RIZVI COLLEGE OF ARTS, SCIENCE & COMMERCE

Sub: ELECTRONICS (Bifocal)

Std : XII

Chapter/Topic : <u>**_Op - Amp_**</u>

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Dept : Bifocal Electronics Junior College

Op Amp means

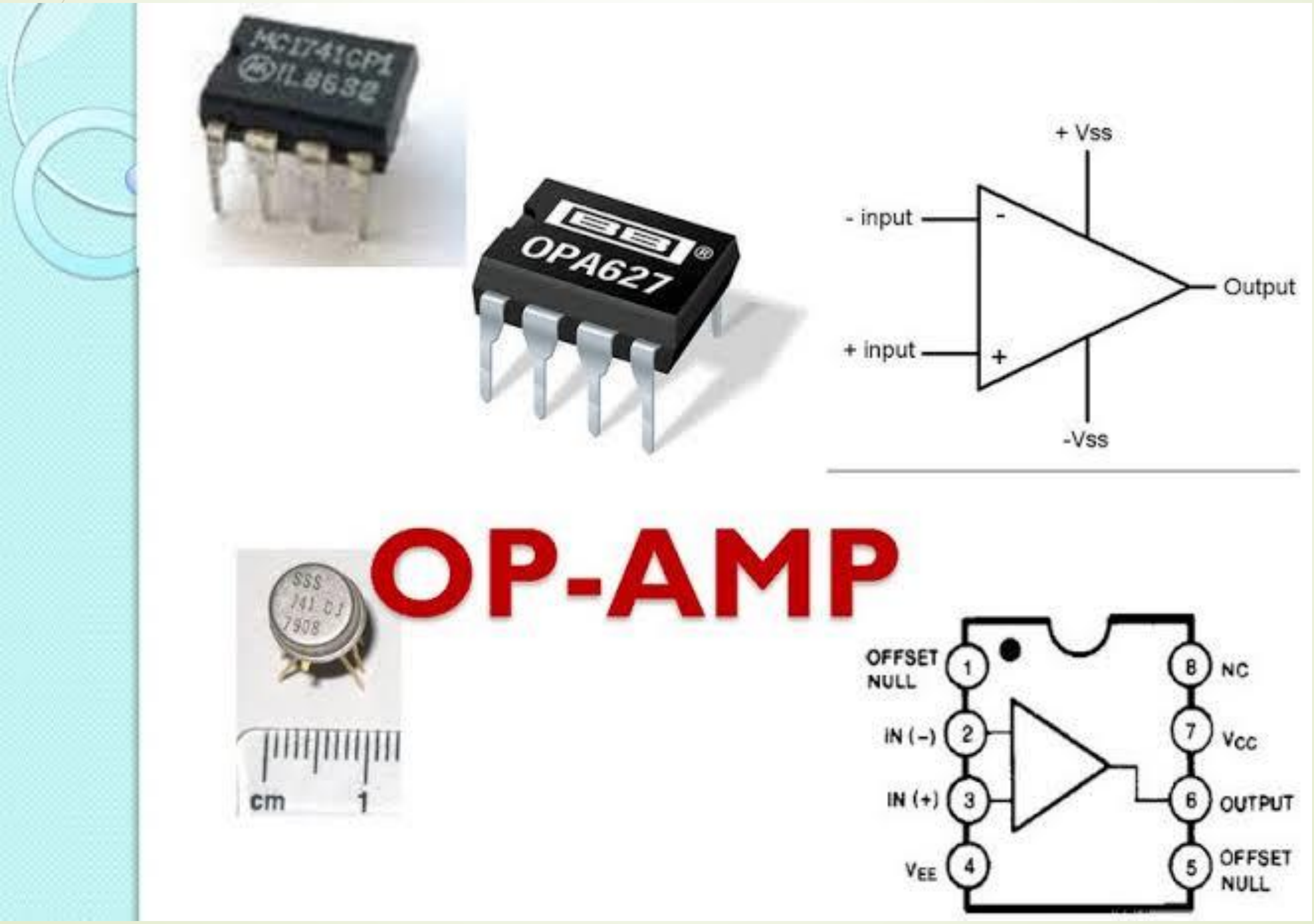
Operational Amplifier

It performs

Mathematical Operations Like
Addition, Subtraction, Integration, Differentiation

Amplification means
Increasing Amplitude of input signal

DIL Pack , Symbol ,



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- An amplifier with high gain and high input impedance (usually with external feedback), used especially in circuits for performing mathematical operations on an input voltage.
- An operational amplifier is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op-amp produces an output potential that is typically hundreds of thousands of times larger than the potential difference between its input terminals

Contents

- Introduction
- OPAMP Symbol
- Internal block diagram
- Open-loop configuration
- Common mode rejection ratio CMRR
- Slew Rate
- OPAMP equivalent circuit
- Ideal OPAMP characteristics
- Closed-loop configuration

Applications

- Inverting Amplifier
- Non-inverting Amplifier
- Summing Amplifier Difference Amplifier
- Differentiator
- Integrator
- Buffer

Reference book

- OPAMPS and Linear Integrated Circuits
  by Ramakanth Gayakwad

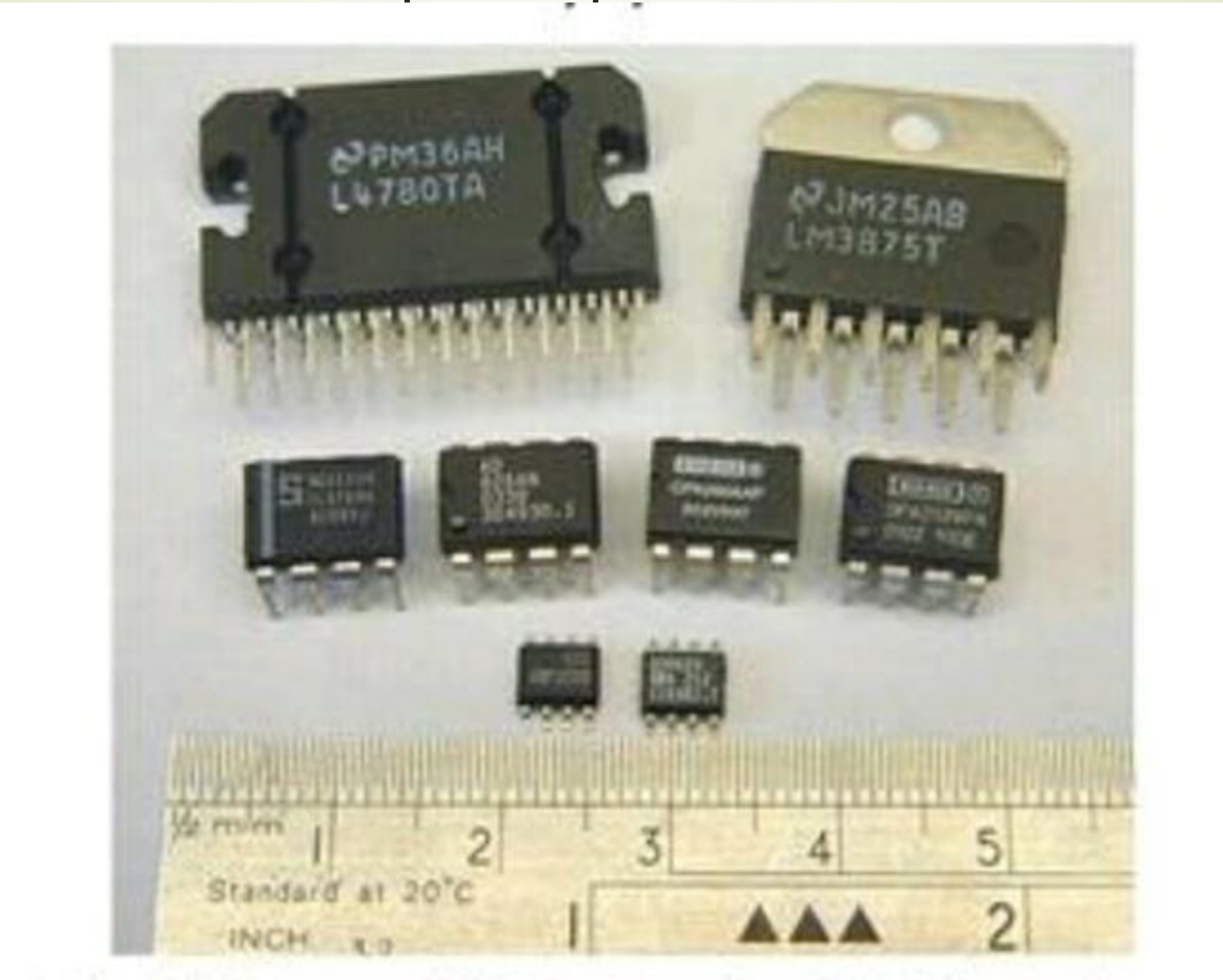
Introduction

- Op-AMP is a very high gain amplifier fabricated on Integrated Circuit (IC)
- Combination of many transistors, FETs, Resistors in a pin head space
- Finds application in
  - Audio amplifier
  - Signal generator
  - Signal filters
  - Biomedical Instrumentation
    - And numerous other applications

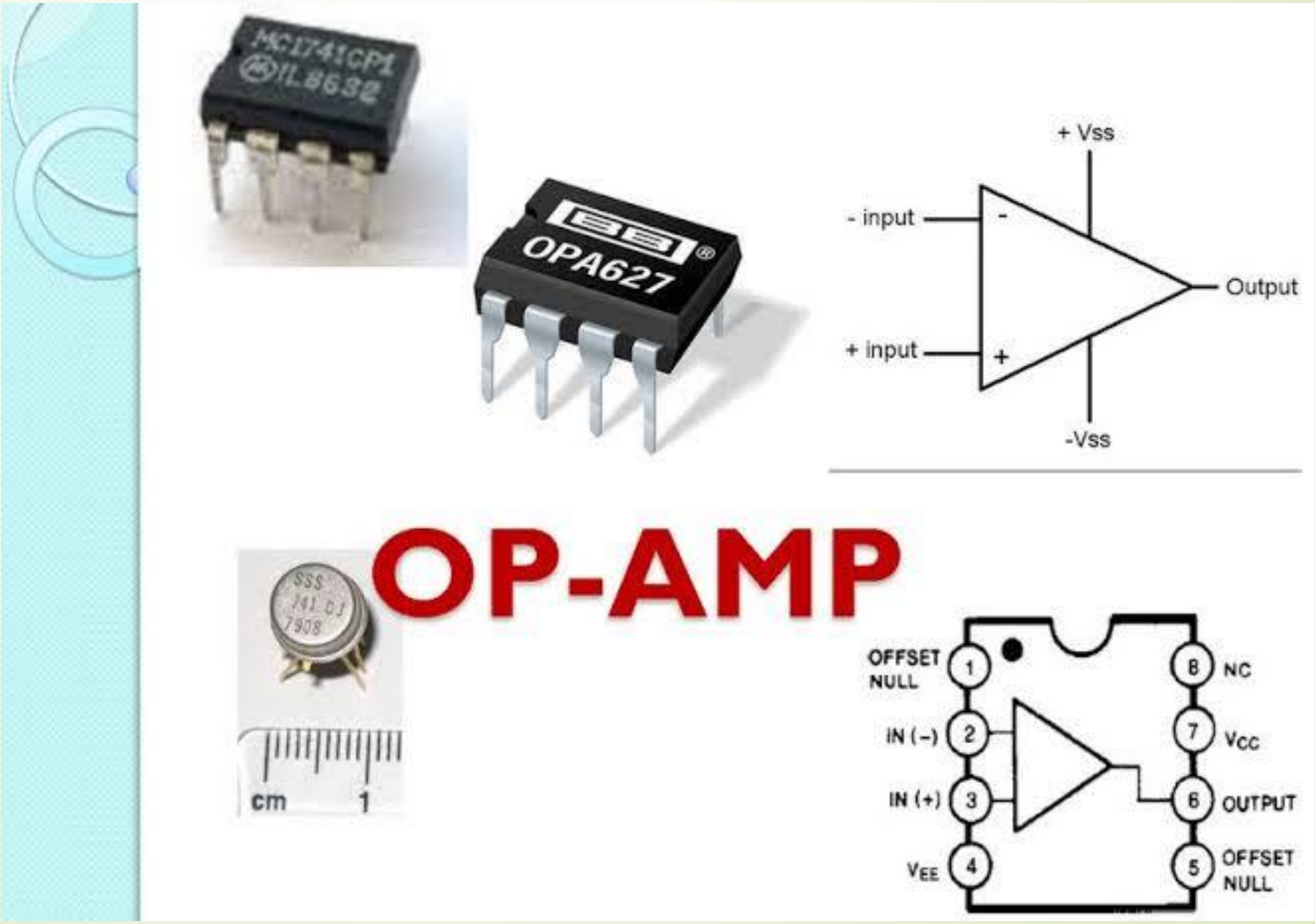
Introduction

- Advantages of OPAMP over transistor amplifier
  - Less power consumption
  - Costs less
  - More compact
  - More reliable
  - Higher gain can be obtained
  - Easy design

How OpAmp Looks Like



Ic Pin Diagram, Symbol



OpAmp Pin counting Notch

Uses

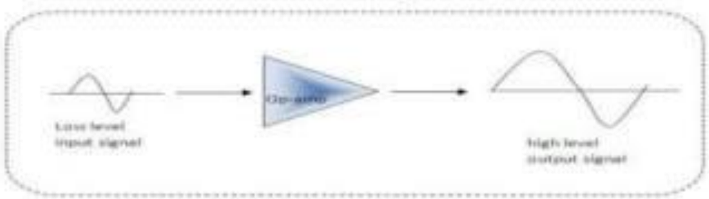
741 general purpose op-amp made by Fairchild Semiconductor

An op amp is an active circuit element designed to perform mathematical Operations of addition, subtraction, multiplication, division, differentiation, and integration.

More info

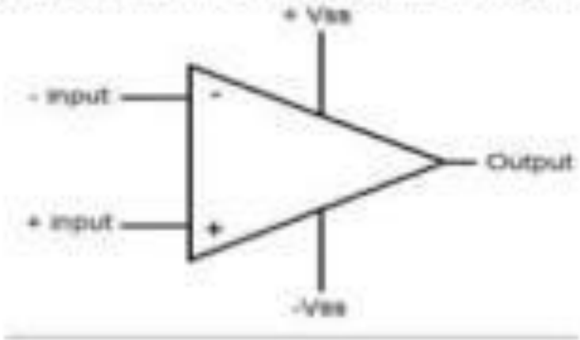
What is Op-Amp ?

- An Operational Amplifier (Op-Amp) is an integrated circuit that uses external voltage to amplify the input through a very high gain .
- Operation Amplifier circuit designed to boost the power of low level signal



WHAT IS OP-AMP?

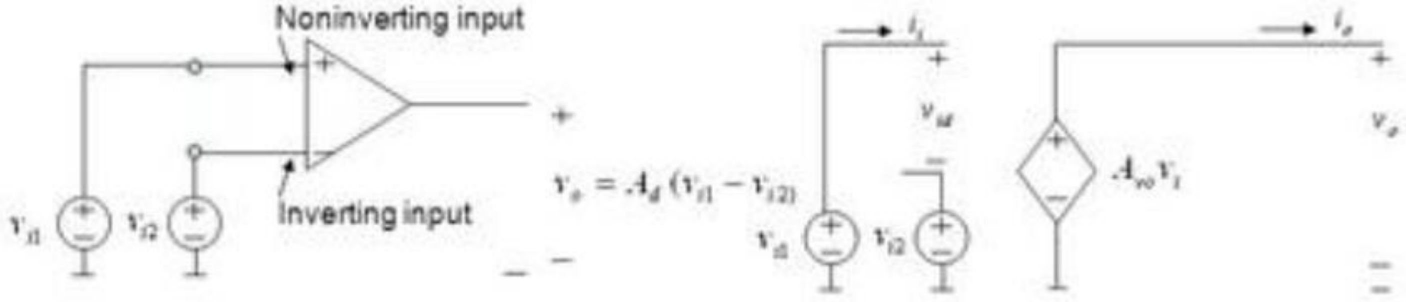
✓ An operational amplifier (op-amp) is a DC-coupled high-gain electronic voltage amplifier
✓ Direct- coupled high gain amplifier usually consisting of one or more differential amplifiers
✓ Output stage is generally a push-pull or push-pull complementary-symmetry pair.



✓ Op amps are differential amplifiers, and their output voltage is proportional to the difference of the two input voltages. The op amp's schematic symbol is shown in the above figure
✓ The two input terminals, called the inverting and non-inverting, are labeled with - and +,
respectively.

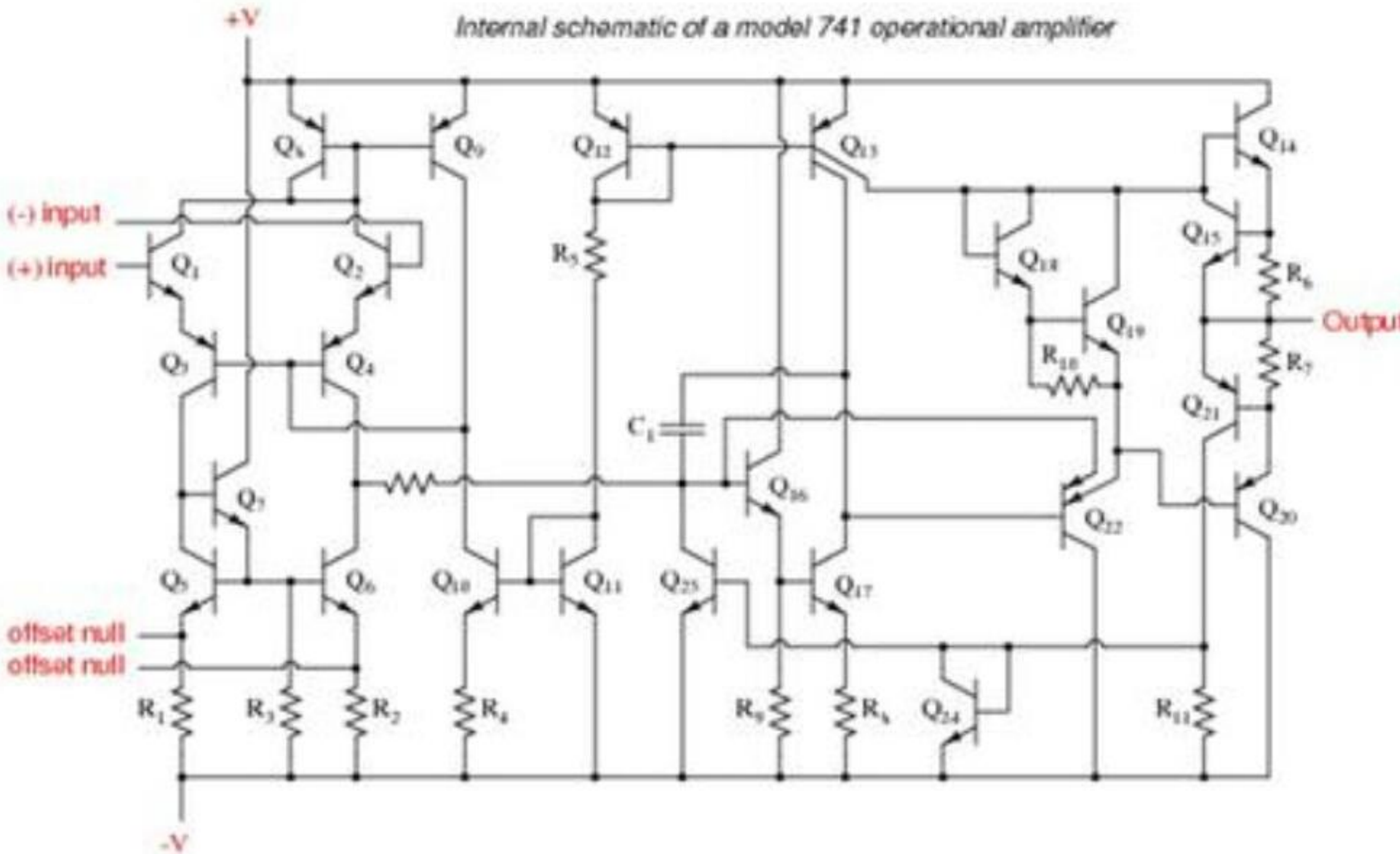
Operational amplifier

- Operational amplifier, or simply *OpAmp* refers to an integrated circuit that is employed in wide variety of applications (including voltage amplifiers)

