# LECTURE 110 – INTRODUCTION AND CHARACTERIZATION OF THE OP AMP

## (READING: GHLM – 404-424, AH – 243-249)

## Objective

The objective of this presentation is:

1.) Introduce and characterize the op amp

## Outline

- Static characteristics of the op amp
- Dynamic characteristics of the op amp
- Op amp architecture
  - Two stage
  - Folded-cascode
- Summary






# INTRODUCTION AND CHARACTERIZATION OF OP AMPS

## High-Level Viewpoint of an Op Amp

Block diagram of a general, two-stage op amp:

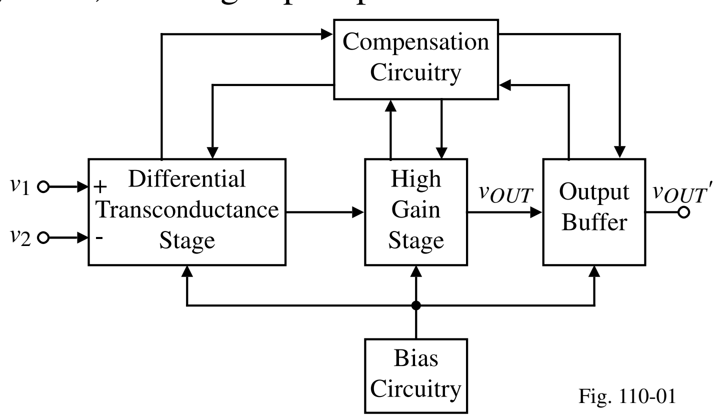


Fig. 110-01

- Differential transconductance stage:
  Forms the input and sometimes provides the differential-to-single ended conversion.
- High gain stage:
  Provides the voltage gain required by the op amp together with the input stage.
- Output buffer:
  Used if the op amp must drive a low resistance.
- Compensation:
  Necessary to keep the op amp stable when resistive negative feedback is applied.

## Ideal Op Amp

Symbol:

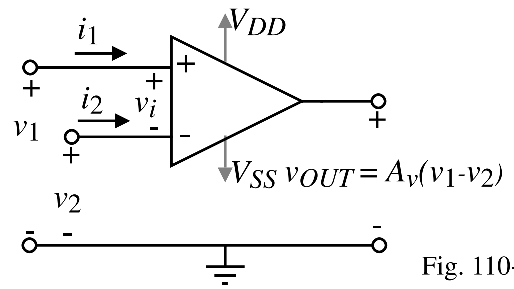


Fig. 110-02

Null port:

If the differential gain of the op amp is large enough then input terminal pair becomes a null port.

A null port is a pair of terminals where the voltage is zero and the current is zero.

I.e.,

$$v_1 - v_2 = v_i = 0$$

and

$$i_1 = 0 \text{ and } i_2 = 0$$

Therefore, ideal op amps can be analyzed by assuming the differential input voltage is zero and that no current flows into or out of the differential inputs.






## General Configuration of the Op Amp as a Voltage Amplifier

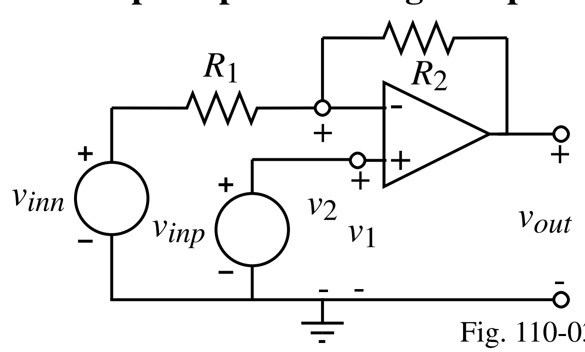


Fig. 110-03

Noniverting voltage amplifier:

$$v_{inn} = 0 \quad \Rightarrow \quad v_{out} = \left(\frac{R_1+R_2}{R_1}\right)v_{inp}$$

Inverting voltage amplifier:

$$v_{inp} = 0 \quad \Rightarrow \quad v_{out} = -\left(\frac{R_2}{R_1}\right)v_{inn}$$

## Example 1 - Simplified Analysis of an Op Amp Circuit

The circuit shown below is an inverting voltage amplifier using an op amp. Find the voltage transfer function, $v_{out}/v_{in}$.

