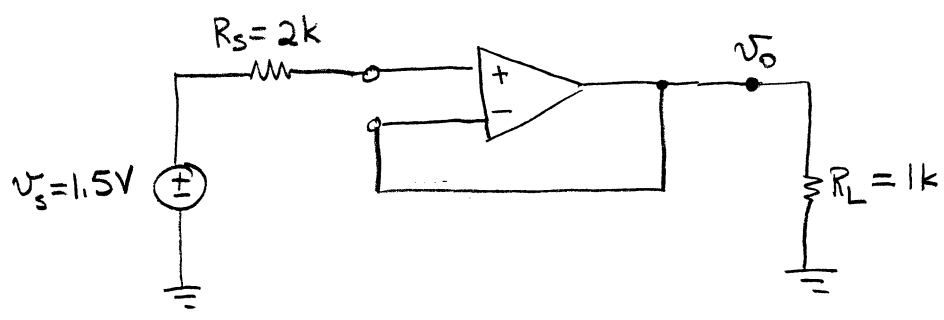
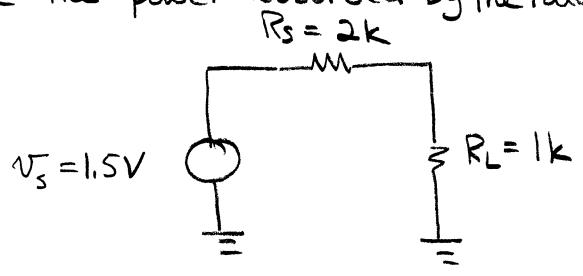


Exercise 4-10



Compute the maximum power available from the source.
 Compute the power absorbed by the load resistor in the above circuit.
 Compute the power absorbed by the load in the direct connection.



The maximum power available from the source is

$$P_{max} = \frac{V_T^2}{4 R_T} = \frac{(1.5)^2}{4(2000)} = 0.281 \text{ mW}$$

The power absorbed by the load resistor connected to the voltage follower is

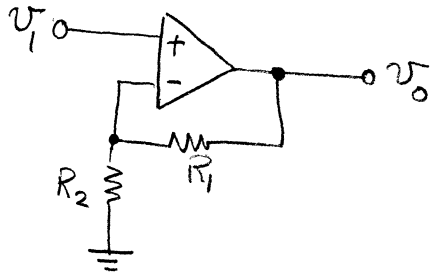
$$P_{LOAD} = \frac{(v_0)^2}{R_L} = \frac{(1.5)^2}{1000} = 2.25 \text{ mW}$$

The power absorbed by the load in a direct connection is

$$P_{LOAD} = \frac{(v_0)^2}{R_L} = \left(\frac{R_L}{R_L + R_S}\right)^2 \frac{(V_S)^2}{R_L} = \left(\frac{1000}{1000 + 2000}\right)^2 \frac{(1.5)^2}{1000}$$

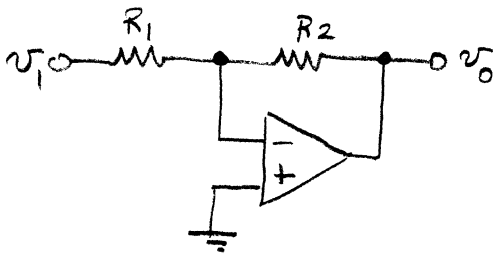
$$P_{LOAD} = 0.250 \text{ mW}$$

Basic OP AMP Building blocks.



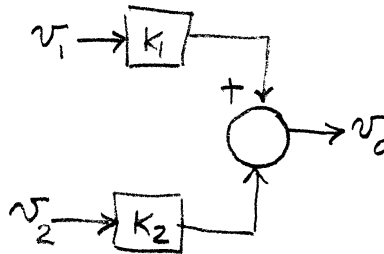
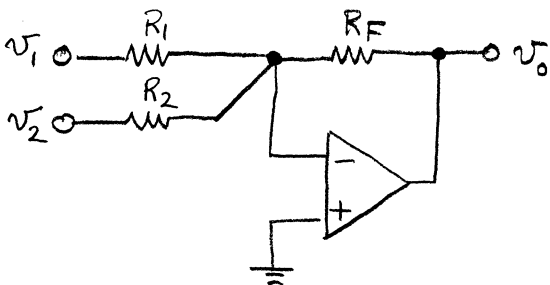
$$K = \frac{R_1 + R_2}{R_2}$$

