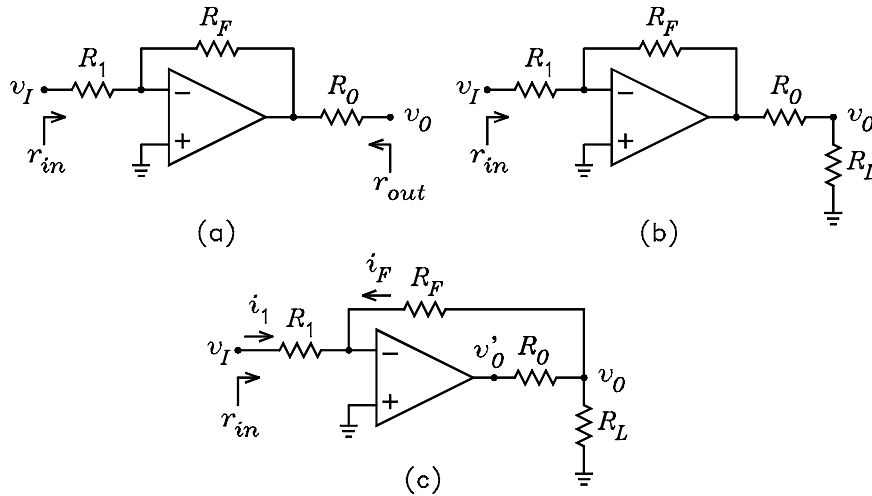


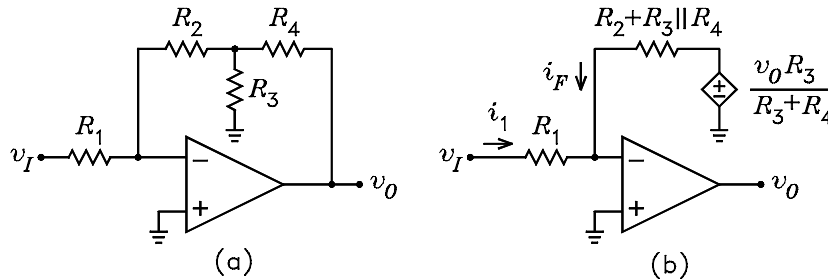
ECE3040 – Assignment 9

1. The figures show inverting amplifier circuits.

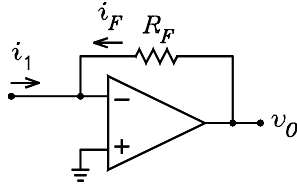
- (a) For the circuit of Fig. (a), specify  $R_1$ ,  $R_F$ , and  $R_O$  for a voltage gain of  $-50$ , an input resistance of  $2\text{ k}\Omega$ , and an output resistance of  $1\text{ k}\Omega$ . If the op amp clips at a peak output voltage of  $12\text{ V}$ , specify the maximum peak input voltage 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  $|v_{I(\text{peak})}| = 0.24\text{ V}$ .
- (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  $|v_{O(\text{peak})}| = 6\text{ V}$ .
- (c) Repeat part (b) if the circuit is modified as shown in Fig. (c). Answers:  $v_O/v_I = -50$  and  $|v_{O(\text{peak})}| = 5.97\text{ V}$ . Hint, use voltage division to solve for  $|v_{O(\text{peak})}|$  in terms of  $|v'_{O(\text{peak})}|$ .



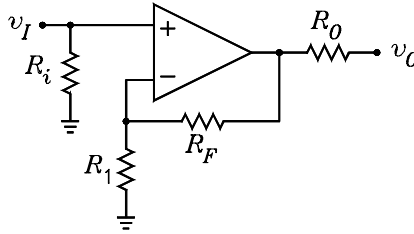
2. Fig. (a) shows an inverting amplifier with a T feedback network. Fig. (b) shows the amplifier with a Thévenin equivalent made looking into the feedback network from the input. The amplifier is to be designed for an input resistance of  $1\text{ k}\Omega$  and a voltage gain of  $-1000$ . If  $R_2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



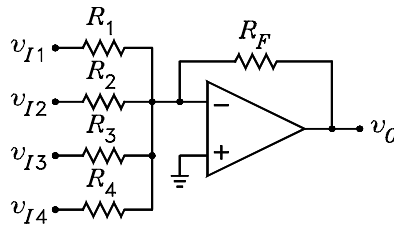
3. The figure shows a current to voltage converter. The circuit is to be designed to convert an input current of  $-50\ \mu\text{A}$  into an output voltage of  $+4\text{ V}$ .