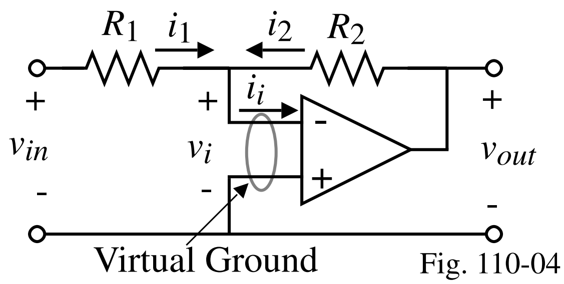


Fig. 110-04

*Solution*

If $A_v \to \infty$, then $v_i \to 0$ because of the negative feedback path through $R_2$.

(The op amp with –fb. makes its input terminal voltages equal.)

$$v_i = 0 \text{ and } i_i = 0$$

Note that the null port becomes the familiar *virtual ground* if one of the op amp input terminals is on ground. If this is the case, then we can write that

$$i_1 = \frac{v_{in}}{R_1} \qquad \text{and} \qquad i_2 = \frac{v_{out}}{R_2}$$

Since, $i_i = 0$, then $i_1 + i_2 = 0$ giving the desired result as $\dfrac{v_{out}}{v_{in}} = -\dfrac{R_2}{R_1}$.






## Linear and Static Characterization of the Op Amp

A model for a nonideal op amp that includes some of the linear, static nonidealities:

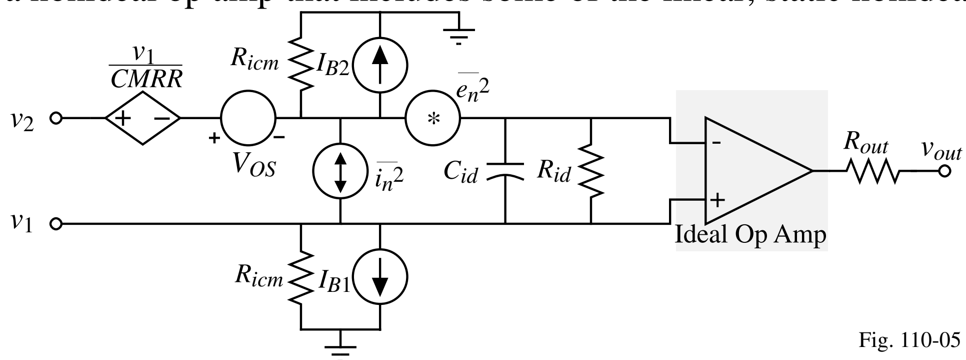


Fig. 110-05

where

- $R_{id}$ = differential input resistance
- $C_{id}$ = differential input capacitance
- $R_{icm}$ = common mode input resistance
- $V_{OS}$ = input-offset voltage
- $I_{B1}$ and $I_{B2}$ = differential input-bias currents
- $I_{OS}$ = input-offset current ($I_{OS} = I_{B1}$-$I_{B2}$)
- $CMRR$ = common-mode rejection ratio
- $e_n^2$ = voltage-noise spectral density (mean-square volts/Hertz)
- $i_n^2$ = current-noise spectral density (mean-square amps/Hertz)

## Linear and Dynamic Characteristics of the Op Amp

Differential and common-mode frequency response:

$$V_{out}(s) = A_v(s)[V_1(s) - V_2(s)] \pm A_c(s)\left(\frac{V_1(s)+V_2(s)}{2}\right)$$

Differential-frequency response:

$$A_v(s) = \frac{A_{v0}}{\left(\frac{s}{p_1} - 1\right)\left(\frac{s}{p_2} - 1\right)\left(\frac{s}{p_3} - 1\right)\cdots} = \frac{A_{v0}\, p_1 p_2 p_3 \cdots}{(s - p_1)(s - p_2)(s - p_3)\cdots}$$

where $p_1, p_2, p_3, \cdots$ are the poles of the differential-frequency response (ignoring zeros).

