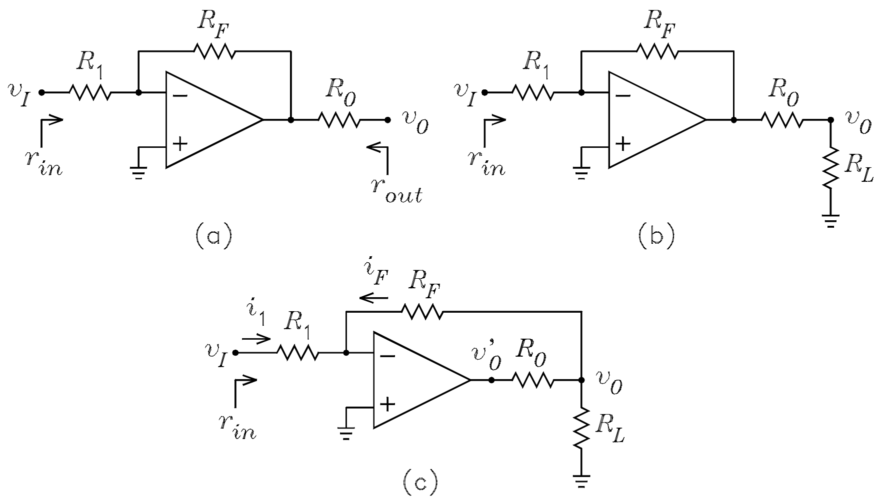
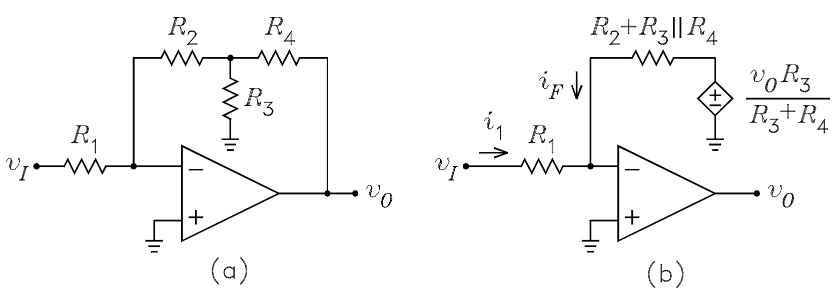
ECE3050 – Assignment 17

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 $2\,\mathrm{k}\Omega$, and an output resistance of $1\,\mathrm{k}\Omega$. If the op amp clips at a peak output voltage of $12\,\mathrm{V}$, specify the maximum peak input voltage if the op amp is not to be driven into clipping. Answers: $R_1 = 2\,\mathrm{k}\Omega$, $R_F = 100\,\mathrm{k}\Omega$, $R_O = 1\,\mathrm{k}\Omega$, and $\left|v_{I(peak)}\right| = 0.24\,\mathrm{V}$.
   (b) Fig. (b) shows the circuit of Fig. (a) with a load resistor connected to the output. Calculate the new voltage gain if $R_L = 1\,\mathrm{k}\Omega$. What is the maximum peak output voltage if the op amp is not to clip? Answers: $v_O/v_I = -25$ and $\left|v_{O(peak)}\right| = 6\,\mathrm{V}$.
   (c) Repeat part (b) if the circuit is modified as shown in Fig. (c). Answers: $v_O/v_I = -50$ and $\left|v_{O(peak)}\right| = 5.97\,\mathrm{V}$. Hint, use voltage division to solve for $\left|v_{O(peak)}\right|$ in terms of $\left|v'_{O(peak)}\right|$.

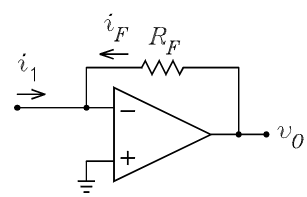


2. Fig. (a) shows an inverting amplifier with a T feedback network. Fig. (b) shows the amplifier with a Thévenin equivalent made looking into the feedback network from the input. The amplifier is to be designed for an input resistance of $1\,\mathrm{k}\Omega$ and a voltage gain of -1000. If $R_2 = R_4$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



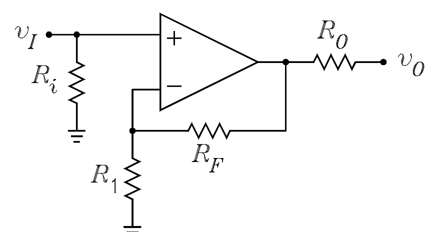
3. Show that the same expression for the voltage gain of the circuit in figure (a) of problem 2 is obtained if Norton equivalent circuits are made looking out of the negative input through R_1 and R_2 and the sum of the two Norton currents is set to zero. Hint: First show that the Norton current looking into R_2 is $[v_O/(R_4 + R_2 \| R_3)] \times R_3/(R_2 + R_3)$.

