

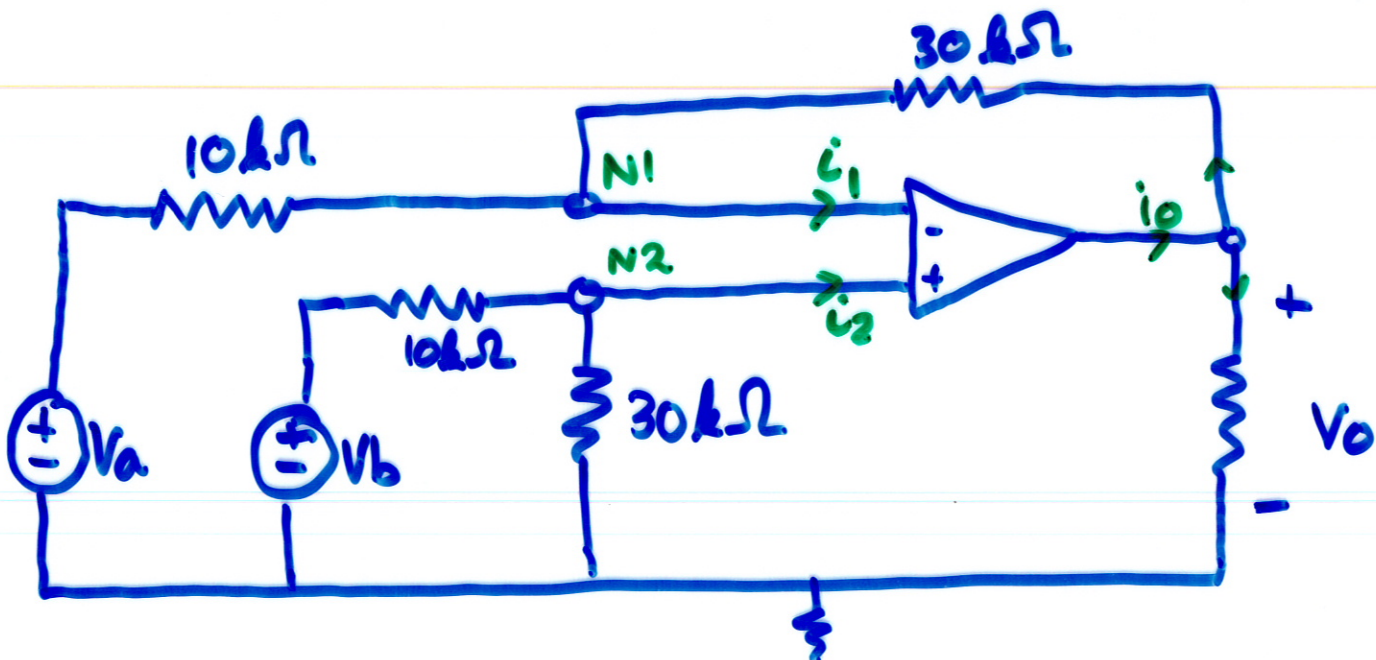
ANALYSIS OF OP AMP CIRCUITS.

Nodal analysis is usually the most convenient.

Important Points

1. Node voltages at inputs to ideal op amp are equal.
2. Currents into an ideal op-amp are zero
3. The output current is not zero in general if the output current is not required then we do not need KCL at output node

EXAMPLE - DIFFERENCE AMPLIFIER.