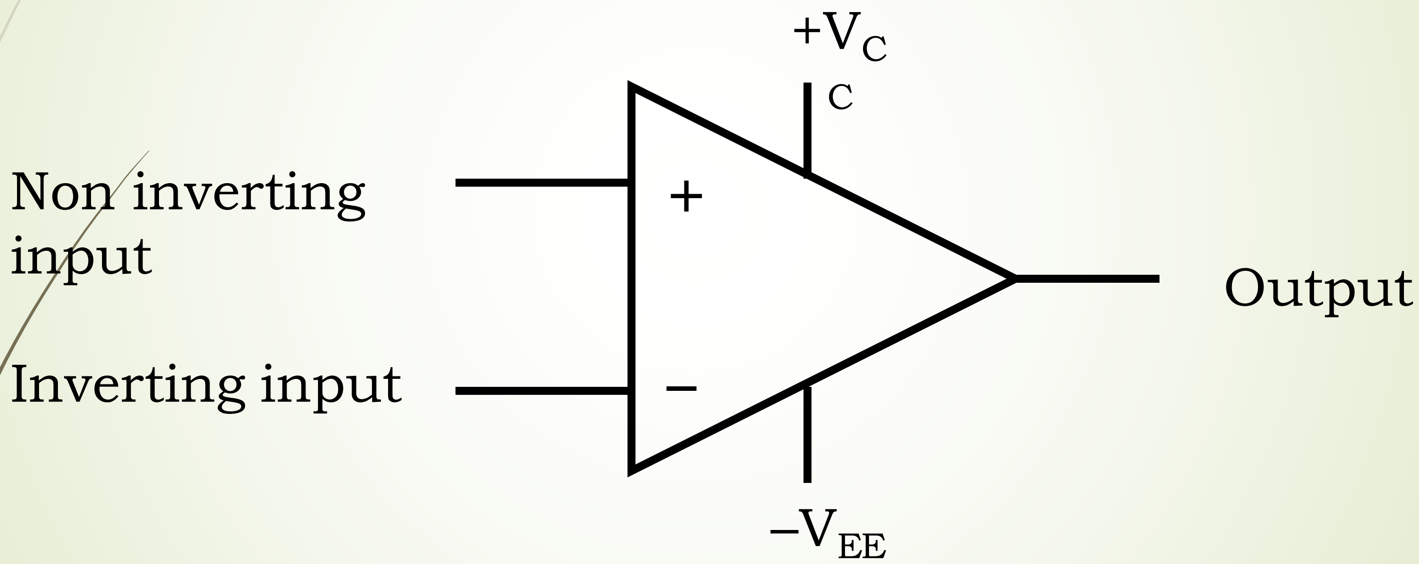


- OpAmp is a differential amplifier having both inverting and non-inverting terminals
- What makes an ideal OpAmp
  - infinite input impedance
  - Infinite open-loop gain for differential signal
  - zero gain for common-mode signal
  - zero output impedance
  - Infinite bandwidth

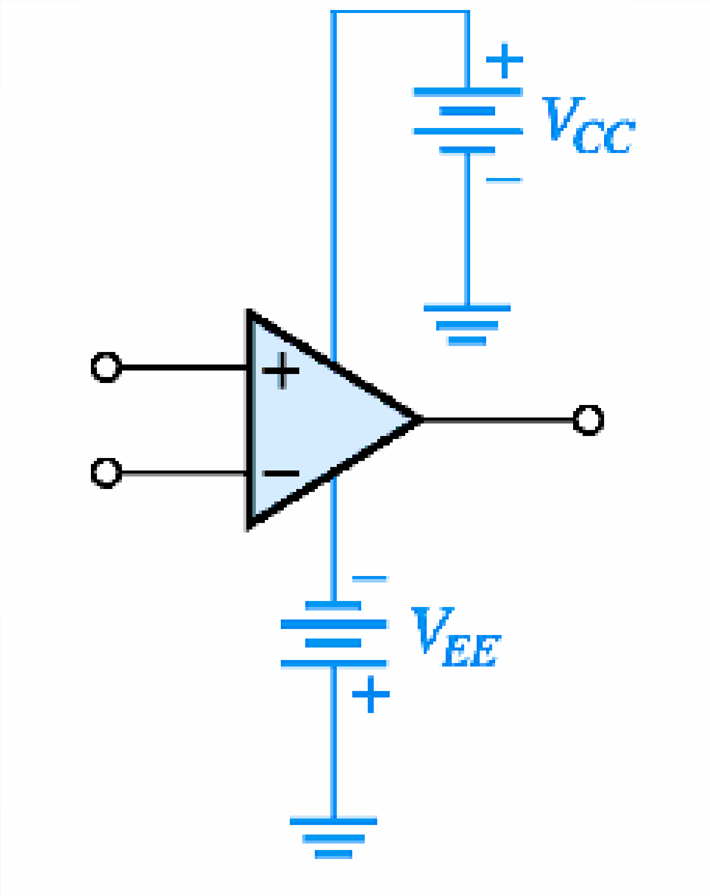
Operational Amplifiers (Op-Amps)



OPAMP terminals



OPAMP terminals



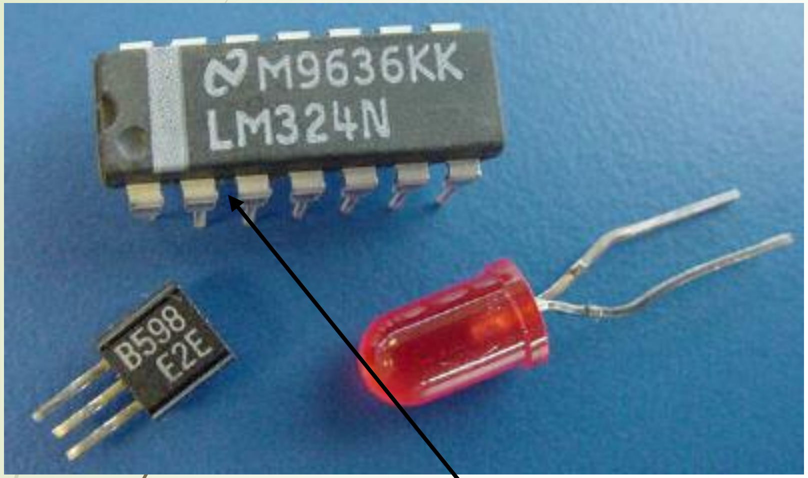
OPAMP terminals

- 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

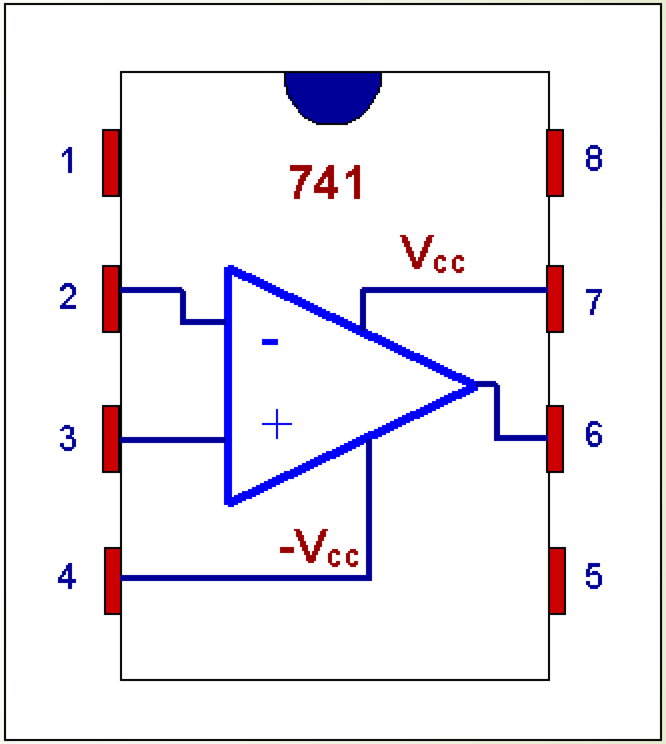
OPAMP terminals

- 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

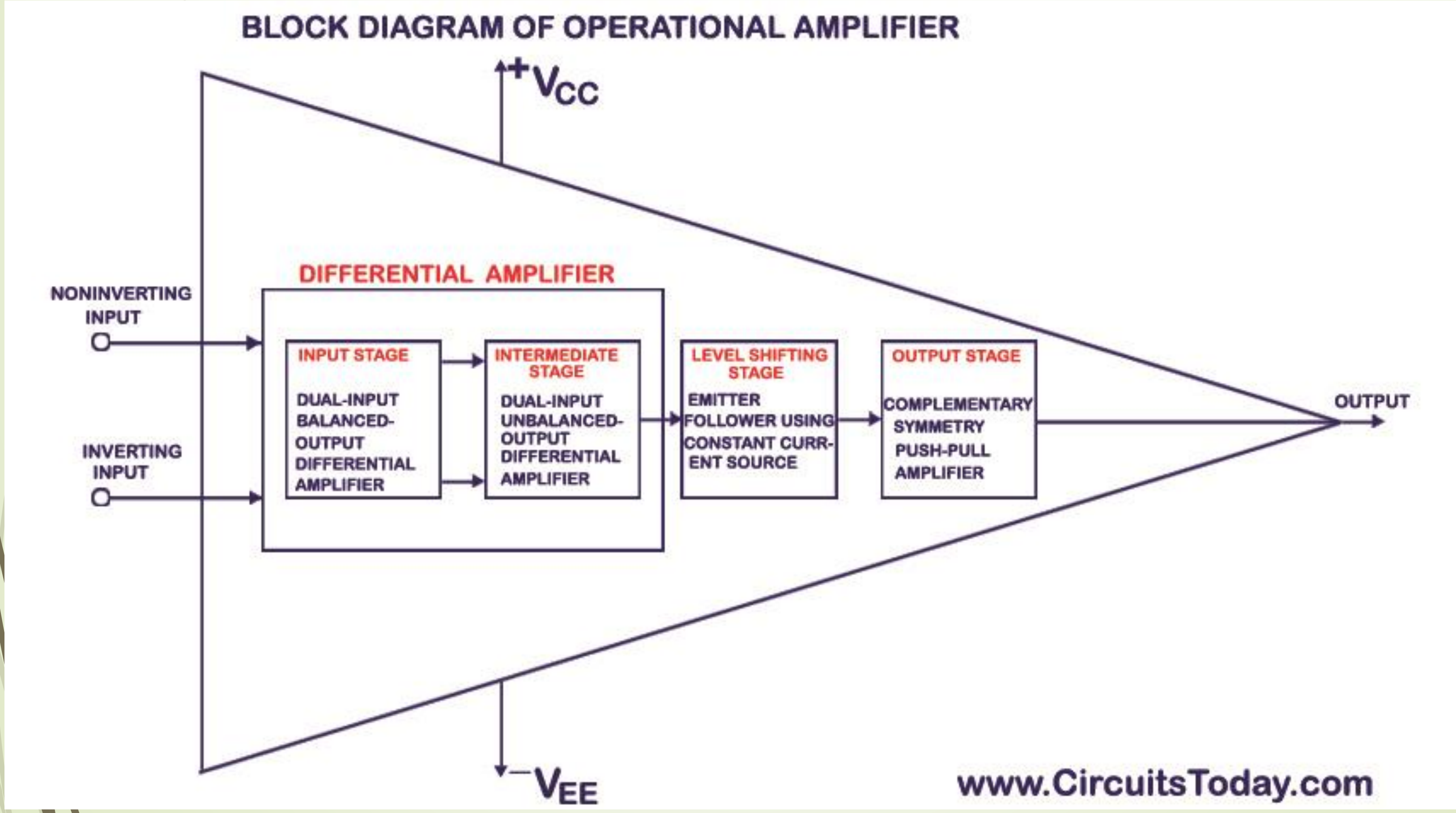
OPAMP terminals



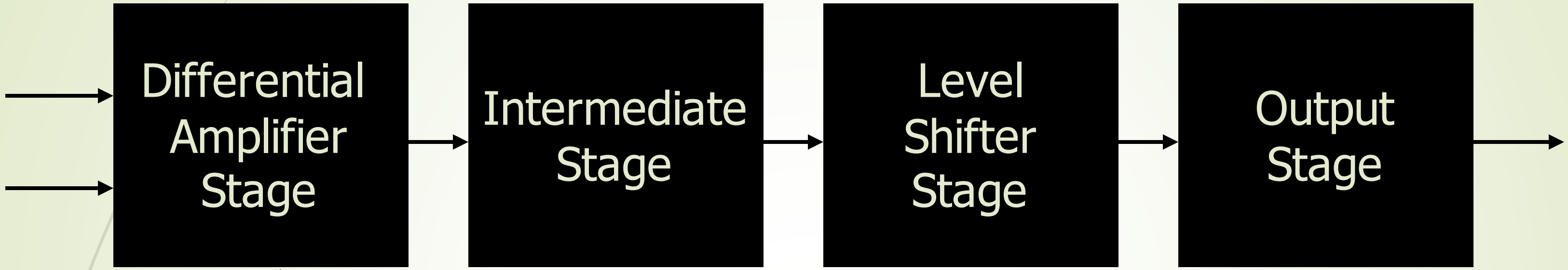
Integrated Circuit



Block Diagram of OpAmp



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

Internal Block Diagram

- 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

Balanced I/P Balanced O/P

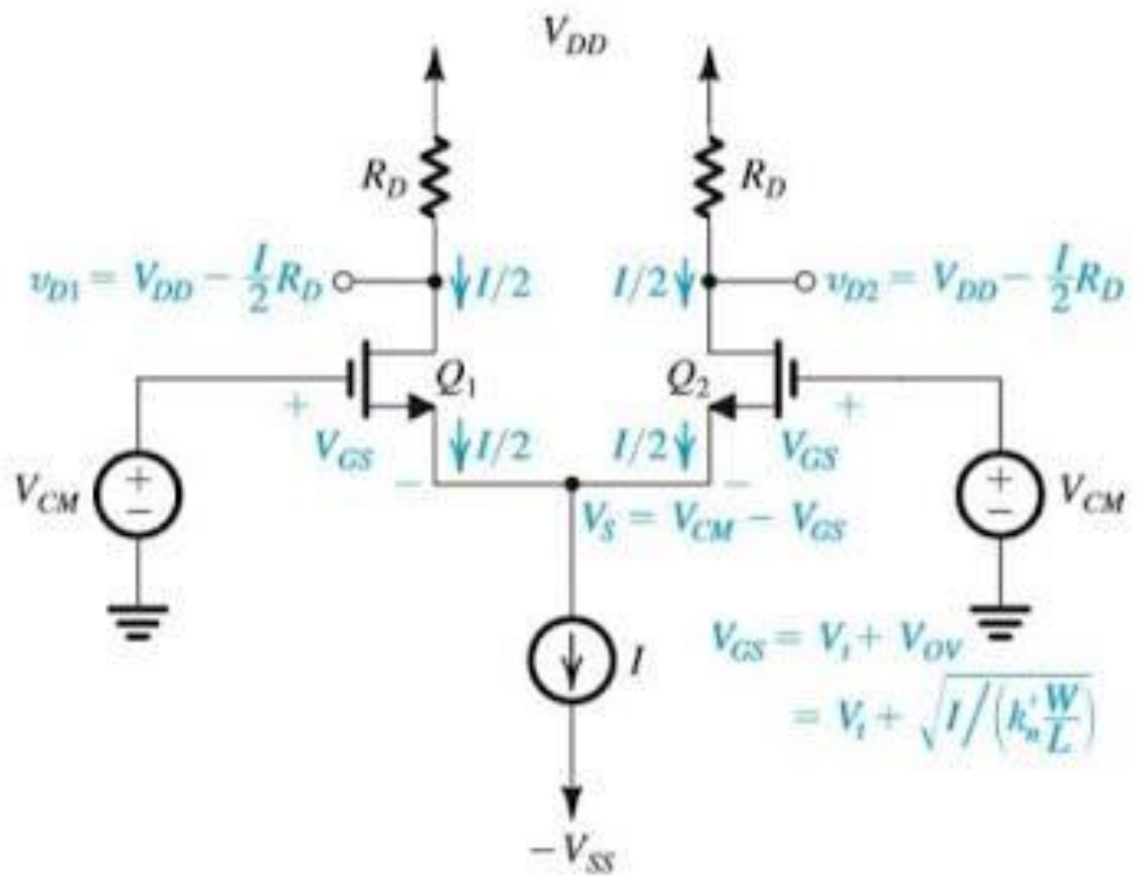
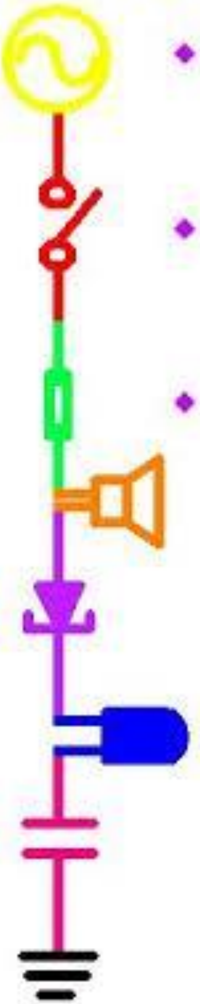


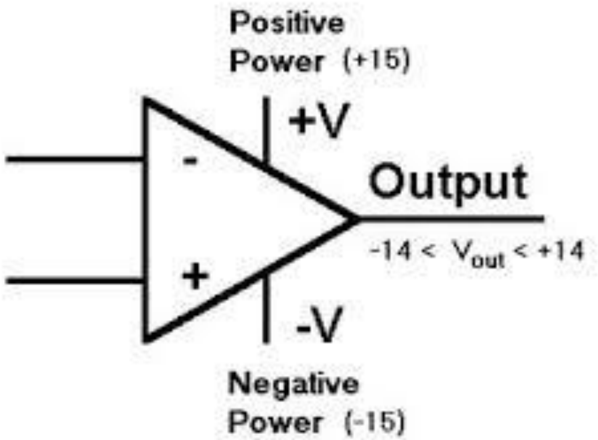
Figure 9.2 The MOS differential pair with a common-mode input voltage V_{CM}.