4. The figure shows a current to voltage converter. The circuit is to be designed to convert an input current of $-50\,\mu$A into an output voltage of $+4$ 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: $i_{1(peak)} = 150\,\mu$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: $v_O/v_I = -400$.

5. 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 $R_F = 47.5\,\mathrm{k}\Omega$.

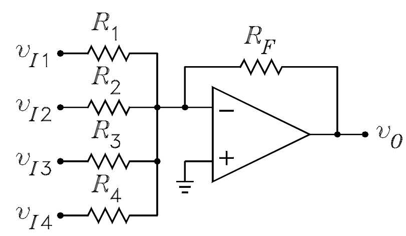


6. For the inverting amplifier circuit of Fig. (c) in Problem 1, let the open-loop gain of the op amp be denoted by A. In this case, the open-circuit output voltage is given by $v_O = A(v_+ - v_-)$.
(a) Solve for v_O as a function of v_I, R_1, R_F, and A
(b) If $A \to \infty$, what is v_O given by?

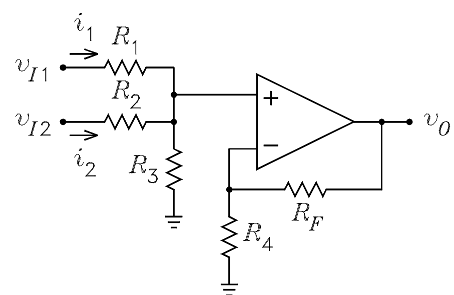
7. Repeat Problem 5 for the non-inverting amplifier of Problem 4.

8. 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

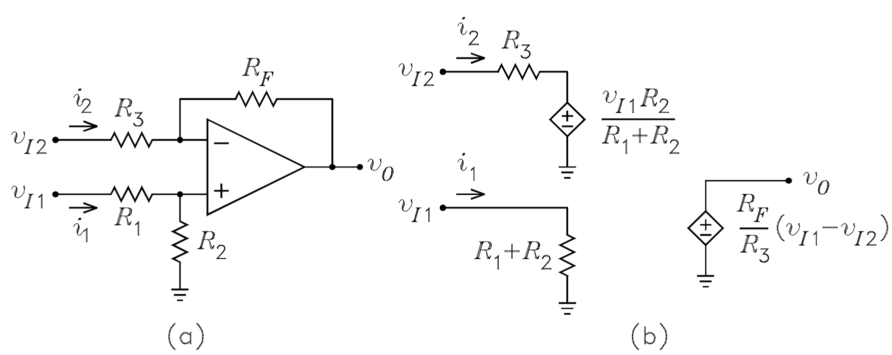
voltage is 10 V, the current through R_F is to be 0.5 mA. Specify the resistors in the circuit. Answers: $R_F = 20\,\mathrm{k\Omega}$, $R_1 = 10\,\mathrm{k\Omega}$, $R_2 = 5\,\mathrm{k\Omega}$, $R_3 = 3.33\,\mathrm{k\Omega}$, and $R_4 = 2.5\,\mathrm{k\Omega}$.



9. 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 $R_2 = 21.5\,\mathrm{k\Omega}$.



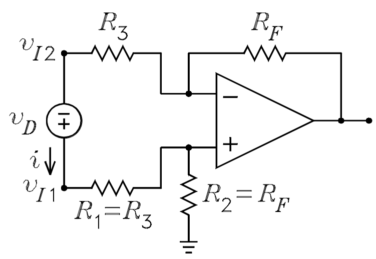
10. Fig. (a) shows a differential amplifier. Fig. (b) shows the equivalent circuit for the special case $R_1 = R_3$ and $R_2 = R_F$. It is desired to design the circuit so that $v_O = 10\,(v_{I1} - v_{I2})$. In addition, the input resistance seen between the two input nodes is to be $10\,\mathrm{k\Omega}$.