KCL at N_2

$$\frac{v_2}{30k\Omega} + \frac{v_2 - v_b}{10k\Omega} + i_2 = 0$$

Ideal op-amp $\Rightarrow v_2 = v_1, i_2 = 0.$

$$\Rightarrow \frac{v_1}{30k} + \frac{v_1 - v_b}{10k} = 0.$$

$$\Rightarrow v_1 = \frac{3v_b}{4}$$

KCL at N_1

$$\frac{v_1 - v_a}{10k} + \frac{v_1 - v_o}{30k} + i_1 = 0.$$

but $i_1 = 0$ and $v_1 = 3v_b/4.$

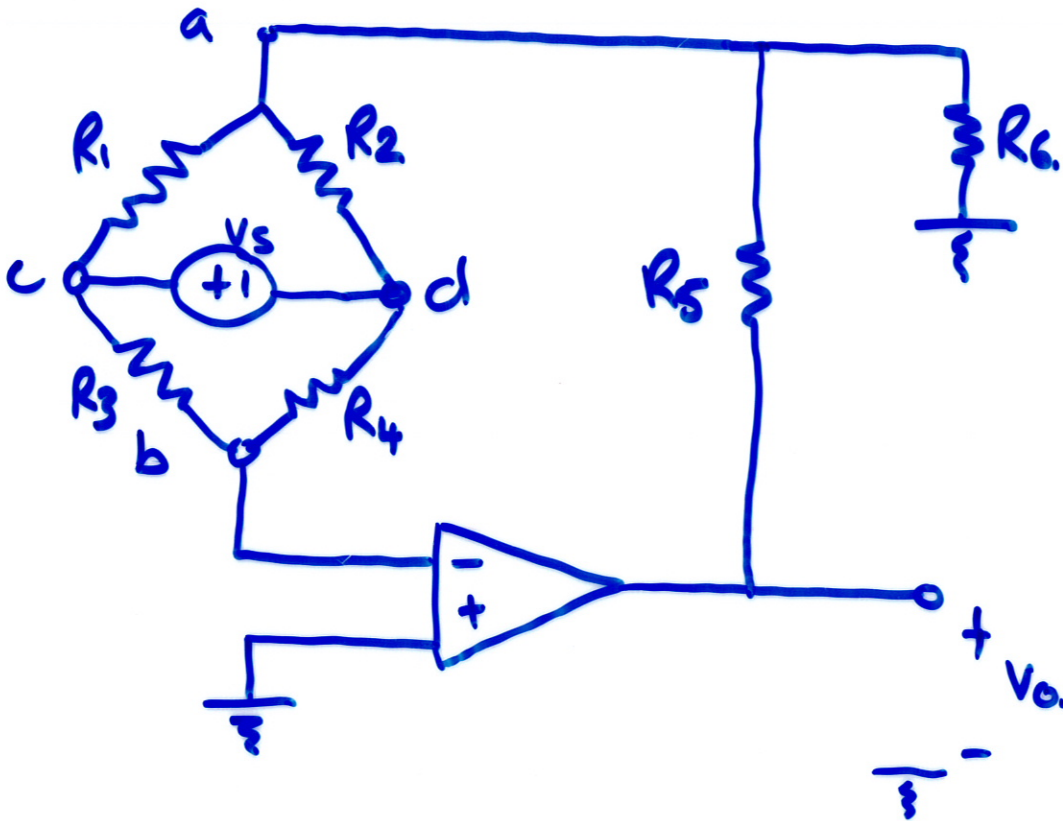
$$\Rightarrow \frac{0.75v_b - v_a}{10k} + \frac{0.75v_b - v_o}{30k} = 0$$

$$\Rightarrow v_o = 3(v_b - v_a)$$

Hence difference amplifier

Applications - analog computing
- stereo radio

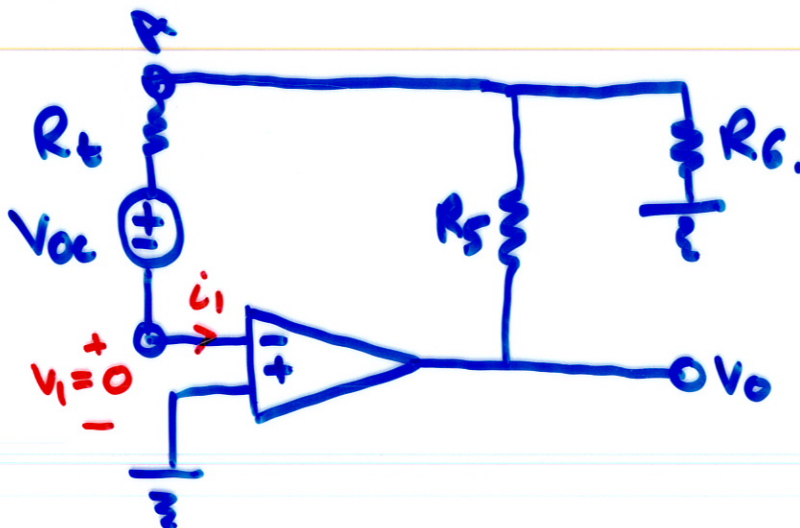
ANOTHER EXAMPLE



Find the gain.

Has 6 nodes, equations could be complicated
What to do?

