Electronic Circuits

Operational Amplifier

Lecture 1

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The Course Grades

➢ **The Total Course grades** **150 Marks**

- **Midterm (أعمال السنة) 30 Marks.**
- **Laboratory (عملي) 20 Marks**
- **Final Exam (الامتحان النهائي) 100 Marks**

جدول رقم (11)

خطة الدراسة للفرقة الثانية - قسم هندسة الالكترونيات والاتصالات

الفصل الدراسى الأول

كود المقرر	اسم المقرر	عدد الساعات الأسبوعية				توزيع الدرجات			عدد ساعات الامتحان التحريرى	مجموع درجات المقرر	الساعات المعتمدة
		محاضرة	تطبيقات		مجموع	أعمال سنة	عملى وشفوى	تحريرى			
			تمرين	معمل							
إلك 2403	الدوائر الإلكترونية	2	1	1	4	30	20	100	3	150	2

The Course Contents:

1- Feedback Amplifier

2- Power Amplifier

3- Current Mirror

4- Operational Amplifier

The Operational Amplifier Contents:

1. Introduction to Amplifiers
2. Operational Amplifier architecture
3. Operational Amplifier Properties
4. Operational Amplifier Applications

Introduction

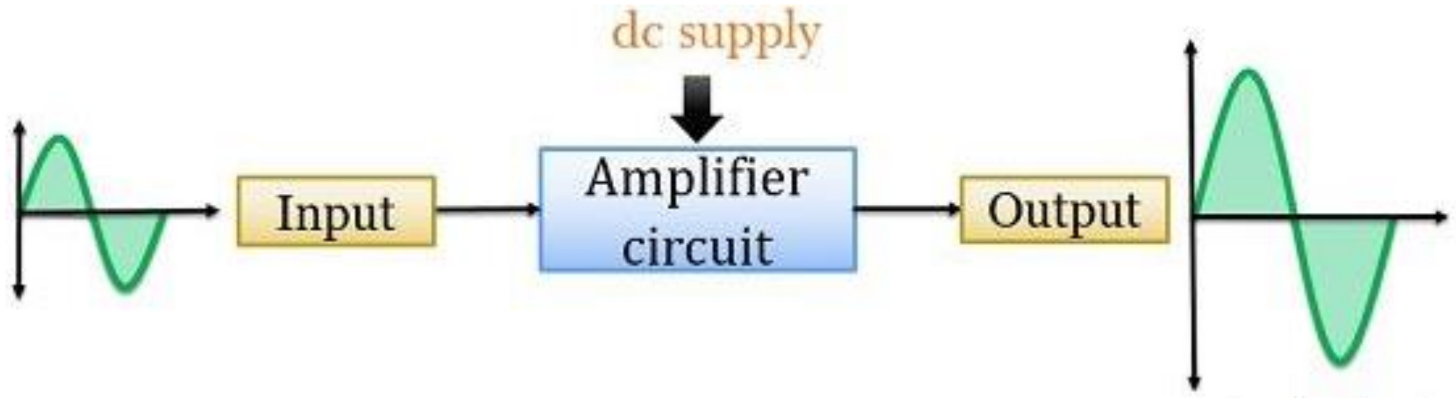
Amplification

Develop understanding of linear amplification concepts such as:

- Voltage gain, current gain, and power gain
- Gain conversion to decibel representation
- Two-port representations of amplifiers

Amplification

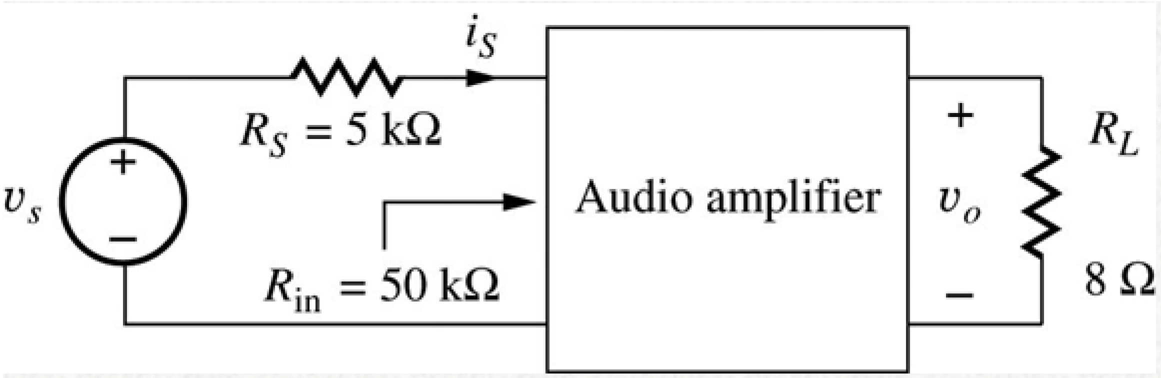
- The Function of amplifier is to provide an output which is greater than input.



The Main Types are:

- **Voltage Amplifier**: Intended to provide Voltage gain
- **Current Amplifier**: Intended to give current gain without gain in voltage.
- **Power Amplifier**: Both current and voltage can be amplified.
- **Inverting Amplifier**: Gives an amplified output out of phase from input.

Amplification



- We consider only one component with amplitude Vs = 1 mV and frequency ω_s with 0 phase (signal is used as reference):

$$v_s = V_s \sin\omega_s t$$

- Amplifier output is sinusoidal with same frequency but different amplitude Vo and phase θ:

$$v_o = V_o(\sin\omega_s t + \theta)$$

- The input and output currents :

$$I_s = \frac{V_s}{R_S + R_{in}} \qquad I_o = \frac{V_o}{R_L}$$

$$i_o = I_o(\sin\omega_s t + \theta)$$

Amplification

- The Voltage gain :

$$A_v = \frac{v_O}{v_S} = \frac{V_o\angle\theta}{V_s\angle 0} = \frac{V_o}{V_s}\angle\theta$$

- The Current gain:

$$A_i = \frac{i_O}{i_S} = \frac{I_o\angle\theta}{I_s\angle 0} = \frac{I_o}{I_s}\angle\theta$$

- The Power gain:

$$A_P = \frac{P_O}{P_S} = \frac{V_o I_o}{V_s I_s} = |A_v||A_i|$$

Amplification

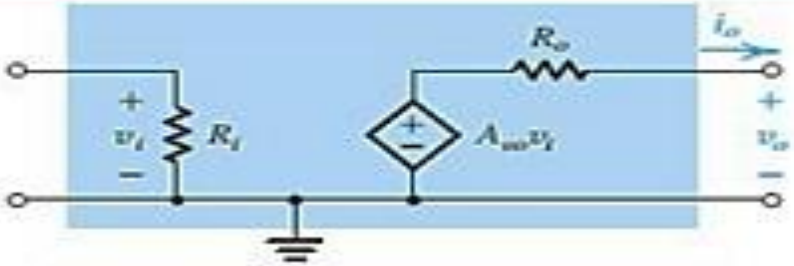
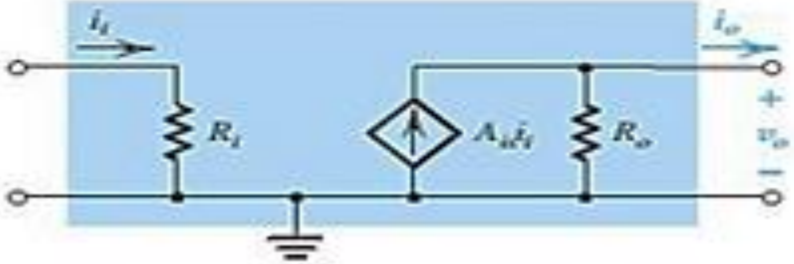
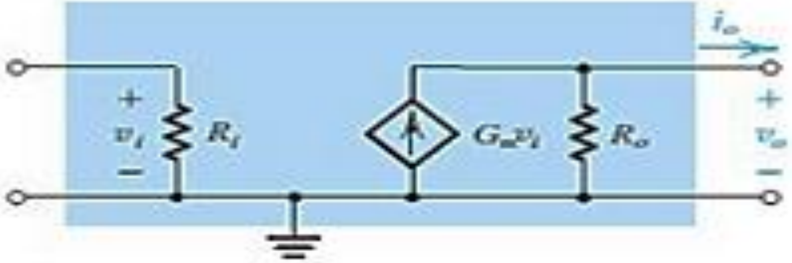
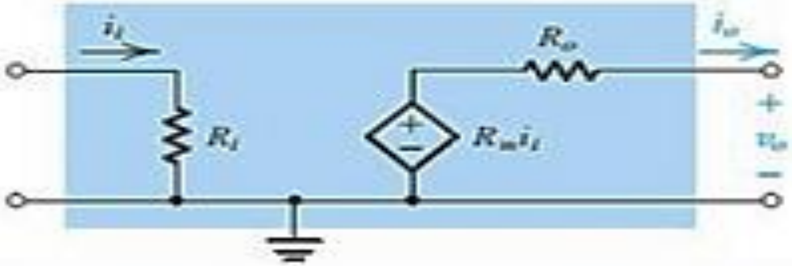
- The logarithmic decibel or dB scale compresses the huge numeric range of gains encountered in real systems.

