UNIT 5: Fundamentals of filters and operational amplifier

(Lecture 37 to 39)

Prepared By:

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Outcome: Analyze the working of operational amplifiers and filters in electronic devices

Fundamentals of filters and operational amplifier : filter examples- band-pass filter, low-pass filter, high-pass filter, operational amplifier abstraction- device properties of the operational amplifier, simple op amp circuits – virtual ground concept, inverting and non-inverting op-amp, op-amp as an adder and subtractor, op-amp RC circuits – op-amp integrator, op-amp differentiator, op-amp as a comparator and its application in anti-lock braking systems

UNIT-V

Fundamentals of filters and operational amplifier

Lecture 37
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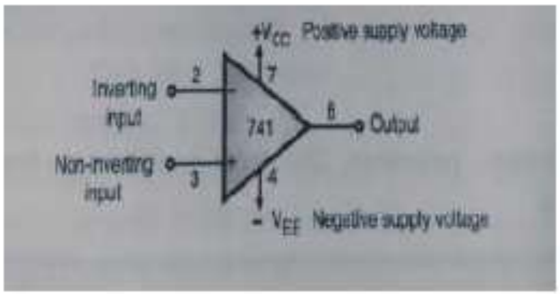
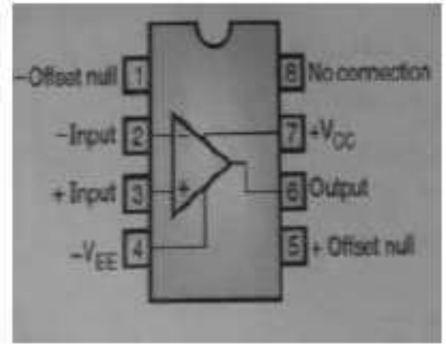
Introduction

- OP-AMP is basically a multistage amplifier which uses a number of amplifier stages interconnected to each other.
- The integrated op amp offers all the advantage of monolithic integrated circuit such as small size ,high reliability ,reduced cost, less power consumption.
- OP-AMP amplifies the difference between two signal and diminish common signal.

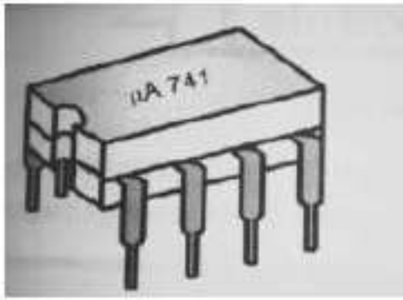
Symbol and terminals



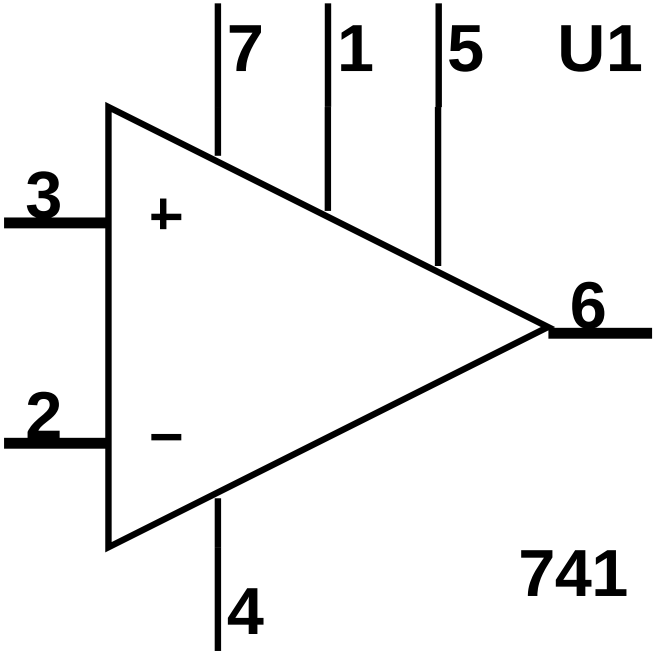


- An OP-AMP has a two input terminal, one output terminal and two supply voltage terminals.
- The input terminal marked with negative(-) sign is called as an inverting terminal .If we connect the input signal to this terminal then the amplified output signal is 180º out of phase with respect to input.

- The input terminal marked with positive (+) sign is called as Non-Inverting terminal. If the input is applied to this pin then the amplified output is in phase with the input.
- Offset null is used to nullify the offset voltage and pin no 8 is dummy pin.

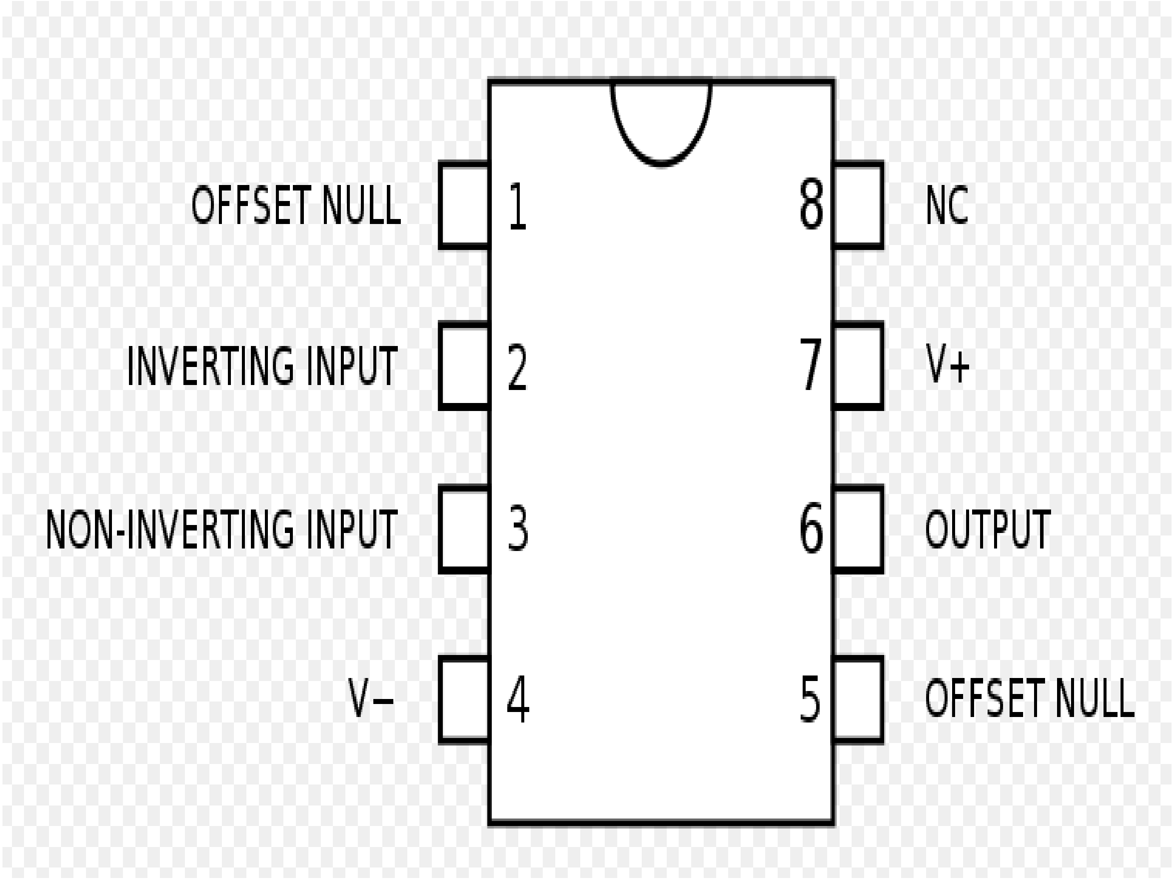


Circuit Symbol and Pin Identification

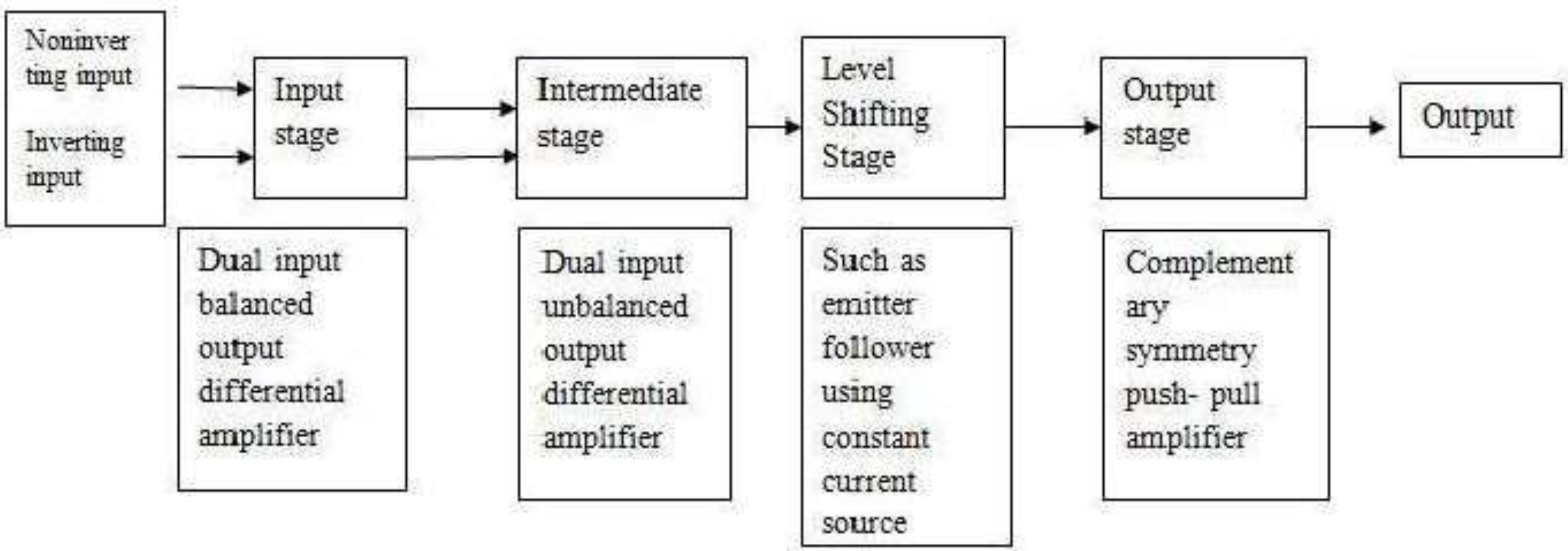


- 2 Inverting Input
- 3 Non-Inverting Input
- 6 Output
- 7 + Voltage Supply V_{CC}
- 4 – Voltage Supply V_{EE}
- 1 and 5 -- Offset Null

What do they really look like?