Use Thévenin equivalent of bit between a and b .



$$V_{oc} = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) V_s.$$

$$R_t = \frac{R_1 R_2}{R_1 + R_2} + \frac{R_3 R_4}{R_3 + R_4}.$$

KCL at node A

$$i_1 + \frac{V_a - V_o}{R_5} + \frac{V_a}{R_6} = 0$$

Source model.



$$V_a = V_b + V_{oc} + R_t i_1$$

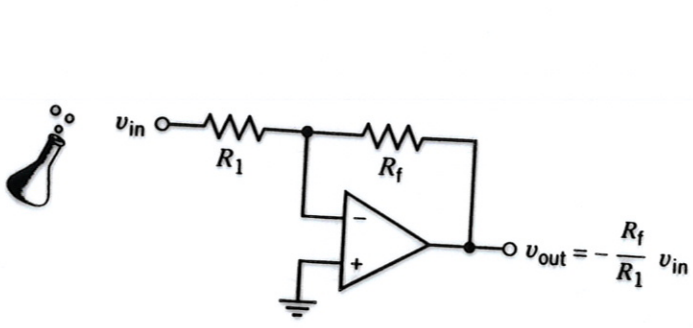
Ideal opamp $\Rightarrow V_b = 0, i_1 = 0.$

$$\Rightarrow V_a = V_{oc}$$

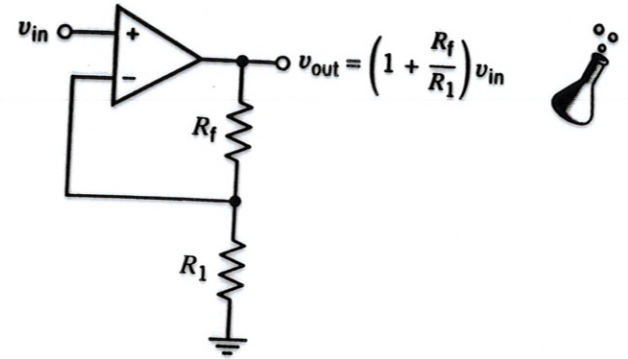
Into KCL eqn.

$$\frac{V_{oc} - V_o}{R_5} + \frac{V_{oc}}{R_6} = 0.$$

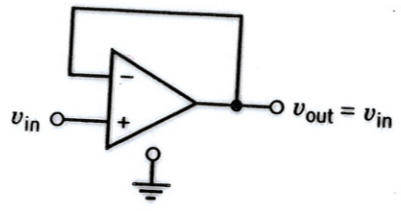
$$\Rightarrow V_o = \left(1 + \frac{R_5}{R_6} \right) V_{oc} = \left(1 + \frac{R_5}{R_6} \right) \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) \times V_s.$$



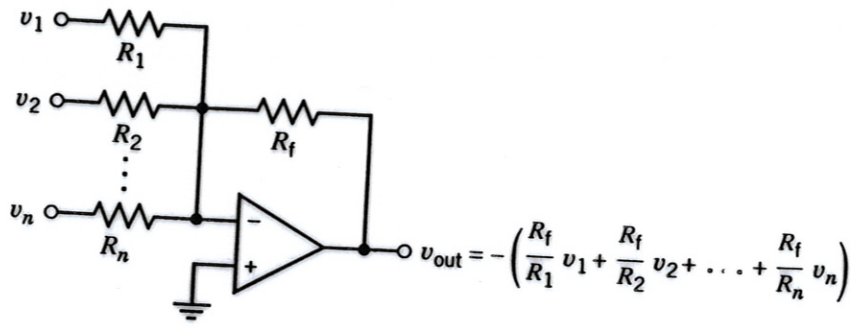
(a) Inverting amplifier



(b) Noninverting amplifier

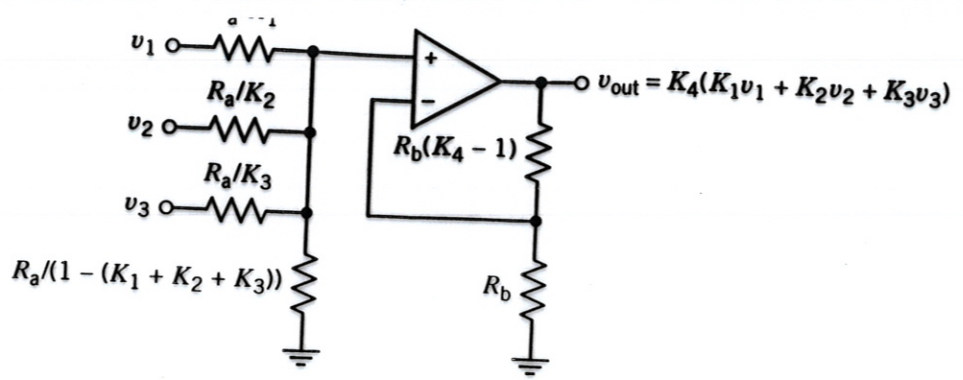


(c) Voltage follower (buffer amplifier)

