Operational Amplifiers (Op-Amp)

Background

- **Originally invented in early 1940s using vacuum tube technology**

  Initial purpose was to execute math operations in analog electronic calculating machines

- **Shrunk in size with invention of transistor**

- **Most now made on integrated circuit (IC)**

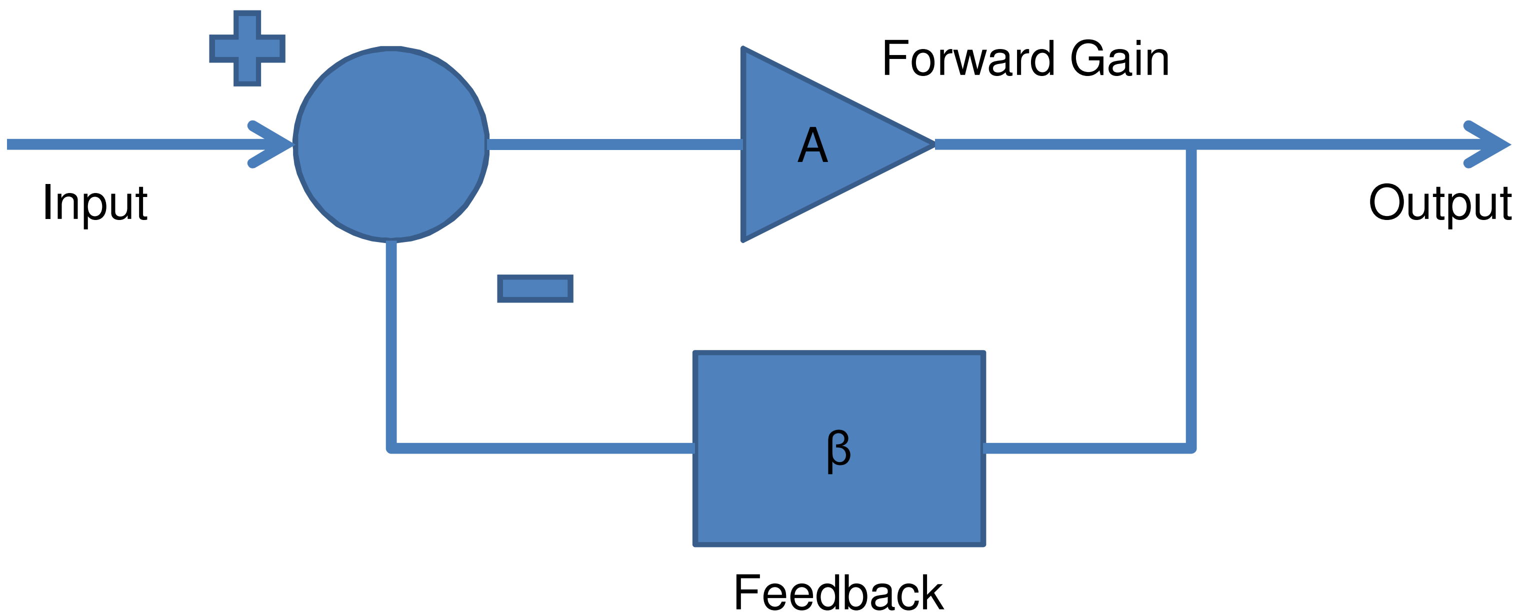
  Only most demanding applications use discrete components

  - adding signals
  - subtracting signals
  - integrating signals

- **Huge variety of applications, low cost, and ease of mass production make them extremely popular**

History of the Op-Amp – The Dawn

- **Before the Op-Amp: Harold S. Black develops the feedback amplifier for the Western Electric Company (1920-1930)**



Introduction

- **An Operational Amplifier (Op-Amp) is an integrated circuit that uses external voltage to amplify the input through a very high gain.**
- **We recognize an Op-Amp as a mass-produced component found in countless electronics.**

- ***Operational Amplifier (OPAMP) is a very high gain amplifier fabricated on Integrated Circuit (IC)***
- Finds application in
  - Audio amplifier : Speakers and microphone circuits in cell phones, computers, mpg players, boom boxes, etc.
  - Signal generator
  - Signal filters
  - Power amplifiers
  - Biomedical Instrumentation : Biomedical systems including heart monitors and oxygen sensors.