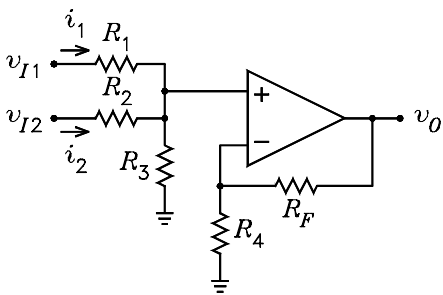
- (a) Calculate the required value of  $R_F$ . Answer:  $R_F = 80 \text{ k}\Omega$ .
- (b) If the op amp clips at a peak output voltage of  $12 \text{ V}$ , calculate the maximum peak input current. Answer:  $i_{1(\text{peak})} = 150 \mu\text{A}$ .
- (c) The circuit is driven from an amplifier which can be modeled by a voltage-controlled voltage source with an open-circuit voltage gain of  $10$  and an output resistance of  $2 \text{ k}\Omega$ . 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  $10 \text{ k}\Omega$ , and output resistance of  $100 \Omega$ , and an open-circuit voltage gain of  $20$ . When the peak output voltage is  $10 \text{ V}$ , the current through  $R_F$  and  $R_1$  is to be  $0.2 \text{ mA}$ . Specify the resistors in the circuit. Answers:  $R_i = 10 \text{ k}\Omega$ ,  $R_O = 100 \Omega$ ,  $R_1 = 2.5 \text{ k}\Omega$ , and  $R_F = 47.5 \text{ k}\Omega$ .



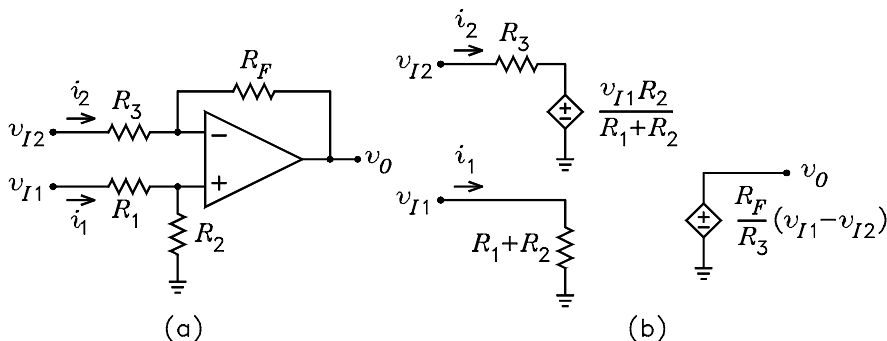
5. The figure shows a 4 input inverting summer. The circuit is to be designed for an output voltage given by  $v_O = -(2v_{I1} + 4v_{I2} + 6v_{I3} + 8v_{I4})$ . When the peak output voltage is  $10 \text{ V}$ , the current through  $R_F$  is to be  $0.5 \text{ mA}$ . Specify the resistors in the circuit.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



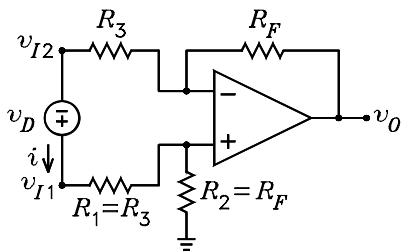
6. The figure shows a non-inverting summer. The gain  $v_O/v_+$  is specified to be  $50$ . If  $R_3 = R_4 = 1 \text{ k}\Omega$ , specify  $R_1$ ,  $R_2$ , and  $R_F$  for an output voltage given by  $v_O = 5v_{I1} + 2v_{I2}$ . Answers:  $R_F = 49 \text{ k}\Omega$ ,  $R_1 = 8.6 \text{ k}\Omega$ , and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