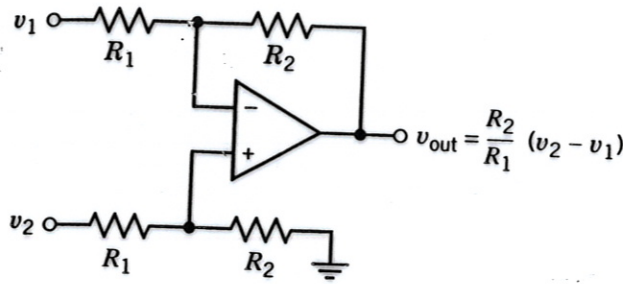


(d) Summing amplifier

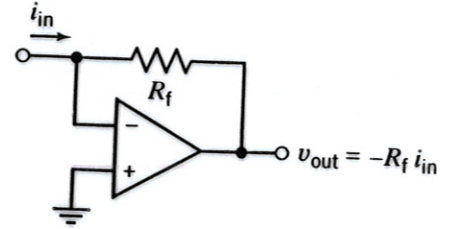
Figure 6.6-1 A brief catalog of operational amplifier circuits. Note that all node voltages are referenced to the ground node.



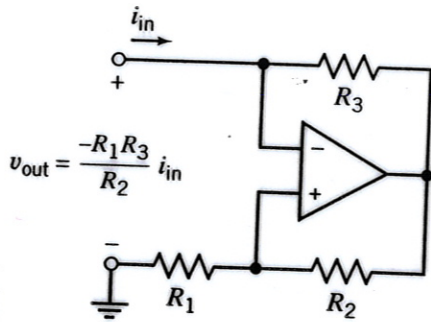
(e) Noninverting summing amplifier



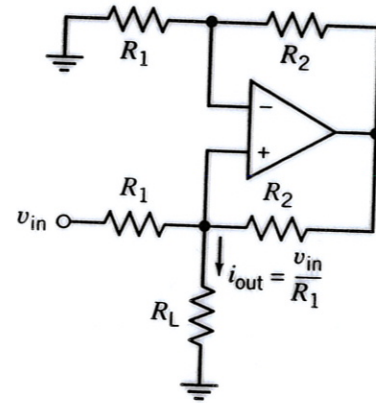
(f) Difference amplifier



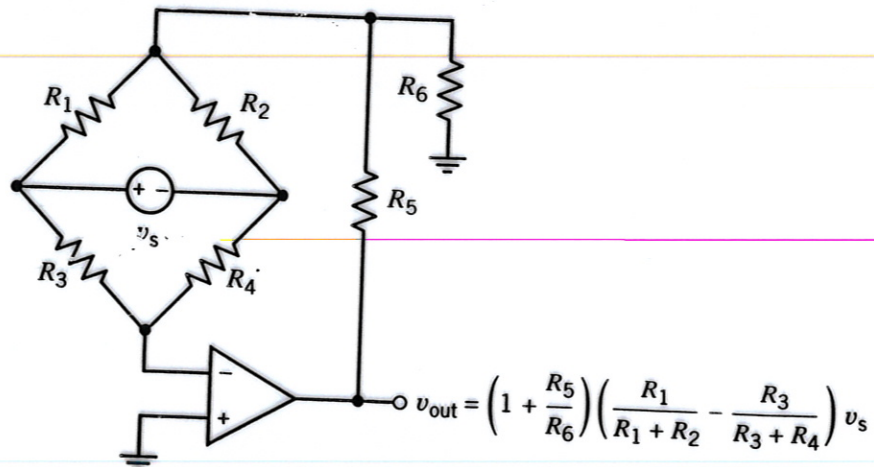
(g) Current-to-voltage converter



(h) Negative resistance convertor



(i) Voltage-controlled current source (VCCS)



(j) Bridge amplifier

Figure 6.6-1 (cont.) A brief catalog of operational amplifier circuits

IDEAL OP AMPS

- op amps have linear + non-linear regions

- linear region limited by.