Block diagram

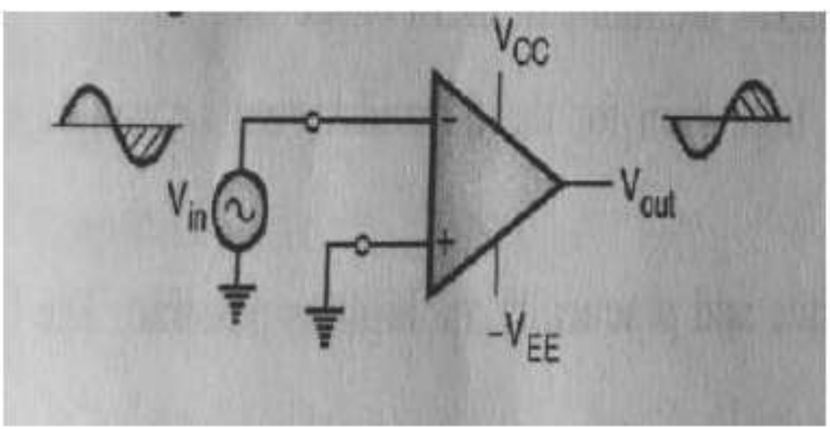


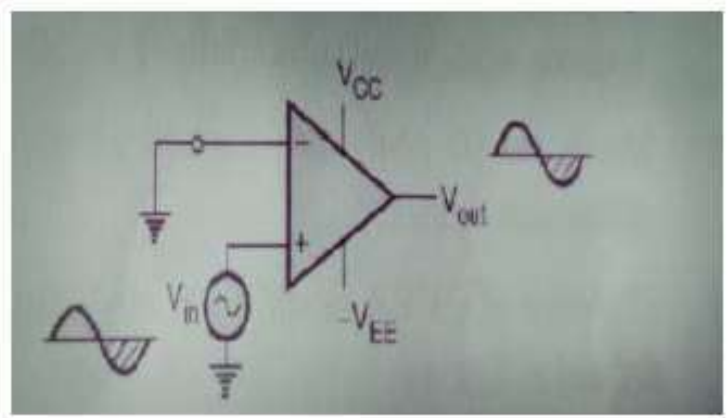
- **Input stage** provides most of the voltage gain of OP-AMP and decides input resistance.
- **Intermediate stage** is another differential amplifier which is driven by the output of input stage.
- Due to direct coupling between the first two stages, the input of level shifting is an amplified signal with some non zero dc level. **Level shifting stage** is used to bring this dc level to zero volts with respect to ground.
- **Output stage** increase the current supplying capability of OP-AMP and also provides low output resistance.

OP-AMP input modes

- **Single ended mode**

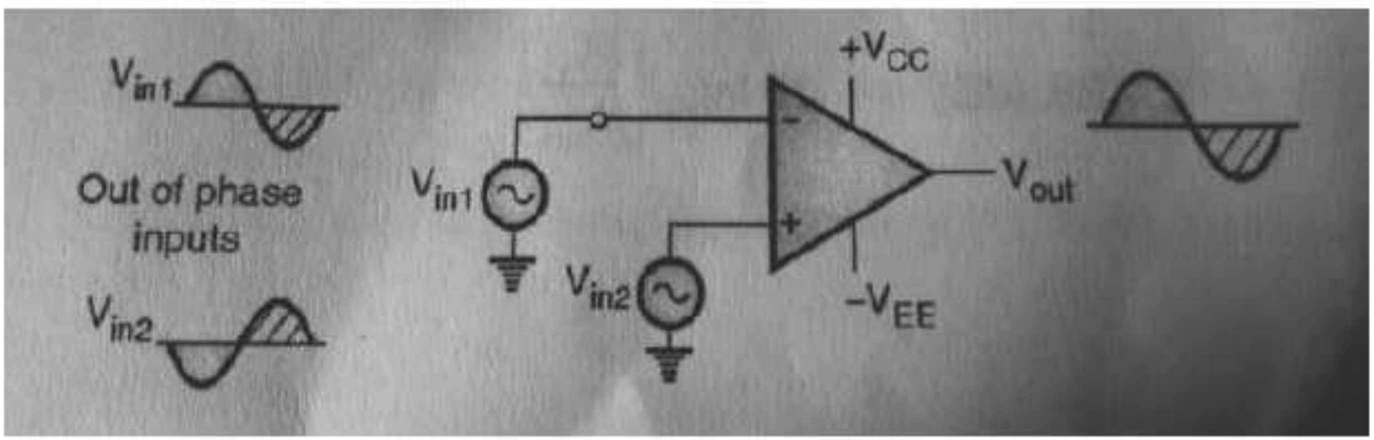
  If the input signal is applied to only one of the inputs and the other input terminal is connected to ground it is said to be operating in single ended mode.





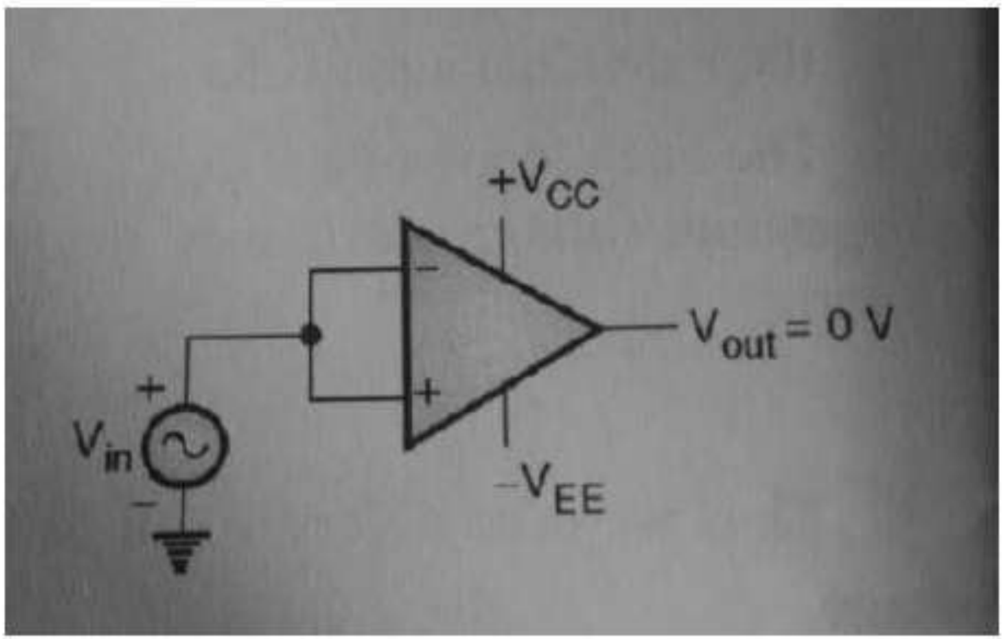
- **Differential mode/double ended**

In differential mode ,two opposite polarity signal are applied to the two inputs of op amp. The difference between the input signal is amplified appears at the output.



- **Common mode**

In the common mode of operation, the same input signal is applied to both the input terminals. Ideally a zero voltage should be produced by the op amp.



Characteristics of an OP-AMP

- The OP-AMP characteristics(parameters) are important in practice because, we can use them to compare the performance of various op amp ICs and select the best suitable from them for the required application.
- OP-AMP characteristics are classified into two categories namely AC characteristic and DC characteristic .

- **Open loop voltage gain-**It is the differential gain of an OP-AMP in the open loop mode of operation.
- **Input resistance-**It is defined as the equivalent resistance which can be measured at either at inverting or non-inverting terminal with the other terminal connected to ground.
- **Output resistance-**It is the resistance measured by looking into the output terminal of OP-AMP, with the input source short circuited.

- **Bandwidth-**It is the range over which all signal frequencies are amplified almost equally.
- **Common mode rejection ratio-**It is defined as the ratio of differential gain to common mode gain.
- **Slew rate-**It is defined as the maximum rate of change of output voltage per unit time.
- **Power supply rejection ratio-**It is the change in an OP-AMPs input offset voltage caused by variation in the supply voltage.

- **Input offset voltage-**Ideally, for a zero input voltage output should be zero. But practically it is not so. This is due to unavoidable unbalances inside the OP-AMP.
- **Input bias current-**It is the average of the currents flowing into the two input terminal of the OP-AMP.
- **Input offset current-** It is the algebraic difference between the currents flowing into the inverting and non-inverting terminal of OP-AMP.

Comparison of ideal and practical OP-AMP

characteristics	Practical value	Ideal value
Voltage gain	2×10^5	∞
Input resistance	2MΩ	∞
Output resistance	75Ω	0
Bandwidth	1 MHz	∞
CMRR	90 dB	∞
Slew rates	0.5V/μs	∞
PSRR	150μV/V	0
Input offset voltage	2mV	0
Input bias current	50 nA	0
Input offset current	6 nA	0

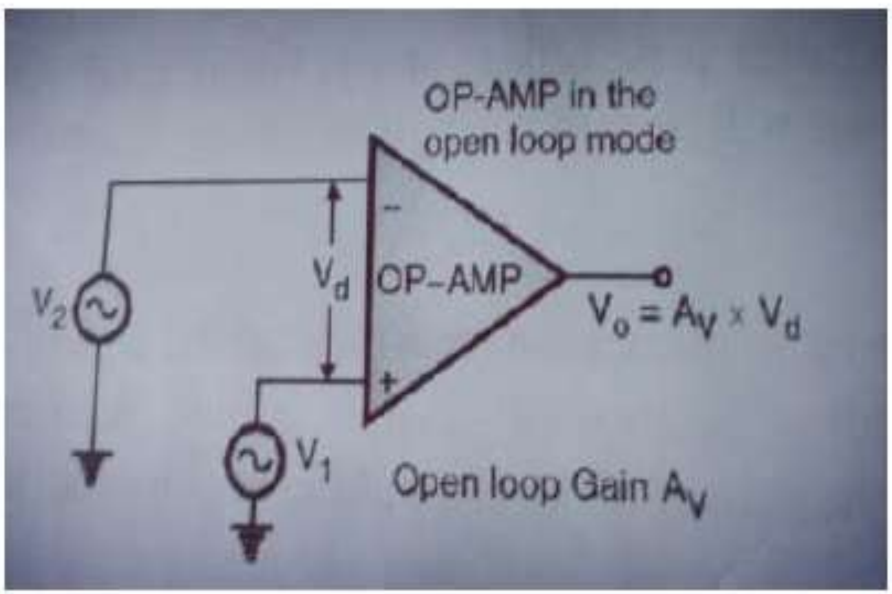
CONFIGURATION OF OP-AMP

- **Open loop configuration**

  In open loop configuration , there is no feedback from output to input.

  The differential signal present between the inputs will be amplified by it's open loop gain.($Av=2\times10^5$)

- Therefore even for very small magnitude of differential voltage output will reach positive or negative saturation



Why is OP-AMP not used as an amplifier in the open loop configuration?

- Due to very open loop gain, distortion is introduced in the amplified output signal.
- The open loop gain does not remain constant but varies with temperature and power supply as well due to mass production technique.
- The bandwidth of an OP-AMP is very small almost equal to zero. For this reason the open loop OP-AMP is not used in practice as an amplifier.

- **Close loop configuration**

In close loop configuration , a feedback is introduced i.e. a part of output is fed back to the input.

