General Purpose Operational Amplifiers

Lecture 20, 10/17/05
Corrected 10/19/05

OUTLINE

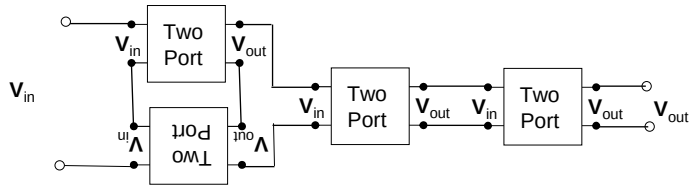
- Op-Amp from 2-Port Blocks
- Op-Amp Model and its Idealization
- Negative Feedback for Stability
- Components around Op-Amp define the Circuit Function

Reading

Hambley 14.1-14.2, pp. 644

General Purpose Amplifier

- General purpose amplifiers called Operational Amplifiers (Op-Amps) were developed before general purpose computers (Microprocessors).
- These Op-Amps can be viewed as being built from two-port circuits.



Stages => Differential High Gain Low R_0

EE 105

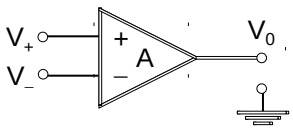
Assemble as amplifier in EE 140

High Quality Dependent Source In an Amplifier

AMPLIFIER SYMBOL

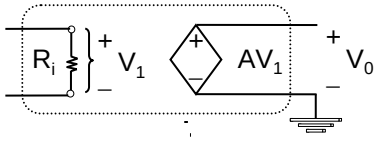
Differential Amplifier

$V_0 = A(V_+ - V_-)$



AMPLIFIER MODEL

Circuit Model *in linear region*

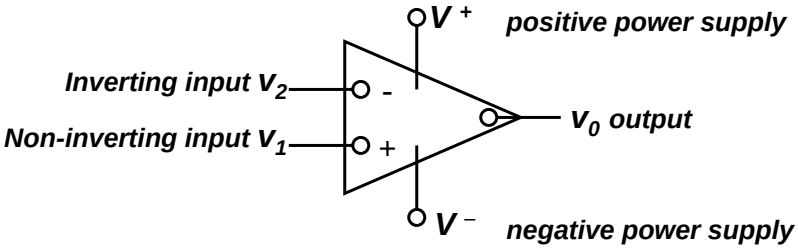


V_0 depends only on input $(V_+ - V_-)$

See the utility of this: this Model when used correctly mimics the behavior of an amplifier but omits the complication of the many many transistors and other components.

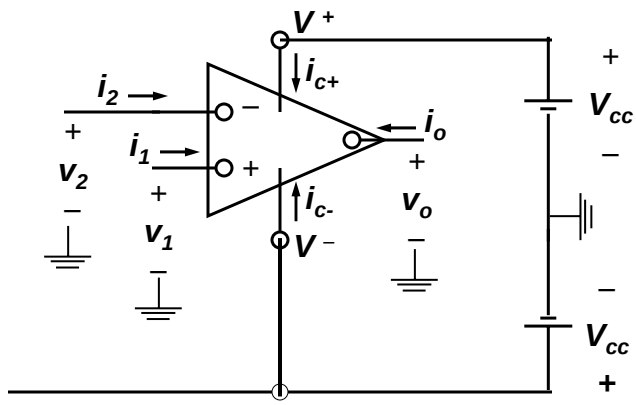
Op Amp Terminals

- 3 signal terminals: 2 inputs and 1 output
- IC op amps have 2 additional terminals for DC power supplies
- Common-mode signal= $(v_1+v_2)/2$
- Differential signal = v_1-v_2



Op Amp Terminal Voltages and Currents

- **All voltages are referenced to a common node.**
- **Current reference directions are <u>into</u> the op amp.**



common node
(external to the op amp)

Model for Internal Operation

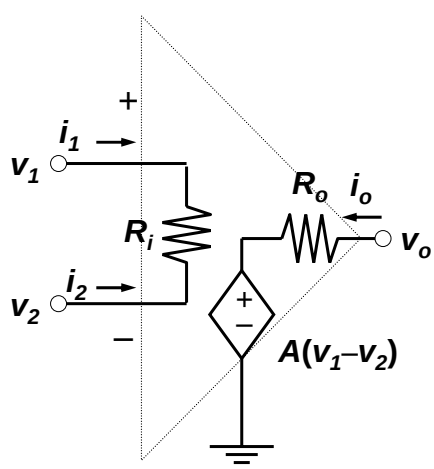
- A is differential gain or open loop gain
- Ideal op amp

$$A \to \infty$$
$$R_i \to \infty$$
$$R_o = 0$$

  – Common mode gain = 0

$$v_{cm} = \frac{(v_1 + v_2)}{2} \quad , v_d = v_1 - v_2$$
$$v_o = A_{cm} v_{cm} + A_d v_d$$
$$Since \;\; v_o = A(v_1 - v_2) \quad , A_{cm} = 0$$