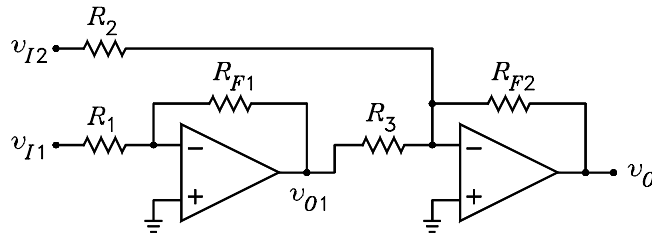
7. Fig. (a) shows a differential amplifier. Fig. (b) shows the equivalent circuit for the special case  $R_1 = R_3$  and  $R_2 = R_F$ . It is desired to design the circuit so that  $v_O = 10(v_{I1} - v_{I2})$ . In addition, the input resistance seen between the two input nodes is to be  $10\text{ k}\Omega$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



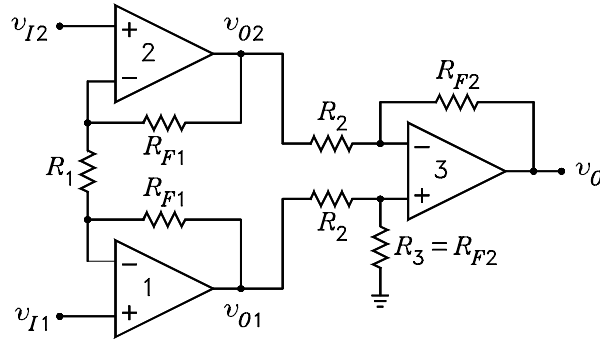
- (a) Specify the resistors in the circuit. Answers:  $R_1 = R_3 = 5\text{ k}\Omega$ ,  $R_2 = R_F = 50\text{ k}\Omega$ .  
 (b) For  $v_{I2} = 0$ , solve for the resistance seen looking into the  $v_{I1}$  input. Answer:  $55\text{ k}\Omega$ .  
 (c) For  $v_{I1} = 0$ , solve for the resistance seen looking into the  $v_{I2}$  input. Answer:  $5\text{ k}\Omega$ .
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:  $v_O/v_D = 10$ ,  $v_{I1} = 5.5v_D$ ,  $v_{I2} = 4.5v_D$ ,  $v_+ = v_- = 5v_D$ ,  $v_{ICM} = v_O/2 = 5v_D$ .



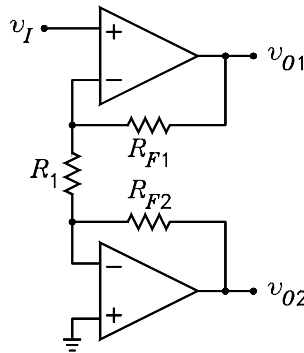
9. The figure shows a two op amp diff amp. Design the circuit for an output voltage given by  $v_O = 50(v_{I1} - v_{I2})$ . The input resistance to each input is to be  $5\text{ k}\Omega$ . Answers:  $R_1 = R_2 = R_{F1} = R_3 = 5\text{ k}\Omega$ ,  $R_{F2} = 250\text{ k}\Omega$ .



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  $v_O = 2\text{ V}$ .