Expressing Gain in Decibels

$$A_{vdB} = 20 \log |A_v|$$
$$A_{idB} = 20 \log |A_i|$$
$$A_{PdB} = 10 \log A_P$$

|GAIN|	A_{vdB} or A_{idB}	A_{PdB}
1000	60 dB	30 dB
500	54 dB	27 dB
300	50 dB	25 dB
100	40 dB	20 dB
20	26 dB	13 dB
10	20 dB	10 dB
$\sqrt{10} = 3.16$	10 dB	5 dB
2	6 dB	3 dB
1	0 dB	0 dB
0.5	−6 dB	−3 dB
0.1	−20 dB	−10 dB

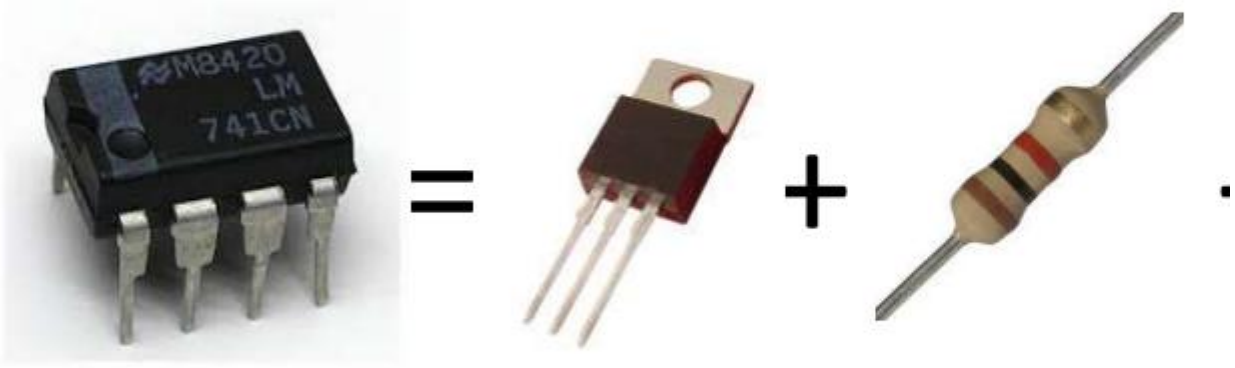
Amplification

Type	Circuit Model	Gain Parameter	Ideal Characteristics
Voltage Amplifier		Open-Circuit Voltage Gain $A_{vo} \equiv \left.\frac{v_o}{v_i}\right\|_{i_o=0}$ (V/V)	$R_i = \infty$ $R_o = 0$
Current Amplifier		Short-Circuit Current Gain $A_{is} \equiv \left.\frac{i_o}{i_i}\right\|_{v_o=0}$ (A/A)	$R_i = 0$ $R_o = \infty$
Transconductance Amplifier		Short-Circuit Transconductance $G_m \equiv \left.\frac{i_o}{v_i}\right\|_{v_o=0}$ (A/V)	$R_i = \infty$ $R_o = \infty$
Transresistance Amplifier		Open-Circuit Transresistance $R_m \equiv \left.\frac{v_o}{i_i}\right\|_{i_o=0}$ (V/A)	$R_i = 0$ $R_o = 0$

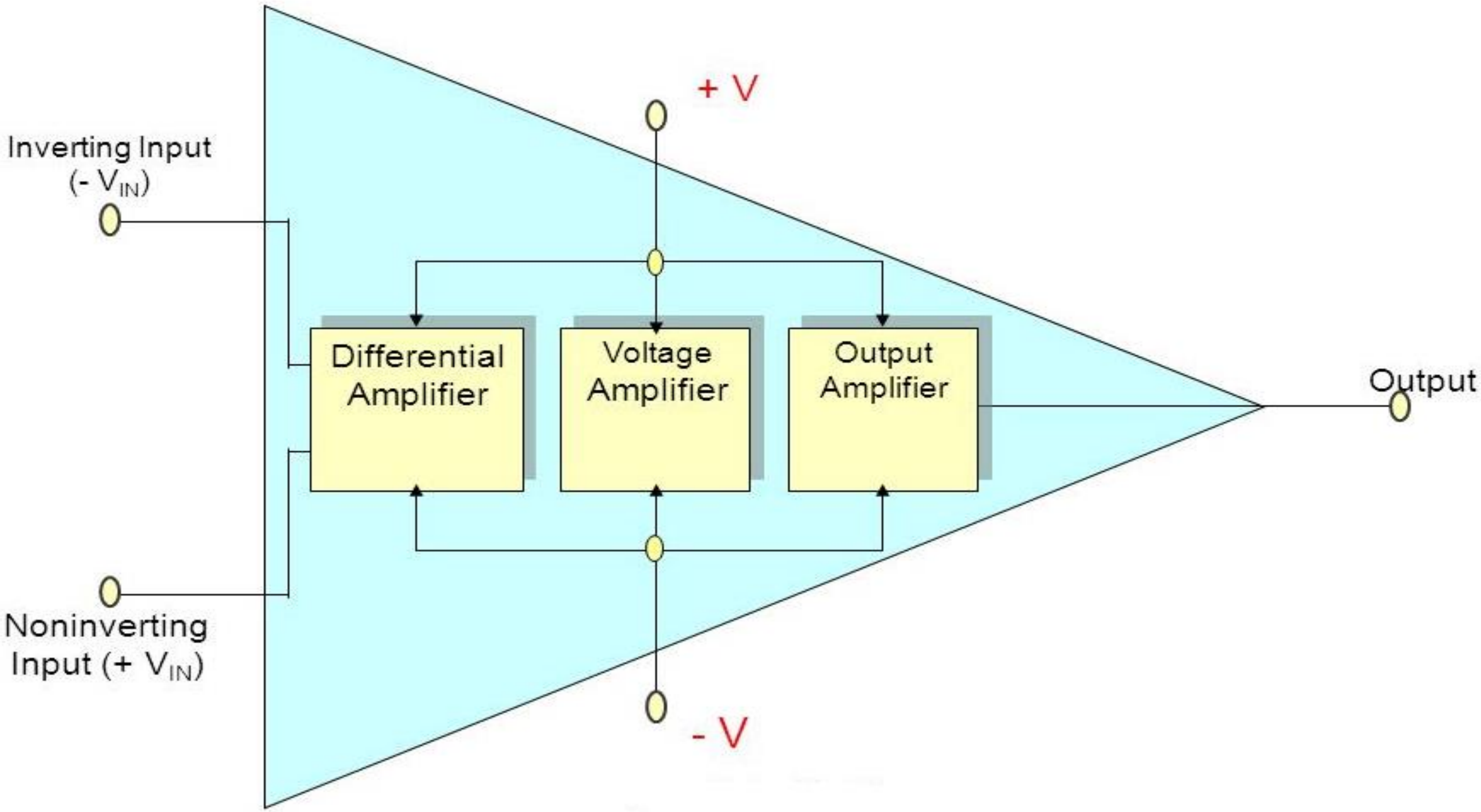
Operational Amplifier architecture

Operational Amplifier (Op-Amp)

- An Op-Amp is a very high gain differential amplifier with very high input impedance (typically a few Mega ohm) and a low output impedance (less than 500Ω)
- An Operational Amplifier is basically a three-terminal device which consists of two high impedance inputs and one output
- An Operational Amplifier (It is also called an “Op-Amp”) is a device that is used to amplify a signal using an external power source
- Op-Amps are generally composed of : Transistors, Resistors