The feedback can be of the following two types:

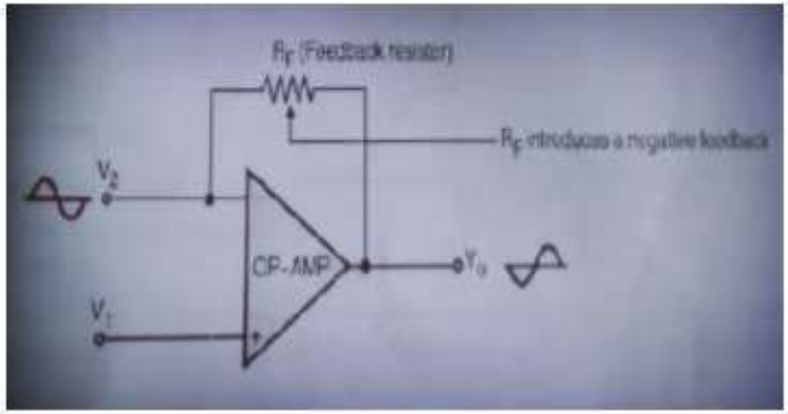
1. **Positive feedback/regenerative feedback**
2. **Negative feedback/degenerative feedback**

Positive feedback

If the feedback signal and the input signal are in phase with each other then it is called as the positive feedback.

It is used in application such as oscillators and schmitt trigger or regenerative comparators.

Negative feedback



If the signal fed back to the input and the original input signal are 180° out of phase, then it is called as the negative feedback.

In application of op amp as an amplifier, the negative feedback is used.

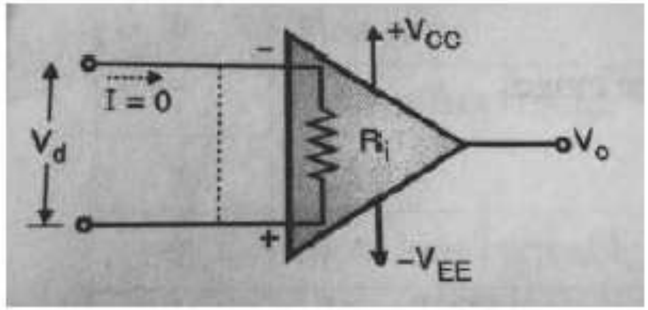
Advantages of negative feedback

- It stabilizes gain
- Reduces the distortion
- Increases the bandwidth
- Reduces the effect of variations in temperature and supply voltage on the output of op amp

The only disadvantage of negative feedback is low gain

Concept of virtual short

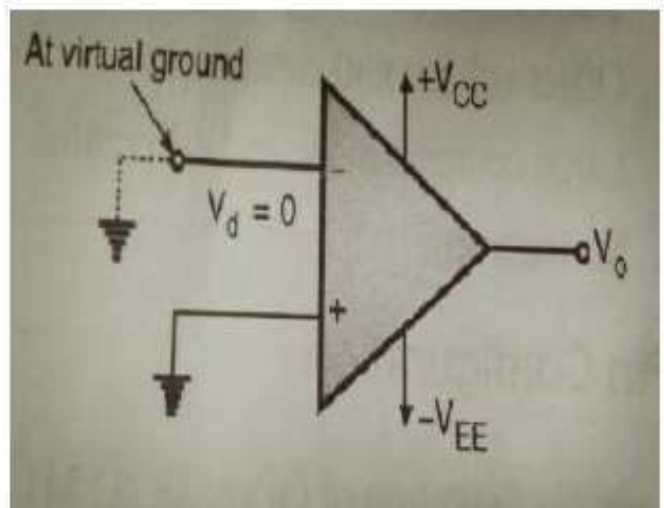
- According to virtual short concept, the potential difference between the two input terminals of an op amp is almost zero.
- In other words both the terminals are approximately at the same potential.



- The input impedance of an OP-AMP is ideally infinite. Hence current flowing from one input terminal to the other will be zero.
- Thus the voltage drop across Ri will be zero and both the terminals will be at the same potential.
- Means they are virtually shorted to each other

Virtual Ground

If one of the terminal of OP-AMP is connected to ground then due to the virtual short existing between the other input terminal, the other terminal is said to be at ground potential.



Zero input current

- As the input resistance of the ideal OP-AMP is infinite, the current flowing into it’s input terminal is zero.
- Even for the practical OP-AMPs, Rin=2MΩ which is very large. Hence for all the practical purposes we assume that the input current of an OP-AMP is zero.

Features of IC 741

- No frequency compensation required
- Short circuit protection
- Offset voltage null
- Large common mode and differential voltage ranges
- No latch ups

Quick Quiz (Poll 1)

- **For an Op-amp with negative feedback, the output is …….**

a) equal to the input
b) increased
c) fed back to the inverting input
d) fed back to the noninverting input

Quick Quiz (Poll 2)

- **The Op-amp can amplify**

- (a) a.c. signals only
- (b) d.c. signals only
- (c) both a.c. and d.c. signals
- (d) neither d.c. nor a.c. signals

UNIT-V

Fundamentals of filters and operational amplifier

Lecture 37

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Revision Questions(Poll 1)

- **When a differential amplifier is operated single-ended, ………..**

a) the output is grounded
b) one input is grounded and signal is applied to the other
c) both inputs are connected together
d) the output is not inverted

Revision Questions(Poll 2)

- **In differential-mode, …………….**

a) opposite polarity signals are applied to the inputs
b) the gain is one
c) the outputs are of different amplitudes
d) only one supply voltage is used

Revision Questions(Poll 3)

- **In the common mode, ……………**

a) both inputs are grounded
b) the outputs are connected together
c) an identical signal appears on both the inputs
d) the output signal are in-phase

Revision Questions(Poll 4)

- **The use of negative feedback ………**

a) reduces the voltage gain of an Op-amp
b) makes the Op-amp oscillate
c) makes linear operation possible
d) answers (1) and (2)

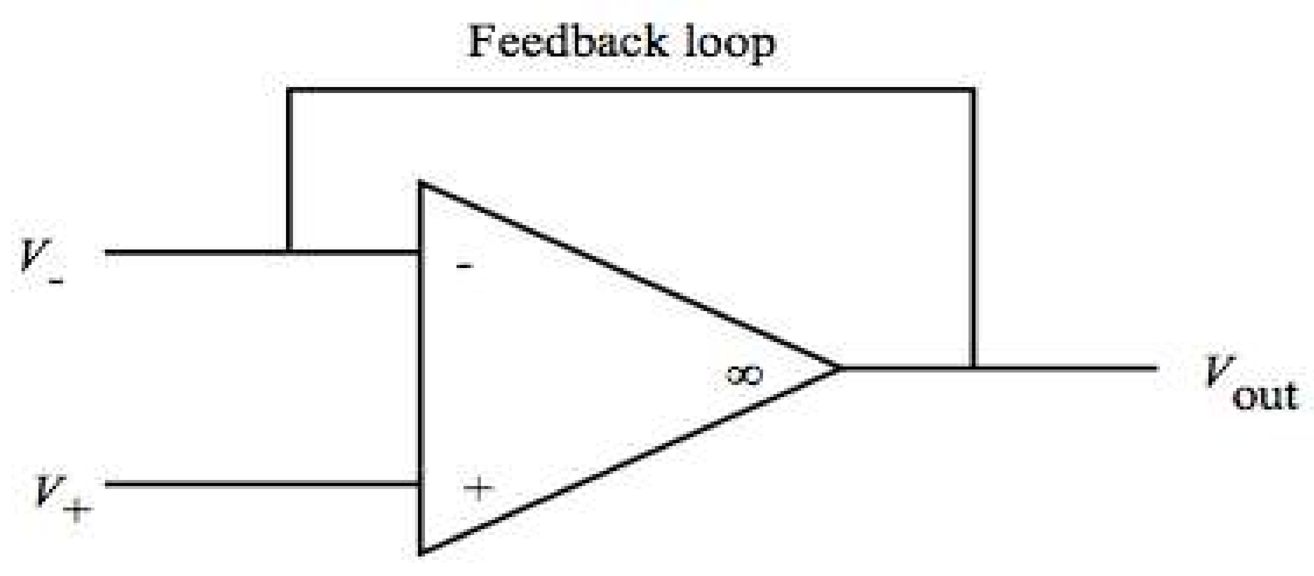
What Is An Operational Amplifier?

- An operational amplifier or op-amp is simply a linear Integrated Circuit (IC) having multiple-terminals. The op-amp can be considered to be a voltage amplifying device that is designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. It is a high-gain electronic voltage amplifier with a differential input and usually a single-ended output. Op-amps are among the most widely used electronic devices today as they are used in a vast array of consumer, industrial and scientific devices.

Op-Amp "Golden Rules"

1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

2. The inputs draw no current.



Op-Amp Operation

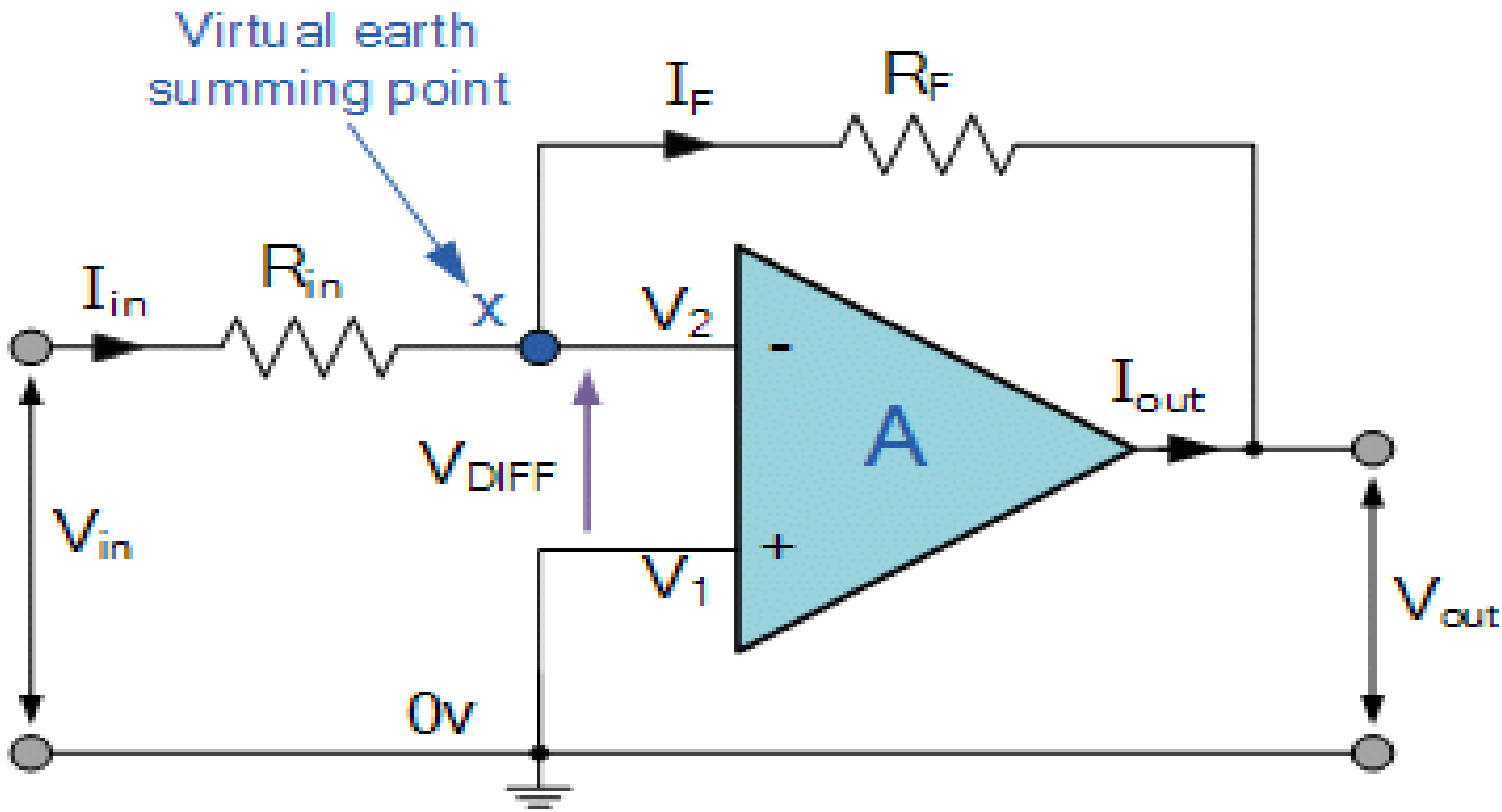
Ideally, an op-amp amplifies only the difference in voltage between the two, also called differential input voltage. The output voltage of the op-amp V_{out} is given by the equation:

$$V_{out} = A_{OL} (V_{+} - V_{-})$$

where A_{OL} is the open-loop gain of the amplifier.