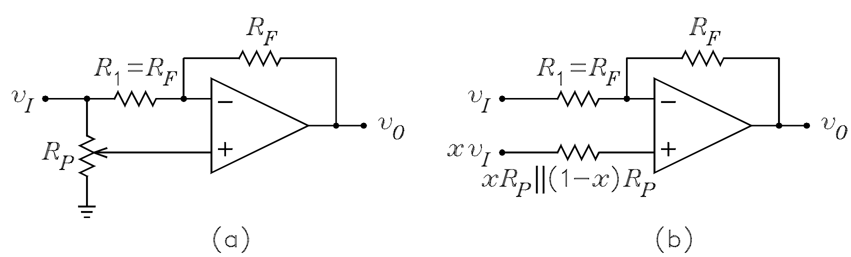
(a) Specify the resistors in the circuit. Answers: $R_1 = R_3 = 5\,\mathrm{k\Omega}$, $R_2 = R_F = 50\,\mathrm{k\Omega}$.
(b) For $v_{I2} = 0$, solve for the resistance seen looking into the v_{I1} input. Answer: $55\,\mathrm{k\Omega}$.
(c) For $v_{I1} = 0$, solve for the resistance seen looking into the v_{I2} input. Answer: $5\,\mathrm{k\Omega}$.

11. 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 10. 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: $v_O/v_D = 10$, $v_{I1} = 5.5v_D$, $v_{I2} = 4.5v_D$, $v_+ = v_- = 5v_D$, $v_{ICM} = v_O/2 = 5v_D$.

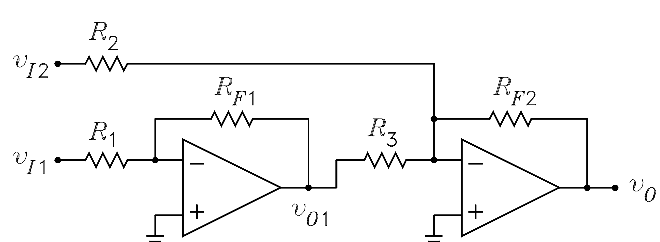


12. Fig. (a) shows a switch hitter circuit. Fig. (b) shows the equivalent circuit which can be used to calculate v_O. It is given that $R_1 = R_F = 10\,\text{k}\Omega$, $R_P = 100\,\text{k}\Omega$, the resistance below the potentiometer wiper is xR_P, and the resistance above the wiper is $(1-x)\,R_P$, where $0 \le x \le 1$. Note that $xR_P + (1-x)\,R_P = R_P$.

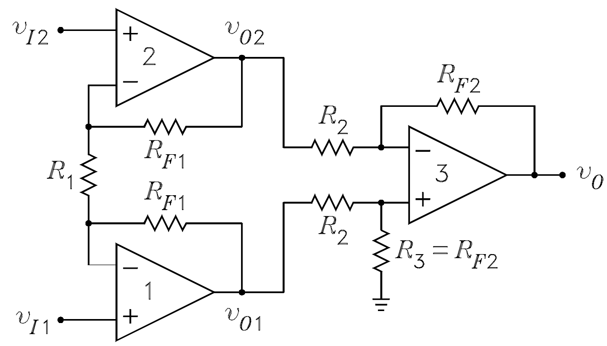


(a) Prove that the Thévenin equivalent circuit seen looking out of the v_+ input is the one shown in Fig. (b). What is the maximum source resistance of this Thévenin circuit? Answer: $25\,\text{k}\Omega$.
(b) Solve for v_O. Answer: $v_O = (2x-1)\,v_I$.
(c) The v_I node of the switch hitter is connected to the v_{I1} input of the inverting summer in problem 8. The v_O node is connected to the v_{I2} input of the inverting summer. The other inputs to the inverting summer are connected to ground. Solve for v_O of the inverting summer. Answer: $v_O = (2-8x)\,v_I$.

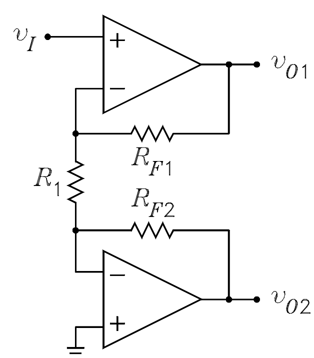
13. The figure shows a two op amp diff amp. Design the circuit for an output voltage given by $v_O = 50\,(v_{I1} - v_{I2})$. The input resistance to each input is to be $5\,\text{k}\Omega$. Answers: $R_1 = R_2 = R_{F1} = R_3 = 5\,\text{k}\Omega$, $R_{F2} = 250\,\text{k}\Omega$.