Powering the Op-Amp

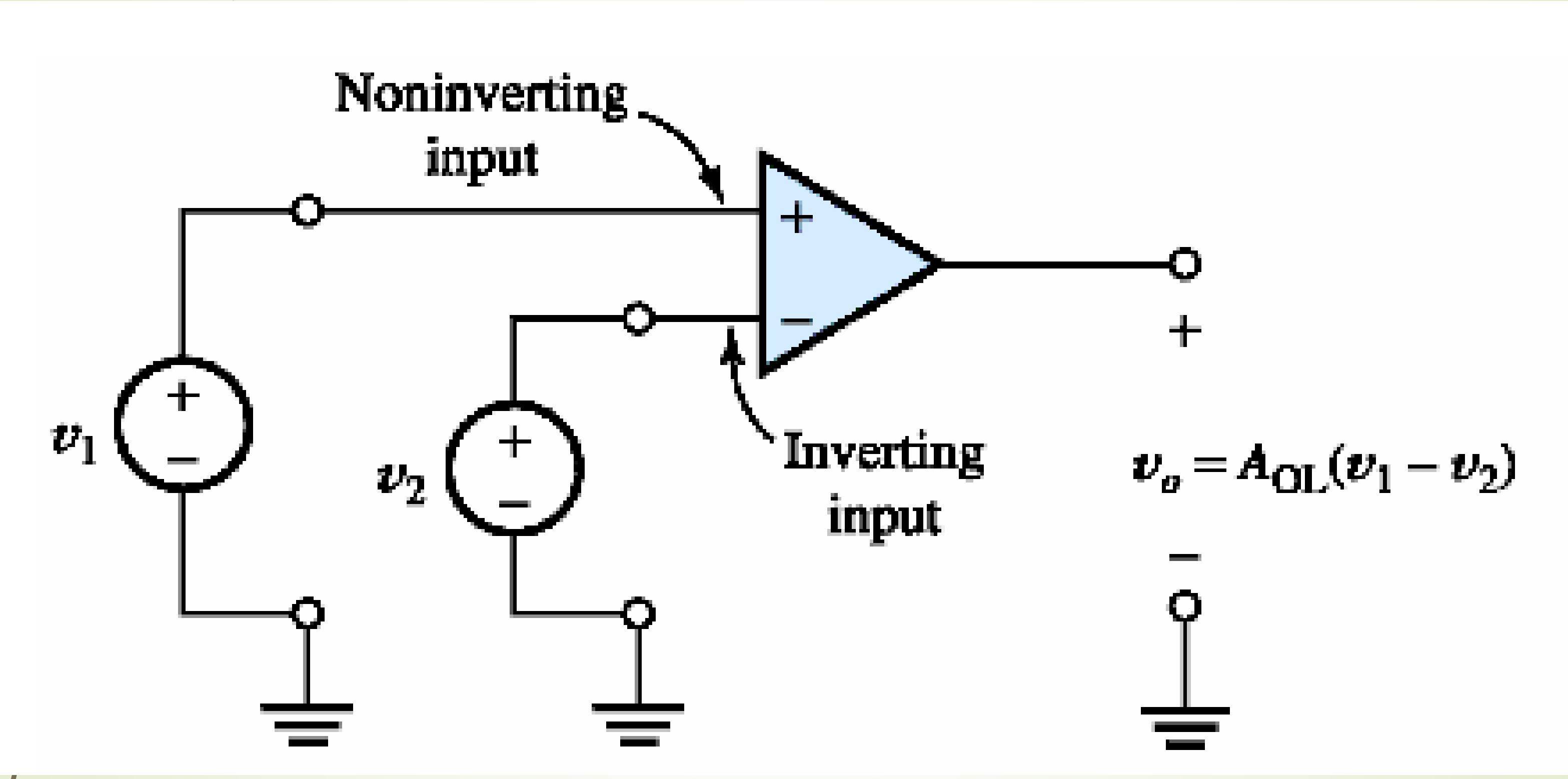


- Since op-amps are used as amplifiers, they need an external source of power.
- The op-amp must be connected to an external constant DC source in order to function.
- Typically, this source will supply +15V at +V and -15V at -V. The op-amp will output a voltage range of of somewhat less because of internal losses.

The power inputs determine the output range of the op-amp. It can never output more than you put in. Here the maximum range is about 28 volts.



Open-loop configuration



If $v_1 = 0$, then $v_o = -A_{OL}v_2$ Inverting amplifier

If $v_2 = 0$, then $v_o = A_{OL}v_1$ Non inverting amp

Open-loop configuration

- A_{OL} is the open-loop voltage gain of OPAMP
  Its value is very high
  Typical value is 0.5 million
- So, even if input is in micro volts, output will be in volts
- But output voltage cannot cross the value of power supply V_{CC}
- So, if input is in mili volts, output reaches saturation value $V_{sat} = V_{CC}$ (or V_{EE})

Open-loop configuration

- If $v_1 = v_2$, then **ideally** output should be **zero**
- But in practical Op-Amp, there is output and equal to
- Vo = $A_{CM} (v_2 - v_1)$

Where, A_{CM} is the common-mode gain of Op-Amp

$$= A_d(\upsilon_1 - \upsilon_2) + A_{cm}\left(\frac{\upsilon_1 + \upsilon_2}{2}\right)$$

$$\upsilon_o = A_d \upsilon_{id} + A_{cm} \upsilon_{icm}$$

Open-loop configuration

- Common-mode rejection ratio
  - It is a measure of the ability of Op-Amp to reject the signals common to both input terminals (noise)
  - Defined as ratio of Differential mofe gain to Common mode gain.
  - CMRR = $A_{DM} \,/\, A_{CM}$

$$(CMRR)_{dB} = 20\log_{10}\left(\frac{A_d}{A_{cm}}\right)$$

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

Problems

- An OPAMP has differential voltage gain of 100,000 and CMRR of 60 dB. If non inverting input voltage is 150 μV and inverting input voltage is 140 μV, calculate the output voltage of OPAMP

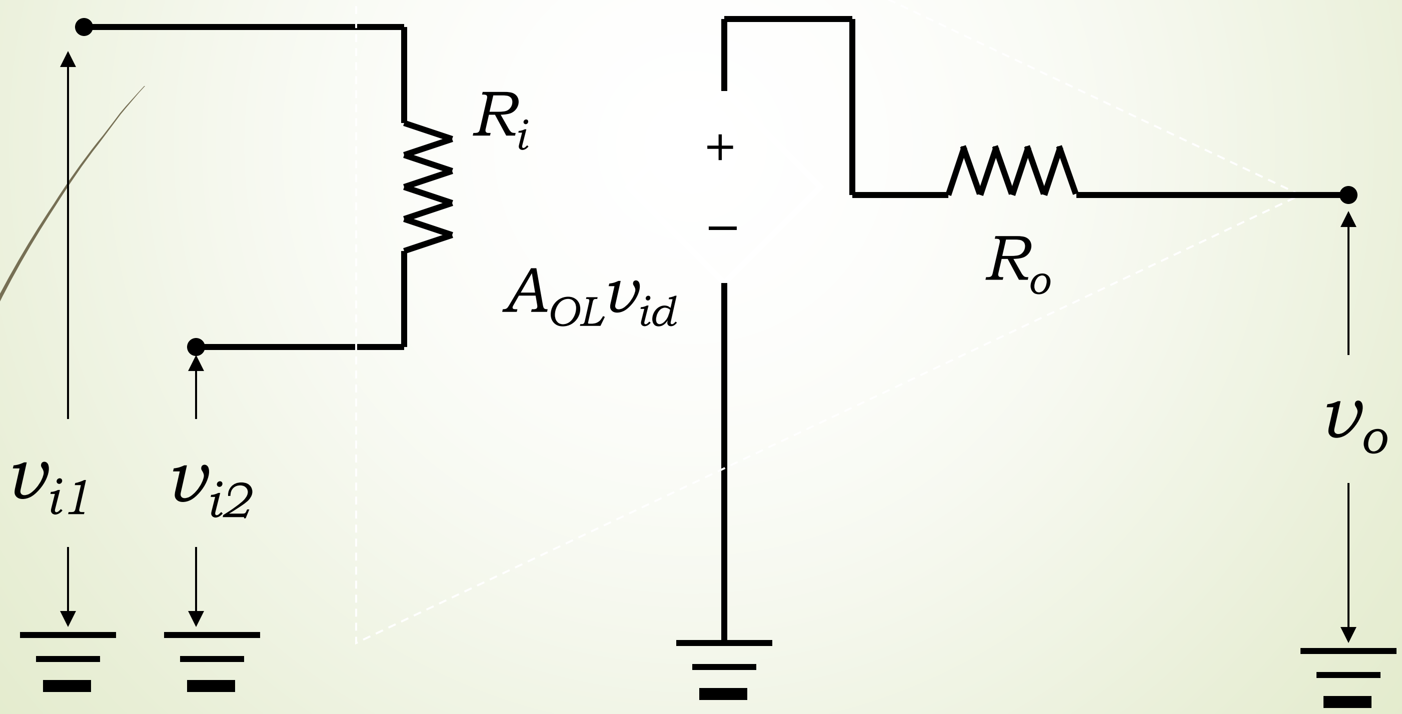
  Ans: 1.01 V

- For an OPAMP, when v1 is 0.5 mV and v2 is –0.5 mV, output voltage is 8 V. For the same OPAMP, when v1 = v2 = 1 mV, output voltage is 12 mV. Calculate the CMRR of the OPAMP

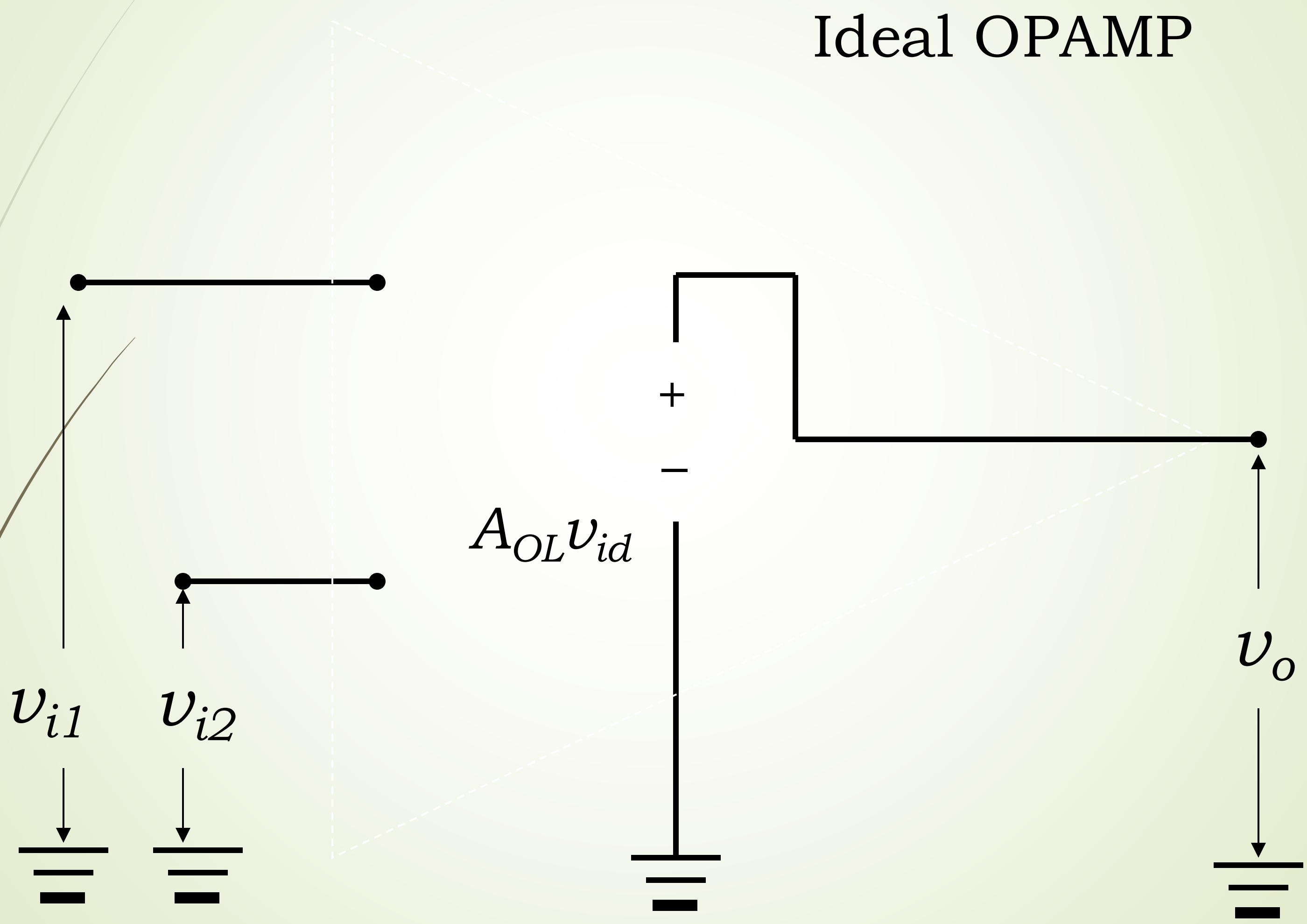
  Ans: 56.48 dB

OPAMP equivalent circuit

Practical OPAMP



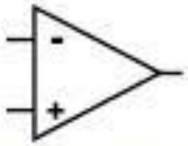
OPAMP equivalent circuit



Components - The Operational Amplifier

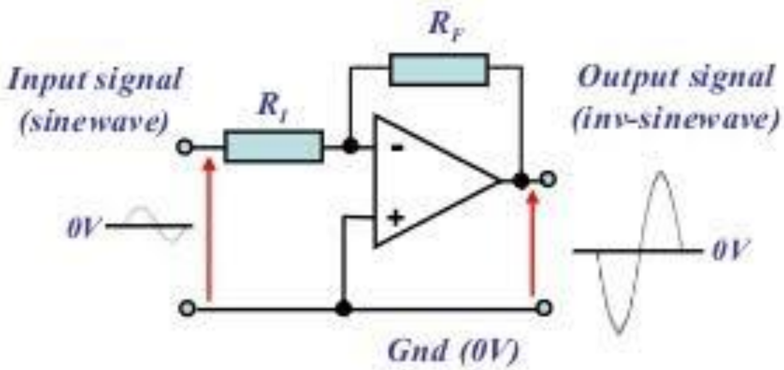
The operational amplifier (op-amp) is an extremely versatile device. Formed as an integrated circuit op-amps offer virtually infinite voltage gain and input resistance. The addition of two resistors will produce an amplifier with a precisely defined gain. Op-amps are Active components since they provide gain.

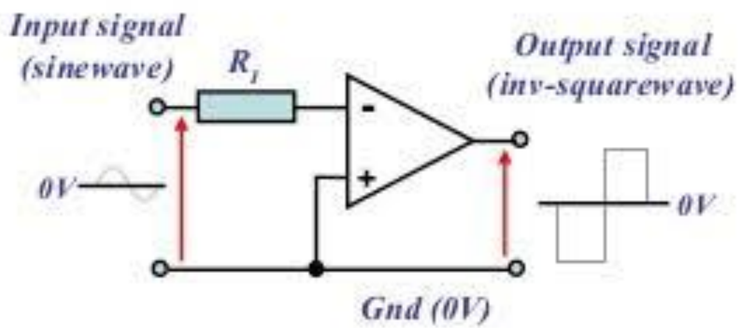
Example



Circuit Symbol

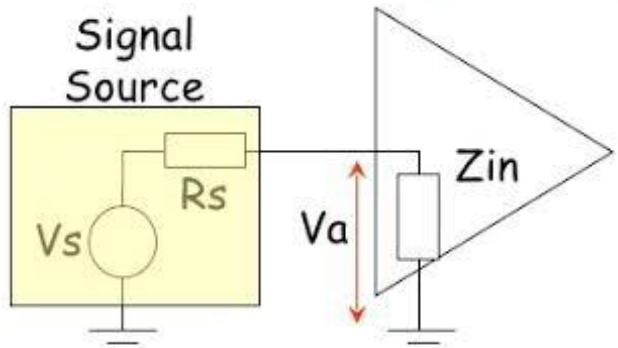
The op-amp can be used as a signal amplifier or as a comparator for example to increase the amplitude of a signal or switch on an LED.





Input Impedance

Input Impedance (Resistance)



Va is the voltage that appears on the input of the amplifier and will be amplified. Rs is the source resistance and cannot be altered.

Note Va does not equal Vs

$$Va = \frac{Vs \times Zin}{Rs + Zin}$$

How can we make $Va = Vs$?

Zin should be as large as possible so that $Zin + Rs \approx Zin$

If this is so then $Va = Vs$

Therefore we may wish to look for an amplifier with a very large input impedance.

Ideal Characteristics

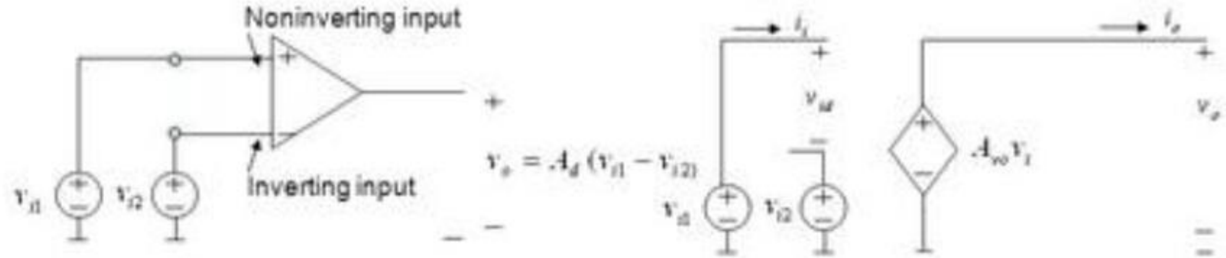
- Ideal OPAMP
  - Infinite differential mode gain. Adm = Infinite
  - Infinite input Impedance.
  - Infinite CMRR
  - Infinite bandwidth
  - Infinite slew rate

  - Zero common mode gain Acm =0
  - Zero output impedance.
  - Zero input offset voltage
  - Zero input offset current
  - Zero output offset voltage

Ideal Characteristics

Operational amplifier

- Operational amplifier, or simply *OpAmp* refers to an integrated circuit that is employed in wide variety of applications (including voltage amplifiers)



- OpAmp is a differential amplifier having both inverting and non-inverting terminals
- What makes an ideal OpAmp
  - infinite input impedance
  - Infinite open-loop gain for differential signal
  - zero gain for common-mode signal
  - zero output impedance
  - Infinite bandwidth

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

OPAMP Characteristics

- 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

OPAMP Characteristics

- Output offset voltage V_{oo}
  - It is the output voltage when both input voltages are zero
  - Denoted as V_{oo}
- 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
  - $V_{io} = |v_1 - v_2| \quad \text{for } v_o = 0$

OPAMP Characteristics

- 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 $v_1 = v_2 = 0$

OPAMP Characteristics

- 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 (Not in portion)

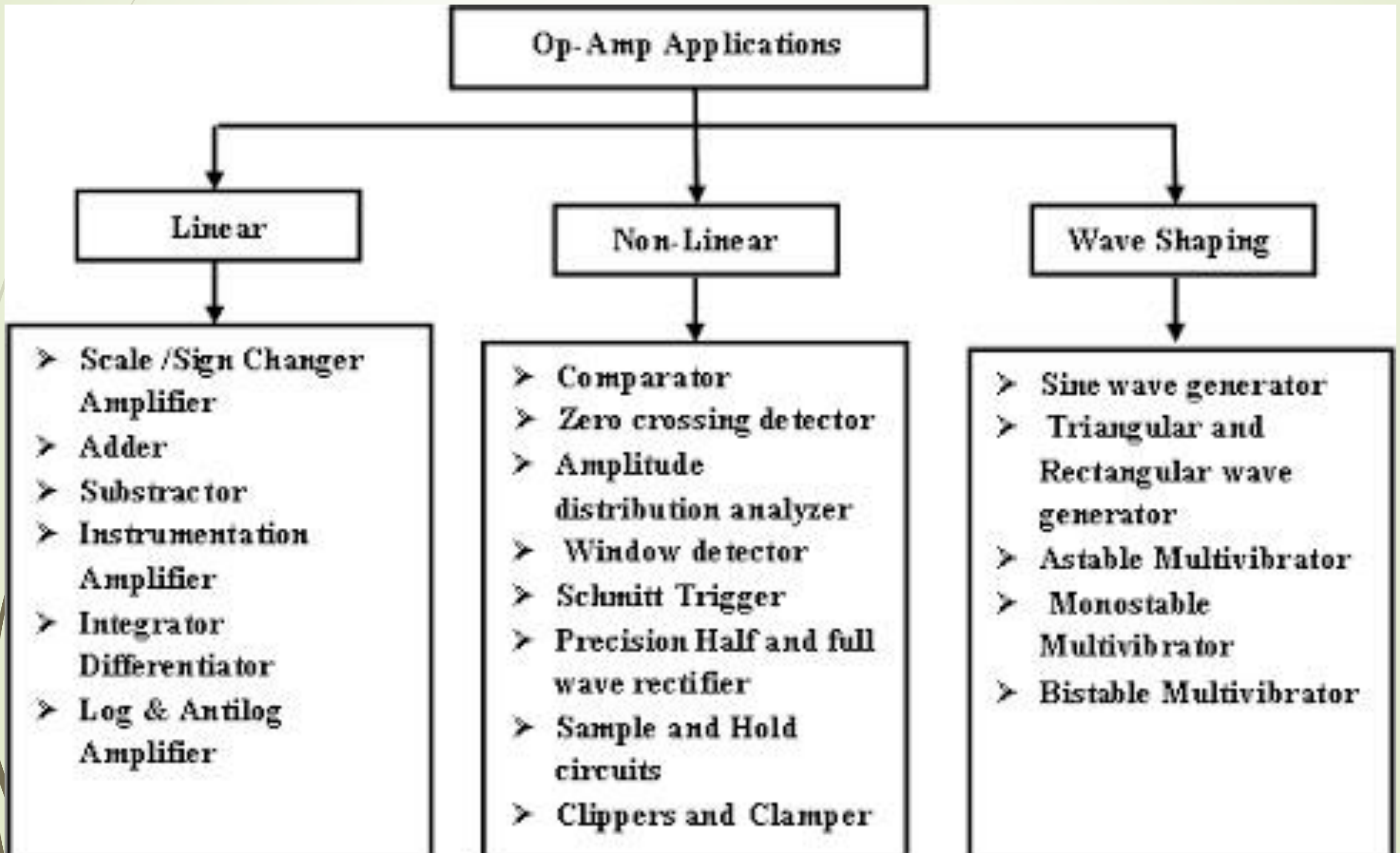
OPAMP Characteristics / Specifications.

