_3}{R_1}\right) \frac{1 + (R_1 \| R_3 + R_2)\, Cs}{1 + R_2 Cs}$$

The element values are $R_1 = 1\,\mathrm{k}\Omega$, $R_2 = 100\,\Omega$, $R_3 = 9\,\mathrm{k}\Omega$, and $C = 15.92\,\mu$F.

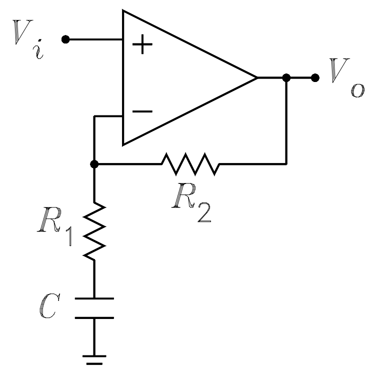
17. For the circuit shown, show that

$$V_o = \frac{R_2}{R_1}\frac{V_{i1} - V_{i2}}{1 + R_2 C s}$$



18. For the circuit shown, show that

$$\frac{V_o}{V_i} = \frac{1 + (R_1 + R_2)\,Cs}{1 + R_1 Cs}$$

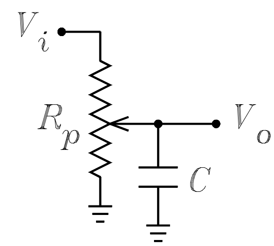


19. For the potentiometer circuit shown, let the resistance below the wiper be xR_p and the resistance above the wiper be $(1 - x)\,R_p$.Show that

$$\frac{V_o}{V_i} = \frac{x}{1 + x\,(1 - x)\,RCs}$$

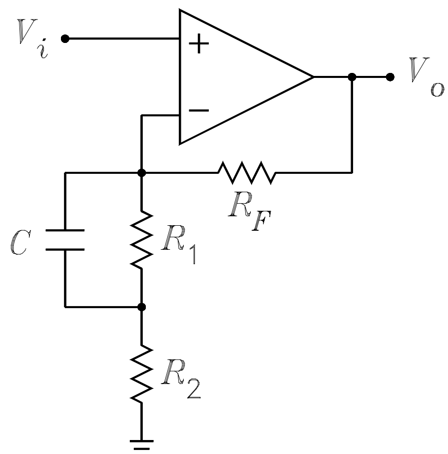
Show that the circuit has a minimum bandwidth when $x = 0.5$ and that the corresponding pole frequency is given by

$$f_{pole} = \frac{1}{\pi RC}$$



20. For the circuit shown, show that

$$\frac{V_o}{V_i} = \left(1 + \frac{R_F}{R_1 + R_2}\right) \frac{1 + [R_1 \| (R_2 + R_F)]\, Cs}{1 + (R_1 \| R_2)\, Cs}$$



21. The figure shows a Schmidt trigger. It is given that $V_{\mathrm{SAT}} = 12\,\mathrm{V}$ and $R_F = 10\,\mathrm{k}\Omega$. Solve for V_{REF} and R_1 for $V_A = -4\,\mathrm{V}$ and $V_B = +2\,\mathrm{V}$. Answers: $R_1 = 3.33\,\mathrm{k}\Omega$, $V_{REF} = -1.33\,\mathrm{V}$.