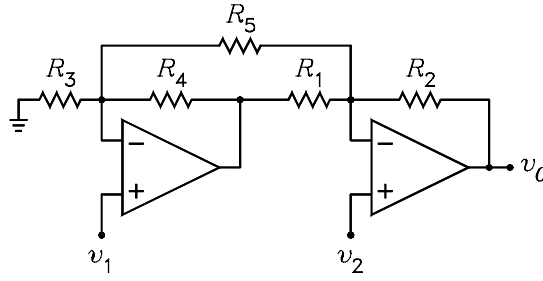


11. The figure shows a balanced output amplifier. Design the circuit so that  $v_{O1} = -v_{O2} = 6v_I$ . When  $v_{O1} = \pm 12\text{ V}$  and  $v_{O2} = \mp 12\text{ V}$ , the current through  $R_{F1}$  and  $R_{F2}$  is not to exceed  $1\text{ mA}$ . Answers: for  $1\text{ mA}$ ,  $R_1 = 2\text{ k}\Omega$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



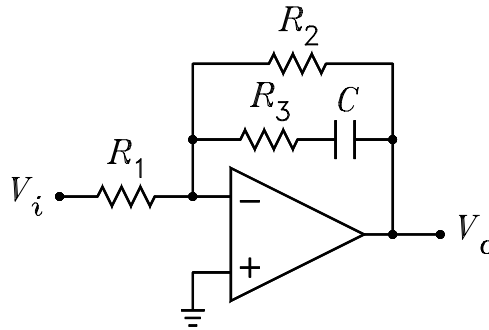
12. For the circuit shown, use superposition of  $v_1$  and  $v_2$  to show that  $v_O$  is given by

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



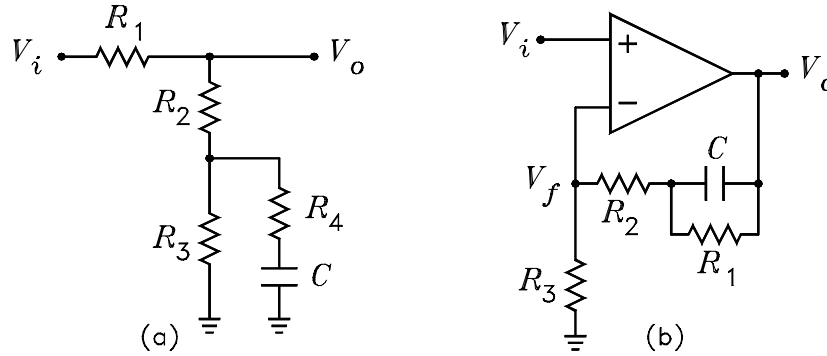
13. Solve for the transfer function for  $V_o/V_i$  for the circuit below. Sketch the Bode plot, label the break frequencies, and label the gain on the zero-slope asymptotes. Answer:

$$\frac{V_o}{V_i} = -\frac{Z_F}{R_1} = -\frac{R_2}{R_1} \frac{1 + R_3Cs}{1 + (R_2 + R_3)Cs}$$



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:  $10\text{ k}\Omega$ , pole frequency:  $1\text{ Hz}$ , zero frequency:  $10\text{ Hz}$ . Specify the element values. Answers:  $R_1 = 10\text{ k}\Omega$ ,  $R_2 = 20\text{ k}\Omega$ ,  $R_3 = 2222.2\ \Omega$ , and  $C = 7.1620\ \mu\text{F}$ .

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

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

The transfer function is

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

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

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

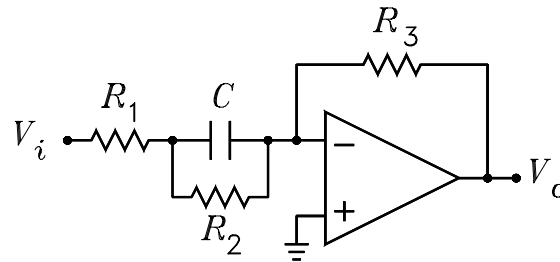
The high-frequency gain is

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

The transfer function is given by

$$\frac{V_o}{V_i} = \left(\frac{V_f}{V_o}\right)^{-1} = \left(1 + \frac{R_1 + R_2}{R_3}\right) \frac{1 + [(R_2 + R_3) \parallel R_1]Cs}{1 + R_1Cs}$$