- Practical characteristics of 741C OPAMP
  - Differential mode gain is 200,000
  - CMRR is 90 dB
  - Input resistance is 2 MΩ
  - Output resistance is 75 Ω
  - Unity-gain Bandwidth is 1 MHz
  - Slew rate is 0.5 V / μs
  - Output offset voltage is 1 mV
  - Input offset current is 20 nA
  - Input bias current is 80 nA

Closed-loop configurations

- Open-loop voltage gain of OPAMP is very high; such high gain is not required in most applications. Ideal gain is infinite.
- In order to reduce gain, a part of output signal is fed back to the inverting input terminal (called negative feedback).
- Many other OPAMP characteristics are improvised with this.

Applications of Op Amp



Linear Applications

LINEAR APPLICATIONS

- Adder
- Subtractor
- Voltage follower
- Current to voltage converter
- Voltage to current converter
- Integrator
- Differentiator
- Active filters

Non Linear Applications

Non-linear applications

- Comparators
- Logarithmic amplifiers
- Exponential amplifiers
- Peak detectors
- Precision rectifiers
- Waveform generators
- Clippers & clampers

What We are going to Study

Linear Applications of OP-AMP

- There are many applications of an OP-AMP.

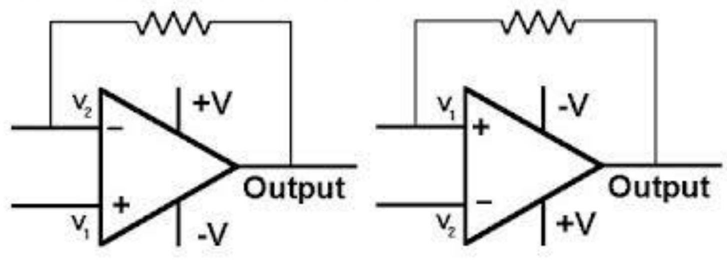
1. Voltage Adder (Summing Amplifier)
2. Difference Amplifier
3. Integrator
4. Differentiator
5. Voltage Follower & etc…

Non linear Applications

- ***Comparator : Without FeedBack (Feed back = Infinite)***
- **Schmitt trigger : With Positive Feed Back. (Feed back to Non Inverting Amplifier.**

Difference bet. Positive & Negative Feedback

Types of Feedback

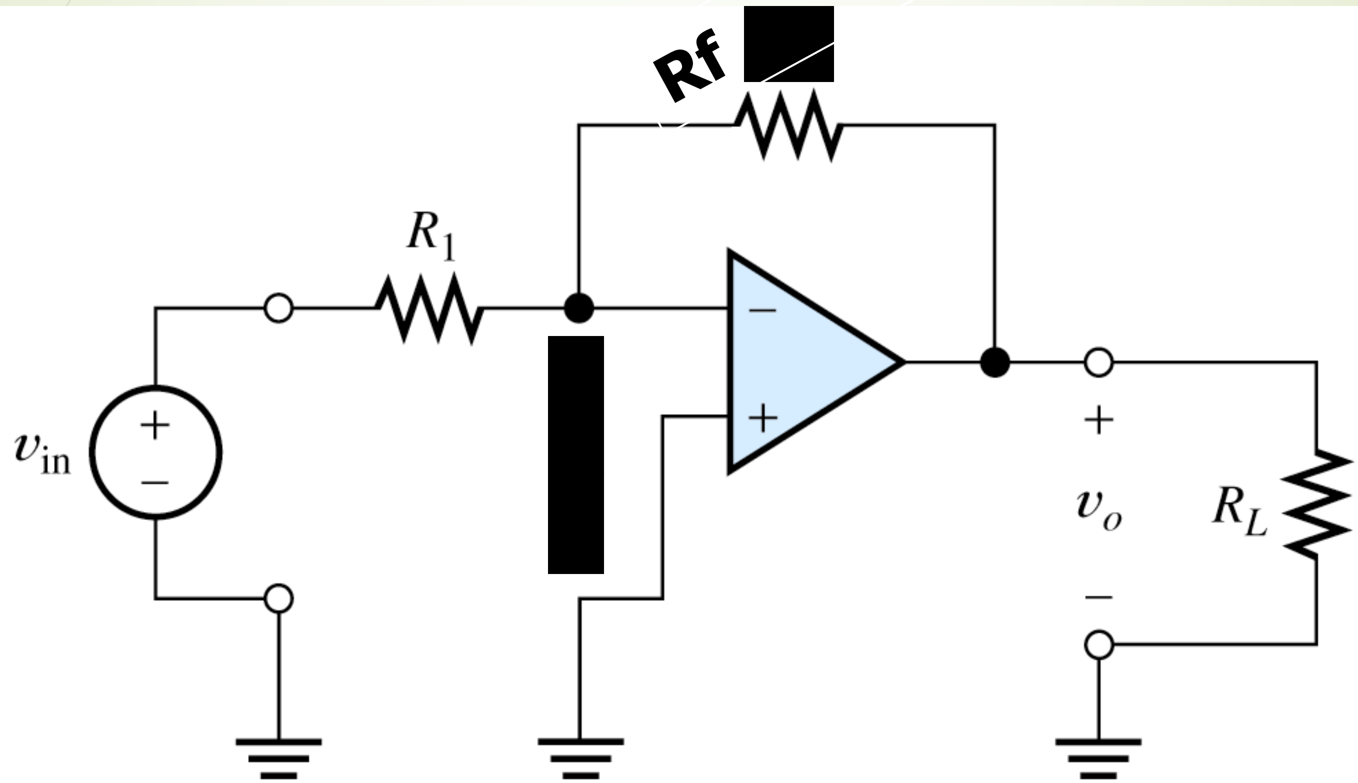


Negative Feedback Positive Feedback

- Negative Feedback
  - As information is fed back, the output becomes more stable. Output tends to stay in the desired range.
  - Examples: cruise control, heating/cooling systems
- Positive Feedback
  - As information is fed back, the output destabilizes. The op-amp will saturate.
  - Examples: Guitar feedback, stock market crash

Let us Start Linear Applications......

Inverting Amplifier Diagram



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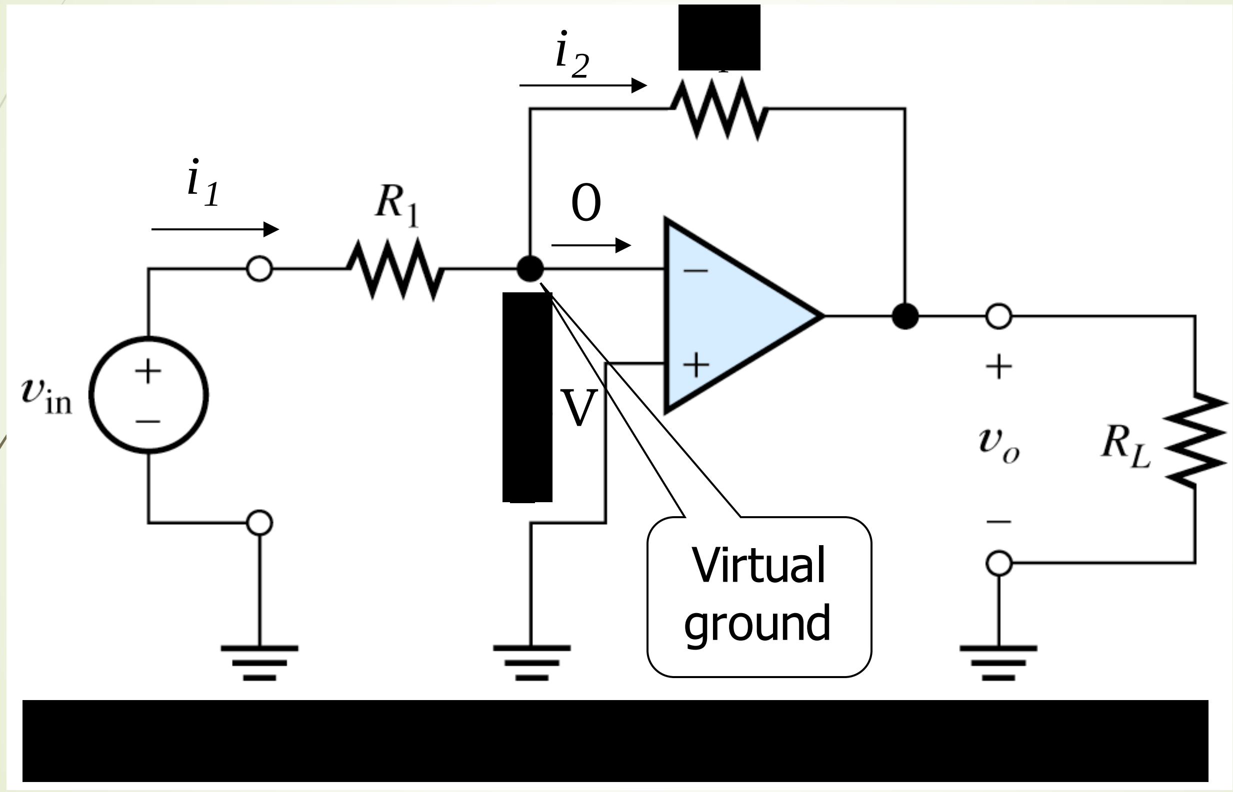
Inverting Amplifier

- Input is applied to inverting terminal
- Non inverting is grounded
- Feedback is given to inverting terminal through resistor R_F
- Assuming v_o is less than V_{CC}

  since A_d is very high, v_{id} should be very small; v_{id} taken as almost zero
- Current entering OPAMP input terminal is almost zero

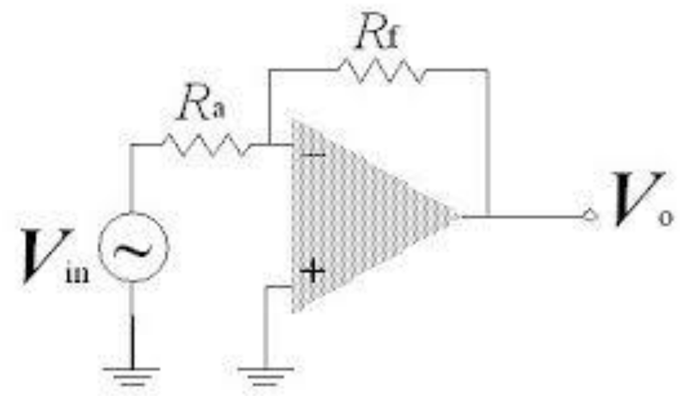
Inverting Amplifier Currents.



Derivation for Vo

Inverting Amplifier

(1) Kirchhoff node equation at V_+ yields, $V_+ = 0$



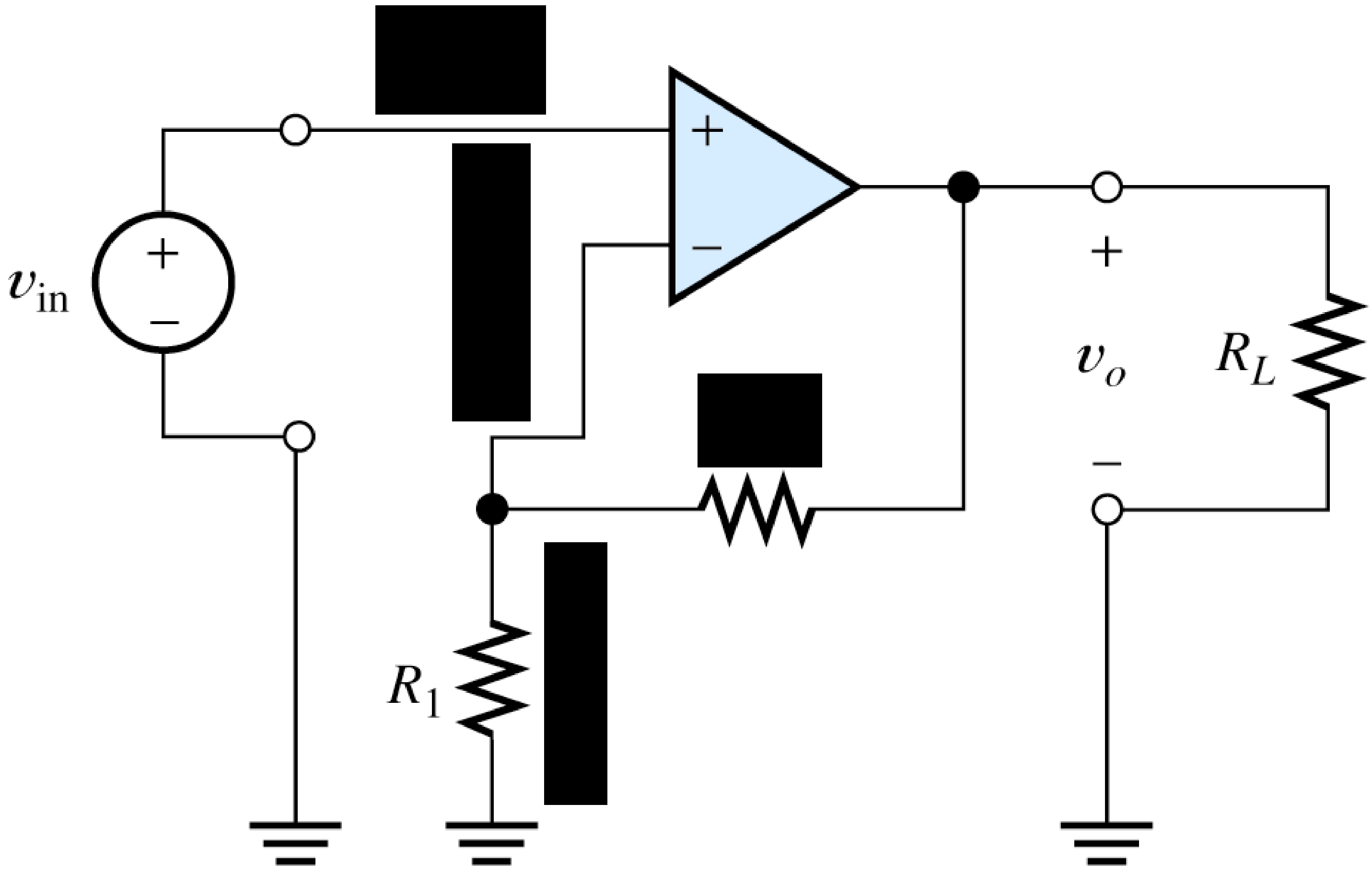
(2) Kirchhoff node equation at V_- yields, $\frac{V_{in} - V_-}{R_a} + \frac{V_o - V_-}{R_f} = 0$

(3) Setting $V_+ = V_-$ yields

$$\frac{V_o}{V_{in}} = \frac{-R_f}{R_a}$$

Notice: The closed-loop gain V_o/V_{in} is dependent upon the ratio of two resistors, and is independent of the open-loop gain. This is caused by the use of feedback output voltage to subtract from the input voltage.

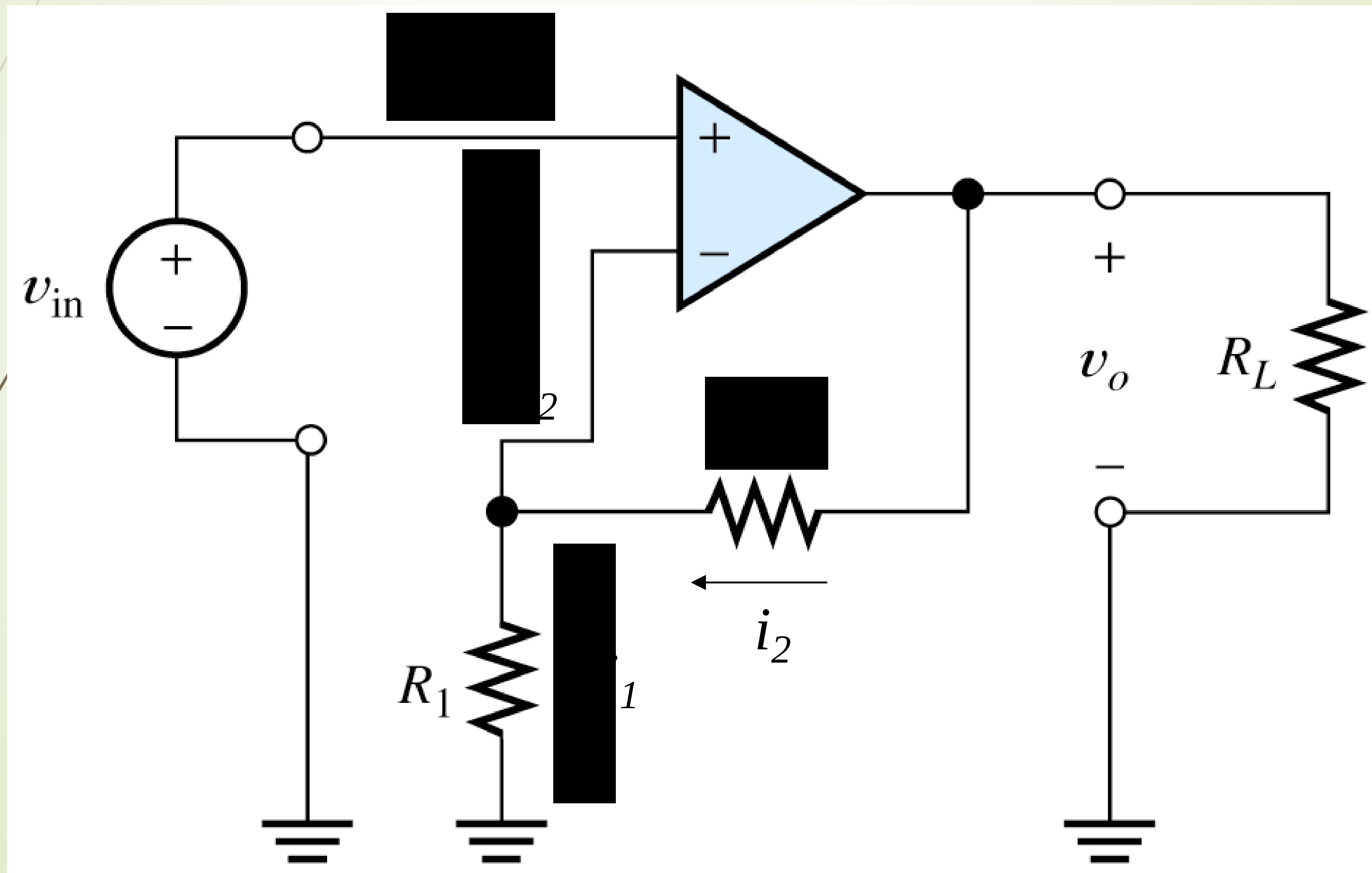
Non Inverting Amplifier Diagram



Non Inverting Amplifier

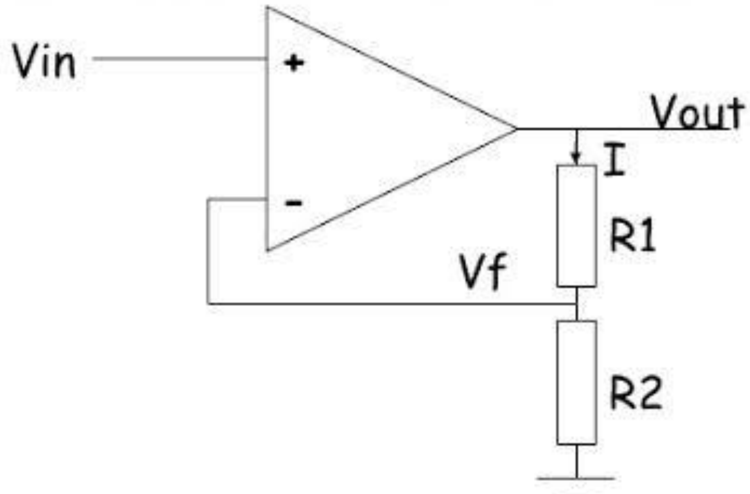
- Input is applied to non inverting terminal
- Feedback is given to inverting terminal
- Output voltage will be in-phase with input voltage
- Here again, the following assumptions are made
  - Since A_d is very high, v_{id} should be very small; v_{id} taken as almost zero
  - Current entering OPAMP input terminal is almost zero

Non Inverting Amplifier Currents.