Operational Amplifier Block diagram

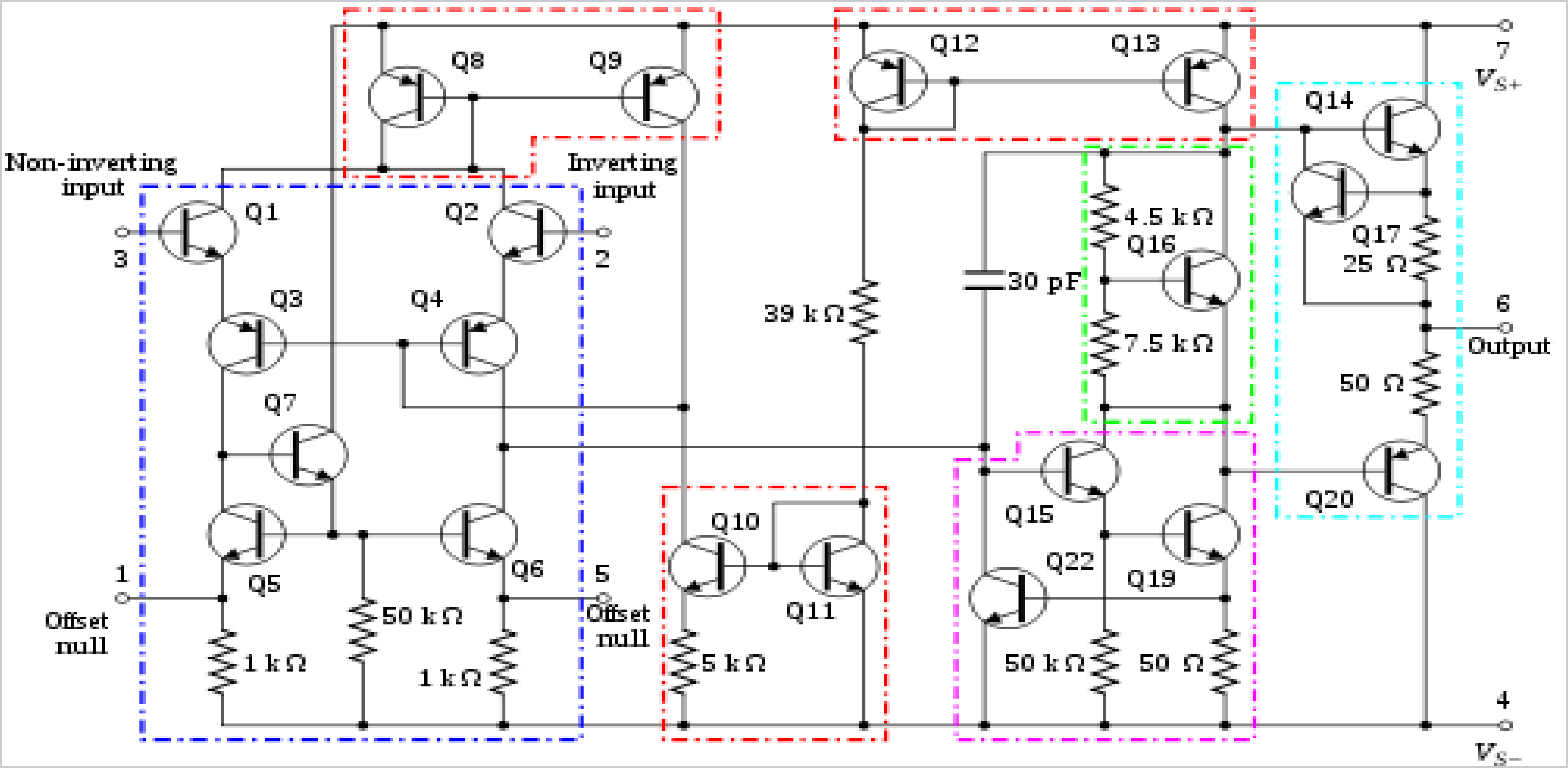


Construction of Operational Amplifier

- A small-scale integrated circuit, the 741 op amp shares with most op amps an internal structure consisting of three gain stages:
- Differential amplifier— provides high differential amplification (gain), with rejection of common-mode signal, low noise, high input impedance, and drives a
- Voltage amplifier — provides high voltage gain, a single-pole frequency roll-off, and in turn drives the
- Output amplifier — provides high current gain (low output impedance), along with output current limiting, and output short-circuit protection.

Current mirror (outlined red) bias circuitry and compensation capacitor.

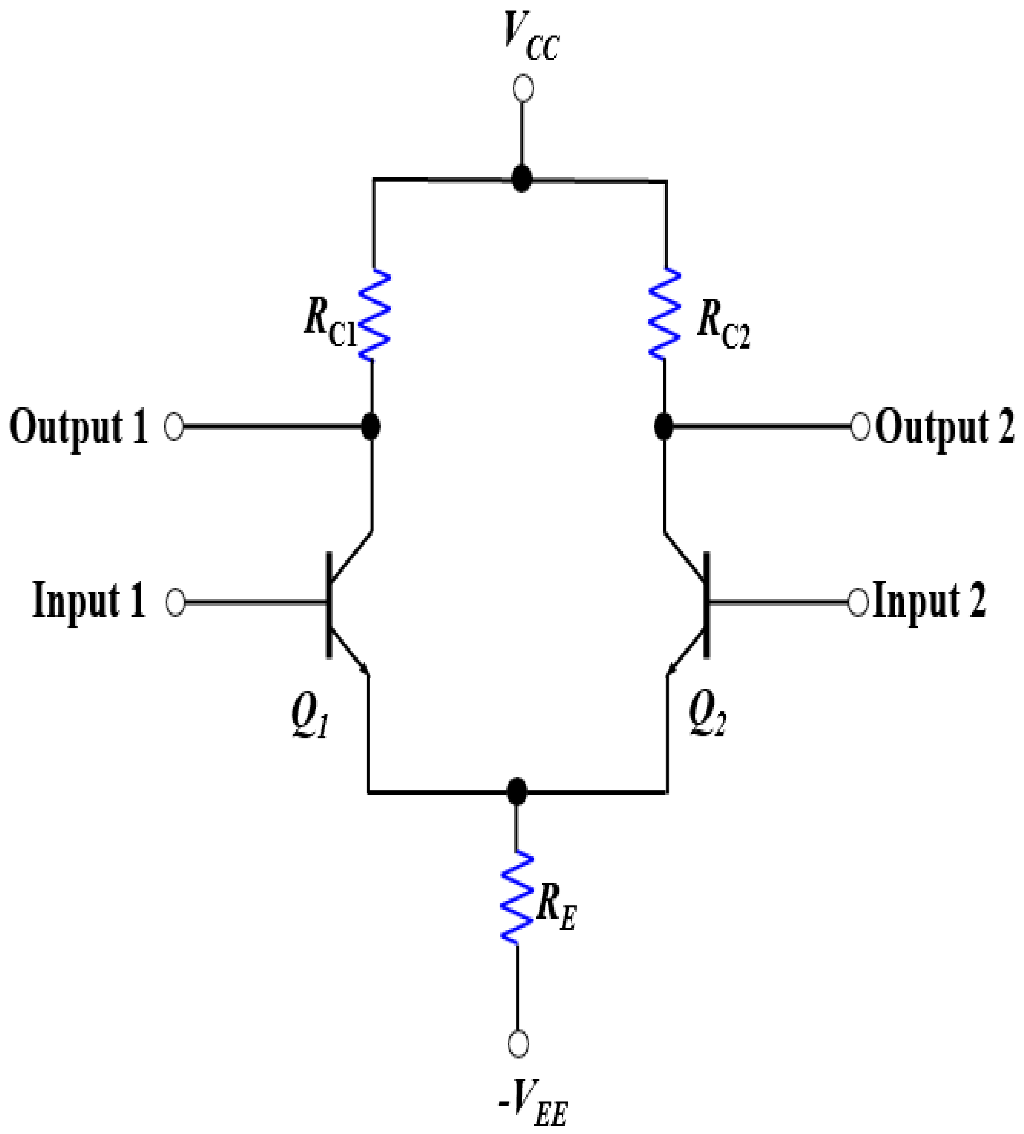
Construction of Operational Amplifier



A component-level diagram of the common 741 op amp. Dotted lines outline: current mirrors; differential amplifier; class A gain stage; voltage level shifter; output stage.