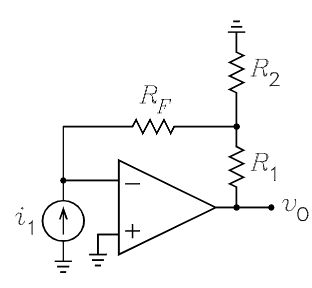
14. The figure shows a three op amp instrumentation amplifier. (a) Design the circuit such that $v_{O1} - v_{O2} = 10\,(v_{I1} - v_{I2})$ and $v_O = 10\,(v_{O1} - v_{O2})$. Answers: $1 + 2R_{F1}/R_1 = 10$, choose $R_1 = 2\,\mathrm{k}\Omega$ and $R_{F1} = 9\,\mathrm{k}\Omega$, $R_{F2}/R_2 = 10$, choose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



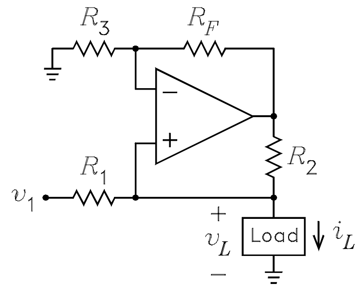
15. The figure shows a balanced output amplifier. Design the circuit so that $v_{O1} = -v_{O2} = 6v_I$. When $v_{O1} = \pm 12\,\mathrm{V}$ and $v_{O2} = \mp 12\,\mathrm{V}$, the current through R_{F1} and R_{F2} is not to exceed $1\,\mathrm{mA}$. Answers: for $1\,\mathrm{mA}$, $R_1 = 2\,\mathrm{k}\Omega$,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



16. For the circuit shown, show that the Thévenin equivalent circuit seen looking into R_F from the v_- node consists of the voltage $v_O R_2/(R_1 + R_2)$ in series with the resistance $R_F + R_1 \| R_2$. Use superposition to show that $v_- = i_1\,(R_F + R_1 \| R_2) + v_O R_2/(R_1 + R_2)$. Set $v_- = 0$ to show that $v_O = -i_1\,[R_1 + R_F\,(1 + R_1/R_2)]$.



17. For the circuit shown, let v_O be the op amp output voltage.



(a) With the load open circuited, i.e. $i_L = 0$, use superposition of v_1 and v_O to show that $v_{L(oc)} = (v_1 R_2 + v_O R_1) / (R_1 + R_2)$. Show that $v_O = v_{L(oc)} (1 + R_F/R_3)$.
(a) Solve the equations from the previous part to show that

$$v_{L(oc)} = v_1 \frac{\dfrac{R_2}{R_1 + R_2}}{1 - \dfrac{R_1}{R_1 + R_2}\left(1 + \dfrac{R_F}{R_3}\right)}$$

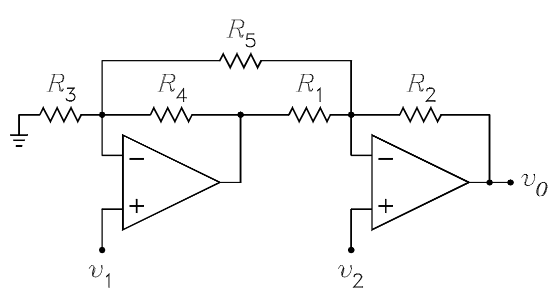
(b) With the load short circuited, i.e. $v_L = 0$, show that $i_{L(sc)} = v_1/R_1$.
(c) The load sees a source resistance given by $v_{L(oc)}/i_{L(sc)}$. Show that this is infinite if

$$\frac{R_3}{R_3 + R_F} = \frac{R_1}{R_1 + R_2}$$

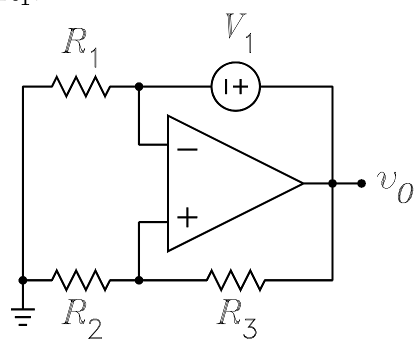
(d) When the above equation holds, show that the load current is given by $i_L = v_1/R_1$ and that this is independent of v_L. Hint, solve for the Norton equivalent circuit seen by the load.