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



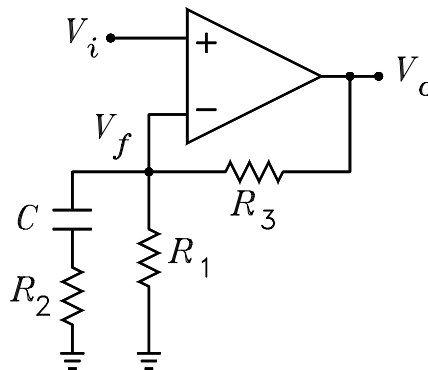
Answer:

$$\frac{V_o}{V_i} = -\frac{R_3}{Z_1} = -\frac{R_3}{R_1 + R_2} \frac{1 + R_2Cs}{1 + (R_1 \parallel R_2)Cs}$$

16. Using a single  $100 \mu\text{F}$  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.



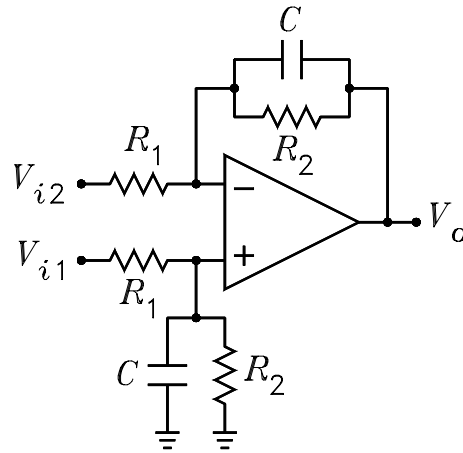
where

$$\frac{V_o}{V_i} = \left(\frac{V_f}{V_o}\right)^{-1} = \left(1 + \frac{R_3}{R_1}\right) \frac{1 + (R_1 \parallel R_3 + R_2)Cs}{1 + R_2Cs}$$

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

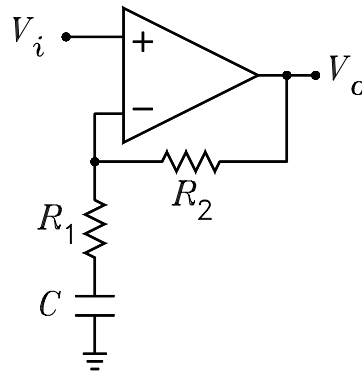
17. For the circuit shown, show that

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



18. For the circuit shown, show that

$$\frac{V_o}{V_i} = \frac{1 + (R_1 + R_2) C s}{1 + R_1 C s}$$

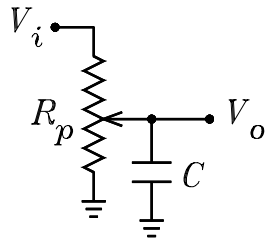


19. For the potentiometer circuit shown, let the resistance below the wiper be  $xR_p$  and the resistance above the wiper be  $(1 - x)R_p$ . Show that

$$\frac{V_o}{V_i} = \frac{x}{1 + x(1 - x) R C s}$$

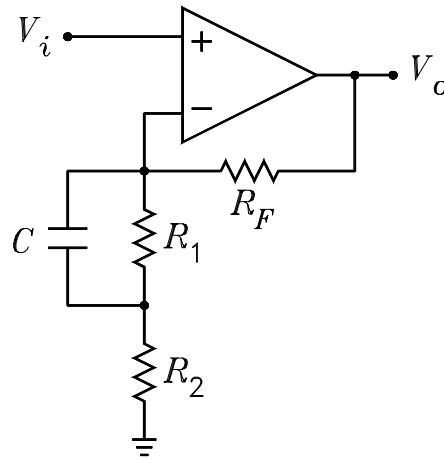
Show that the circuit has a minimum bandwidth when  $x = 0.5$  and that the corresponding pole frequency is given by

$$f_{pole} = \frac{1}{\pi R C}$$



20. For the circuit shown, show that

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



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