a) ~~No~~ max value of V_o , $|V_o| \leq V_{sat}$

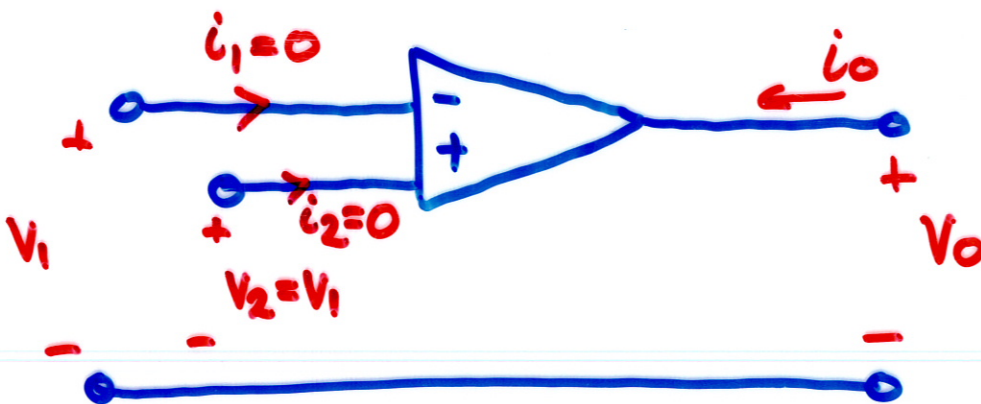
b) output current $|i_o| \leq i_{sat}$

c) slewrate $\left| \frac{dV_o(t)}{dt} \right| \leq SR$

- Typical values ($\mu A741$) with $\pm 15V$ supplies

$V_{sat} = 14V$, $i_{sat} = 2mA$, $SR = 5 \times 10^5 V_s^{-1}$

- If a), b) & c) are satisfied we have the following ideal model.



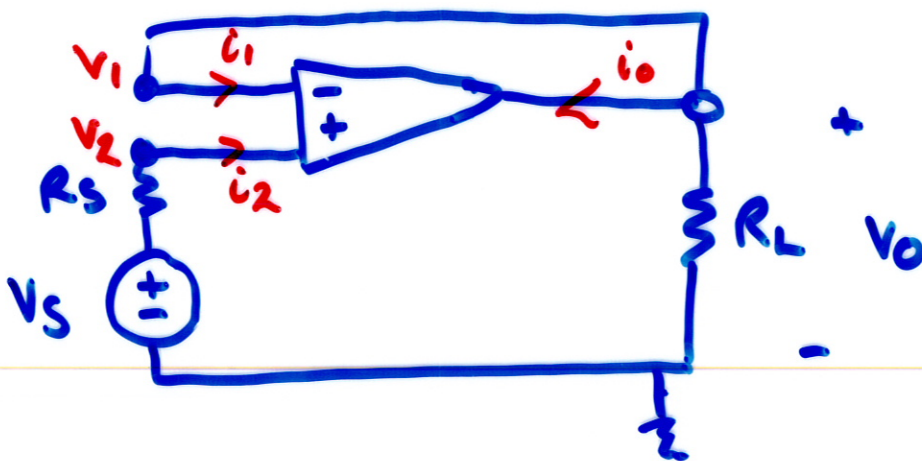
IDEAL OP AMPS

- $i_1 = i_2 = 0$
- $v_2 = v_1$

* We can use these to design circuits under ideal operating conditions

* Common non-idealities will be handled later. (2E14)

Example



Find the gain $\frac{v_o}{v_s}$ if op-amp is ideal

Given previous specifications is the op-amp linear for $v_s = 10V$, $R_L = 20k\Omega$. ?

is it for $v_s = 10V$, $R_L = 2k\Omega$.

Solution (Node Analysis).

- output and node 1 connected by short cct.

$$\Rightarrow V_1 = V_0$$

- Ideal op-amp \Rightarrow input voltages are equal.

$$\Rightarrow V_2 = V_1 = V_0$$

- Currents to the inputs are zero.

$$\Rightarrow i_1 = i_2 = 0.$$

- No current through R_s

$$\Rightarrow V_2 = V_s.$$

- This implies that.

$$V_0 = V_s$$

$$\Rightarrow \text{Gain} = 1.$$

This circuit is often called a "voltage follower" because $V_0 = V_s$.

Now check the specifications

$$|V_o| \leq 14V, \quad |i_o| \leq 2mA, \quad \left| \frac{dV_o}{dt} \right| \leq 5 \times 10^5$$

KCL at output node.

$$i_1 + i_o + \frac{V_o}{R_L} = 0.$$

Since $i_1 = 0 \Rightarrow i_o = -V_o/R_L$

For $V_s = 10V$, $V_o = 10V$ (satisfied)

For $R_L = 20k\Omega$ $i_o = -0.5mA$ (satisfied).

Output voltage is constant (\Rightarrow SR satisfied)

\Rightarrow linear model applies.

For $V_s = 10V$, $R_L = 2k\Omega$

$$i_o = -5mA$$

\Rightarrow linear model does not apply.