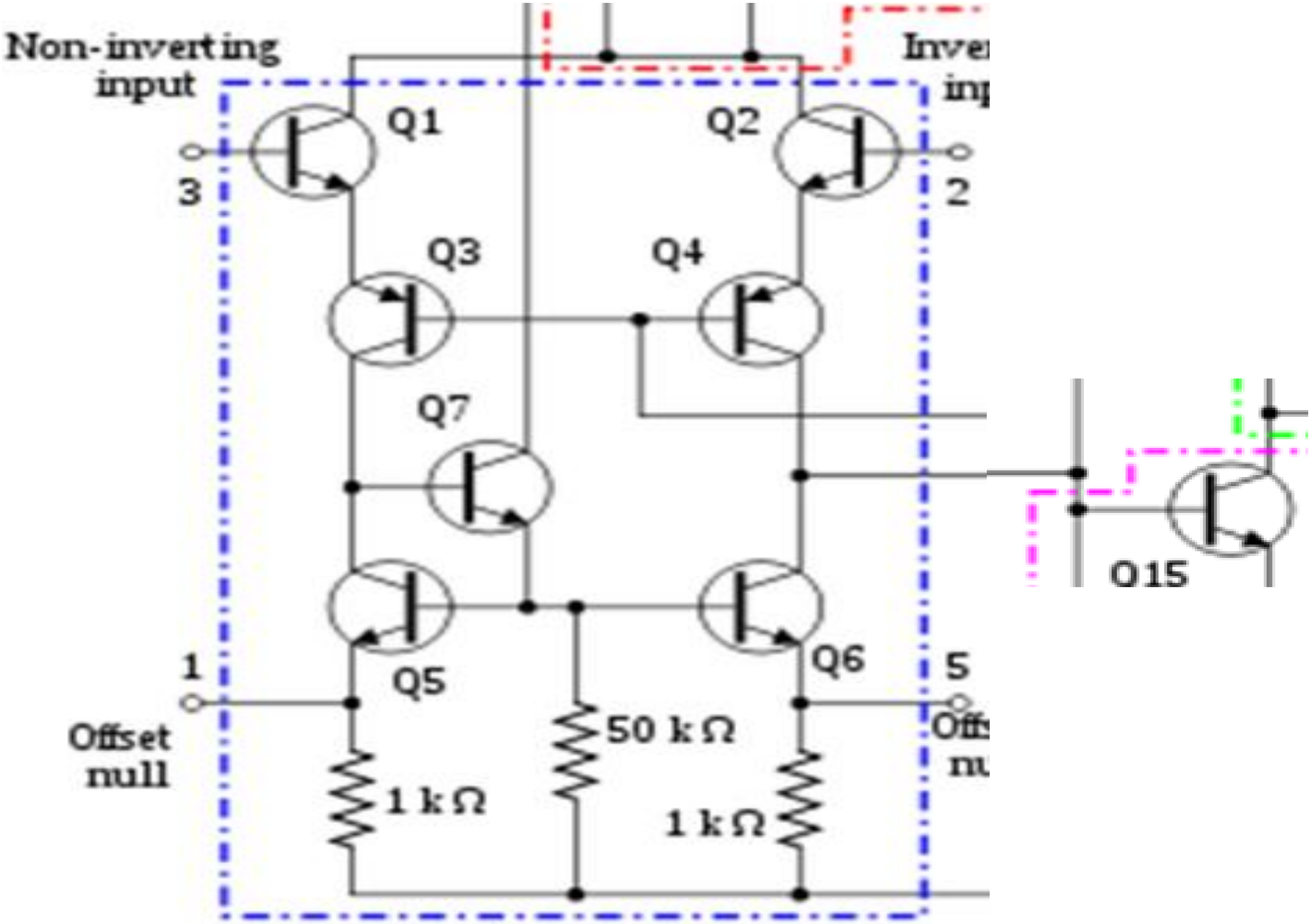
Differential Amplifier (Basic Model)

- **The differential amplifier** is an amplifier that produces outputs that are a function of the difference between two input voltages.
- **The differential amplifier** has two basic modes of operation: differential (in which the two inputs are different) and common mode (in which the two inputs are the same).
- **The differential amplifier** has two inputs and two outputs.



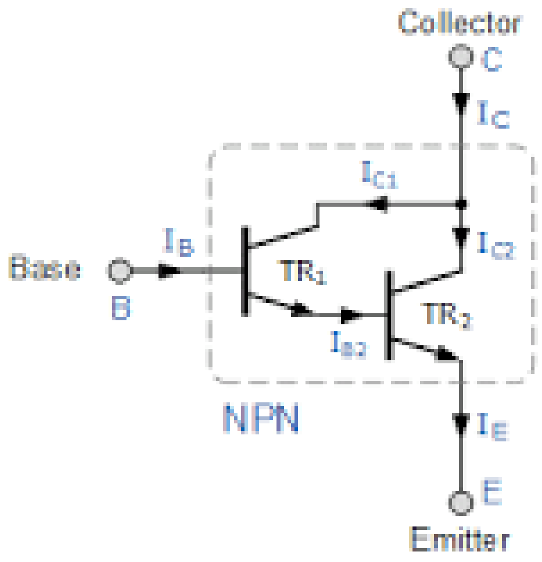
Differential Amplifier

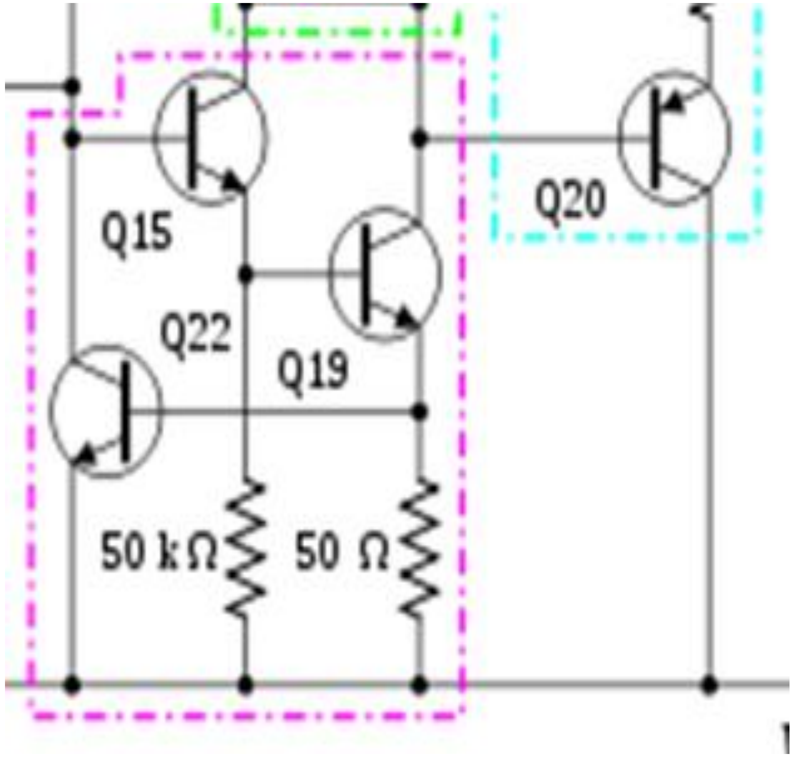
- The input stage consists of a cascaded differential amplifier followed by a current-mirror active load. This constitutes a transconductance amplifier, turning a differential voltage signal at the bases of Q1, Q2 into a current signal into the base of Q15.



Voltage Amplifier

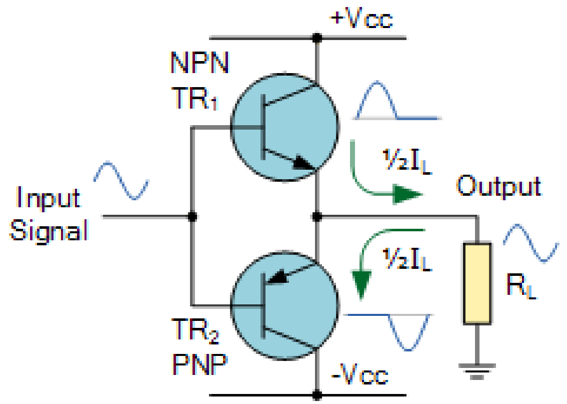
- The (class-A) voltage gain stage consists of the two NPN transistors Q15/Q19 connected in a Darlington configuration and uses the output side of current mirror Q12/Q13 as its collector (dynamic) load to achieve its high voltage gain. The output sink transistor Q20 receives its base drive from the common collectors of Q15 and Q19; the level-shifter Q16 provides base drive for the output source transistor Q14.
- The transistor Q22 prevents this stage from delivering excessive current to Q20 and thus limits the output sink current.