In a linear operational amplifier, the output signal is the amplification factor, known as the amplifier's gain (A) multiplied by the value of the input signal.

Inverting Operational Amplifier



Inverting Operational Amplifier

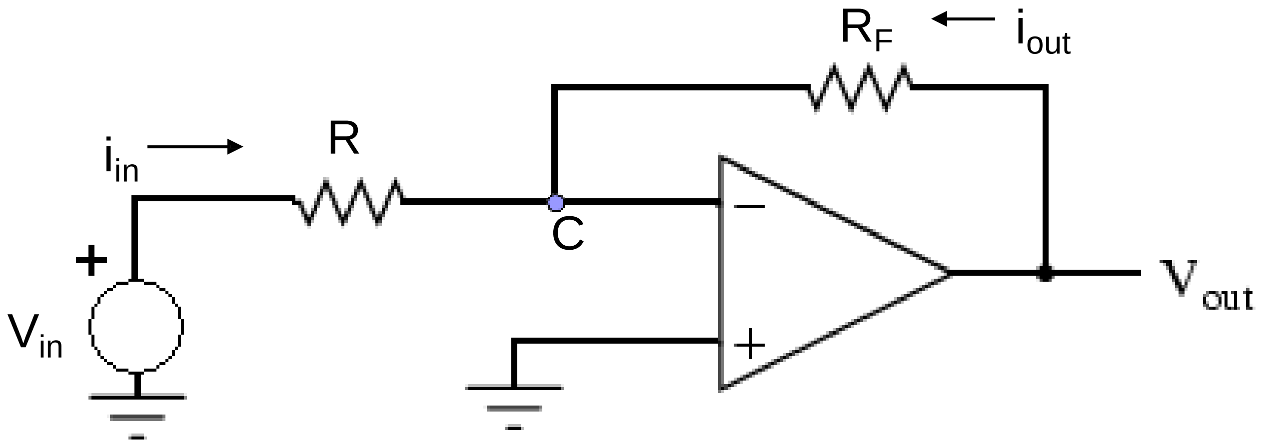
- The Inverting Operational Amplifier configuration is one of the simplest and most commonly used op-amp topologies.

- In this **Inverting Amplifier** circuit the operational amplifier is connected with feedback to produce a closed loop operation. When dealing with operational amplifiers there are two very important rules to remember about inverting amplifiers, these are: “No current flows into the input terminal” and that “V1 always equals V2”. However, in real world op-amp circuits both of these rules are slightly broken.

- This is because the junction of the input and feedback signal (X) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a **“Virtual Earth”**. Because of this virtual earth node the input resistance of the amplifier is equal to the value of the input resistor, Rin and the closed loop gain of the inverting amplifier can be set by the ratio of the two external resistors.

- No Current Flows into the Input Terminals
- The Differential Input Voltage is Zero as V1 = V2 = 0 (Virtual Earth)

Inverting Amplifier



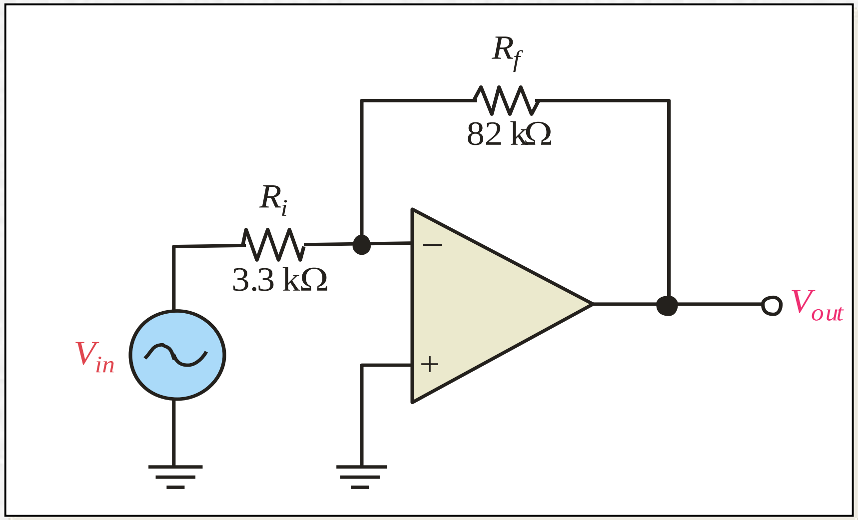
$$\frac{V_{out}}{V_{in}} = -\frac{R_F}{R}$$

Inverting Amplifier

Example:

Determine the gain of the inverting amplifier shown.

Solution:



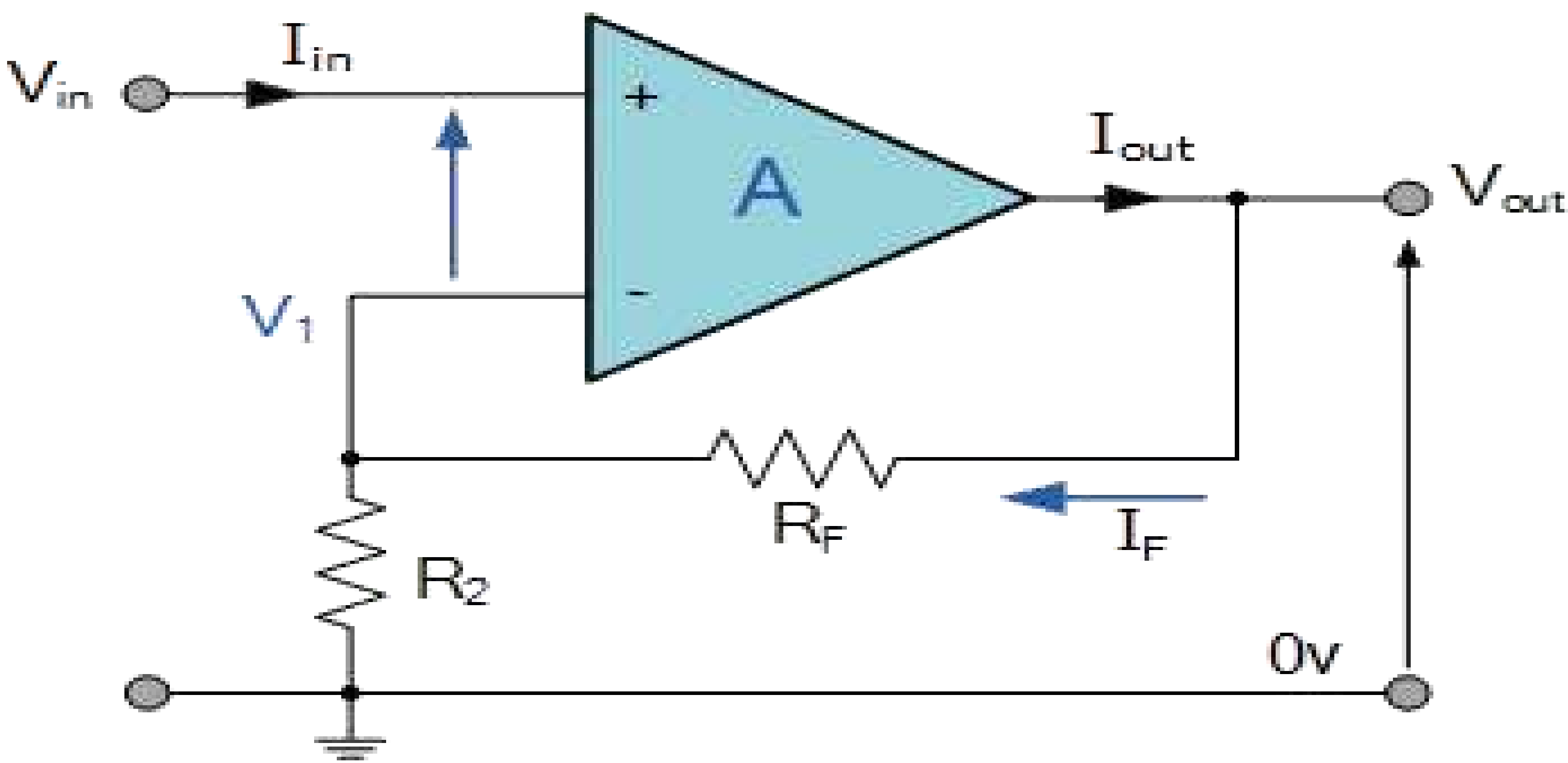
$$A_{cl(\mathrm{I})} = -\frac{R_f}{R_i}$$

$$= -\frac{82\ \mathrm{k}\Omega}{3.3\ \mathrm{k}\Omega}$$

$$= -24.8$$

The minus sign indicates inversion.