NONINVERTING



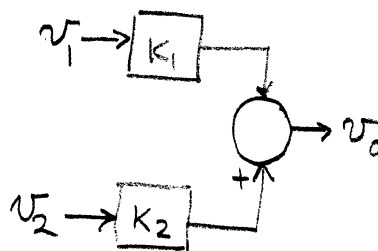
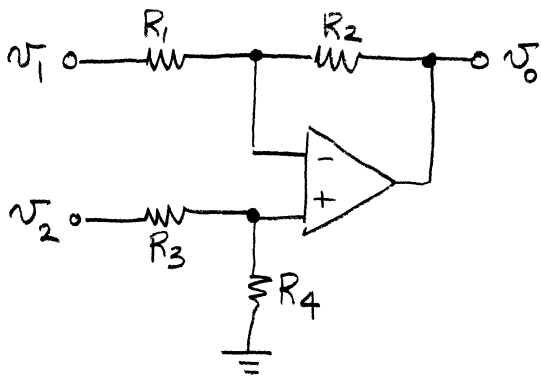
$$K = -\frac{R_2}{R_1}$$

INVERTING



$$K_1 = -\frac{R_F}{R_1}$$

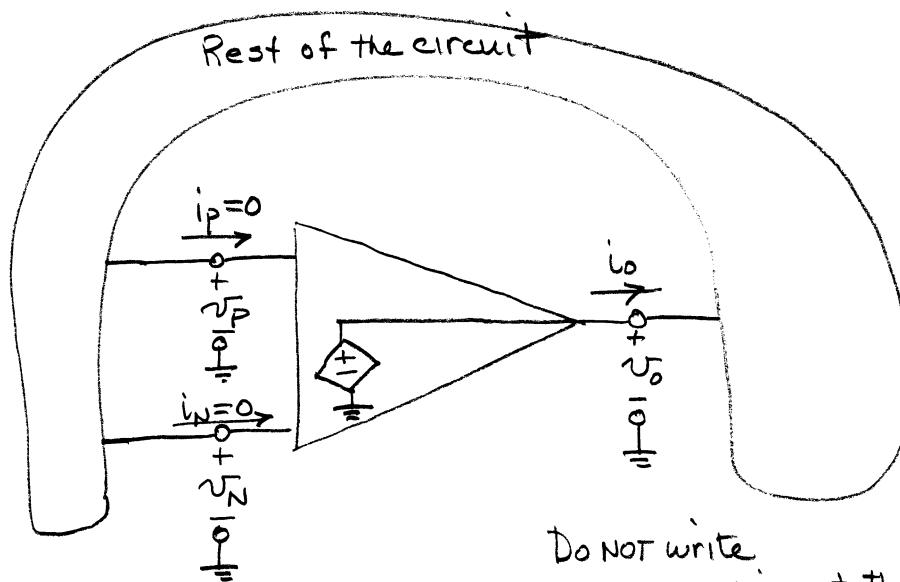
$$K_2 = -\frac{R_F}{R_2}$$



$$K_1 = -\frac{R_2}{R_1}$$

$$K_2 = \left(\frac{R_1 + R_2}{R_1}\right) \left(\frac{R_4}{R_3 + R_4}\right)$$

Node voltage analysis with OP AMPs.
Used for complex circuits.

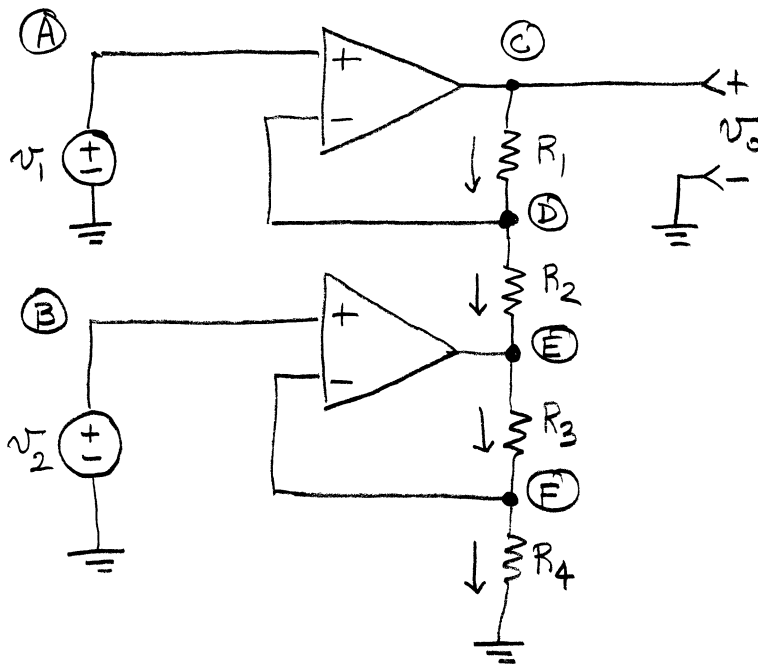


Do NOT write
a node equation at the output
terminal!

STEP 1: Identify a node voltage for all non-reference nodes, including OP AMP outputs, but do NOT formulate node equations at the OP AMP output nodes.

STEP 2: Formulate node equations at the remaining non-reference nodes and then use ideal OP AMP constraint $v_p = v_n$ to reduce the number of unknowns.