•Analog computers

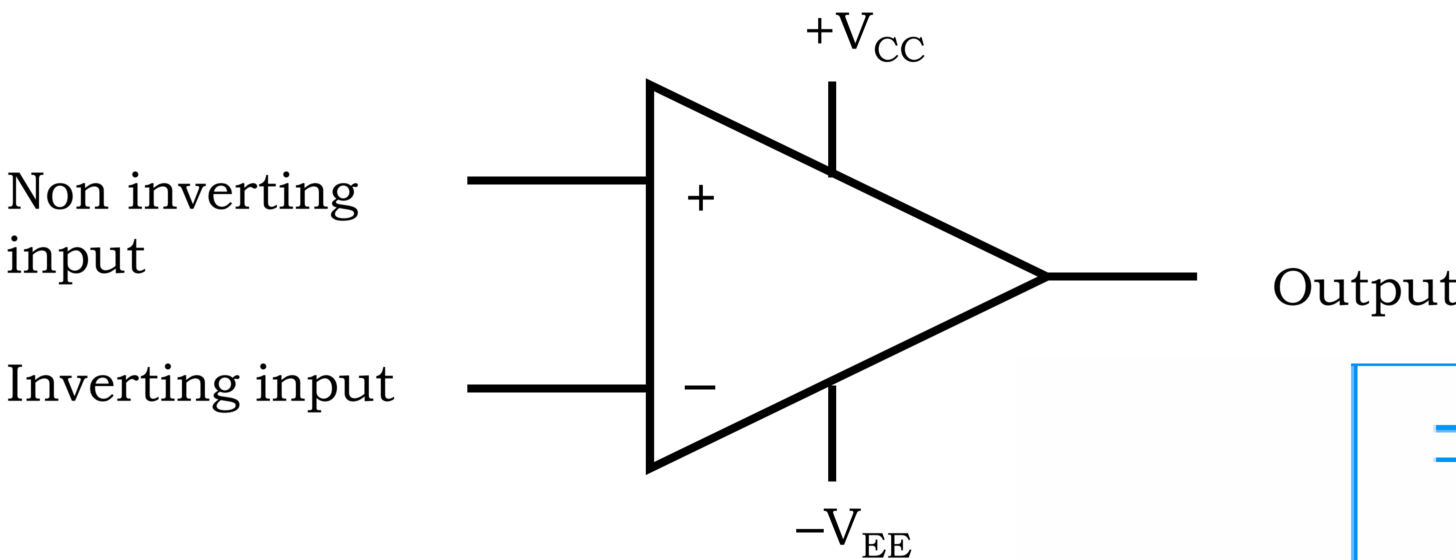
Combination of integrators, differentiators, summing amplifiers, and multipliers

- And numerous other applications

What is an Op-Amp? – The Inside (OPAMP terminals)

The actual count varies, but an Op-Amp contains several Transistors, Resistors, and a few Capacitors and Diodes.

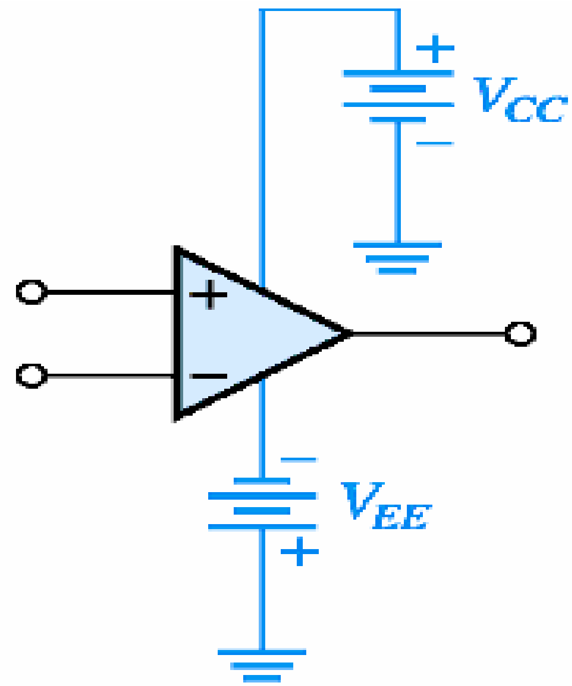
For simplicity, an Op-Amp is often depicted as this:



- ***If input is applied to non inverting input terminal, then output will be in-phase with input***

- ***If input is applied to inverting input terminal, then output will be 180 degrees out of phase with input***

- ***If inputs are applied to both terminals, then output will be proportional to difference between the two inputs***

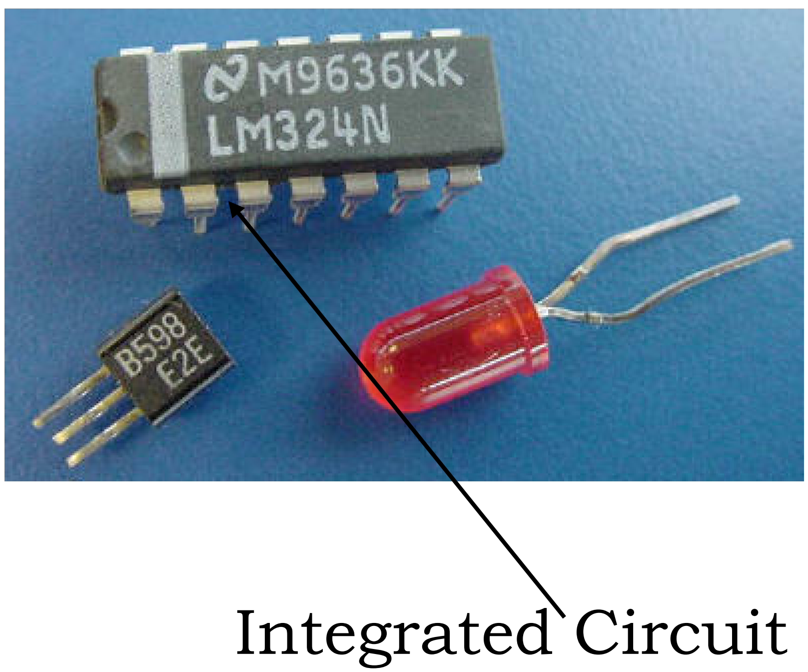


•Two DC power supplies (dual) are required

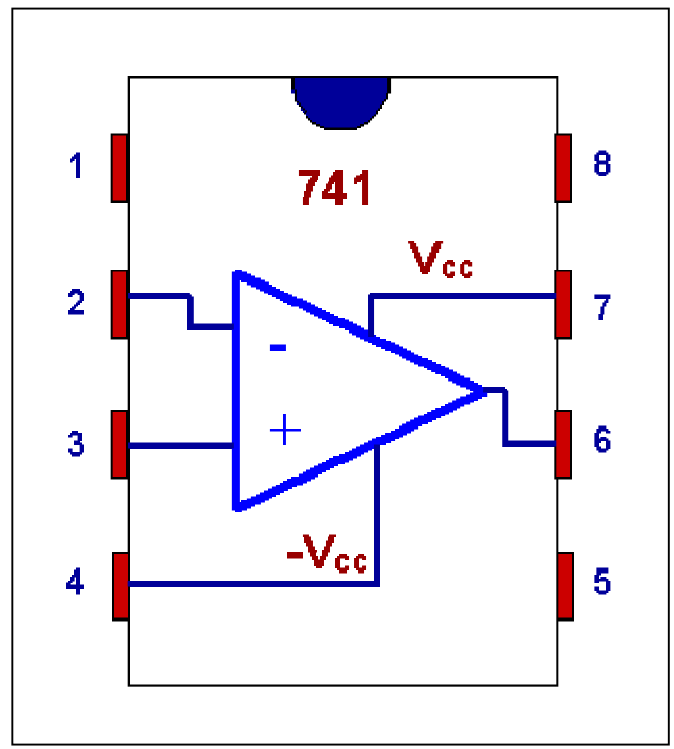
•Magnitudes of both may be same

•The other terminal of both power supplies are connected to common ground

•All input and output voltages are measured with reference to the common ground

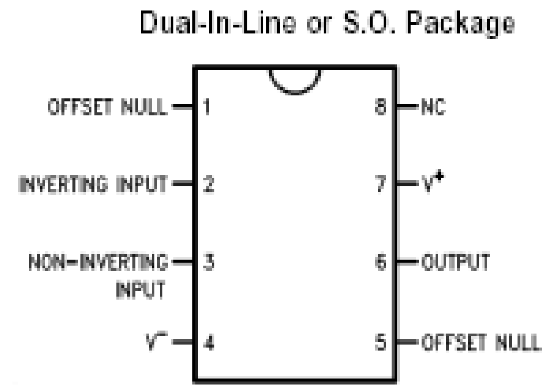