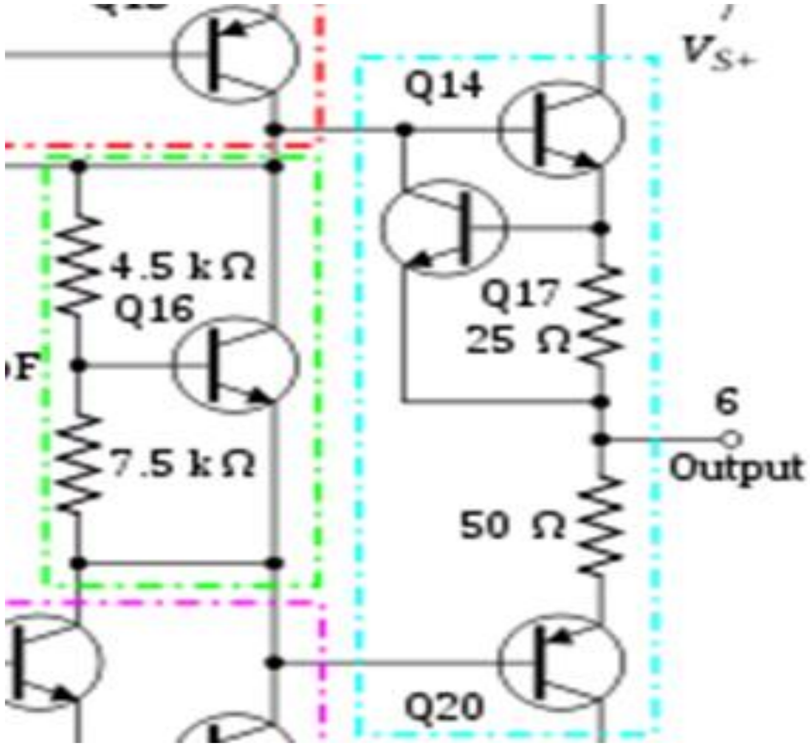




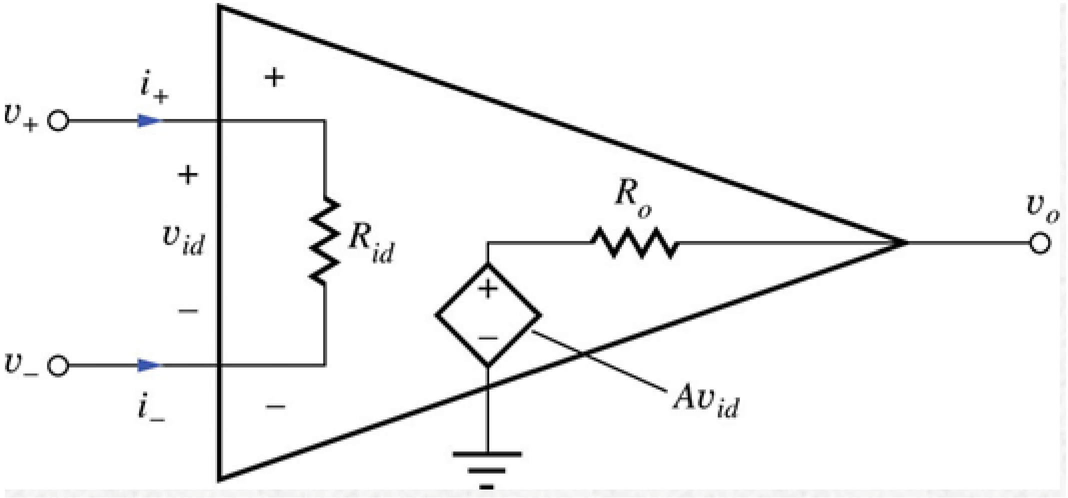
Output Amplifier

- The output stage (Q14, Q20) is a Class AB complementary-symmetry amplifier. It provides an output drive with impedance of ~50 Ω, in essence, current gain.
- Transistor Q16 (outlined in green) provides the quiescent current for the output transistors, and Q17 provides output current limiting.





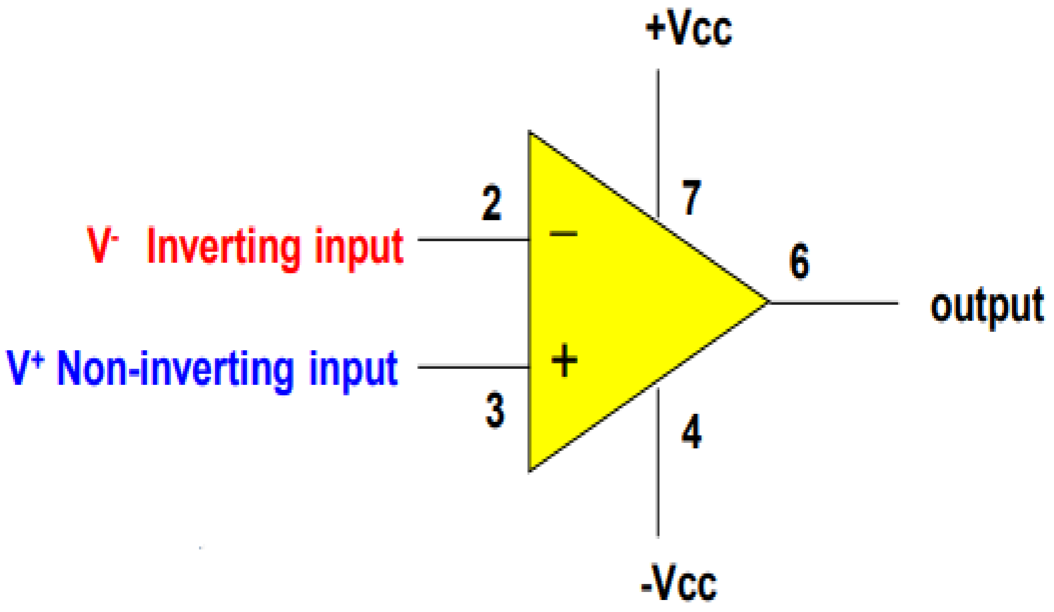
Operational Amplifier (Op-Amp)

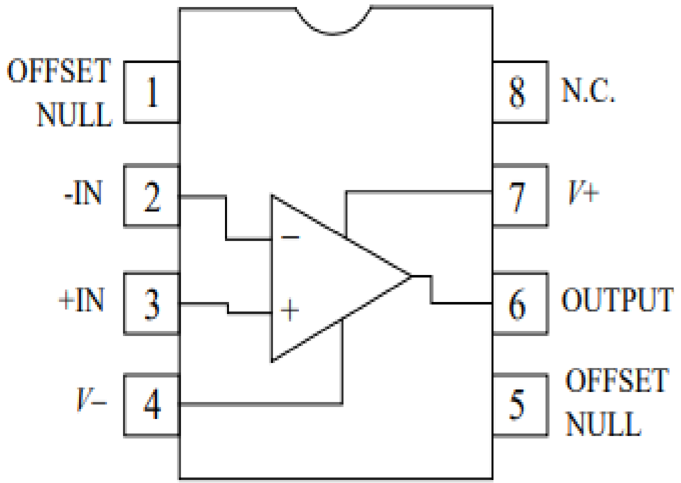


v_o= A v_{id}
A = open-circuit voltage gain
v_{id} = (v_+ - v_-) = differential input signal voltage
v_o= A (v_+ - v_-)
R_{id} = amplifier input resistance
R_o = amplifier output resistance

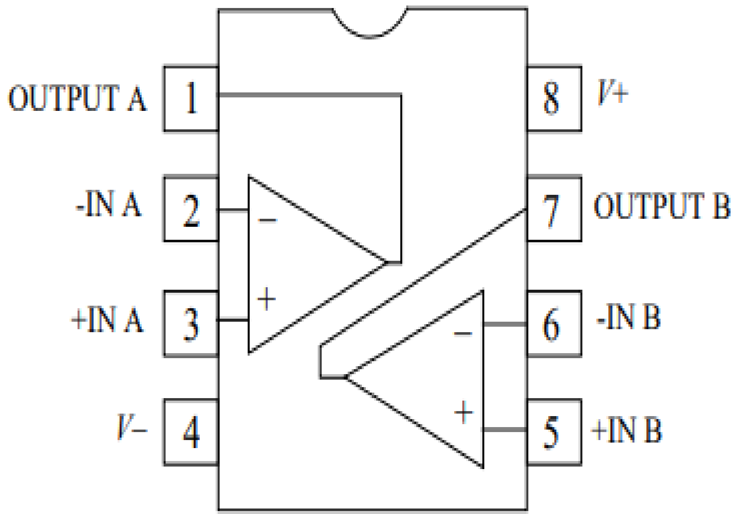
- An ideal differential amplifier produces an output that depends on the voltage difference between its two input terminals.
- Signal developed at amplifier output is in phase with the voltage applied at + input (non-inverting) terminal and 180^o out of phase with that applied at - input (inverting) terminal.