Non- Inverting Amplifier



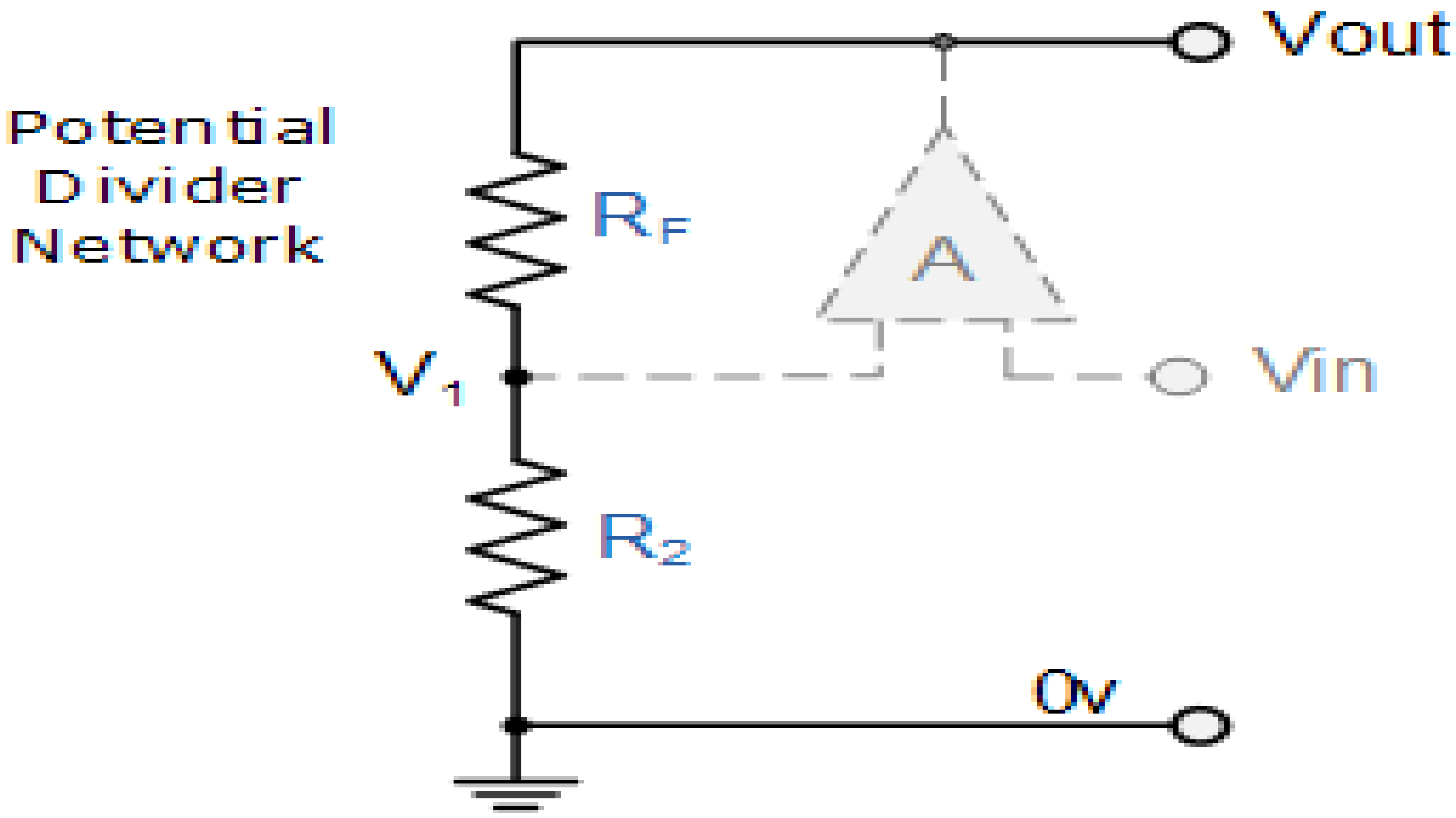
Non- Inverting Amplifier

- The second basic configuration of an operational amplifier circuit is that of a **Non-inverting Operational Amplifier** design.

- In the previous Inverting Amplifier, we said that for an ideal op-amp "No current flows into the input terminal" of the amplifier and that "V1 always equals V2". This was because the junction of the input and feedback signal (V1) are at the same potential.

- In other words the junction is a "virtual earth" summing point. Because of this virtual earth node the resistors, Rf and R2 form a simple potential divider network across the non-inverting amplifier with the voltage gain of the circuit being determined by the ratios of R2 and Rf as shown below.

Non- Inverting Amplifier



$$V_1 = \frac{R_2}{R_2 + R_F} \times V_{OUT}$$

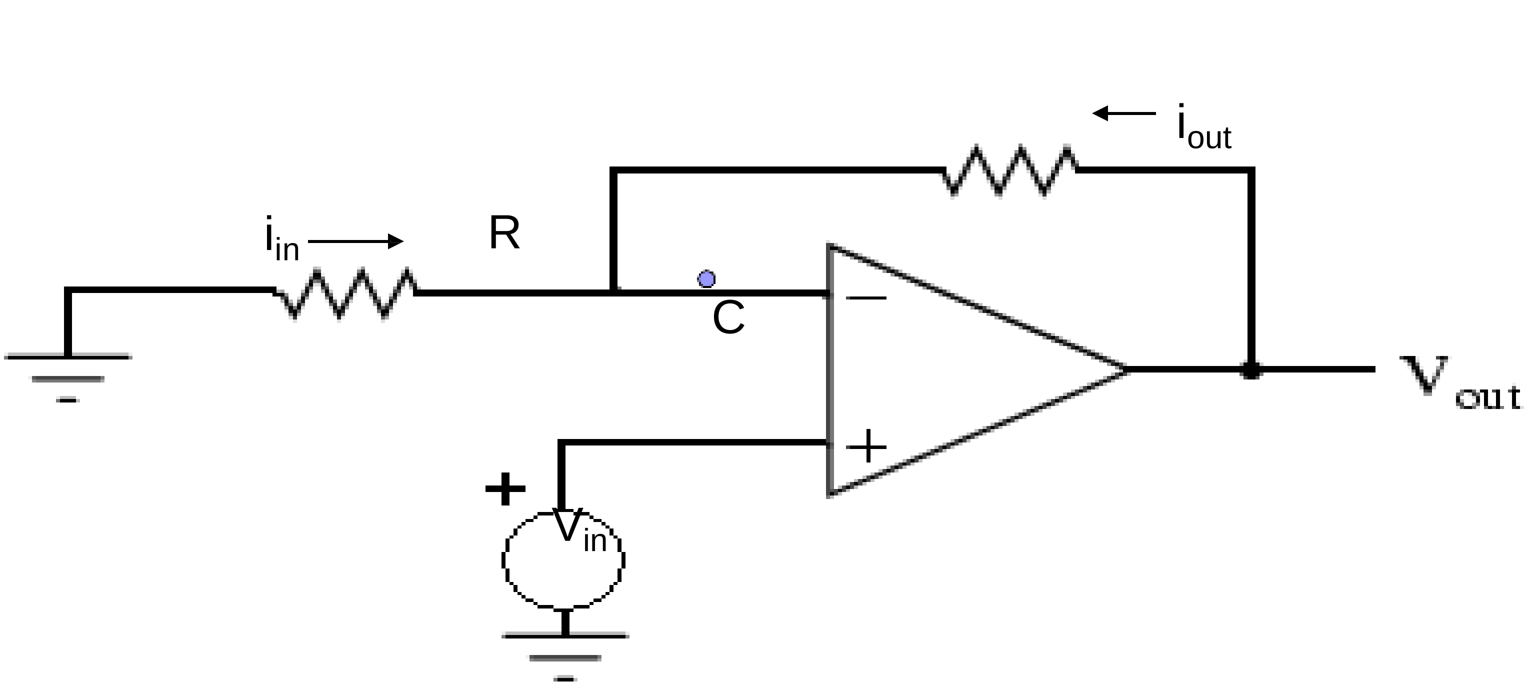
Ideal Summing Point: $V_1 = V_{IN}$

Voltage Gain, $A_{(V)}$ is equal to: $\dfrac{V_{OUT}}{V_{IN}}$

Then, $A_{(V)} = \dfrac{V_{OUT}}{V_{IN}} = \dfrac{R_2 + R_F}{R_2}$

Transpose to give: $A_{(V)} = \dfrac{V_{OUT}}{V_{IN}} = 1 + \dfrac{R_F}{R_2}$

Non-Inverting Amplifier



$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R}$$

Noninverting Amplifier

Example:

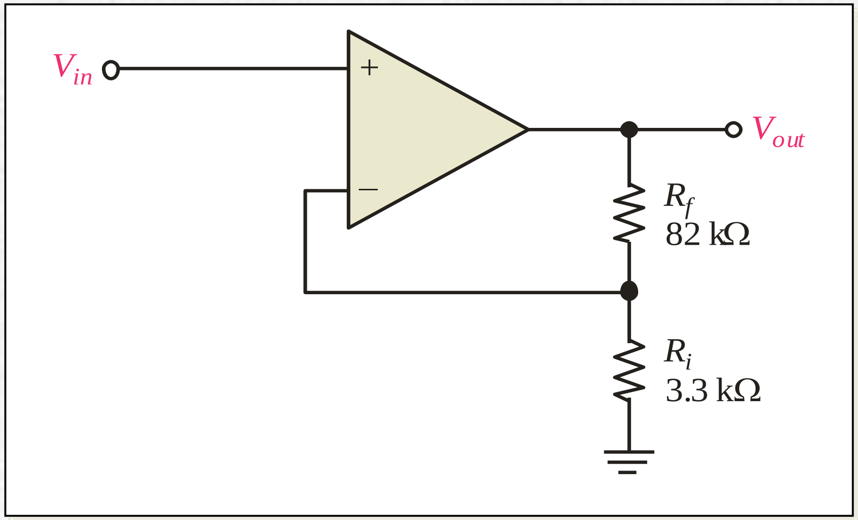
Determine the gain of the noninverting amplifier shown.

Solution:

$$A_{cl(\mathrm{NI})} = 1 + \frac{R_f}{R_i}$$

$$= 1 + \frac{82\ \mathrm{k}\Omega}{3.3\ \mathrm{k}\Omega}$$

$= 35.8$



Applications of op-amp

- Amplifiers
- Active filters
- Arithmetic circuits.
- Log/antilog amp
- Voltage comparators
- Waveform Generators
- Precision rectifiers
- Multipliers
- Timers
- Multivilbrators
- Regulated power supplies

Advantages of OP-AMP over conventional Amplifiers:

- It has smaller size.
- Its reliability is higher than conventional amplifier
- Reduced cost as compared to its discrete circuit parts.
- Less power consumption
- Easy to replace Same OP-AMP can be used for different applications.

UNIT-V

Fundamentals of filters and operational amplifier

Lecture 39
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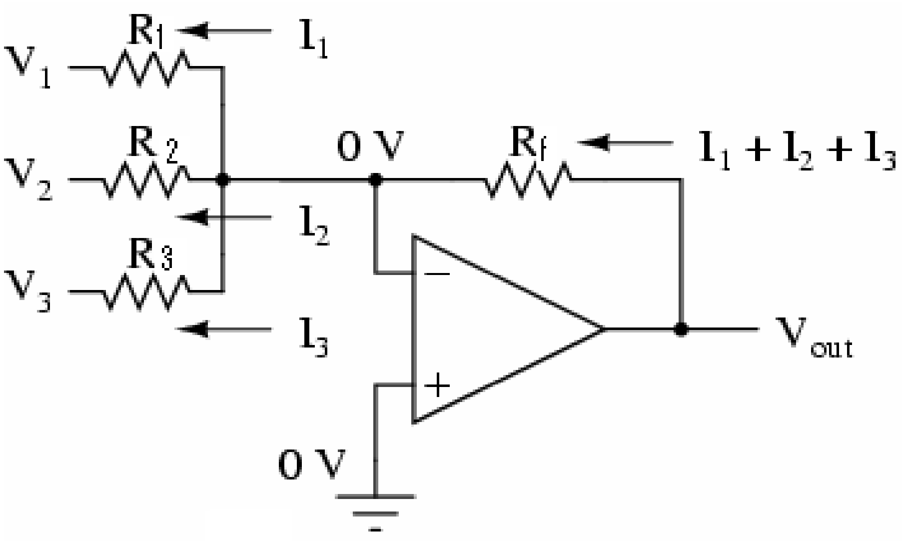
Summing Circuits



- Used to add analog signals
- Voltage averaging function into summing function

Calculate closed loop gain for each input

$$A_{CL1} = \frac{-R_f}{R_1} \quad A_{CL1} = \frac{-R_f}{R_2} \quad A_{CL1} = \frac{-R_f}{R_3}$$

$$V_o = V_{in} \cdot A_{CLn} \qquad V_o = -V_1 \cdot \frac{R_f}{R_1} - V_2 \cdot \frac{R_f}{R_2} - V_3 \cdot \frac{R_f}{R_3}$$