What an Op-Amp looks like to a lay-person



What an Op-Amp looks like to an engineer

Operational Amplifiers



The op amp is built using VLSI techniques. The circuit diagram of an LM 741 from National Semiconductor is shown below.

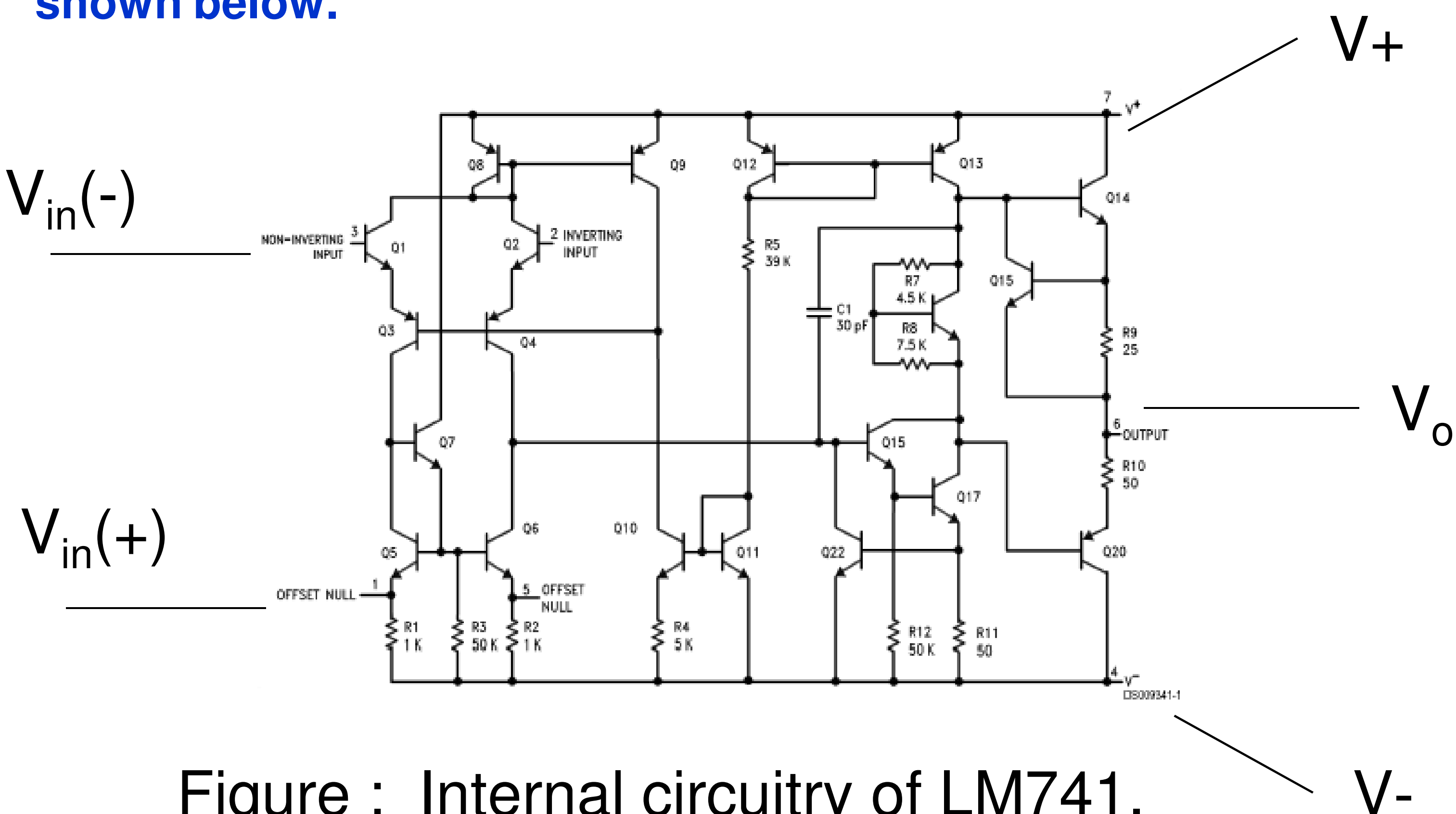
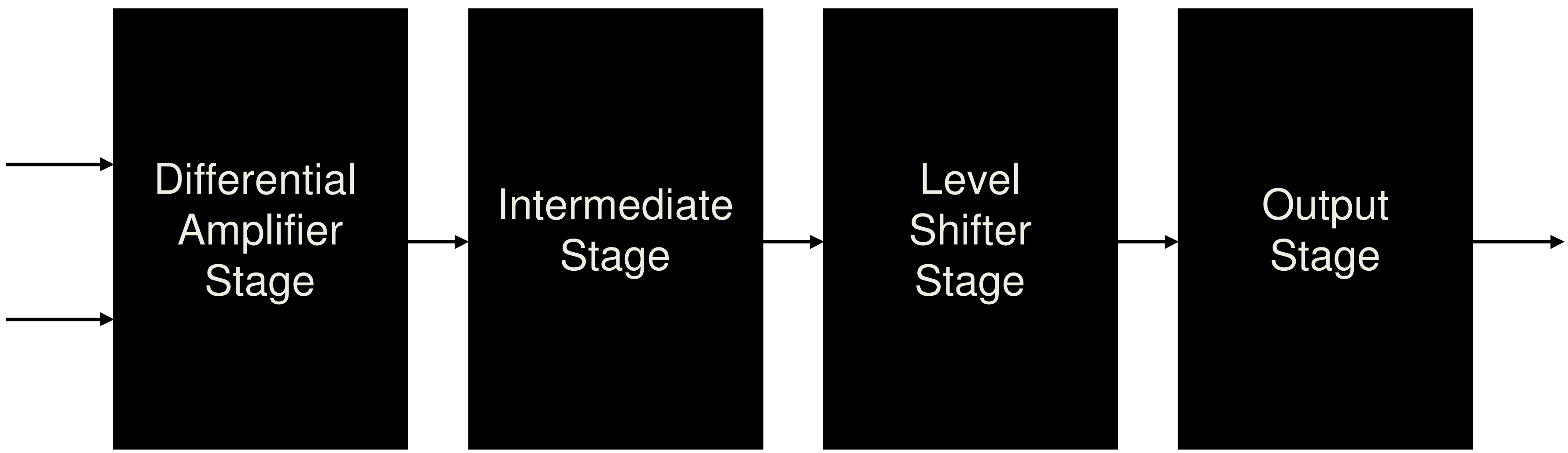