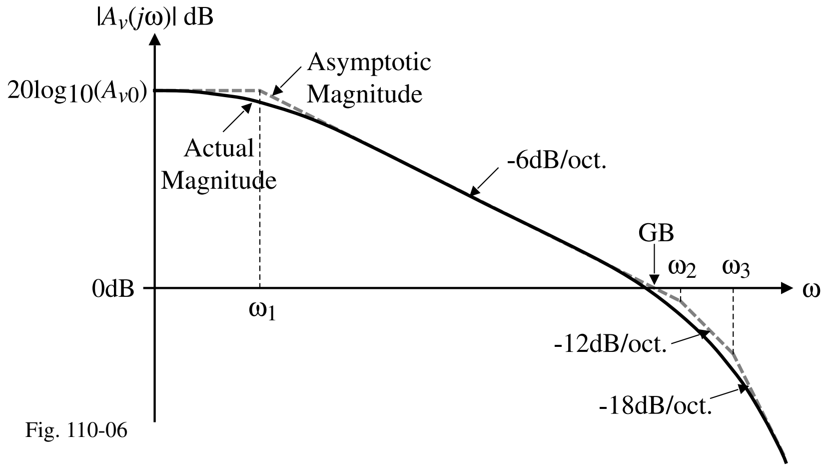

Fig. 110-06





## Other Characteristics of the Op Amp

Power supply rejection ratio ($PSRR$):

$$PSRR = \frac{\Delta V_{DD}}{\Delta V_{OUT}} A_v(s) = \frac{V_o/V_{in}\ (V_{dd}=0)}{V_o/V_{dd}\ (V_{in}=0)}$$

Input common mode range ($ICMR$):

$ICMR$ = the voltage range over which the input common-mode signal can vary without influence the differential performance

Slew rate ($SR$):

$SR$ = output voltage rate limit of the op amp

Settling time ($T_s$):

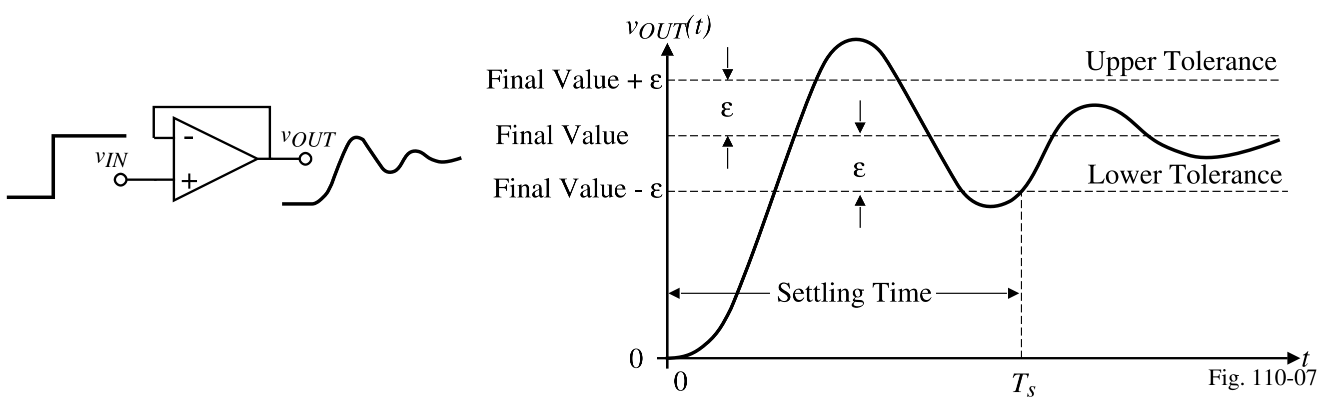

Fig. 110-07

## Classification of CMOS Op Amps

Categorization of op amps:

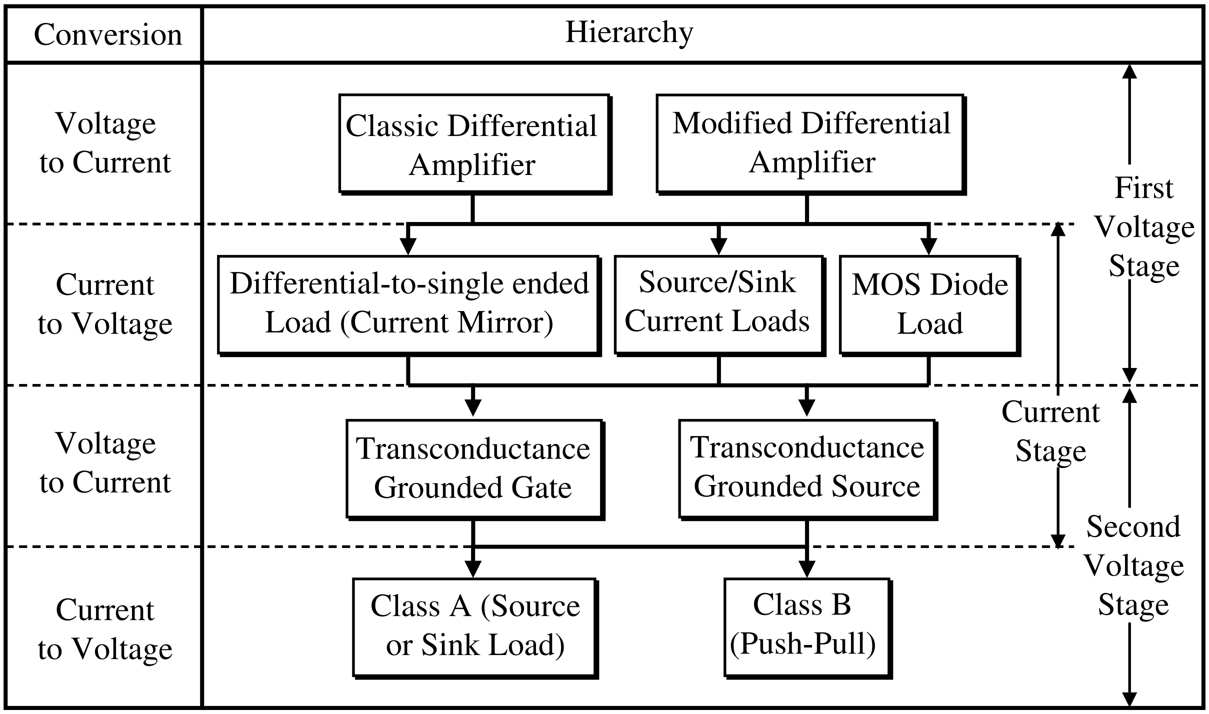


Table 110-01





## Two-Stage Op Amp Architecture

Simple two-stage op amp broken into voltage-to-current and current-to-voltage stages:

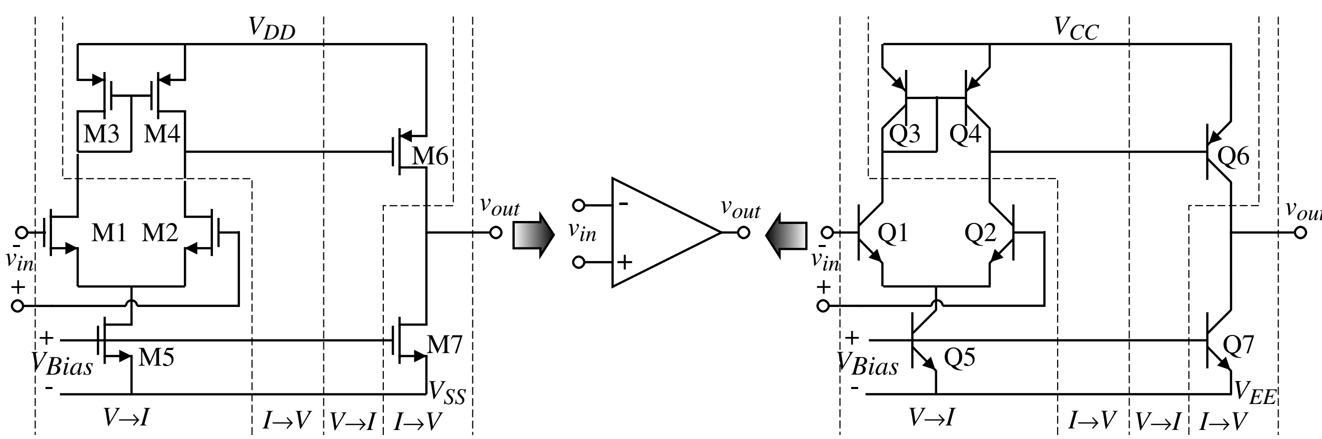


Fig. 110-08

## Folded-Cascode Op Amp Architecture

Simple folded-cascode op amp broken into voltage-to-current and current-to-voltage stages:

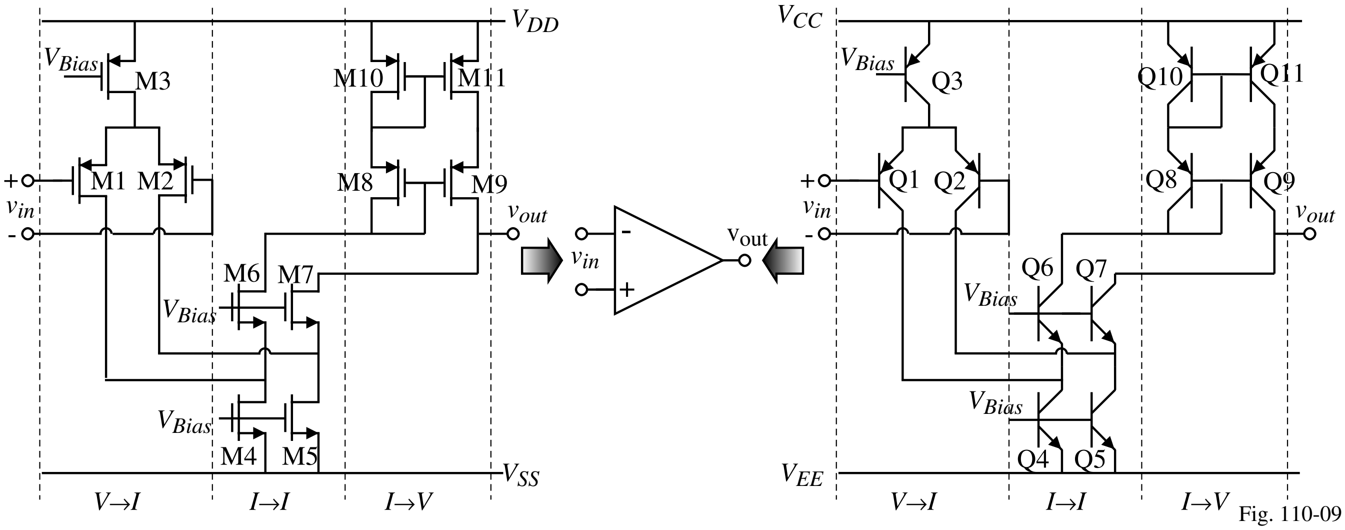


Fig. 110-09





## SUMMARY

- The op amp is an amplifier whose gain approaches ∞
    - The input is a null port which is useful for analysis
    - Two classical op amp configurations – noninverting and inverting amplifier
- Static characteristics include offsets, bias currents, finite resistance, and noise
- Dynamic characteristics include frequency, slew rate, transient response, etc.
- Basic op amp architectures are,
    - Two-stage
    - Cascode and folded-cascode