Non Inverting Amplifier Derivation For V0

NON-INVERTING AMPLIFIER



The current I flows through both resistors as no current flows into the op-amp (assumption 2)

$I = \frac{Vout}{R1 + R2}$ from which $Vf = VR2 = I \times R2 = \frac{Vout \times R2}{R1 + R2}$

But Vf = Vin as the difference in input voltages is zero (assumption 1), so

Problems

- For an inverting amplifier using OPAMP, R_1=1K, R_F=100K, v_{in}=0.1sin(ωt). Find v_o.

  Ans: –10sin(ωt)

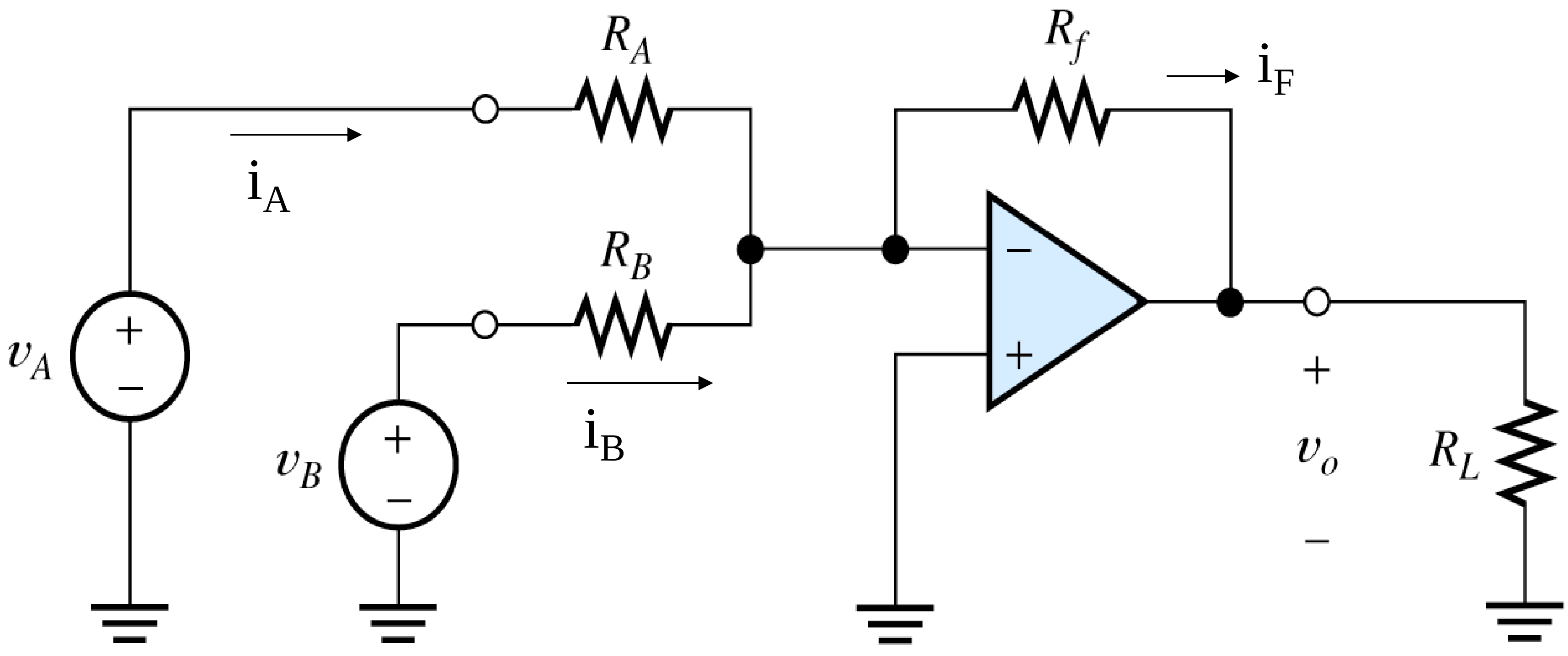
- For a non inverting amplifier, R_1=10K, R_F=100K. Calculate v_o if v_i = 25 mV dc.

  Ans: 275 mV dc

- An ac signal of rms value 2 mV needs to be amplified to 1.024 V rms, 180 degree phase shifted. Design a suitable amplifier choosing R_1=1.2K

  Ans: Inv amplifier with R_F=614.4K

Summing Amplifier (2 i/p inverting Adder)



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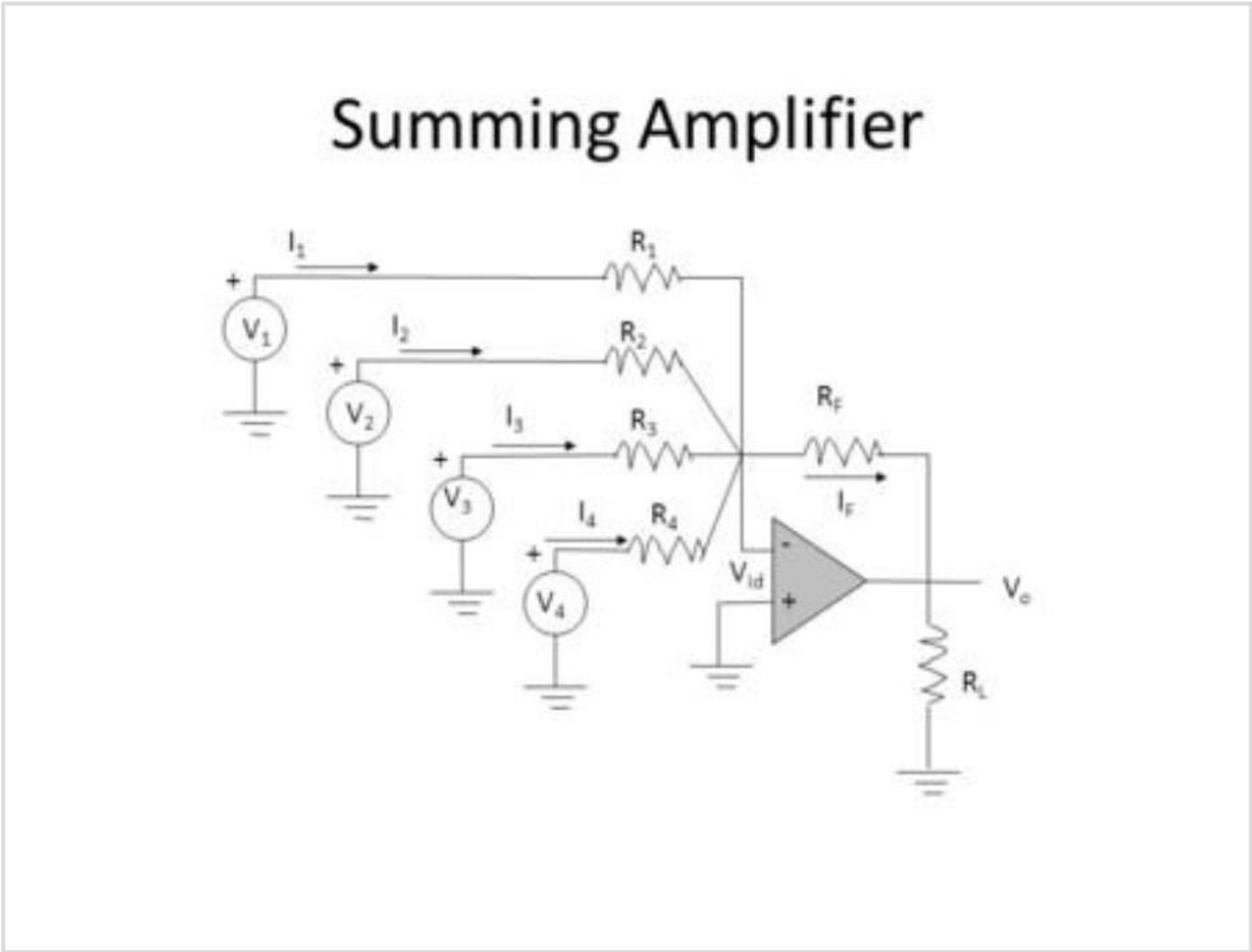
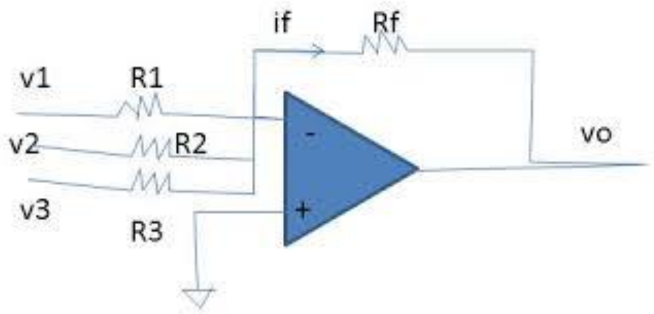
4 inputs Adder



3 inputs Adder

SUMMING Amplifier

The Inverting Amplifier may be extended to for m a circuit that yields sum of several input voltages. Each input voltage V1, V2, V3, …Vk is connected to the negative input of the Op-Amp by individual resistor Rk, the conductance 1/Rk is proportional to the desired weighting.



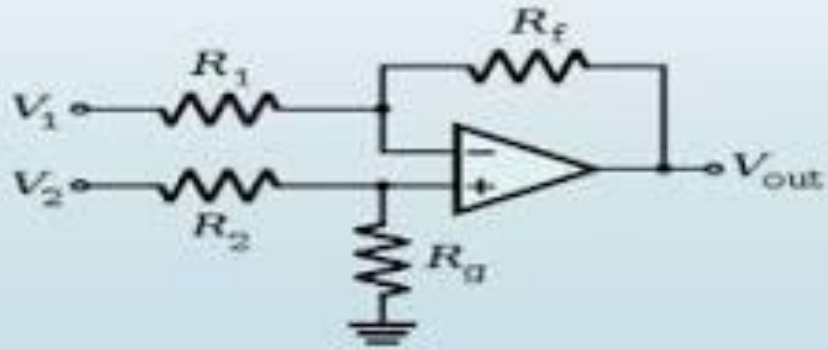
If=I1 +I2 +I3 If=-Vo/Rf ; I1=V1/R1; I2=V2/R2; I3=V3/R3

Vo=-Rf (V1/R1+V2/R2+V3/R3);

Subtracter

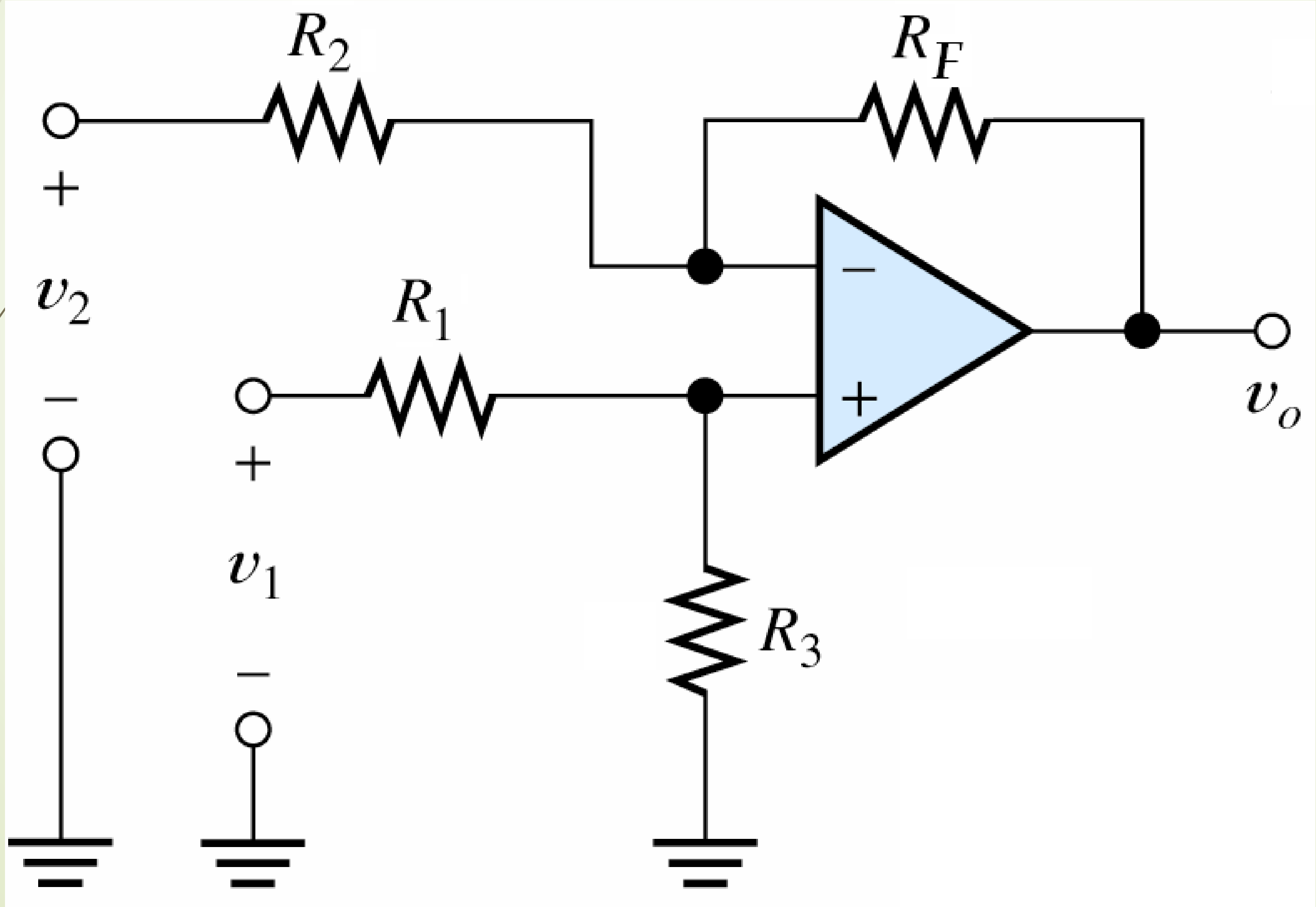
What is differential amplifier?

- *A differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages . It is an analog circuit with two inputs and one output in which the output is ideally proportional to the difference between the two voltages.*



(A differential amplifier)

Difference Amplifier (Subtractor)



Difference Amplifier (Subtractor)

- The circuit is analyzed using superposition theorem
- Consider only v_1 to be present; $v_2=0$

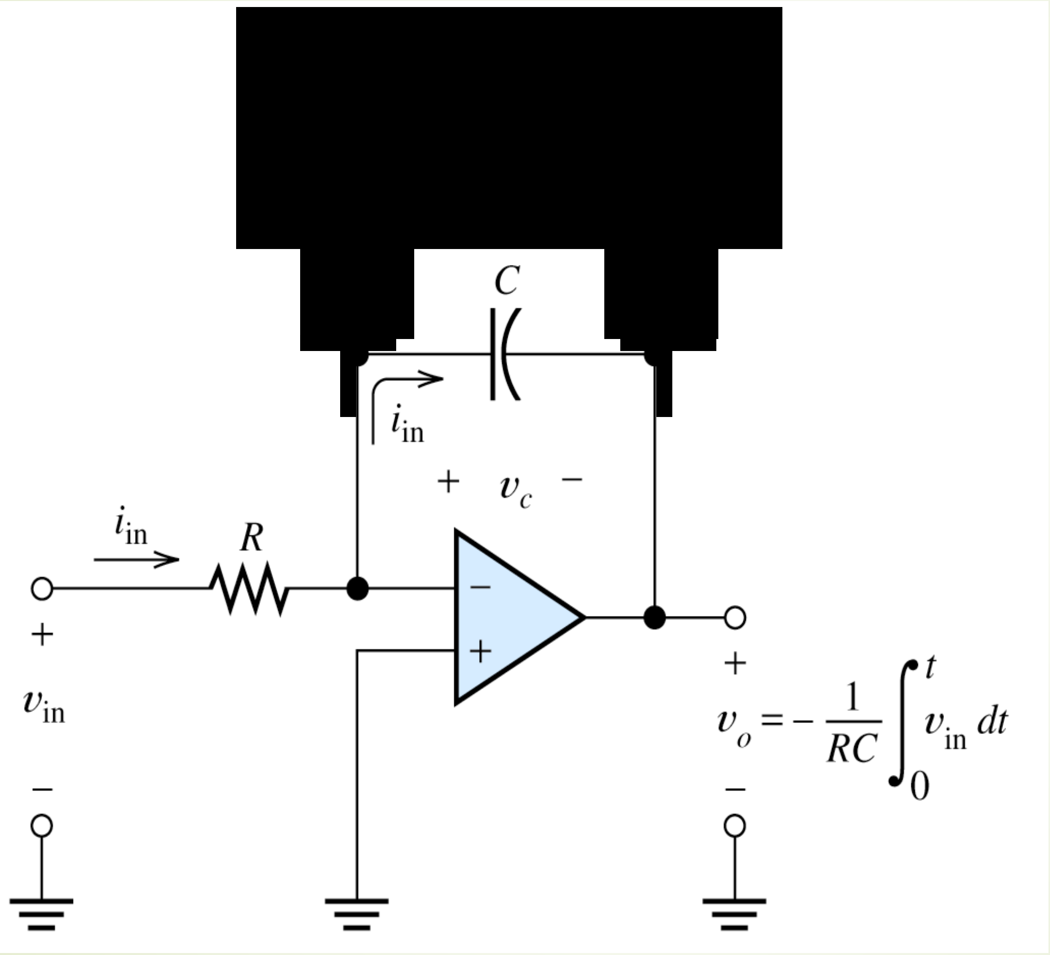
  Now derive expression for output voltage v_{o1}
- Next consider only v_2 to be present; $v_1=0$

  Derive expression for output voltage v_{02}
- Actual output voltage $v_o = v_{o1}+v_{o2}$

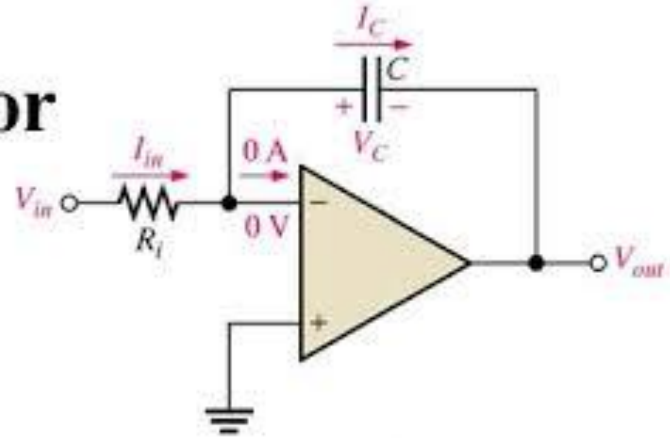
Problems

- Design an OPAMP circuit such that output is given by $v_o = -(0.5v_1 + 0.75v_2)$ where v_1 and v_2 are input voltages. Choose $R_F = 10K$
- Design an OPAMP subtractor to have output given by $v_o = \frac{2}{3} v_1$ Choose $R_F = R_2 = 1K$
- Design an OPAMP adder/subtractor to get output voltage $v_o = -\frac{1}{2} v_1 + \frac{2}{3} v_2 - v_3$

OpAmp as an Integrator



The Op-Amp Integrator



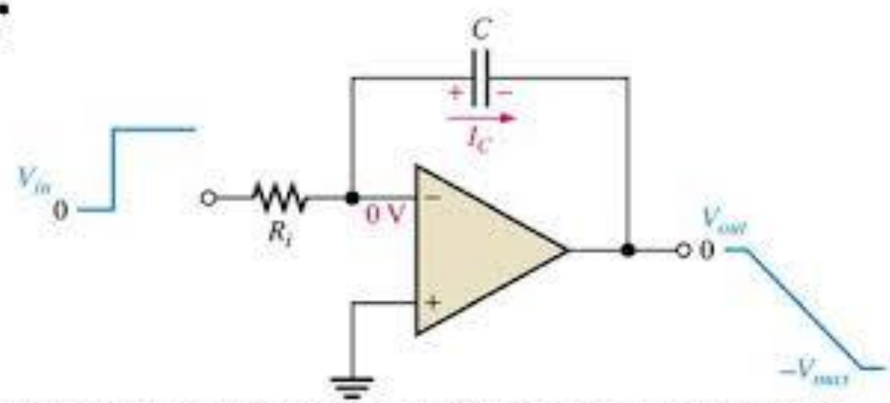
- In figure, the inverting input of the op-amp is at virtual ground (0V), so the voltage across R_1 equals V_{in}. Therefore , the input current is

$$\boxed{I_{in} = V_{in} / R_1}$$

- If V_{in} is a constant voltage, then I_{in} is also a constant because the inverting input is always remains at 0 v, keeping a constant voltage across R_1.
- Because of the very high input impedance of the op-amp, there is negligible current at the inverting input.
- This makes all of the input current go through the capacitor, as indicated in figure, so

$$\boxed{I_c = I_{in}}$$

The Op-Amp Integrator



A constant input voltage produces a ramp on the output of the integrator.

