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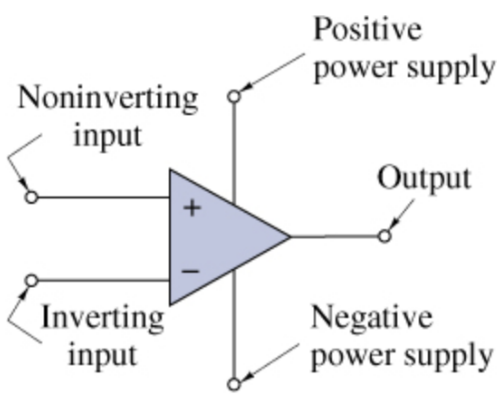
Operational Amplifiers

4 Active Circuits

4.3 The Operational Amplifier

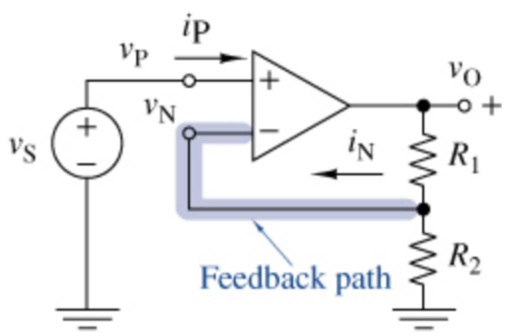
- Op Amps first used in a 1947 National Defence Research Council paper describing high gain amplifier circuits used to carry out mathematical operations.
    - Early op amps were made from vacuum tubes, but by the 70’s, the IC version became dominant.



The global KCL equation for the complete set of variables is $i_O = I_{C_+} + I_{C_-} + i_P + i_N$

- Transfer characteristic is divided into three regions or modes: +saturation, -saturation, and linear.
    - +Saturation mode when $A(v_p - v_n) > V_{CC}$ and $v_O = +V_{CC}$
    - -Saturation mode when $A(v_p - v_n) < -V_{CC}$ and $v_O = -V_{CC}$
    - Linear mode when $A|v_p - -v_n| < V_{CC}$ and $v_O = A(-v_p - v_n)$
- The $i - v$ relationships of the ideal model of the op amp are as:
    - $v_P = v_N$
    - $i_P = i_N = 0$

Non-Inverting OP AMP

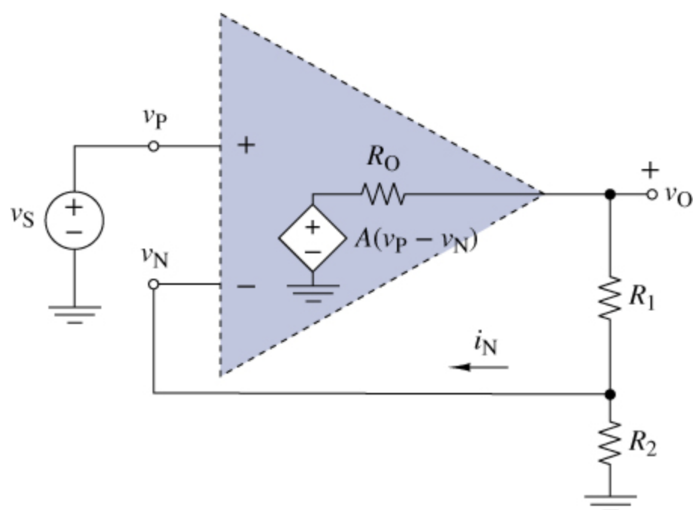


$$v_O = \frac{R_1 + R_2}{R_2} v_S$$

- The proportionality constant K is sometimes called the closed-loop gain because it defines the input-output voltage relationship when the feedback loop is connected (closed).
- There are two types of gains when discussing OP AMP circuits, first is closed-loop gains above.
  - Second is open-loop gain voltage gain provided by the OP AMP device itself.

Effects of Finite OP AMP Gain

- Ideal OP AMP model has infinite gain, but the actual devices have very large but finite gain.