Figure : Internal circuitry of LM741.

Internal Block Diagram



Four stages can be identified –

Input stage or differential amplifier stage can amplify difference between two input signals; Input resistance is very high; Draws zero current from the input sources

Cont…

•Intermediate stage (or stages) use direct coupling; provide very high gain

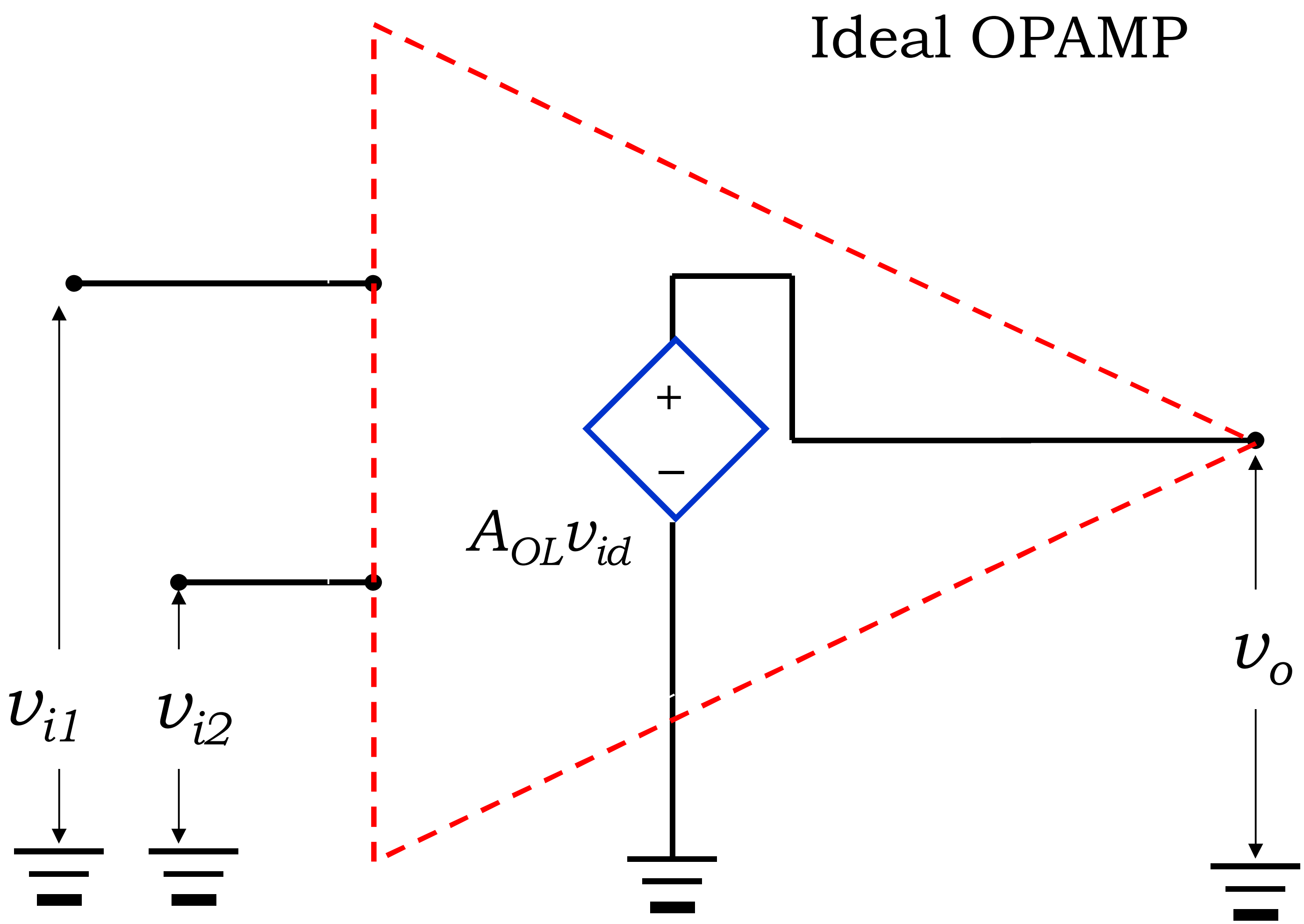
•Level shifter stage shifts the dc level of output voltage to zero (can be adjusted manually using two additional terminals)

•Output stage is a power amplifier stage; has very small output resistance; so output voltage is the same, no matter what is the value of load resistance connected to the output terminal

Ideal Operational Amplifier

- Ideal OPAMP
  - Infinite differential mode gain
  - Zero common mode gain
  - Infinite CMRR
  - Infinite input resistance
  - Zero output resistance
  - Infinite bandwidth
  - Infinite slew rate
  - Zero input offset voltage
  - Zero input offset current
  - Zero output offset voltage

Ideal OPAMP Circuit



Ideal Op Amp:

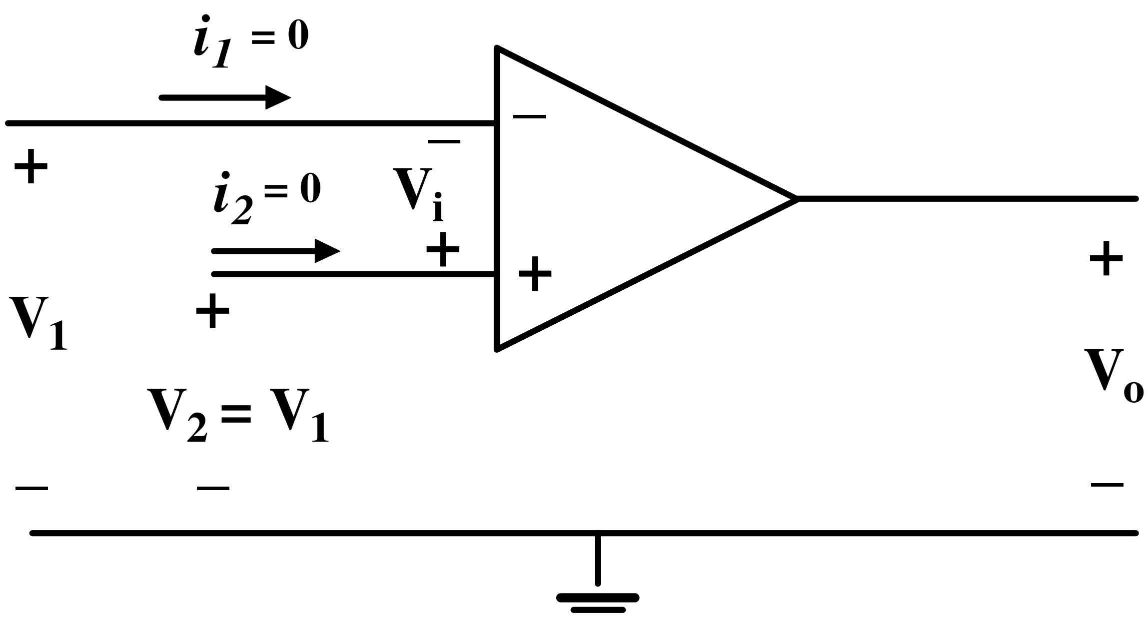
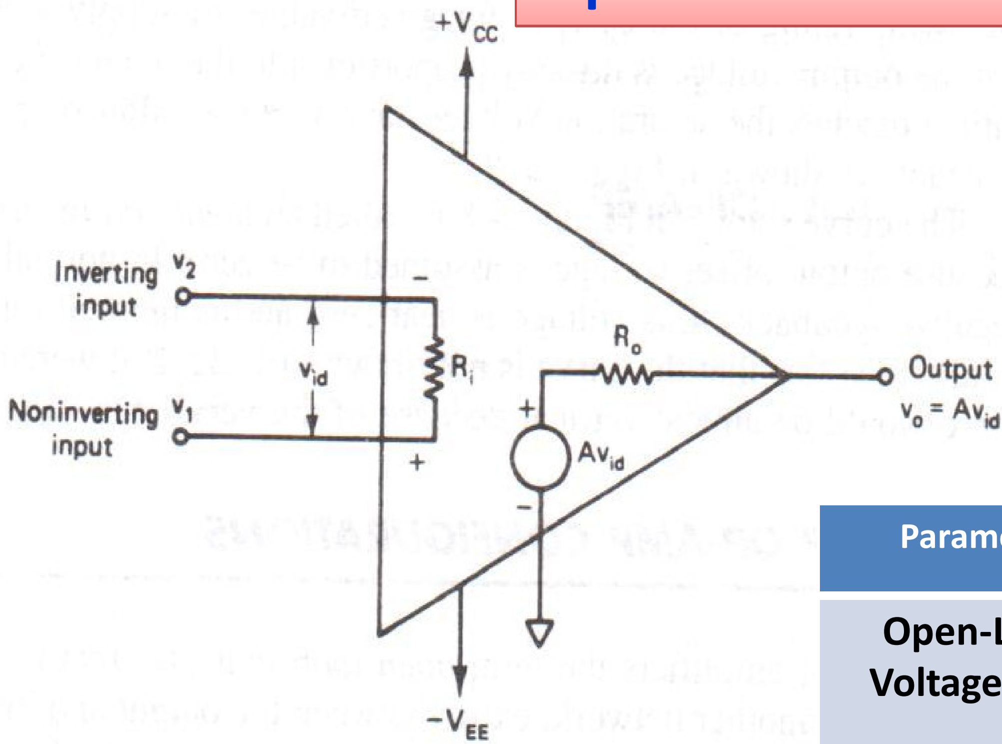


Figure : Ideal op amp.