- ***Rate of change of the output voltage***
- *The rate at which the capacitor charges, and therefore the slope of the output ramp, is set by the ratio* $\boldsymbol{I_C/C}$*,*

as you have seen $\boldsymbol{I_c = V_{in}/R_1}$*, the rate of change or slope of the integrator's output voltage is* $\boldsymbol{\Delta V_{out}/\Delta t}$**.**

$$\frac{\Delta V_{out}}{\Delta t} = \frac{V_{in}}{R_1}$$

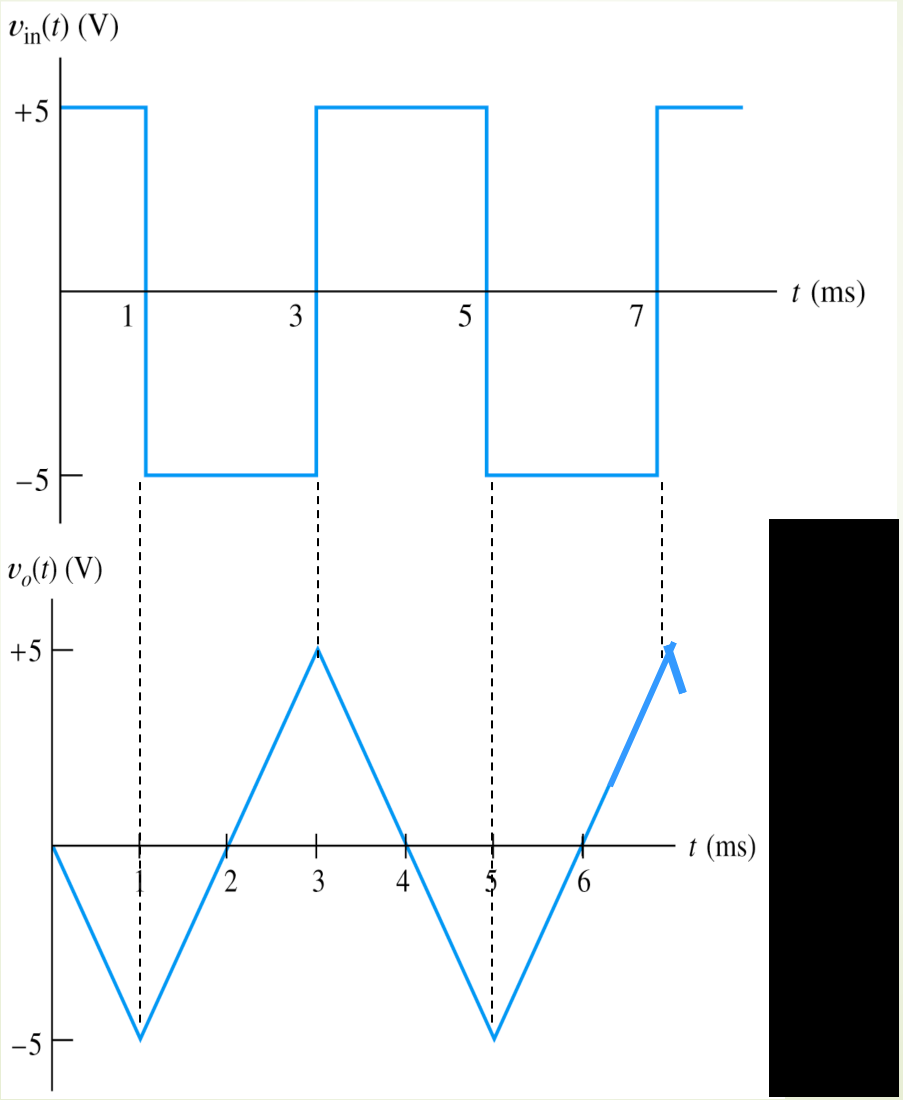
Integrator

- Integrator is a circuit whose output is proportional to (negative) integral of the input signal with respect to time
- Feedback is given through capacitor to inverting terminal

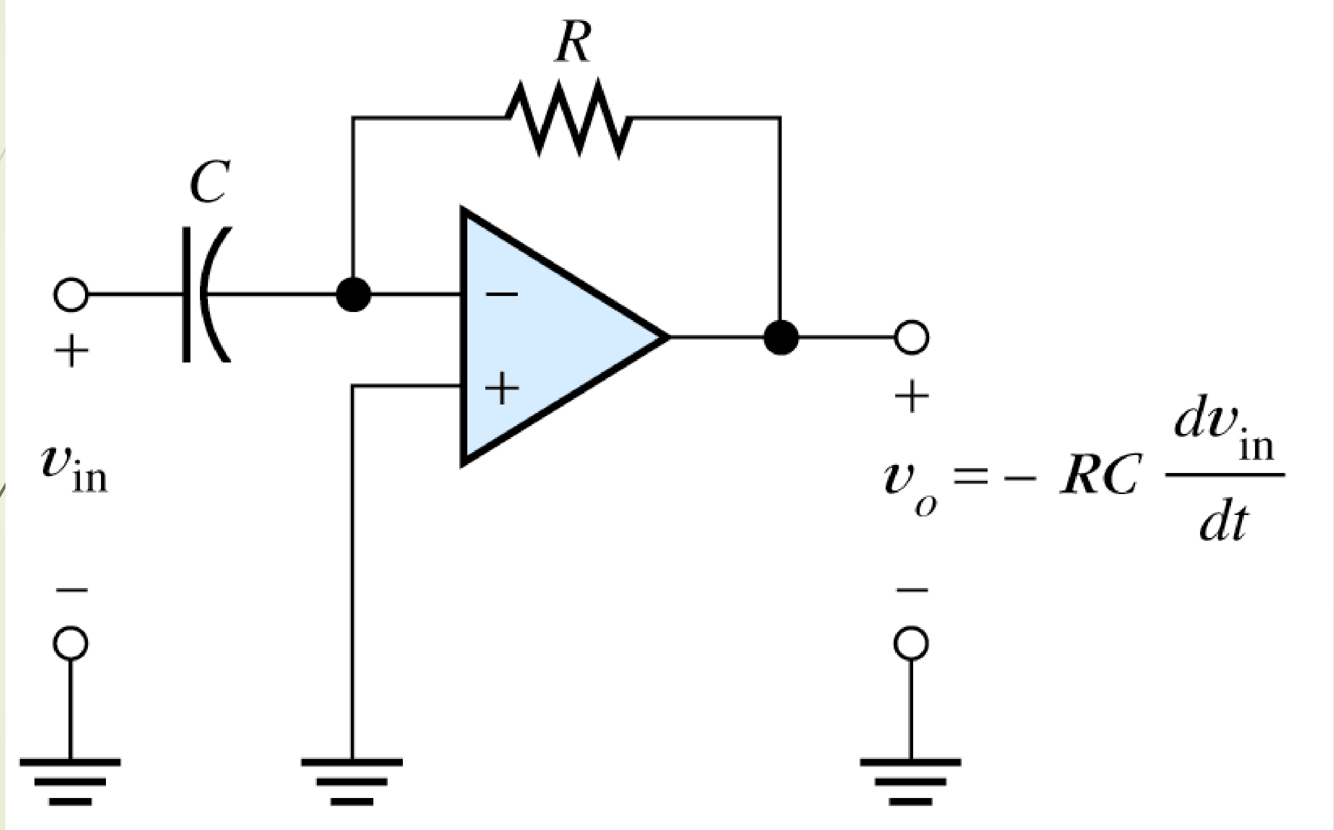
- Since same current flows through R and C,
- Iin = - If

$$\frac{v_{in}}{R} = -C\frac{dv_o}{dt} \qquad v_o = \frac{-1}{RC}\int_0^t v_{in}\,dt$$

Integrator O/P Wave form



OpAmp as a Differentiator



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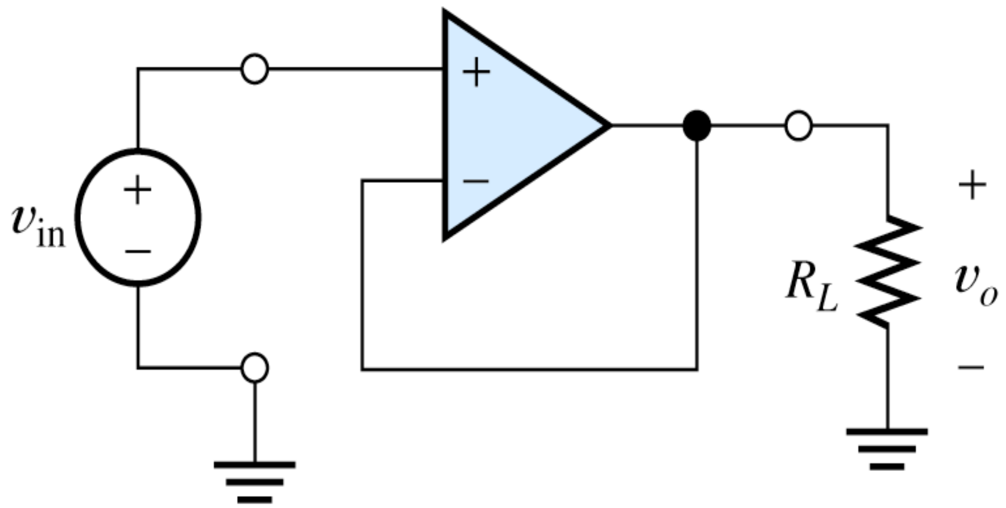
Differentiator

- Differentiator is circuit whose output is proportional to (negative) differential of input voltage with respect to time
- Input is given through capacitor, feedback given through resistor to inv terminal

- Since current through R and C are same,
- Ic = - Ir
- Since Iin = - If

$$C\frac{dv_{in}}{dt} = -\frac{v_o}{R} \qquad v_o = -RC\frac{dv_{in}}{dt}$$

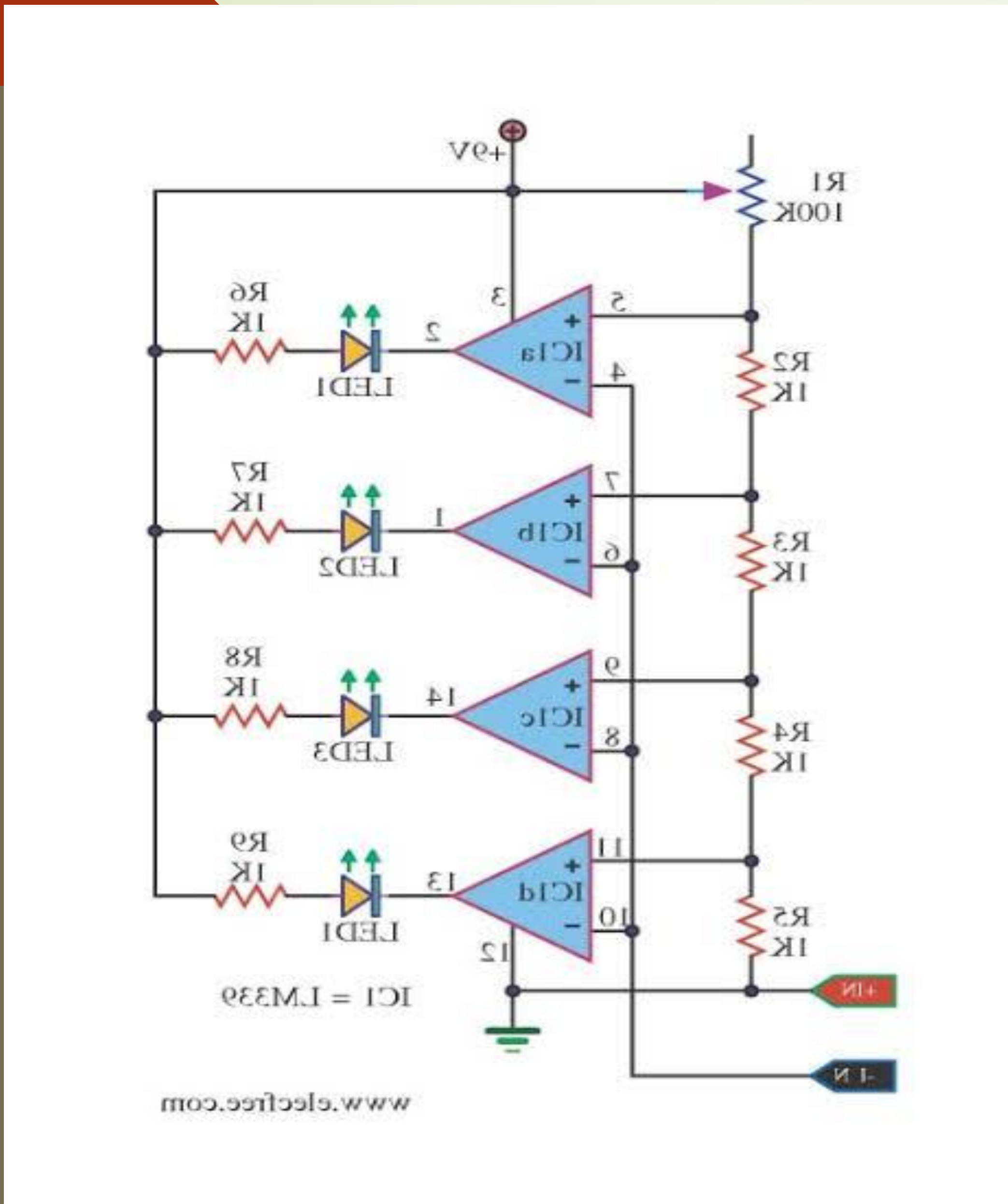
Voltage Follower / Buffer

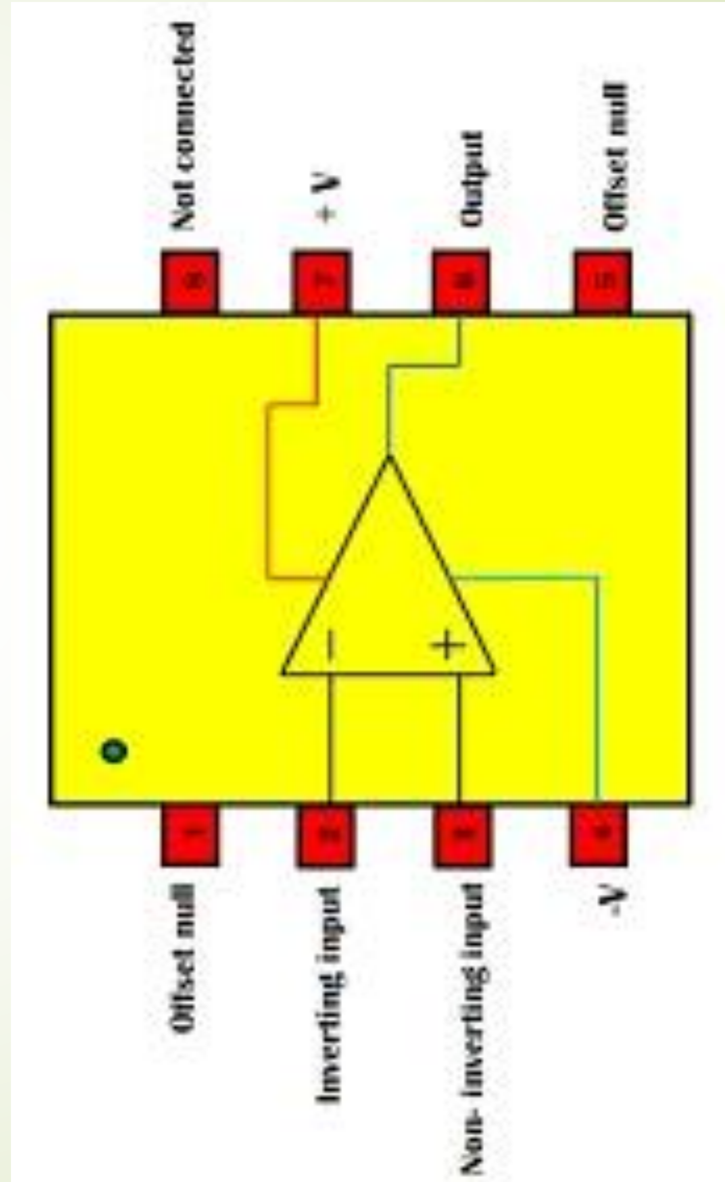


[redacted]

- Special case of non inverting amplifier where R_F=0
- Voltage gain is unity. $v_o = v_{in}$
- Has very high input resistance and very low output resistance; Used as buffer for impedance matching