Start by determining the output voltage

$$
\begin{aligned}
v_O &= \frac{R_1 + R_2}{R_O + R_1 + R_2} A(v_P - v_N) \\
&= \left[\frac{R_1 + R_2}{R_0 + R_1 + R_2}\right] A \left[v_S - \frac{R_2}{R_1 + R_2} v_O\right] \\
&= \frac{A(R_1 + R_2)}{R_O + R_1 + R_2(1 + A)} v_S
\end{aligned}
$$

Now we take $A \to \infty$

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

4.4 OP AMP Circuit Analysis

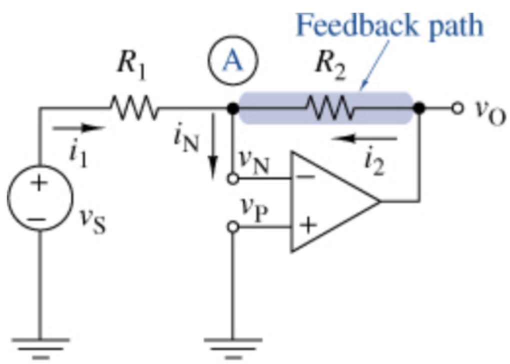
- OP AMP circuit analysis uses advantage of OP AMPS being connected in cascade (like in series)

Voltage Follower

- Also called a buffer
- Feedback is a direct path to the inverting input
- Since there is no input current $i_P = 0$ there is no voltage across R_S and thus $v_P = v_N$
    - Hence $v_O = v_S$ and the name is the voltage “follower”
- This is used in interface circuits to separate the source from the load.

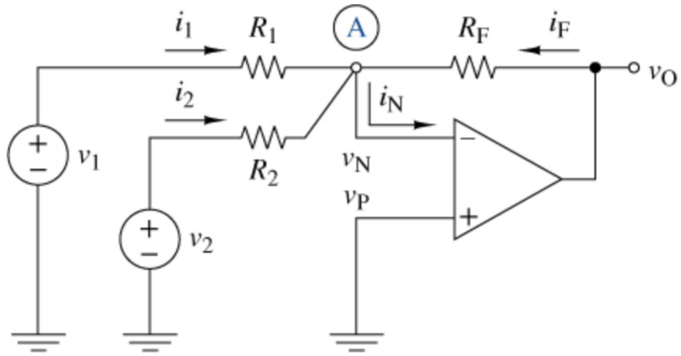
The Inverting Amplifier

$$
v_O = -\left(\frac{R_2}{R_1}\right) v_S
$$



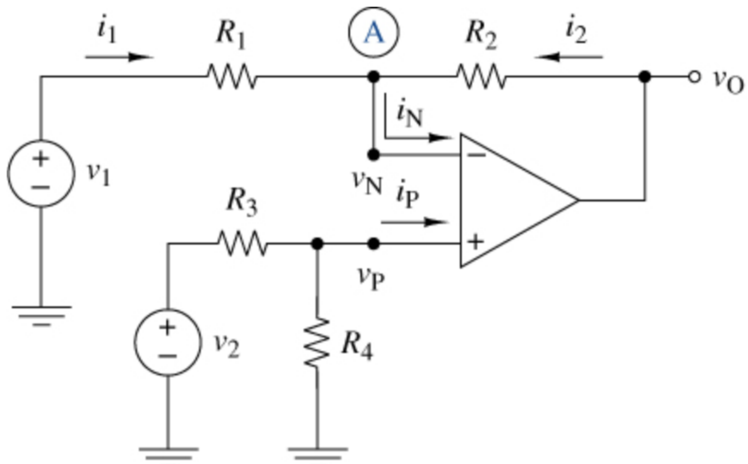
The Summing Amplifier

$$v_O = \left(- \frac{R_F}{R_1} \right) v_1 + \left(- \frac{R_F}{R_2} \right) v_2$$



The Differential Amplifier

$$v_O \frac{R_2}{R_1} (v_2 - v_1)$$



Node-Voltage Analysis with OP AMP Circuits

1. Identify a node voltage at all non-reference nodes, including OP AMP outputs, but do not formulate node equations at the OP AMP output nodes.
2. Formulate node equations at the remaining non-reference nodes and then use the ideal OP AMP voltage constraint $v_P = v_N$ to reduce the number of unknowns.