If all resistors are equal in value:

$$V_o = -(V_1 + V_2 + V_3)$$

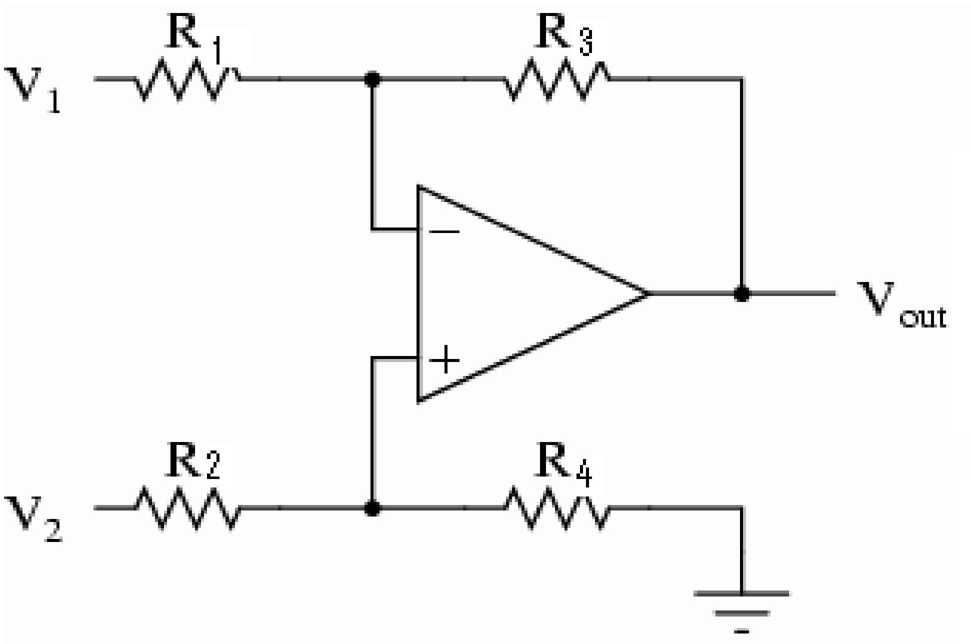
Op amp Summing circuits

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right]$$

$$\text{Inverting Equation: } Vout = -\frac{Rf}{Rin} \times Vin$$

$$\text{then, } -Vout = \left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$$

Difference Circuit

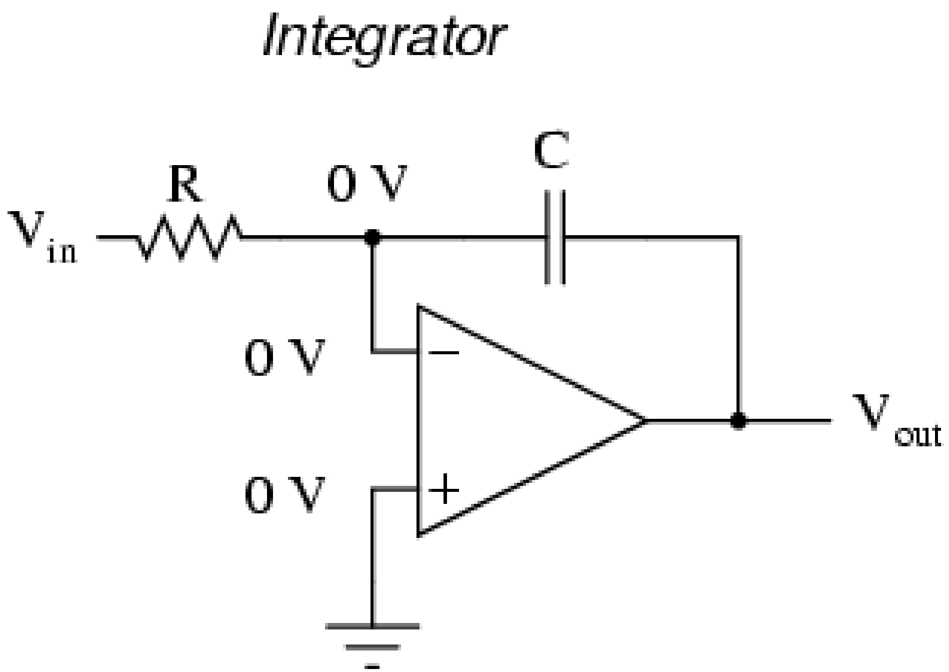


- Used to subtract analog signals
- Output signal is proportional to difference between two inputs

$$V_{out} = \frac{V_2(R_3 + R_1)R_4}{(R_4 + R_2)R_1} - \frac{V_1 R_3}{R_1}$$

If all resistors are equal: $V_{out} = V_2 - V_1$

Integrating Circuit



- Replace feedback resistor of inverting op-amp with capacitor
- A constant input signal generates a certain rate of change in output voltage
- Smoothes signals over time

$$\frac{dv_{out}}{dt} = -\frac{V_{in}}{RC}$$

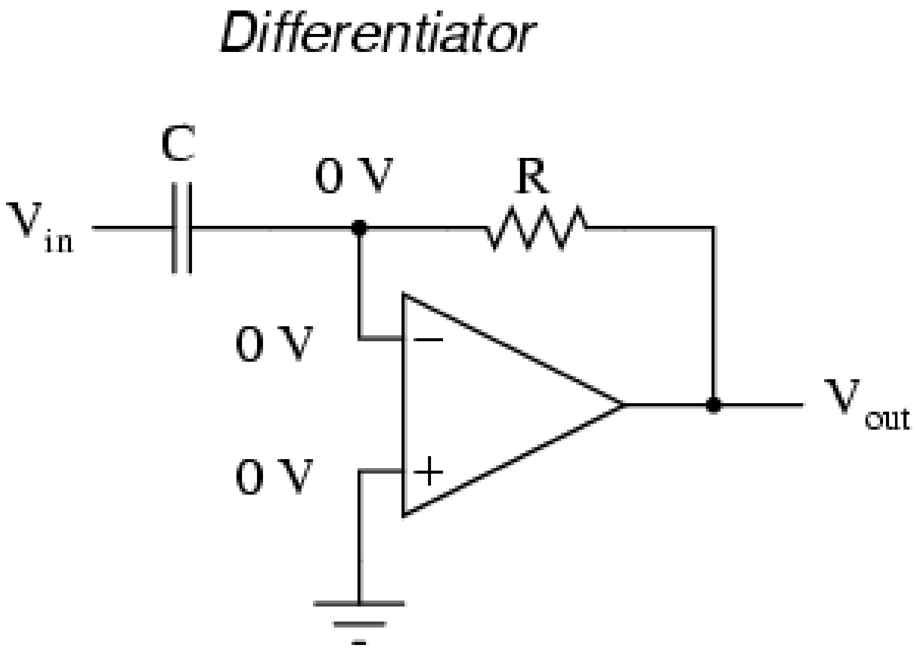
or

$$V_{out} = \int_0^t -\frac{V_{in}}{RC}\,dt + c$$

Where,

c = Output voltage at start time $(t=0)$

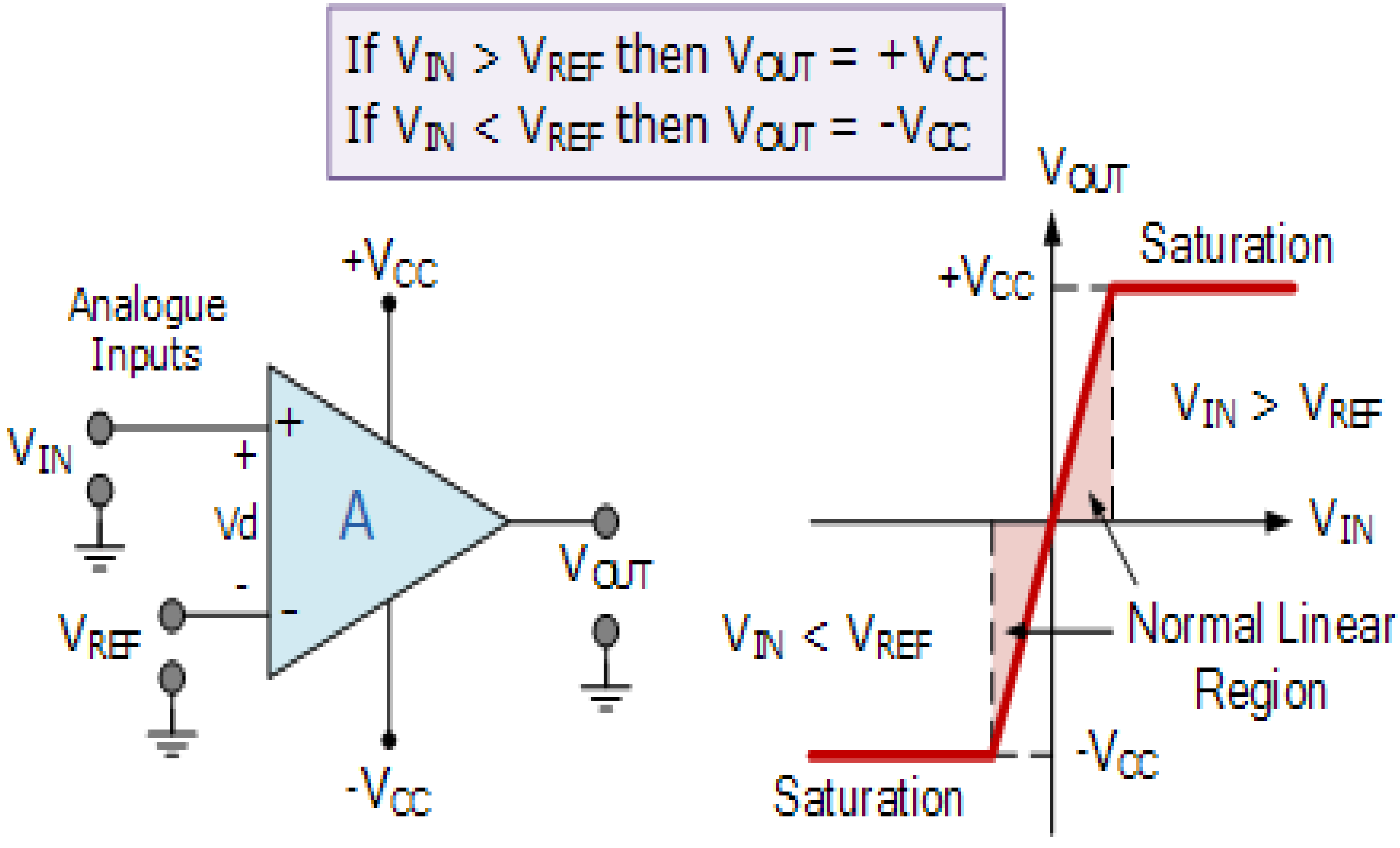
Differentiating Circuit



- Input resistor of inverting op-amp is replaced with a capacitor
- Signal processing method which accentuates noise over time
- Output signal is scaled derivative of input signal

$$V_{out} = -RC \frac{dv_{in}}{dt}$$

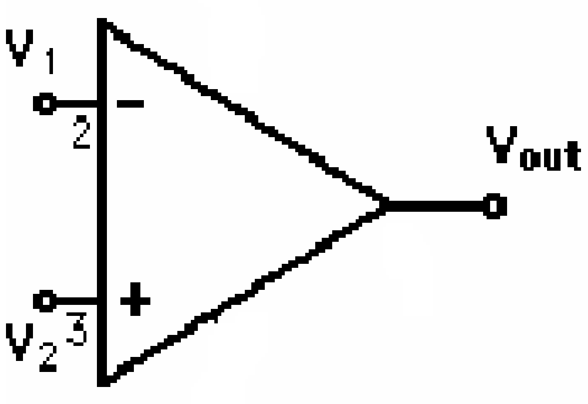
Op-amp comparator



Comparator Circuit

V_1 is V_{ref}

V_2 is V_{in}



$$v_{out} = \begin{cases} +V_{max} & v_+ > v_- \\ -|V_{min}| & v_+ < v_- \end{cases}$$