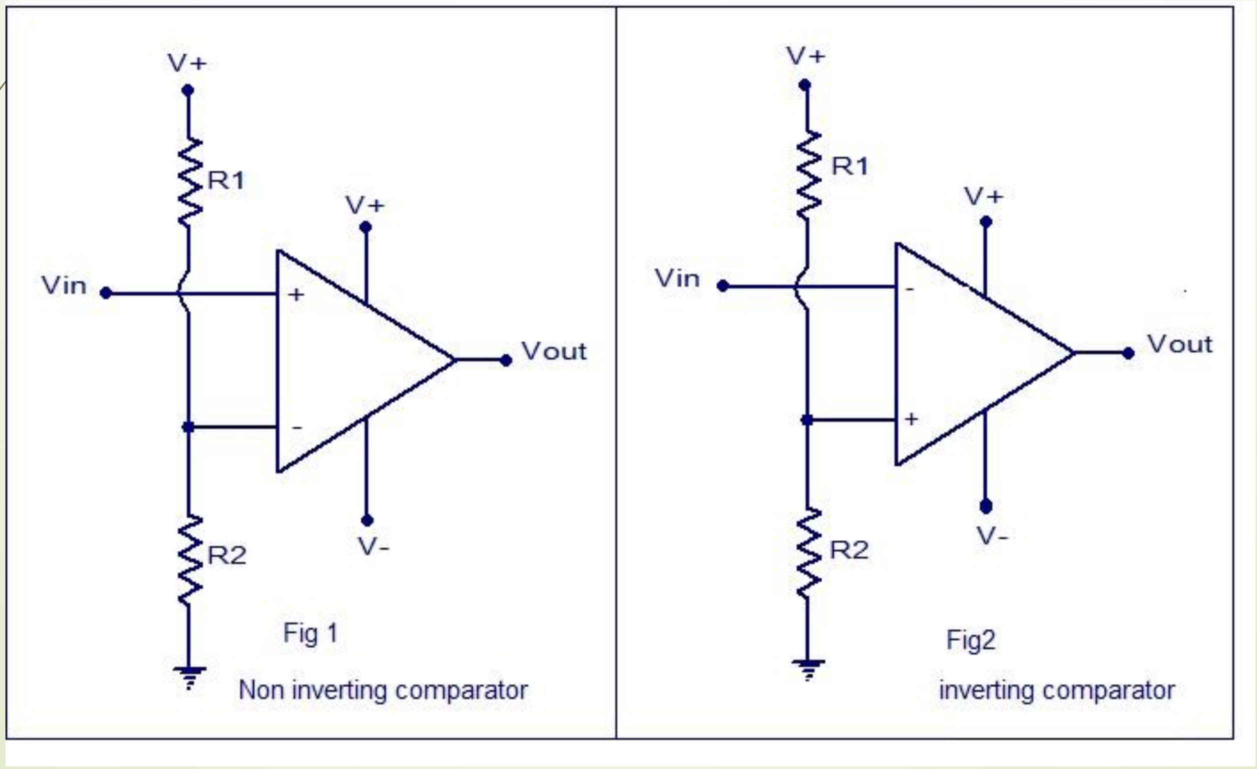
Non Linear Applications

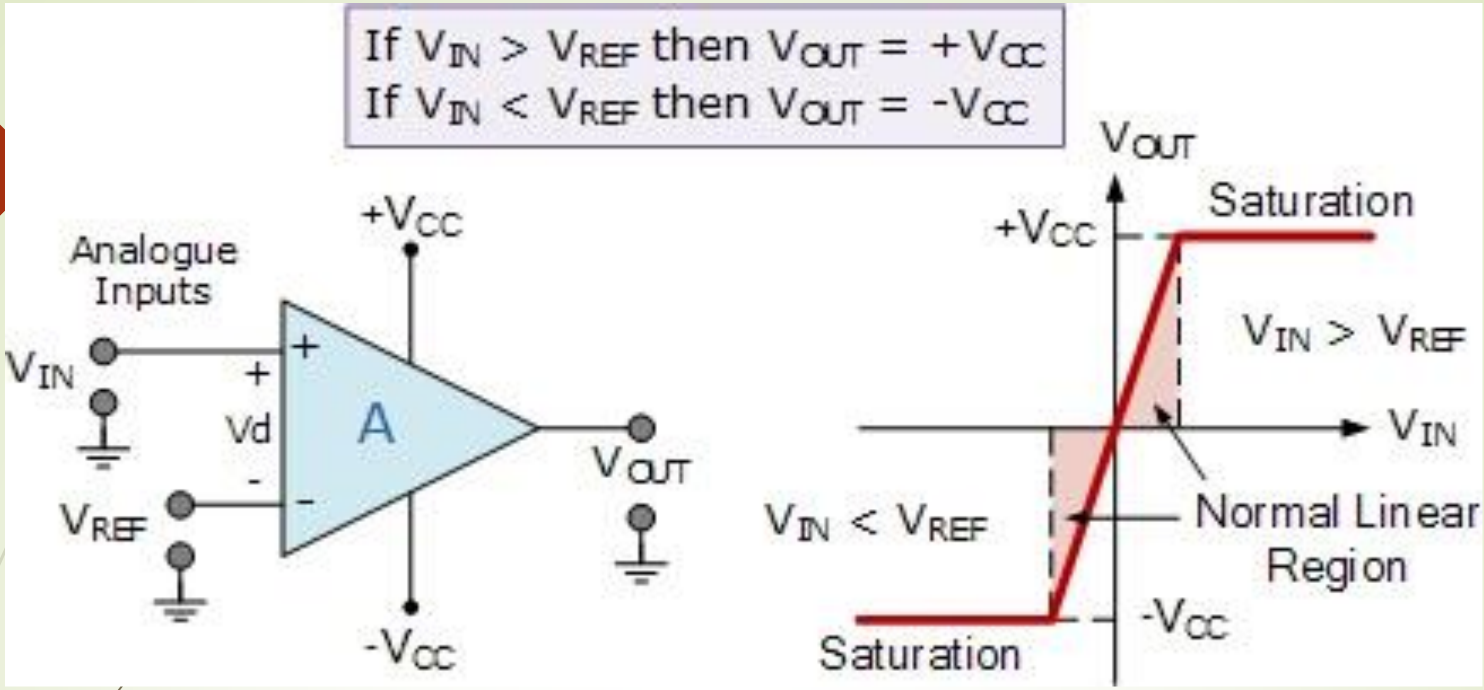




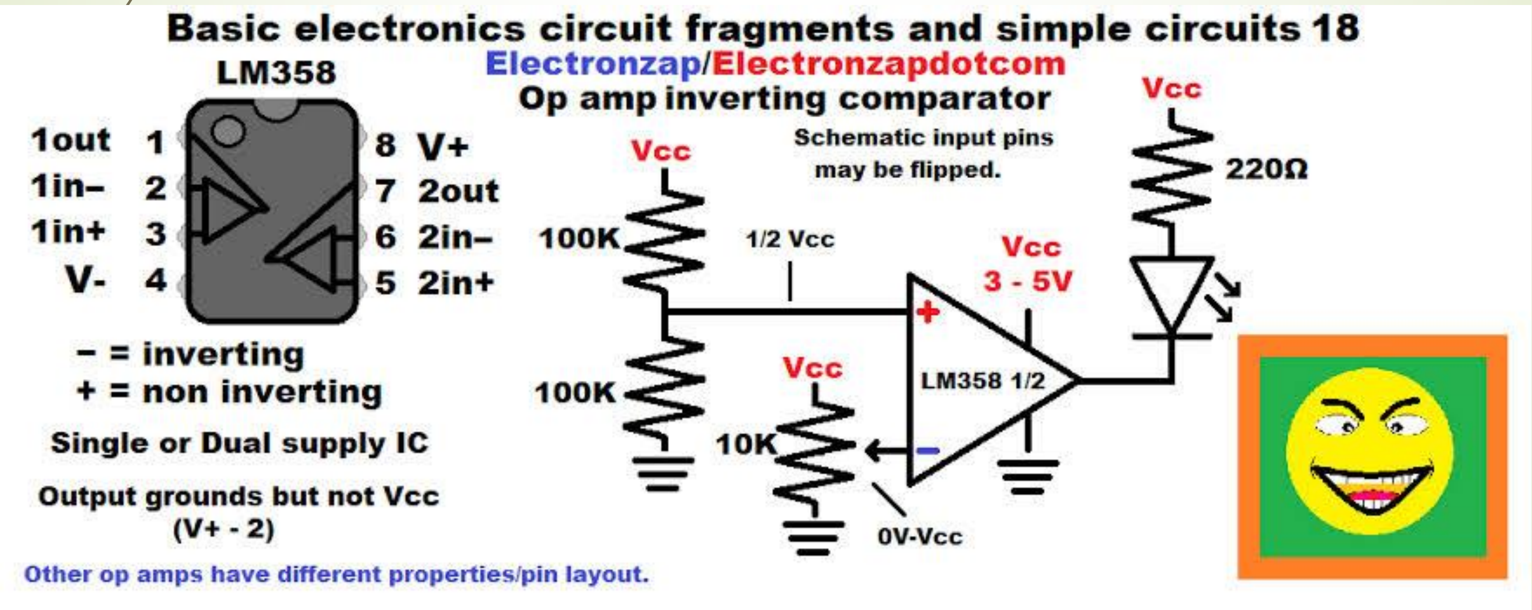
Comparator

- A comparator is a device that compares two voltages or currents and outputs a digital signal indicating which is larger. It has two analog input terminals and and one binary digital output. The output is ideally A comparator consists of a specialized high-gain differential amplifier

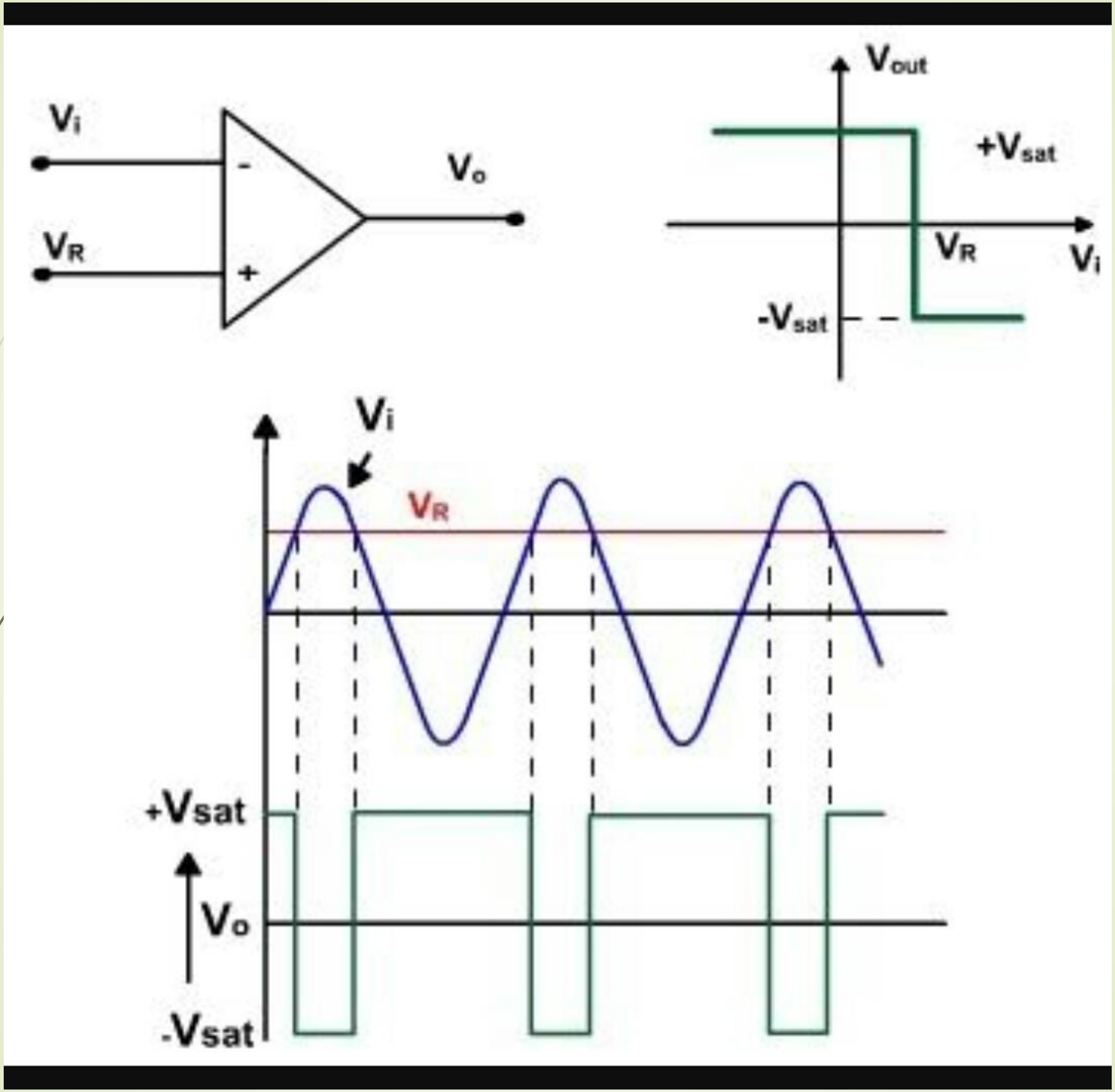




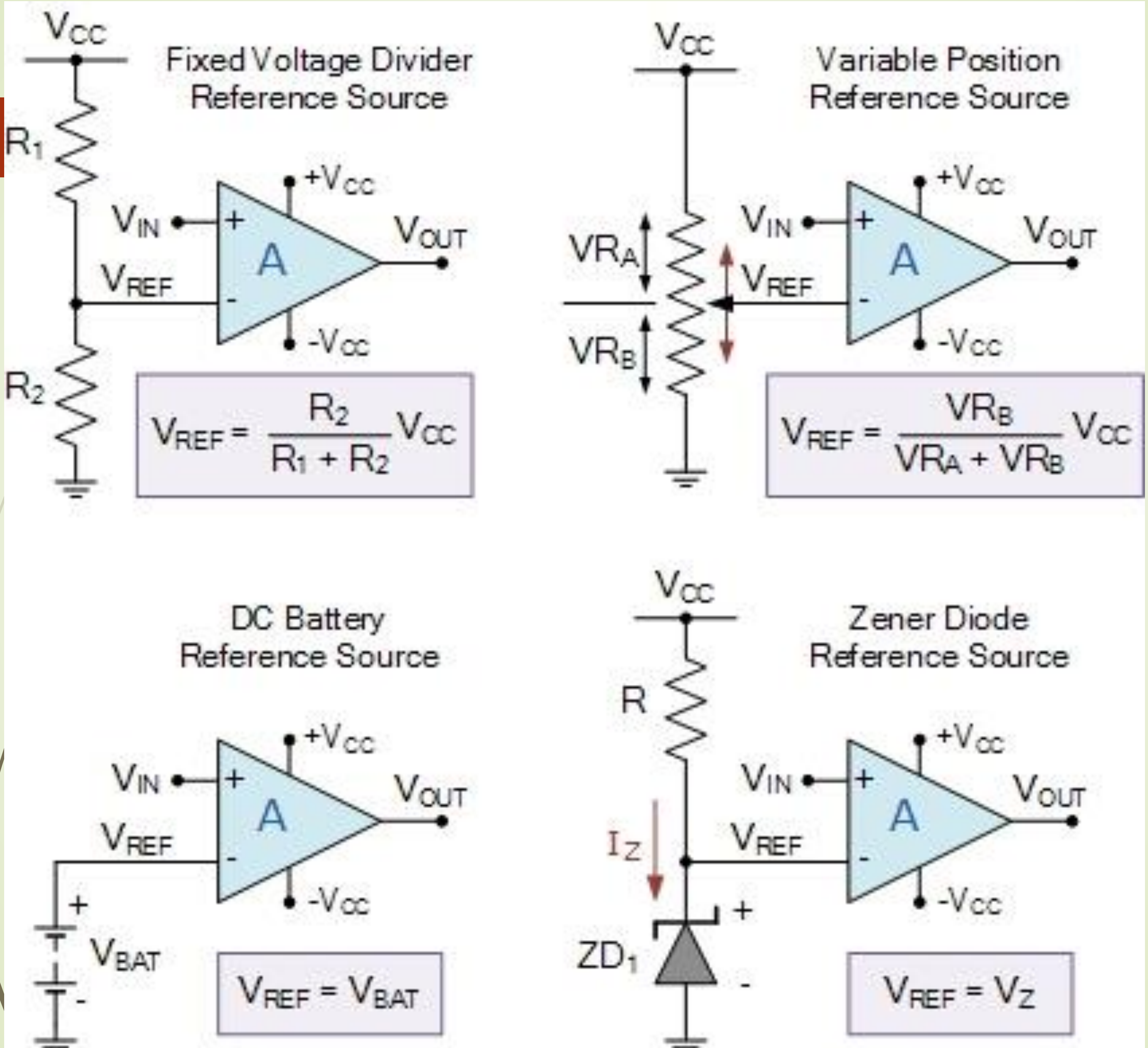
If $V_{IN} > V_{REF}$ then $V_{OUT} = +V_{CC}$
If $V_{IN} < V_{REF}$ then $V_{OUT} = -V_{CC}$
Analogue Inputs
$+V_{CC}$
$-V_{CC}$
V_{IN}
V_{REF}
Vd
A
V_{OUT}
Saturation
$V_{IN} > V_{REF}$
$V_{IN} < V_{REF}$
Normal Linear Region

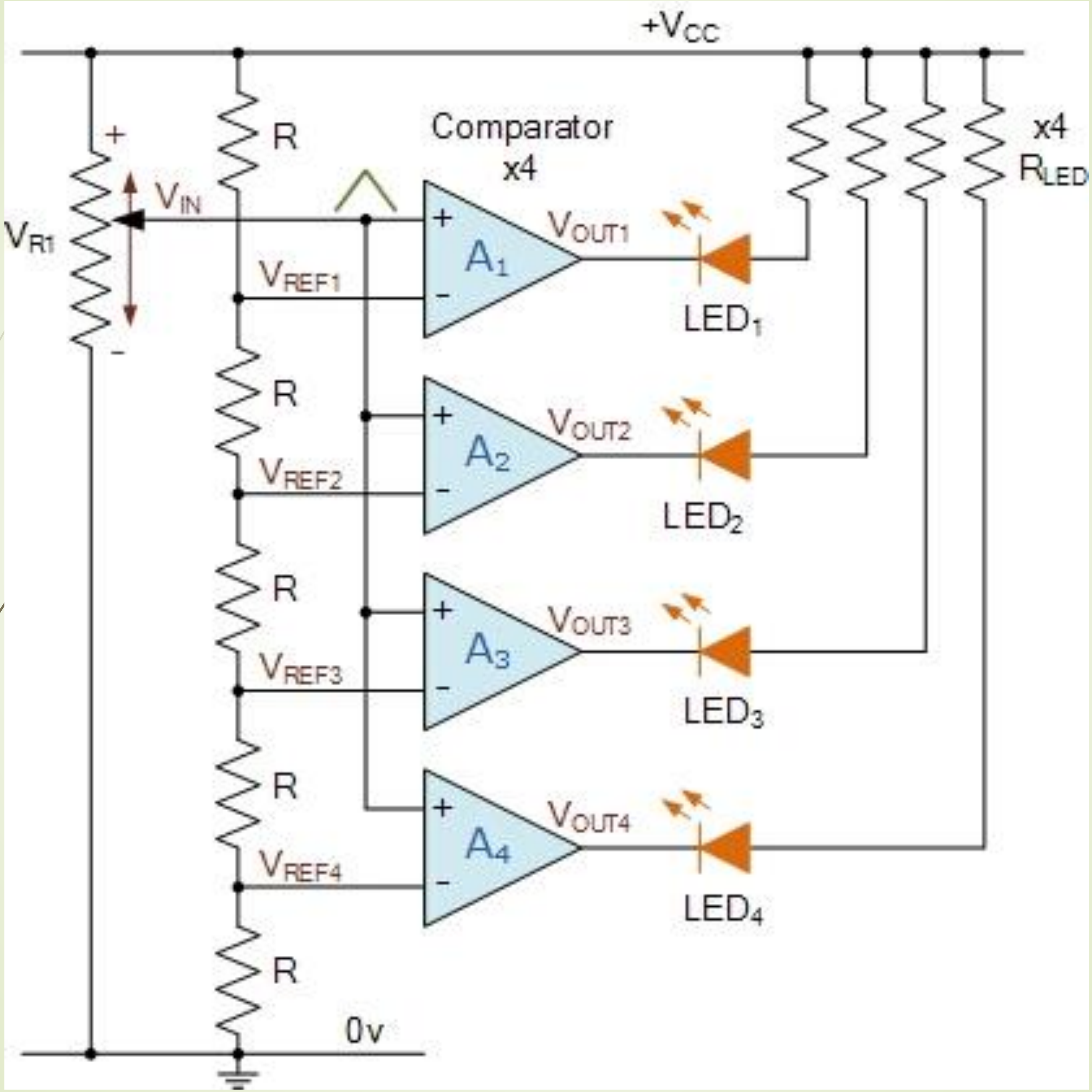


Basic electronics circuit fragments and simple circuits 18
Electronzap/Electronzapdotcom
Op amp inverting comparator
LM358
1out 1
1in– 2
1in+ 3
V- 4
8 V+
7 2out
6 2in–
5 2in+
– = inverting
+ = non inverting
Single or Dual supply IC
Output grounds but not Vcc (V+ - 2)
Other op amps have different properties/pin layout.
Vcc
100K
100K
1/2 Vcc
Schematic input pins may be flipped.
Vcc 3 - 5V
LM358 1/2
10K
0V-Vcc
220Ω



Vi
VR
-
+
Vo
Vout
+Vsat
VR
Vi
-Vsat
Vi
VR
+Vsat
Vo
-Vsat


Fixed Voltage Divider Reference Source
Vcc
R1
R2
VIN
VREF
VOUT
A
+Vcc
-Vcc
VREF = R2 / (R1 + R2) Vcc
Variable Position Reference Source
Vcc
VRA
VRB
VIN
VREF
VOUT
A
+Vcc
-Vcc
VREF = VRB / (VRA + VRB) Vcc
DC Battery Reference Source
VIN
VREF
VOUT
A
+Vcc
-Vcc
VBAT
VREF = VBAT
Zener Diode Reference Source
Vcc
R
IZ
ZD1
VIN
VREF
VOUT
A
+Vcc
-Vcc
VREF = VZ