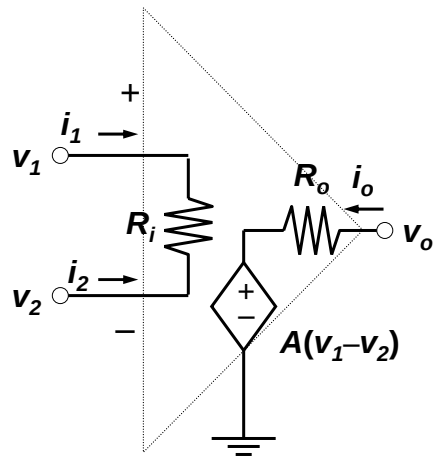
- Circuit Model



Model and Feedback

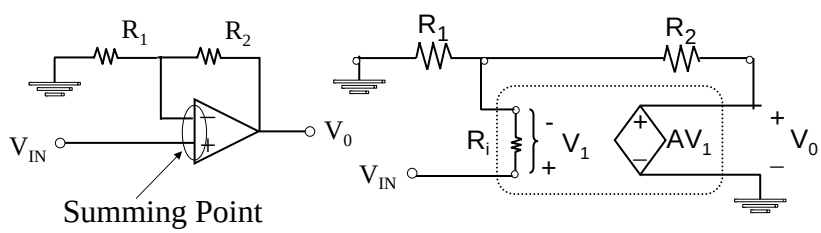
- Negative feedback
  - connecting the output port to the negative input (port 2)
- Positive feedback
  - connecting the output port to the positive input (port 1)

- Circuit Model



Op-Amp and Use of Feedback

A very high-gain differential amplifier can function in an extremely linear fashion as an operational amplifier by using negative feedback.



Circuit Model

Negative feedback $\Rightarrow$ **Stabilizes** the output

Hambley Example pp. 644 for Power Steering

We can show that that for $A \to \infty$ and $R_i \to \infty$,

$$V_0 \cong V_{IN} \cdot \frac{R_1 + R_2}{R_1}$$

Stable, finite, and independent of the properties of the OP AMP !

Negative Feedback

Familiar examples of negative feedback:

- Thermostat controlling room temperature
- Driver controlling direction of automobile
- Photochromic lenses in eyeglasses

Fundamentally pushes toward stability

Familiar examples of positive feedback:

- Microphone "squawk" in room sound system
- Mechanical bi-stability in light switches
- Thermonuclear reaction in H-bomb

Fundamentally pushes toward instability or bi-stability

Summing-Point Constraint

- Check if under negative feedback
  - Small v_i result in large v_o
  - Output v_o is connected to the inverting input to reduce v_i
  - Resulting in v_i=0
- Summing-point constraint
  - $v_1 = v_2$
  - $i_1 = i_2 = 0$
- Virtual short circuit
  - Not only voltage drop is 0 (which is short circuit), input current is 0
  - This is different from short circuit, hence called "virtual" short circuit.

Ideal Op-Amp Analysis Technique

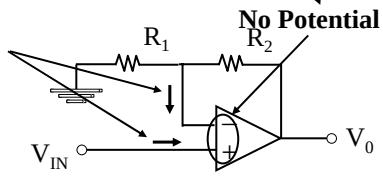
Applies only when Negative Feedback is present in circuit!

Assumption 1: The potential between the op-amp input terminals, $v_{(+)} - v_{(-)}$, equals zero.

Assumption 2: The currents flowing into the op-amp's two input terminals both equal zero.

No Currents

No Potential Difference



EXAMPLE

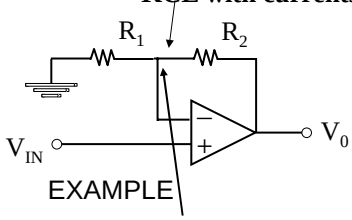
Ideal Op-Analysis: Non-Inverting Amplifier

Yes Negative Feedback is present in this circuit!

Assumption 1: The potential between the op-amp input terminals, $v_{(+)} - v_{(-)}$, equals zero.

Assumption 2: The currents flowing into the op-amp's two input terminals both equal zero.

KCL with currents in only two branches



EXAMPLE

V_{IN} appears here

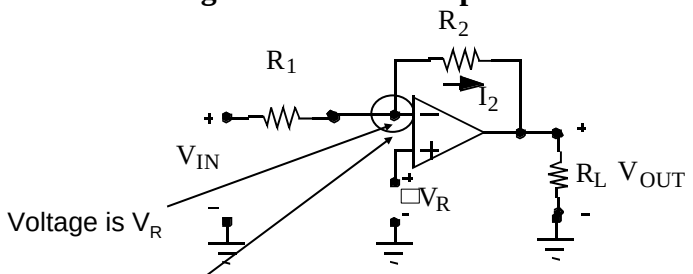
$$\frac{v_{in}}{R_1} + \frac{v_{in} - v_{out}}{R_2} = 0$$

$$v_{out} = \frac{R_1 + R_2}{R_1} v_{in}$$

Non-inverting Amplifier

Ideal Op-Amp Analysis: Inverting Amplifier

Yes Negative Feedback is present in circuit!



Only two currents for KCL

$$\frac{V_R - V_{IN}}{R_1} + \frac{V_R - V_{OUT}}{R_2} = 0$$

$$V_{OUT} = V_R - \frac{R_2}{R_1}\left(V_{in} - V_R\right)$$

Inverting Amplifier with reference voltage

The Operational Amplifier

- The ***operational amplifier*** ("***op amp***") is a basic building block used in analog circuits.
  - Its behavior is modeled using a dependent source.
  - When combined with resistors, capacitors, and inductors, it can perform various useful functions:
    - **amplification/scaling** of an input signal
    - **sign changing** (inversion) of an input signal
    - **addition** of multiple input signals
    - **subtraction** of one input signal from another
    - **integration** (over time) of an input signal
    - **differentiation** (with respect to time) of an input signal
    - **analog filtering**
    - **nonlinear functions** like exponential, log, sqrt, etc