Operational Amplifier (Op-Amp)





DIP-741



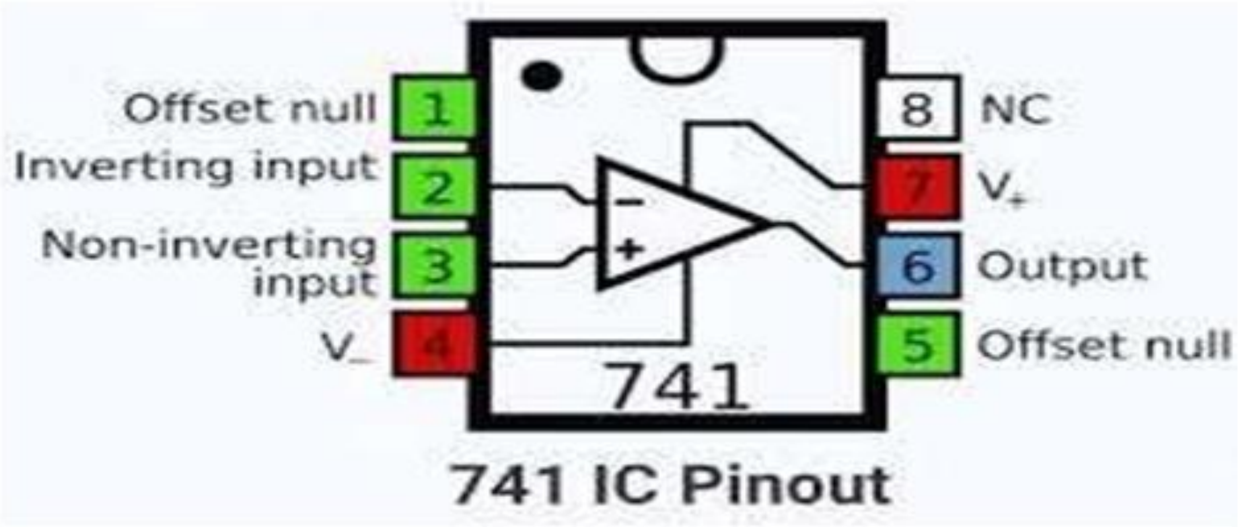
Dual op-amp 1458 device

- An Operational Amplifier is basically a three-terminal device (There are two inputs Inverting and Non-inverting and one output).
- One of the inputs is called the Inverting input, marked with a negative or “minus” sign, (–). The other input is called the Non- inverting input, marked with a positive or “plus” sign (+).

$$v_o = A\,(v_+ - v_-)$$

Operational Amplifier (IC 741)

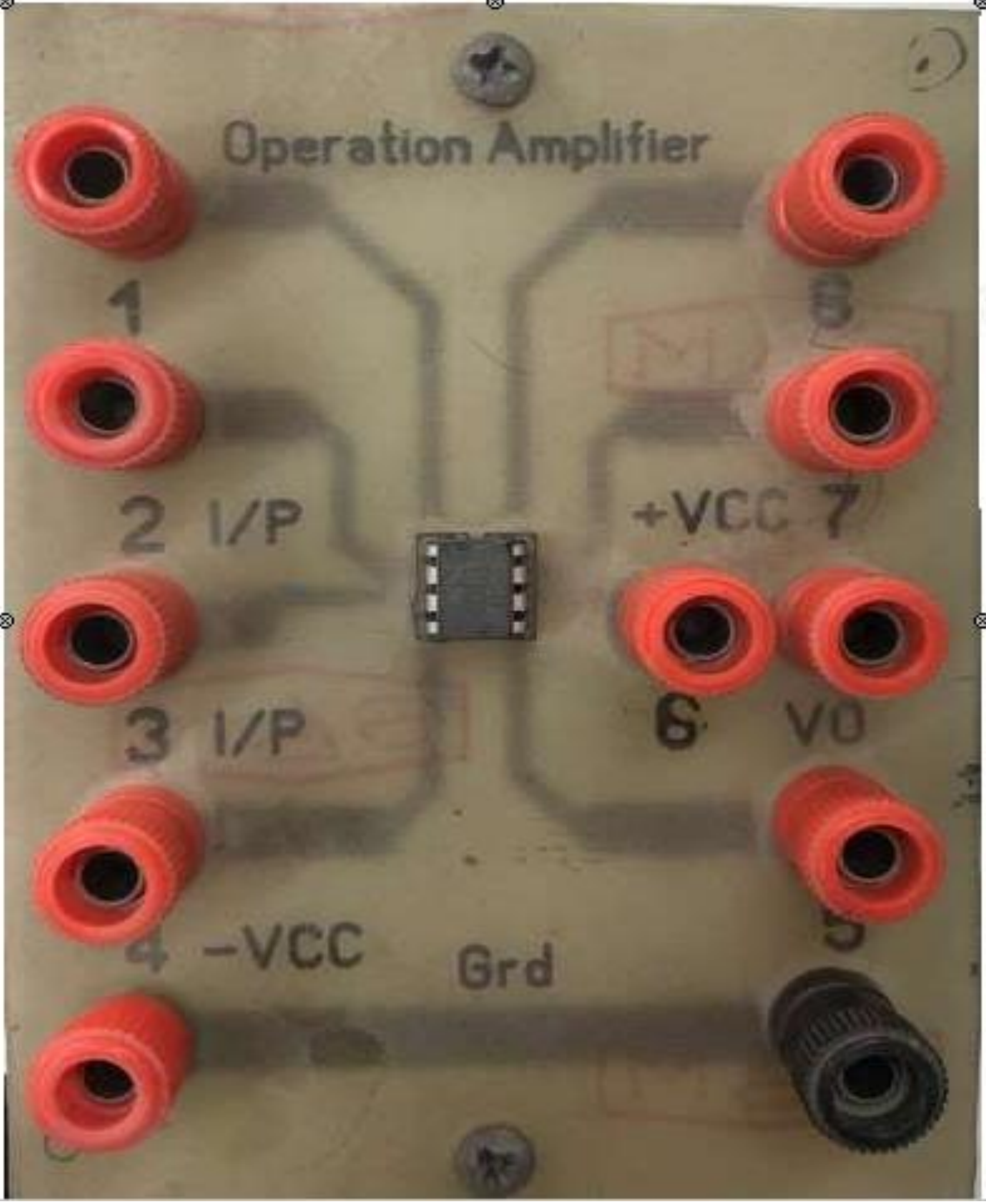
- An operational amplifier, is an integrated circuit primarily designed for performing analogue computations. It has a very high voltage gain, typically of the order of 10^5 (100dB).
- The 741 Op Amp IC is a monolithic integrated circuit, comprising of a general purpose Operational Amplifier. It was first manufactured by Fairchild semiconductors in the year 1963.
- The number 741 indicates that this operational amplifier IC has 7 functional pins, 4 pins capable of taking input and 1 output pin.

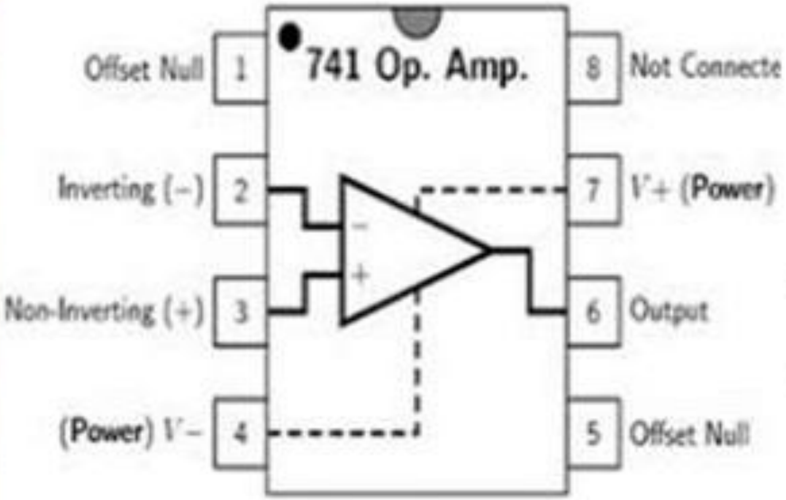


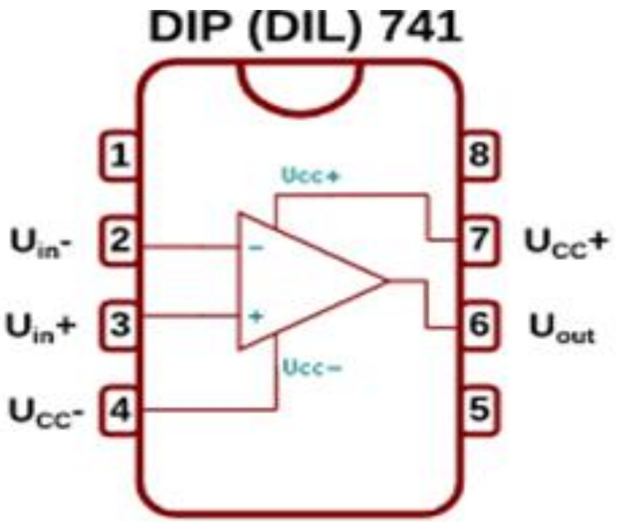
Operational Amplifier (IC 741)

- **Pin4 & Pin7 (Power Supply):** Pin7 is the positive voltage supply terminal and Pin4 is the negative voltage supply terminal. The between 5V and 18V.
- **Pin6 (Output):** This is the output pin of IC 741. The voltage at this pin depends on the signals at the input pins and the feedback mechanism used.
- **Pin2 & Pin3 (Input):** Pin2 is the inverting input and Pin3 is the non-inverting input. These are input pins for the IC.
- **Pin1 & Pin5 (Offset Null):** Because of high gain provided by 741 Op-Amp, even slight differences in voltages at the inverting and non-inverting inputs, caused due to irregularities in manufacturing process or external disturbances, can influence the output. To nullify this effect, an offset voltage can be applied at pin1 and pin5, and is usually done using a potentiometer.
- **Pin8 (N/C):** This pin is not connected to any circuit inside 741 IC. It’s just a dummy lead used to fill the void space in standard 8 pin packages.