- Determines if one signal is bigger than another
- No negative feedback, infinite gain and circuit saturates
- Saturation: output is most positive or most negative value

Op-amp Comparator

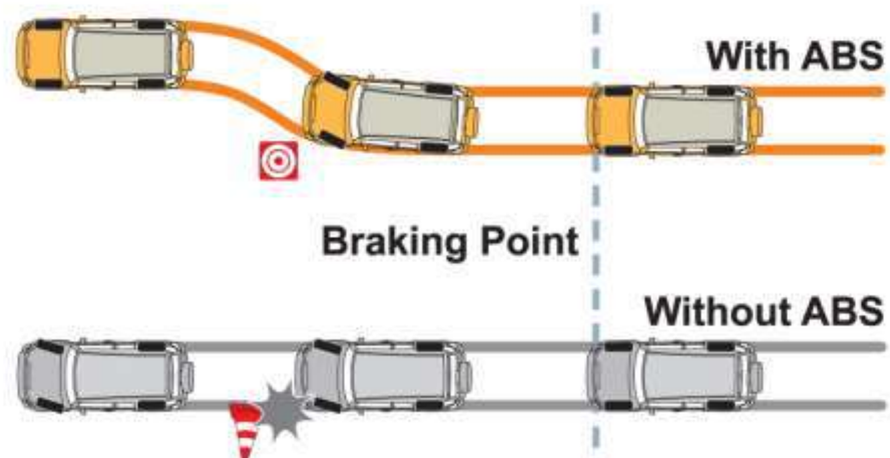
- The comparator is an electronic decision making circuit that makes use of an operational amplifiers very high gain in its open-loop state, that is, there is no feedback resistor.
- The **Op-amp comparator** compares one analogue voltage level with another analogue voltage level, or some preset reference voltage, V_{REF} and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two.

- We have seen in previous tutorials that the operational amplifier can be used with negative feedback to control the magnitude of its output signal in the linear region performing a variety of different functions. We have also seen that the standard operational amplifier is characterised by its open-loop gain A_O and that its output voltage is given by the expression: $V_{OUT} = A_O(V+ – V-)$ where V+ and V- correspond to the voltages at the non-inverting and the inverting terminals respectively.

Anti-lock braking System (ABS)

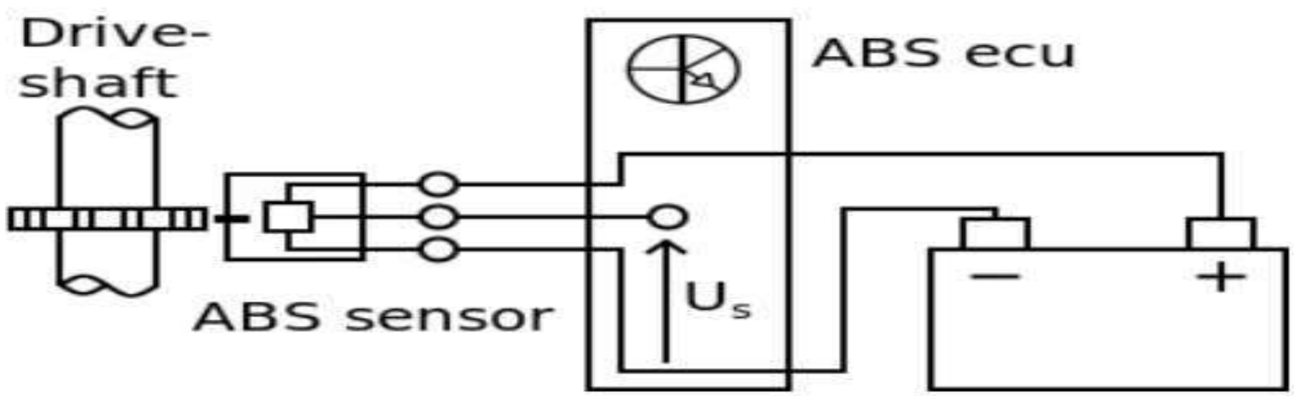
Anti-lock brake system is merely traction based braking equipment installed on most of the modern cars with an aim of ensuring the safety of the users. Majority of cars using this braking system are four-wheeler and require a mechanism for fast brakes on the road. The mechanism installed on the ABS makes the wheel to keep the normal braking system from locking up, a normal case with the normal brake, which can cause the car to skid out of the road in case of an emergency

https://www.youtube.com/watch?v=ru4JIZ-x8yo



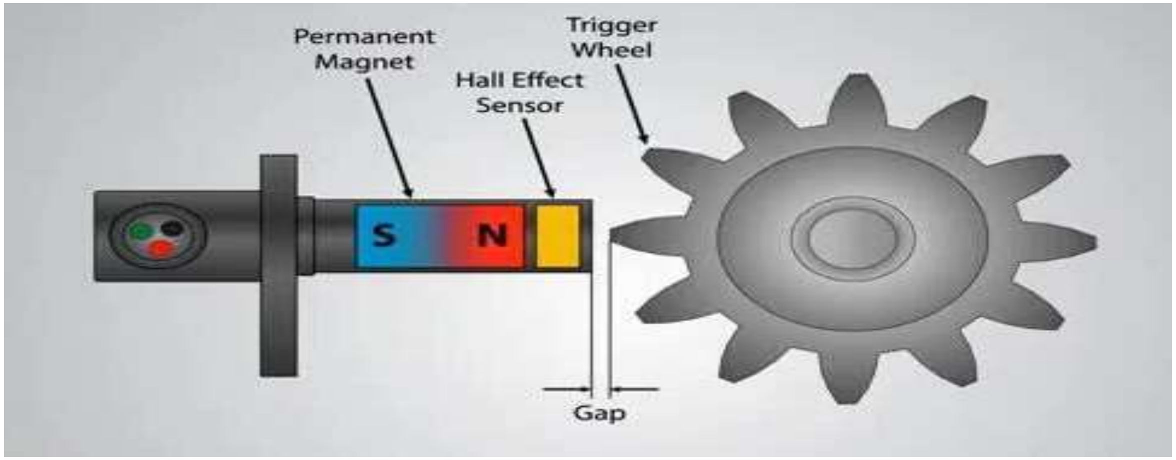
Anti-lock braking System (ABS)

Basically, anti lock braking system (ABS) sensor is used the hall effect sensor for determining wheel rotation speed to prevent wheel lock up when braking. The Hall effect ABS sensor consists of a permanent magnet with a Hall effect sensor next to it. The magnetic field strength changes when a magnetism sensitive object passes through the magnetic field of the magnet. This changing of the magnetic field causes the output of the Hall effect sensor to change.



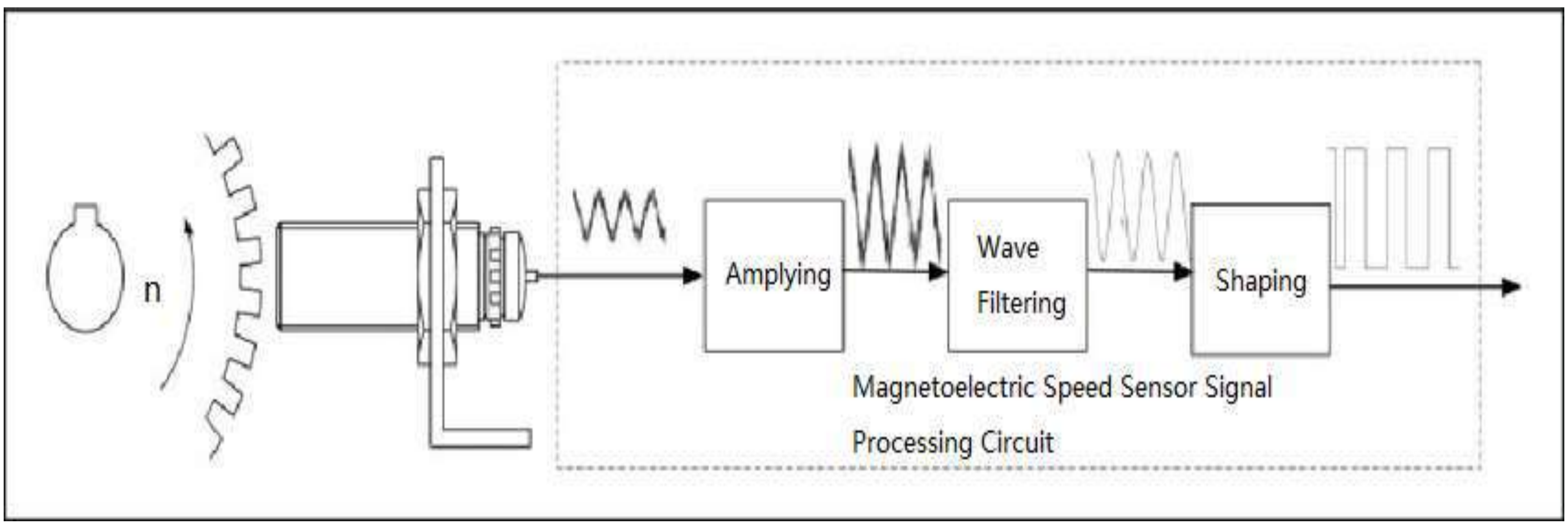
Anti-lock braking System (ABS)

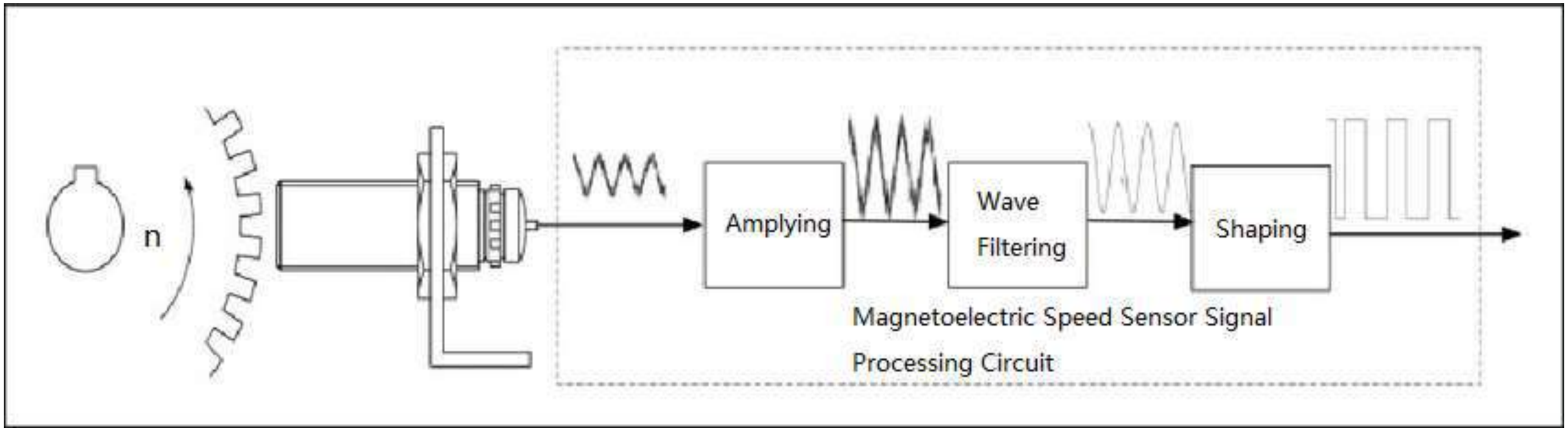
In most cases the object used to influence the magnetic field is a disk or ring with evenly distributed teeth, mounted on the driveshaft or in the bearing. When the wheel is rotating, the teeth are passing the sensor and the pattern in which they are placed is visible in the ABS sensor signal. Each period of the signal is a tooth passing the sensor. The frequency of the signal depends on the rotation speed of the wheel and the amount of teeth on the disk or ring.