Example 4-18



This circuit has 6 non-reference nodes
 A & B are connected to independent voltage sources,
 C & E are connected to OP AMP outputs.
 Write equations for only nodes D & F using KCL.

$$\textcircled{D} \quad \frac{v_C - v_D}{R_1} - \frac{v_D - v_E}{R_2} = 0$$

$$\textcircled{F} \quad \frac{v_E - v_F}{R_3} - \frac{v_F - 0}{R_4} = 0$$

$$\text{but } v_A = v_1 = v_D$$

$$v_B = v_2 = v_F$$

$$\frac{1}{R_1} v_C - \frac{1}{R_1} v_1 - \frac{1}{R_2} v_1 + \frac{1}{R_2} v_E = 0$$

$$\frac{1}{R_3} v_E - \frac{1}{R_3} v_2 - \frac{1}{R_4} v_2 = 0$$

Re-arranging into standard form

$$\frac{1}{R_1} v_C + \frac{1}{R_2} v_E = \left(\frac{1}{R_1} + \frac{1}{R_2} \right) v_1$$

$$\frac{1}{R_3} v_E = \left(\frac{1}{R_3} + \frac{1}{R_4} \right) v_2$$

This is now simple to solve by substituting v_E from the second equation into the first.

$$v_E = R_3 \left(\frac{1}{R_3} + \frac{1}{R_4} \right) v_2$$

$$\frac{1}{R_1} v_C + \frac{1}{R_2} R_3 \left(\frac{1}{R_3} + \frac{1}{R_4} \right) v_2 = \left(\frac{1}{R_1} + \frac{1}{R_2} \right) v_1$$

Solving for v_C

$$v_C = R_1 \left(\frac{R_1 + R_2}{R_1 R_2} \right) v_1 - \frac{R_1}{R_2} R_3 \left(\frac{R_3 + R_4}{R_3 R_4} \right) v_2$$

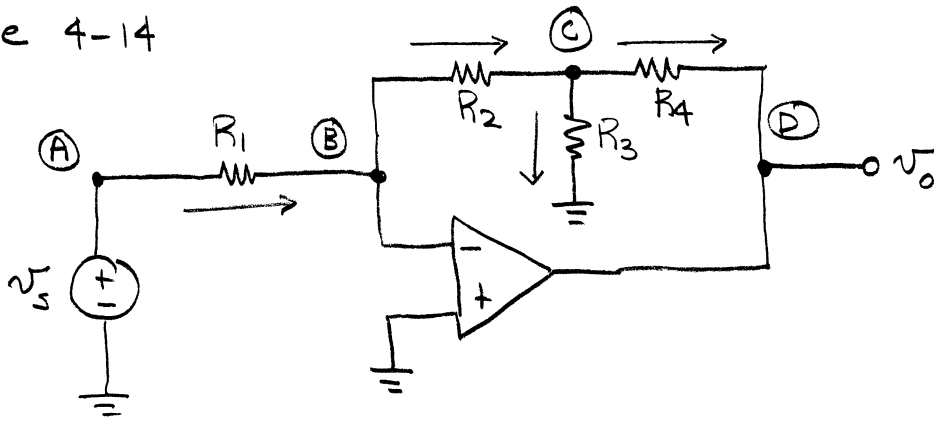
$$v_o = v_C = \frac{R_1 + R_2}{R_2} v_1 - \frac{R_1}{R_2 R_4} (R_3 + R_4) v_2$$

For $R_1 = R_4$ and $R_2 = R_3$ this reduces to

$$v_o = v_C = \frac{R_1 + R_2}{R_2} v_1 - \frac{1}{R_2} (R_2 + R_1) v_2$$

This is a two OP AMP subtractor.

Example 4-14



Label the nodes — 4 non-reference nodes.

Ⓐ is connected to an independent node — no equation

Ⓓ is connected to an OP AMP output — no equation

write equations for Ⓑ and Ⓒ

$$\textcircled{B} \quad \frac{v_A - v_B}{R_1} - \frac{v_B - v_C}{R_2} = 0$$

$$\textcircled{C} \quad \frac{v_B - v_C}{R_2} - \frac{v_C - 0}{R_3} - \frac{v_C - v_D}{R_4} = 0$$

$$\text{using } v_A = v_s, v_B = 0$$

$$\frac{1}{R_1} v_s + \frac{1}{R_2} v_C = 0 \quad (1)$$

$$-\frac{1}{R_2} v_C - \frac{1}{R_3} v_C - \frac{1}{R_4} v_C + \frac{1}{R_4} v_D = 0 \quad (2)$$

Solve (1) for v_C and substitute into (2)

$$v_C = -R_2 \frac{1}{R_1} v_s$$

$$v_o = v_D = R_4 \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \right) v_C = -\frac{R_4 R_2}{R_1} \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \right) v_s$$

$$= -\frac{R_4 R_2 (R_3 R_4 + R_2 R_4 + R_2 R_3)}{R_1 R_2 R_3 R_4} v_s = -\frac{R_2 R_3 + R_2 R_4 + R_3 R_4}{R_1 R_3} v_s$$