Operational Amplifier (IC 741)





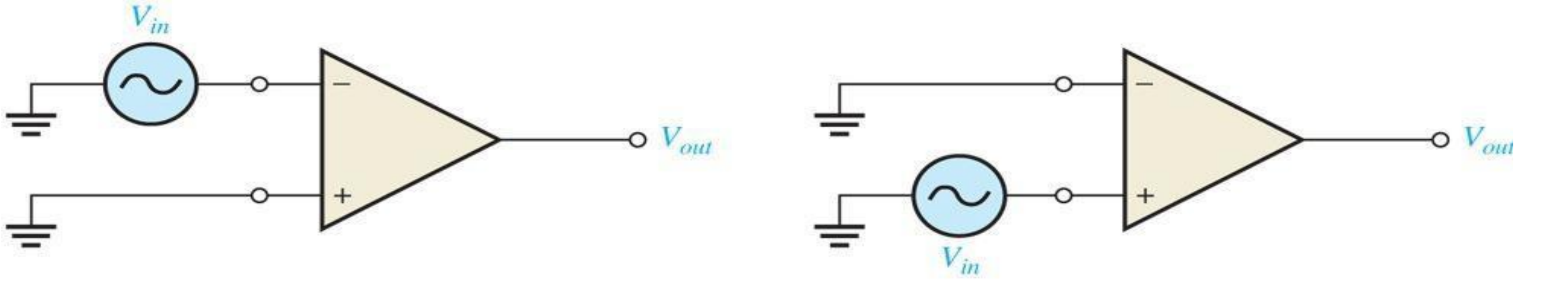


Operational Amplifier Properties

Op-Amp Input Modes

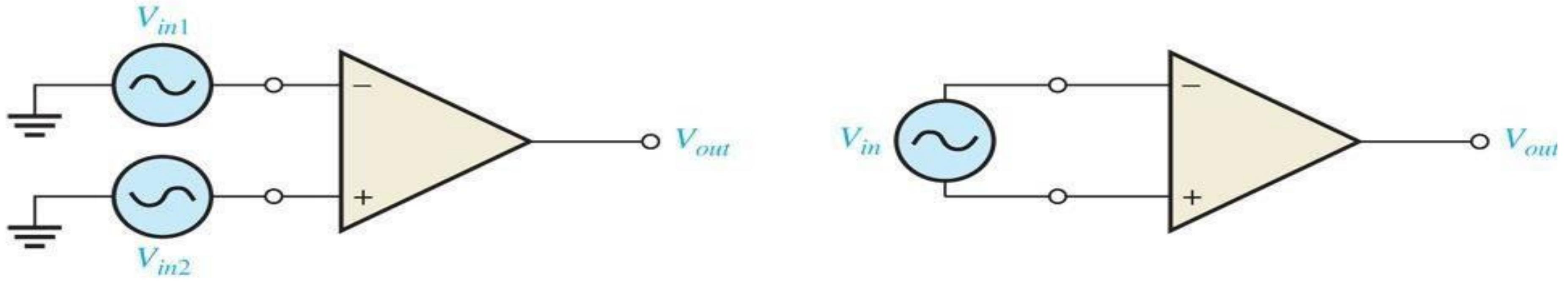
Differential Mode

The differential mode occurs if one input is applied while the other input is grounded (**Single-ended**)



(a) (b)

Or opposite polarity signal are applied to the inputs (**Double- ended**)

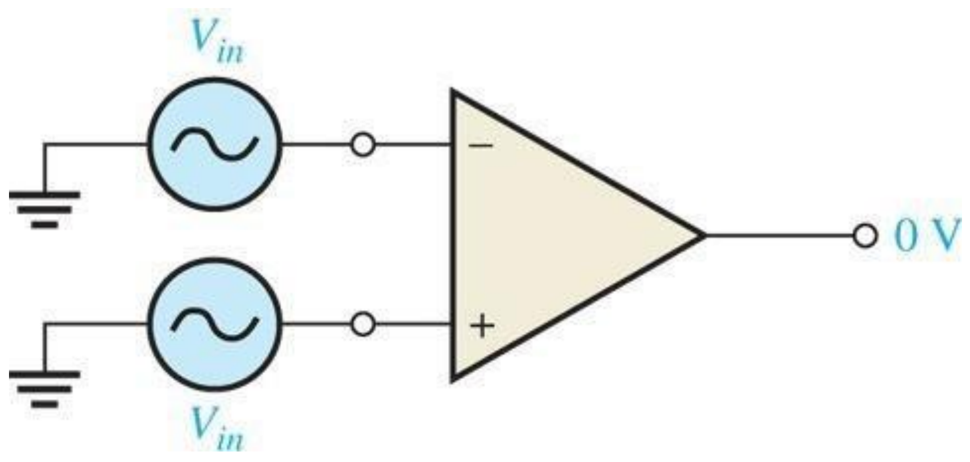


(a) (b)

Op-Amp Input Modes

The Common Mode

- In common mode, two signals voltages of the same amplitude, frequency and phase are applied to the two inputs.
- The same input tend to cancel each other and the output is zero (Common Mode Rejection Ratio CMRR).
- It is useful to reject unwanted signal that appears to both inputs. It is cancelled and does not appear at the output



Op-Amp Parameters

Open-Loop Voltage Gain A_{ol}

- The open-loop voltage gain of an op-amp is the internal voltage gain of the device and represents the ratio of output voltage to input voltage when there are no external components, Open-loop voltage gain is in the range of **200,000 (106 dB).**

Common-Mode Rejection Ratio CMRR

- The ability of an amplifier to reject the common-mode input is a parameter called CMRR (common-mode rejection ratio).
- Op-amp have very low common-mode gain, A_{cm}, (much less than 1) while providing very high open-loop differential voltage gain A_{ol}.

$$CMRR = \frac{A_{ol}}{A_{cm}}$$

Op-Amp Parameters

Maximum Output Voltage Swing $V_{o(pp)}$

- Ideal op-amp have a maximum output voltage swing of $\pm V_{CC}$.
- In practical op-amp, $V_{o(pp)}$, varies with load resistance. The datasheet of KA**741**, for example, shows a typical $V_{o(pp)}$ of ±13V for a $V_{CC} = \pm$ 15V when R_L =2KΩ and $V_{o(pp)}$ of ± 14V when R_L =10KΩ .

Input Offset Voltage (V_{os} or V_{Io})

- The amount of differential input voltage required between the inputs to force the output to zero volts is the input offset voltage, V_{os} or V_{Io}.
- Ideal op-amp produce zero output voltage if the differential input is zero, so V_{out} = 0 for V_{os} =0 .
- Typical value of V_{Io} is about 2mV.