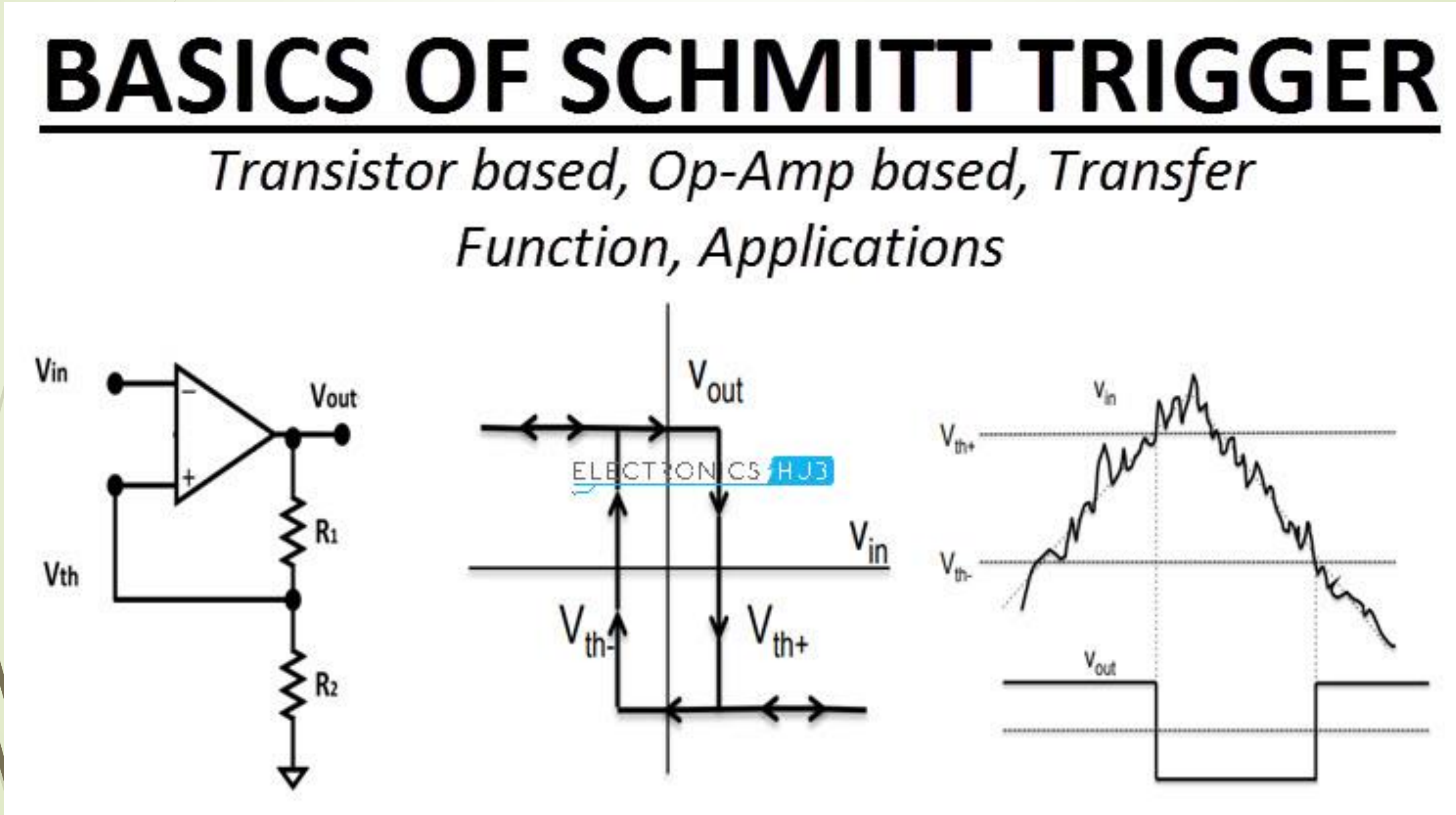


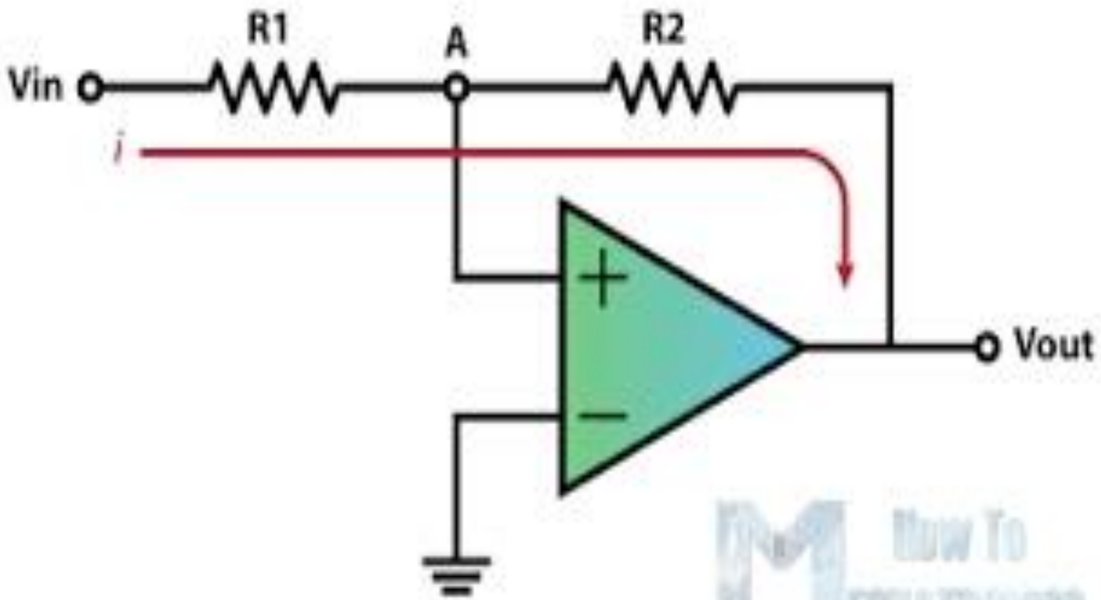
+VCC
Comparator x4
x4 RLED
+
VIN
VR1
-
R
VREF1
+
A1
-
VOUT1
LED1
R
VREF2
+
A2
-
VOUT2
LED2
R
VREF3
+
A3
-
VOUT3
LED3
R
VREF4
+
A4
-
VOUT4
LED4
R
0v

Schmitt Trigger

- electronics, a **Schmitt trigger** is a comparator circuit with hysteresis implemented by applying positive feedback to the noninverting input of a comparator or differential amplifier. It is an active circuit which converts an analog input signal to a digital output signal.

Schmitt Trigger.





Example:

$R1 = 1K ; R2 = 2K ; Vout = +/- 12\ V$

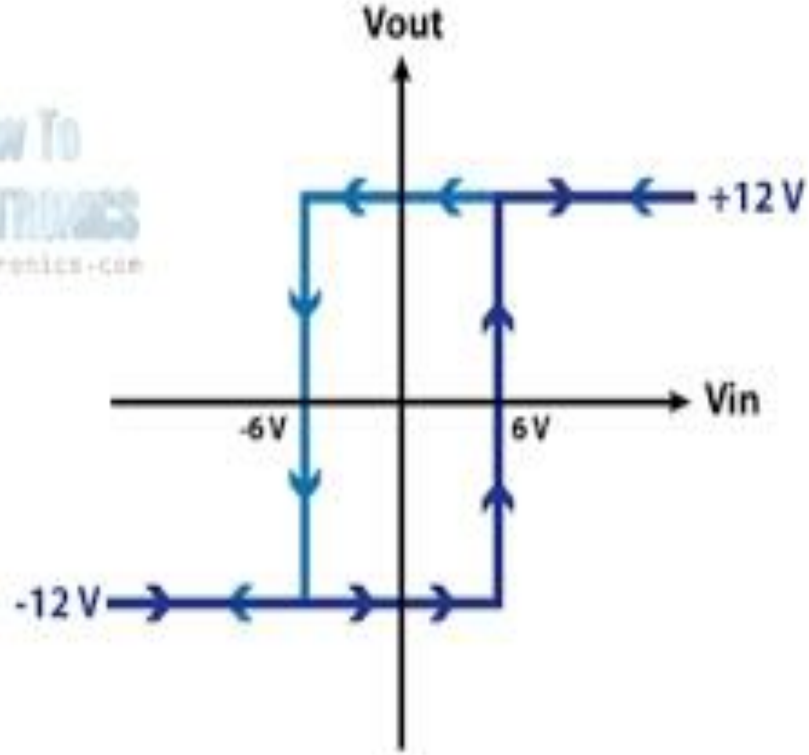
$$Vin = -\frac{1}{2}(+/-12) = +/- 6\ V$$

$$i = \frac{Vin - Va}{R1} = \frac{Va - Vout}{R2}$$

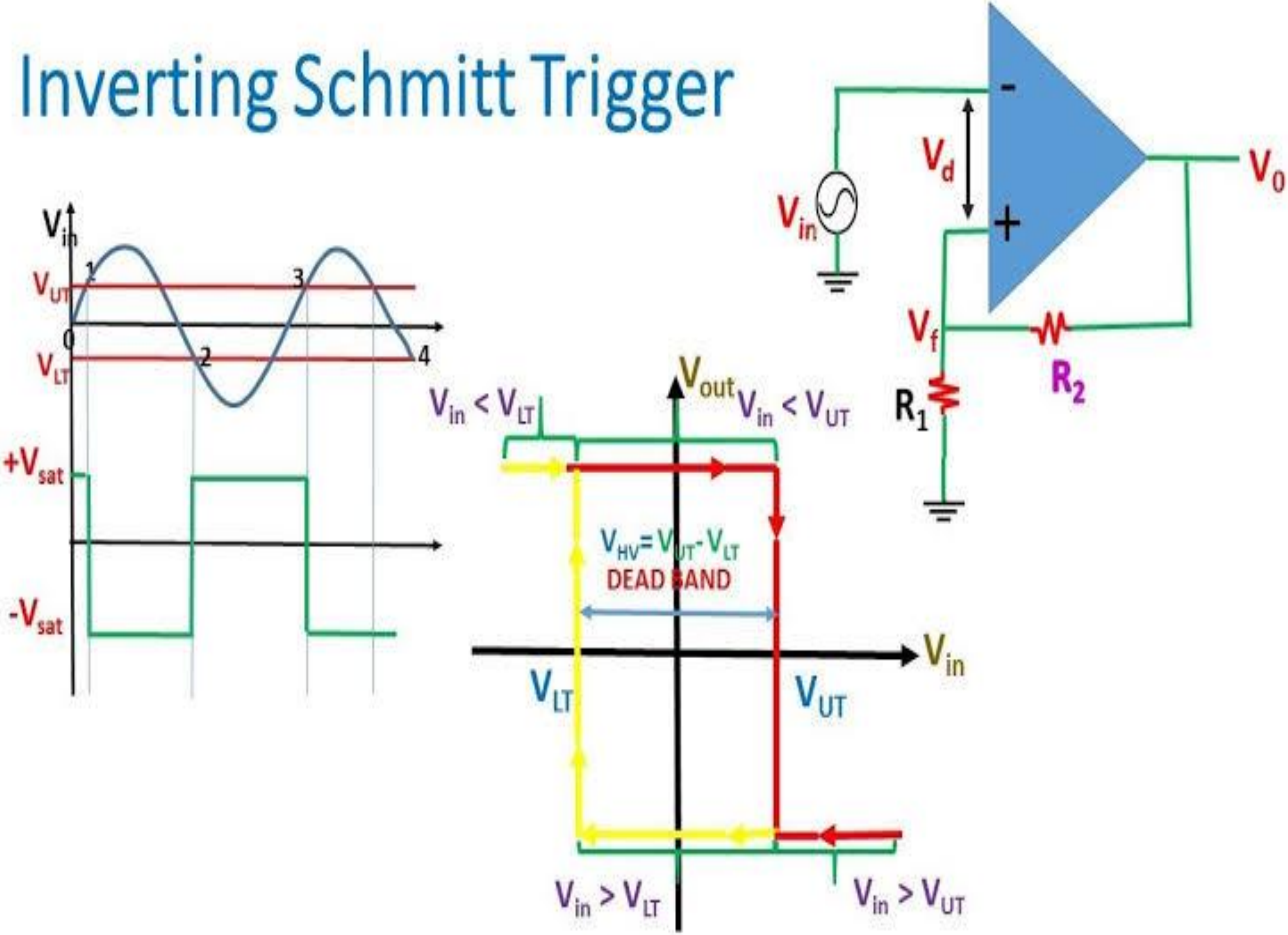
$$Va = 0$$

$$\frac{Vin}{R1} = -\frac{Vout}{R2}$$

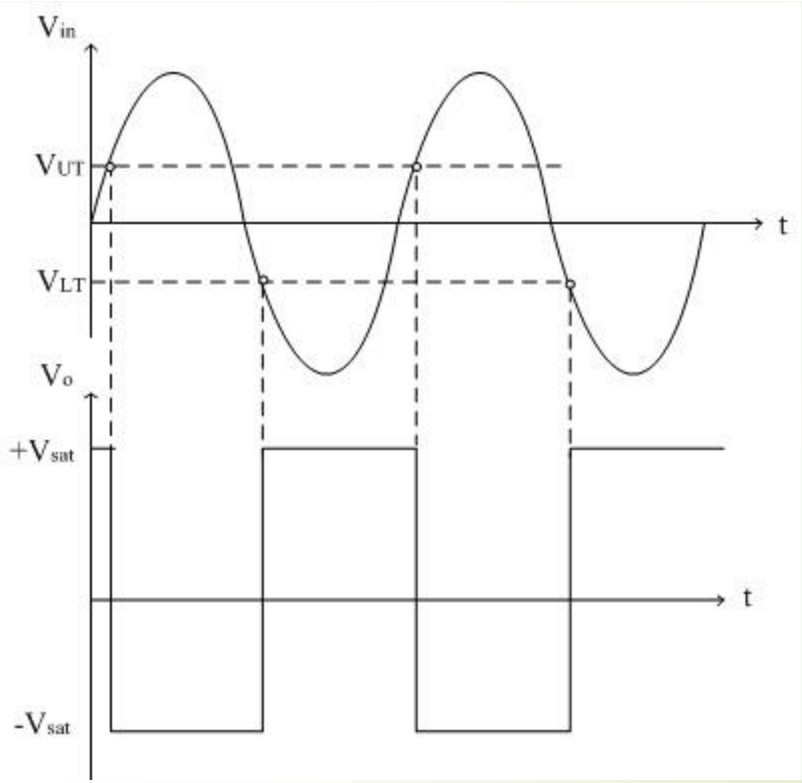
$$Vin = -\frac{R1}{R2}Vout$$

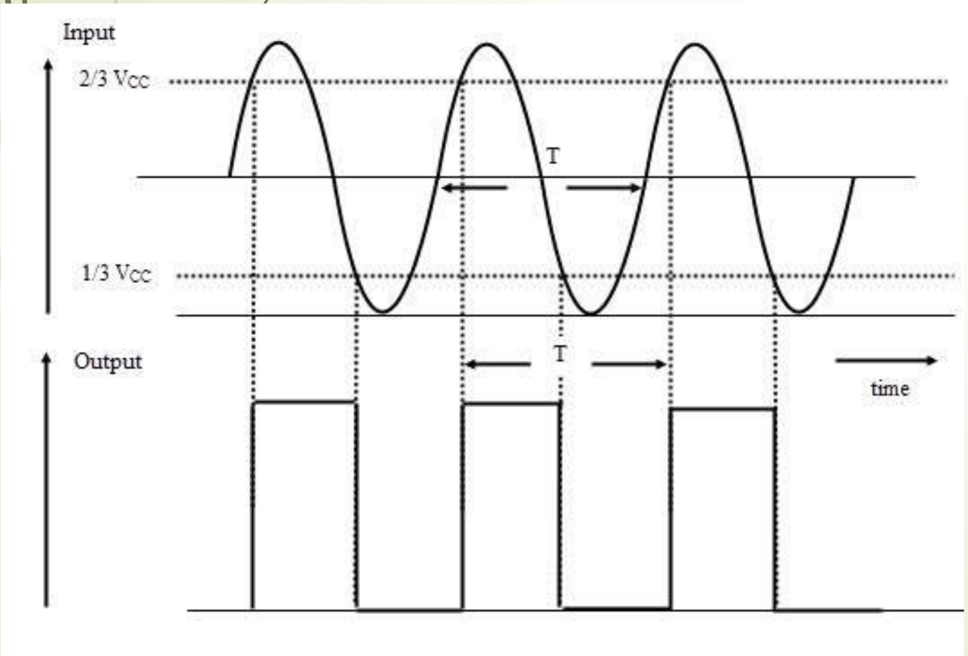


Inverting Schmitt Trigger

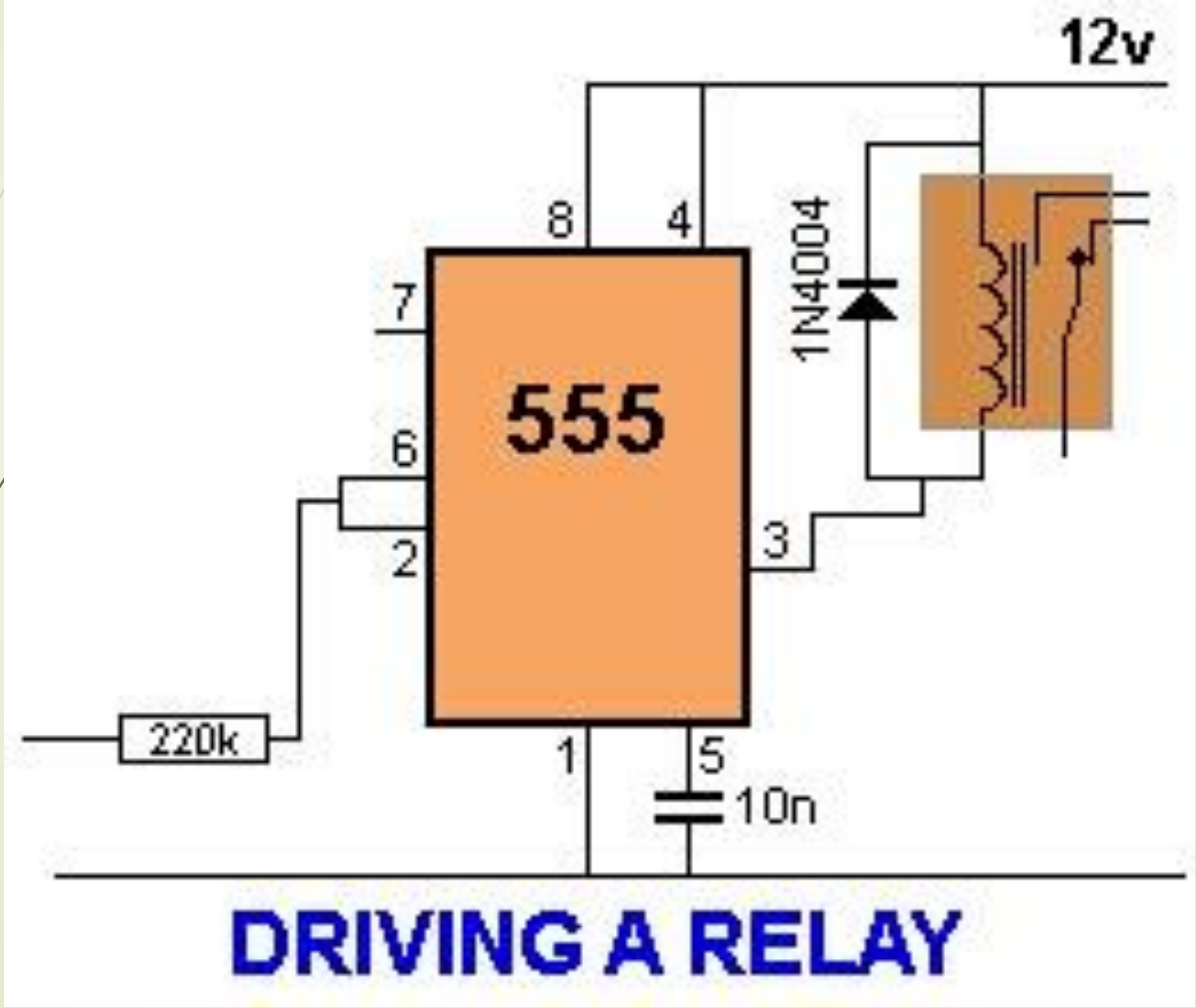


Waveforms





Next IC 555



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Revise Revise and Revise

By Scientific method