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

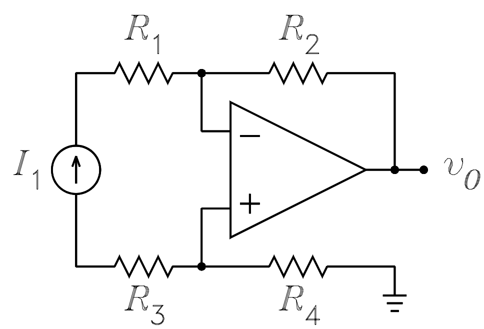
$$v_O = -v_1 \left[\left(1 + \frac{R_4}{R_3 \| R_5}\right)\frac{R_2}{R_1} + \frac{R_2}{R_5}\right] + v_2\left(1 + \frac{R_2}{R_1 \| R_5} + \frac{R_4}{R_5}\frac{R_2}{R_1}\right)$$



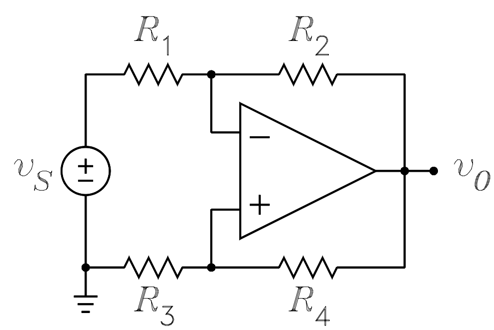
19. For $R_1 = 10\,\mathrm{k}\Omega$, $R_2 = 30\,\mathrm{k}\Omega$, $R_3 = 20\,\mathrm{k}\Omega$, and $V_1 = 4\,\mathrm{V}$, show that $v_O = 10\,\mathrm{V}$. Hint: The answer is independent of R_1.



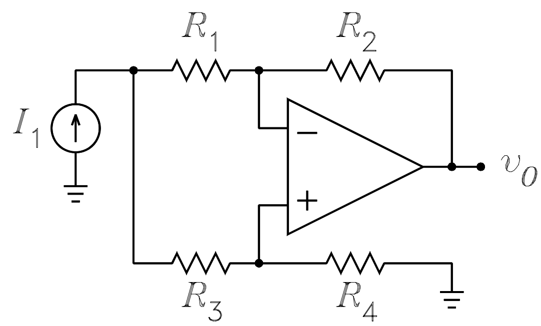
20. For $I_1 = 1\,\mathrm{mA}$, $R_1 = 3\,\mathrm{k}\Omega$, $R_2 = 4\,\mathrm{k}\Omega$, $R_3 = 2\,\mathrm{k}\Omega$, and $R_4 = 1\,\mathrm{k}\Omega$, show that $v_O = -5\,\mathrm{V}$. Hint: The answer is independent of R_1 and R_2.



21. For $R_1 = 50\,\mathrm{k}\Omega$, $R_2 = 20\,\mathrm{k}\Omega$, $R_3 = 10\,\mathrm{k}\Omega$, and $R_4 = 40\,\Omega$, show that $v_O/v_S = 5/9$.

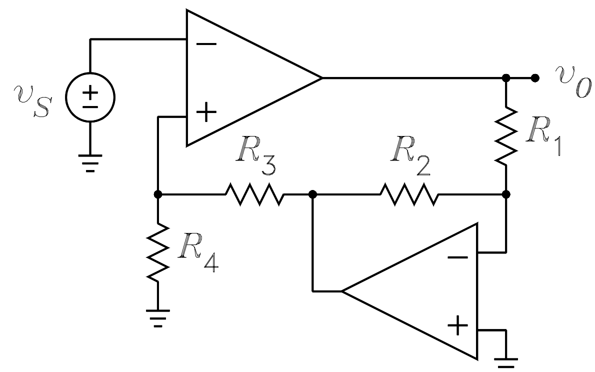


22. For $I_1 = 1\,\mathrm{mA}$, $R_1 = 3\,\mathrm{k}\Omega$, $R_2 = 4\,\mathrm{k}\Omega$, $R_3 = 2\,\mathrm{k}\Omega$, and $R_4 = 1\,\mathrm{k}\Omega$, show that $v_O = -1\,\mathrm{V}$. Hint: Use superposition of I_1 and v_O to solve for the voltage at the two op-amp inputs. Set the voltages equal to each other to solve for v_O.



23. Show that

$$\frac{v_O}{v_S} = -\frac{R_1}{R_2}\left(1 + \frac{R_3}{R_4}\right)$$



24. The figure shows a Schmitt 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: $R_1 = 3.33\,\mathrm{k\Omega}$, $V_{REF} = -1.33\,\mathrm{V}$.