Op-Amp Parameters

Input Offset Current (I_{OS})

- The input offset current is the difference of the input bias currents given as

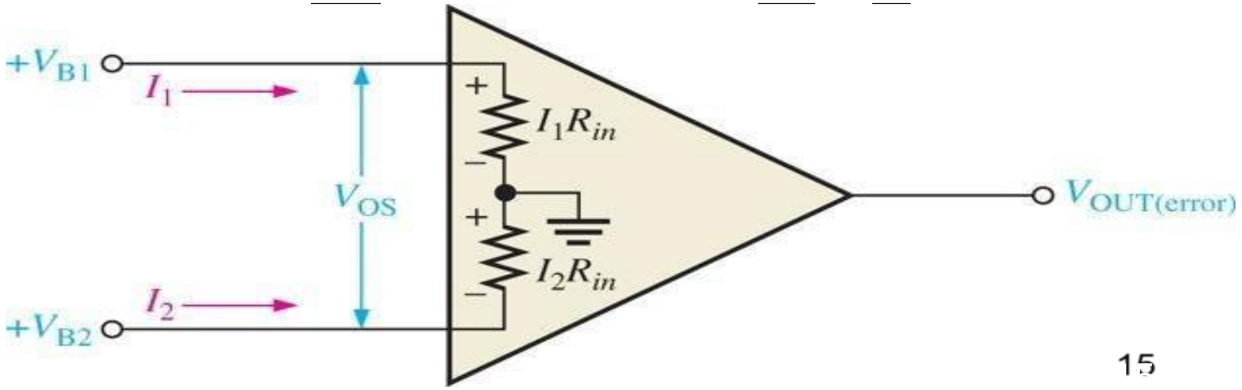
$$I_{OS} = |I_1 - I_2|$$

- It should be as low as possible for op-amps with high voltage gain and high input impedance as it develops an offset voltage given as

$$V_{OS} = I_{OS} R_{in}$$

- This input offset voltage is amplified by voltage gain of the op-amp and appears at the output as $V_{out}(error)$ given by

$$V_{out}(error) = Av\, I_{OS} R_{in}$$

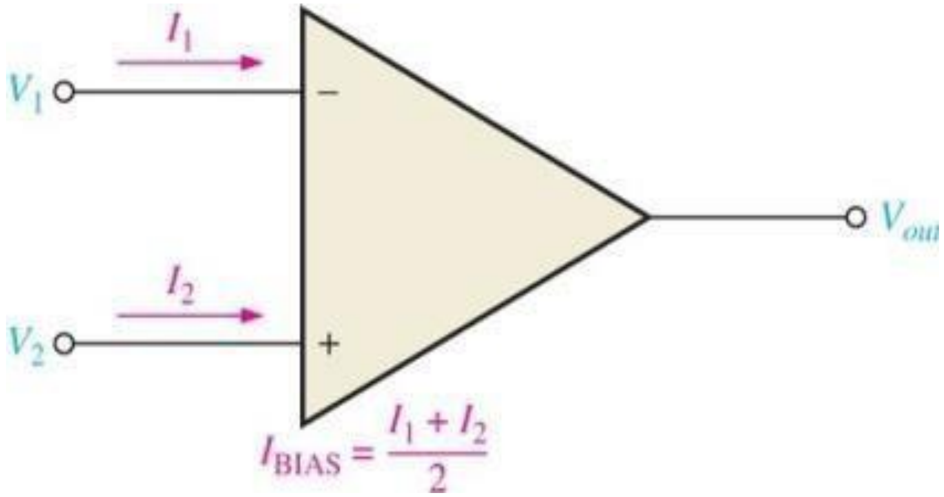


Op-Amp Parameters

Input Bias Current (I_{BIAS})

- The input bias current is the DC current required by the inputs of the op-amp to operate the first stage of the op-amp.

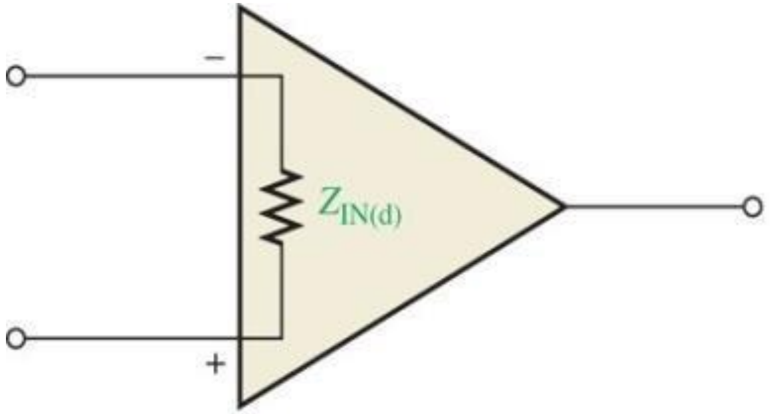
$$I_{BIST} = \frac{I_1 + I_2}{2}$$



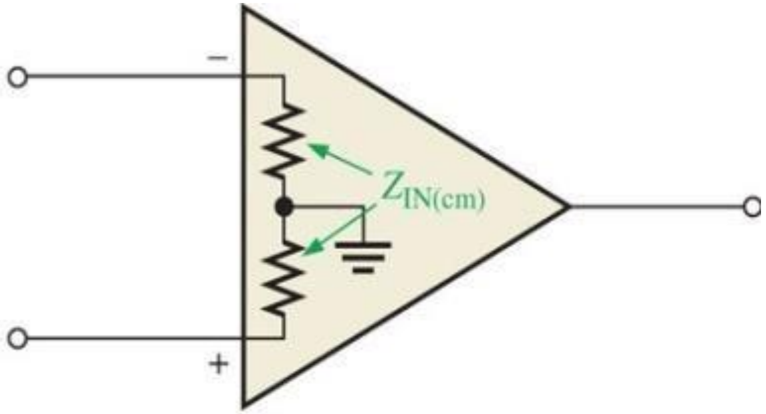
Op-Amp Parameters

Input Impedance

- The input impedance of an op-amp is specified in two ways: differential input impedance and common-mode input impedance.
- Differential input impedance, Z_{IN}(d), is the total resistance between inverting and noninverting input.
- Common-mode input impedance, Z_{IN}(cm), is the resistance between each input and ground.



(a) Differential input impedance

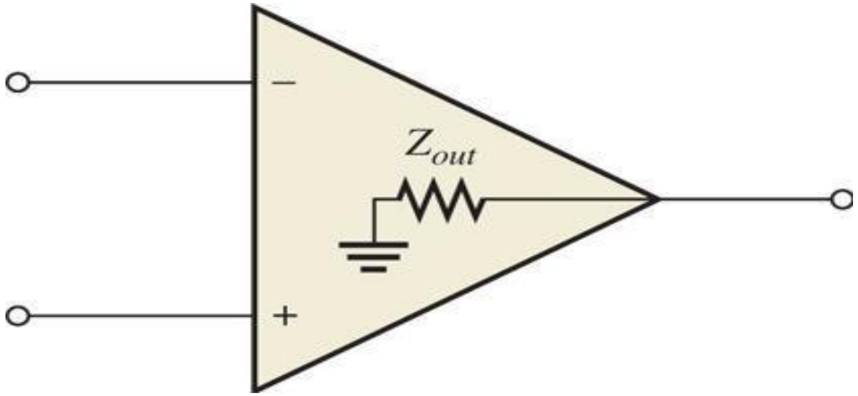


(b) Common-mode input impedance

Op-Amp Parameters

Output Impedance

The output impedance is the resistance as seen from output of the op-amp.

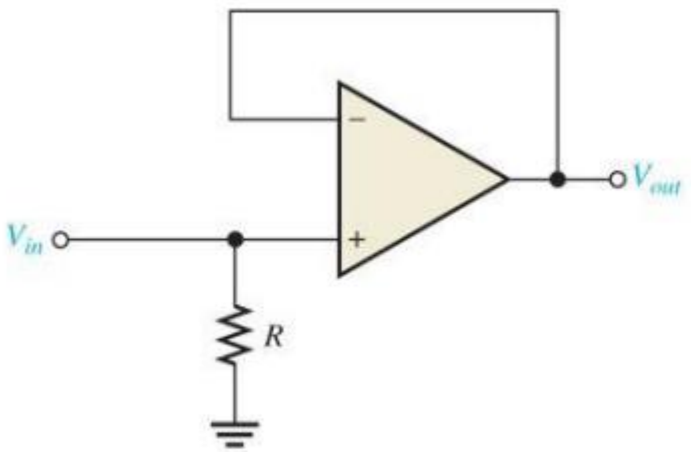


Op-Amp Parameters

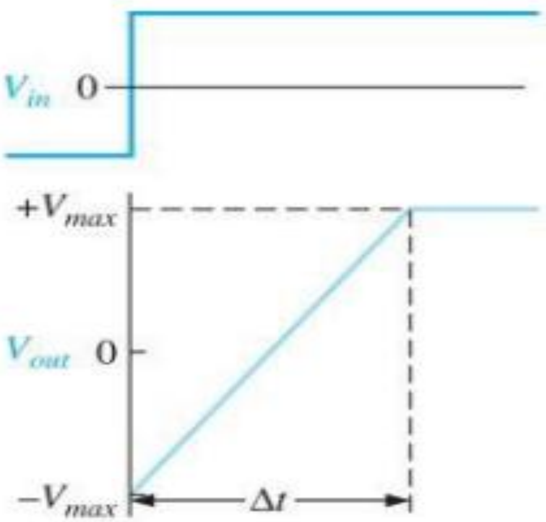
Slew Rate

The maximum rate of change of the output voltage in response to a step input voltage is the slew rate of an op-amp.

$$\boxed{\textit{Slew Rate} = \frac{+V_{max} - (-V_{max})}{\Delta t} = \frac{\Delta V_{out}}{\Delta t}}$$



Test circuit



Step input voltage and the resulting output voltage