(a) $i_1 = i_2 = 0$: Due to infinite input resistance.

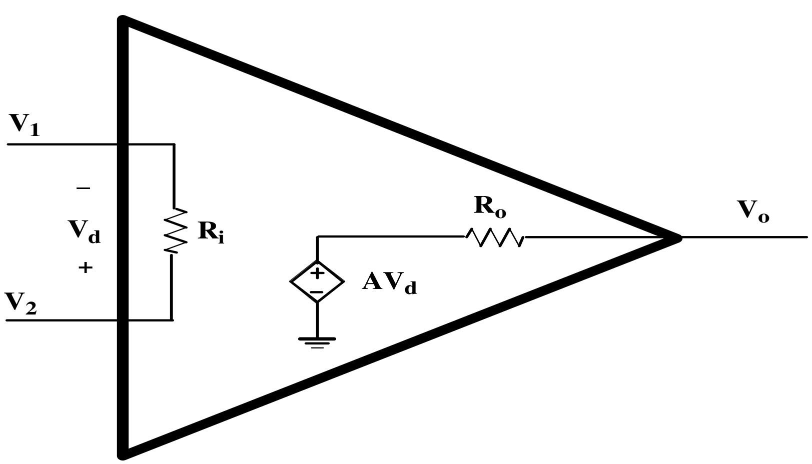
(b) V_i is negligibly small; $V_1 = V_2$.

Equivalent Circuit Of An Op Amp,



$$v_o = Av_{id} = A(v_1 - v_2)$$

where A = large-signal voltage gain
v_{id} = difference input voltage
v_1 = voltage at the noninverting input terminal with respect to ground
v_2 = voltage at the inverting terminal with respect to ground



Parameter	Variable	Typical Ranges	Ideal Values
Open-Loop Voltage Gain	A	10^5 to 10^8	∞
Input Resistance	Ri	10^5 to 10^{13} Ω	∞ Ω
Output Resistance	Ro	10 to 100 Ω	0 Ω
Supply Voltage	Vcc/V+ -Vcc/V-	5 to 30 V -30V to 0V	N/A N/A

OPAMP Characteristics

- **Differential mode gain A_d**
  - **It is the factor by which the difference between the two input signals is amplified by the OPAMP**
- **Common mode gain A_{cm}**
  - **It is the factor by which the common mode input voltage is amplified by the OPAMP**
- **Common mode rejection ratio *CMRR***
  Is the ratio of A_d to A_{cm} expressed in decibels

•Input resistance R_i
It is the equivalent resistance measured between the two input terminals of OPAMP

•Output resistance R_o
It is equivalent resistance measured between output terminal and ground

•Bandwidth
It is the range of frequency over which the gain of OPAMP is almost constant

- **Output offset voltage V_{oo}**
  - **It is the output voltage when both input voltages are zero**
  - **Denoted as V_{oo}**

Cont…

- **Input offset voltage V_{io}**
  - It is the differential input voltage that must be applied at the input terminals in order to make output voltage equal to zero
  - $V_{io} = |v_1 - v_2|$ for $v_o = 0$

•**Input offset current I_{io}**

It is the difference between the currents in the input terminals when both input voltages are zero

$I_{io} = | I_1 - I_2 |$ when $v_1 = v_2 = 0$

•**Input bias current I_{ib}**

It is the average of the currents in the input terminals when both input voltages are zero

$I_{ib} = (I_1 + I_2) / 2$ when $v_1 = v_2 = 0$

•**Slew rate *SR***

It is the maximum rate of change of output voltage with respect to time

Slew rate has to be very high if OPAMP has to operate efficiently at high frequencies

•**Supply voltage rejection ratio *SVRR***

It is the maximum rate at which input offset voltage of OPAMP changes with change in supply voltage