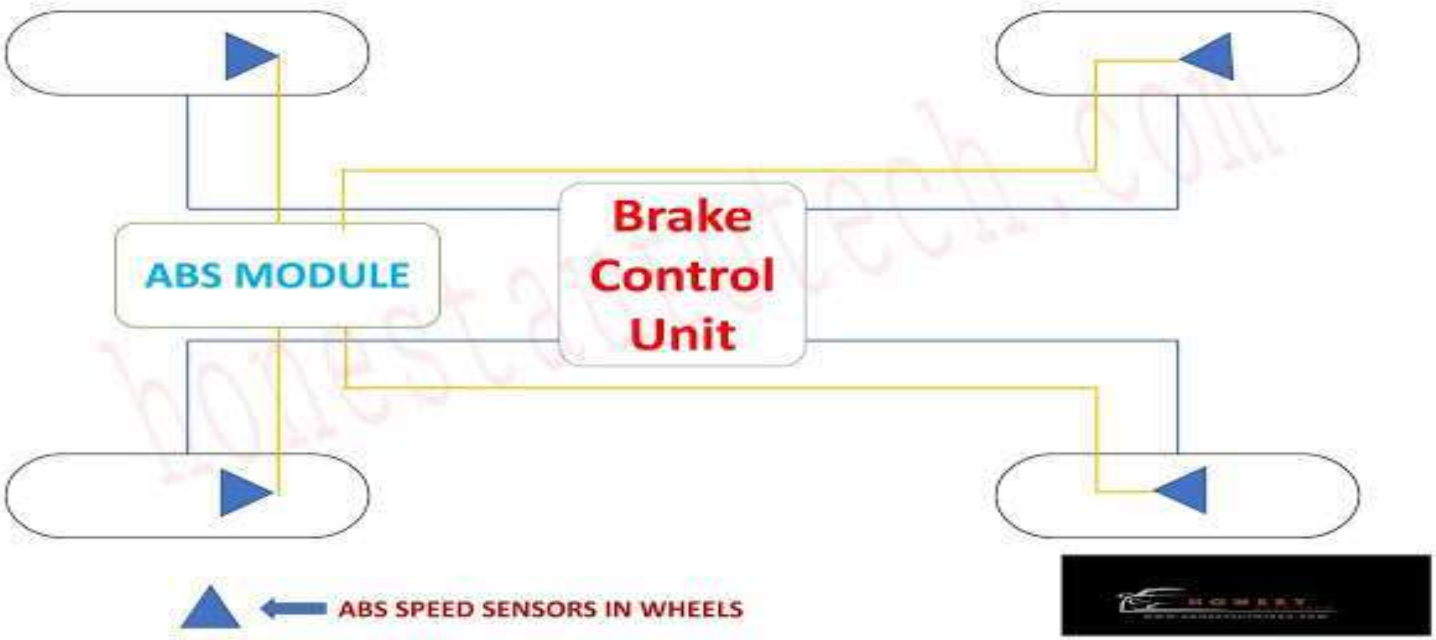


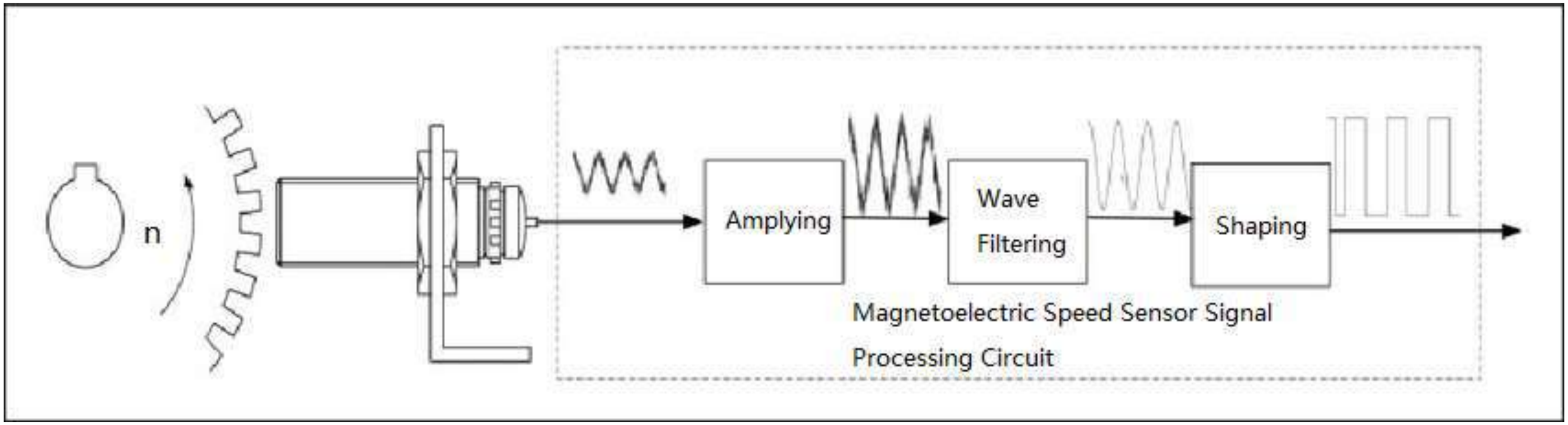
Anti-lock braking System (ABS)

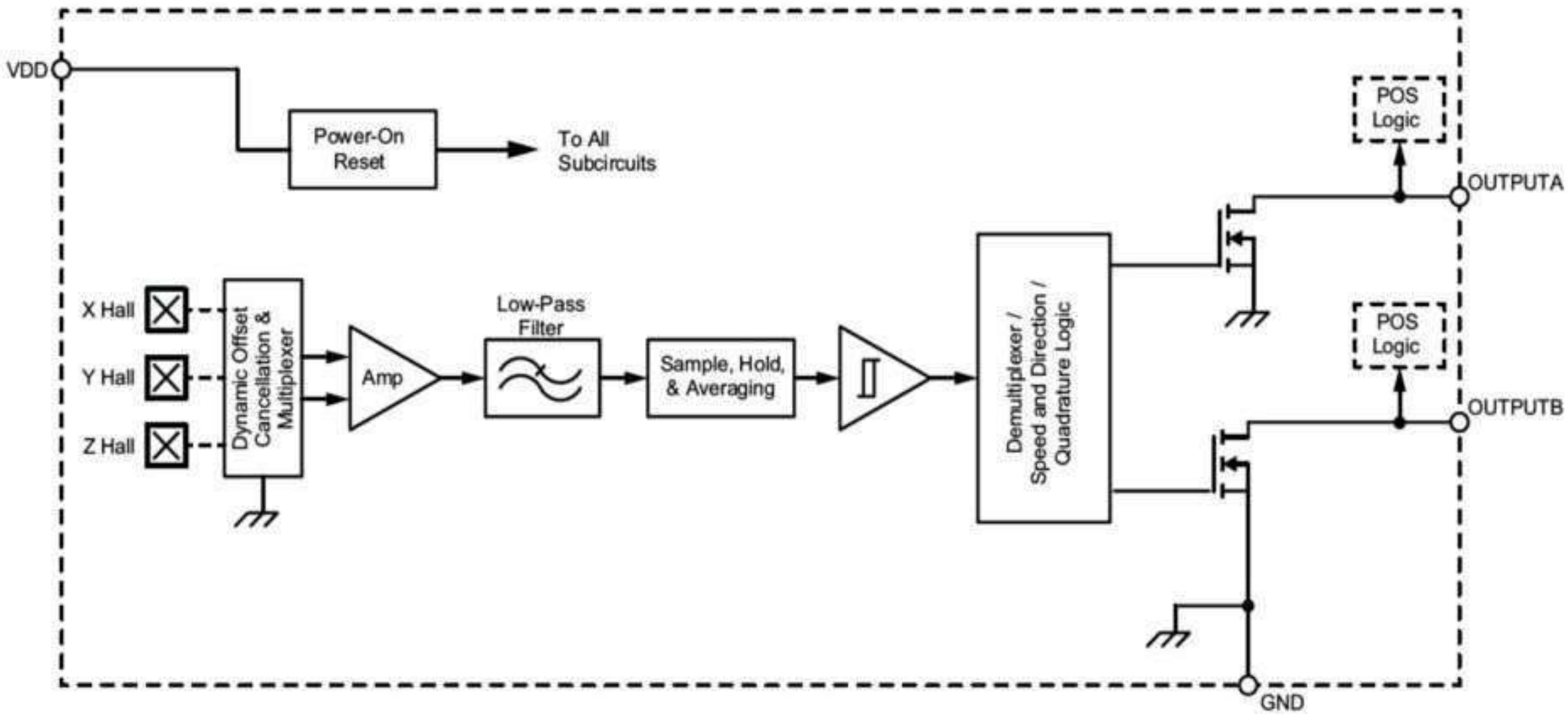
The magnetic induction intensity B changes with the wheel speed to generate hall potential pulse. After amplifying, shaping and amplifying power amplifier in hall IC, pulse train is output to the outside




n
Amplying
Wave
Filtering
Shaping
Magnetoelectric Speed Sensor Signal
Processing Circuit


ABS MODULE
Brake
Control
Unit
ABS SPEED SENSORS IN WHEELS


n
Amplying
Wave
Filtering
Shaping
Magnetoelectric Speed Sensor Signal
Processing Circuit


VDD
Power-On
Reset
To All
Subcircuits
POS
Logic
OUTPUTA
X Hall
Y Hall
Z Hall
Dynamic Offset
Cancellation &
Multiplexer
Amp
Low-Pass
Filter
Sample, Hold,
& Averaging
Demultiplexer /
Speed and Direction /
Quadrature Logic
POS
Logic
OUTPUTB
GND

Summary of Op-amp

- The Operational Amplifier, or Op-amp as it is most commonly called, can be an ideal amplifier with infinite Gain and Bandwidth when used in the Open-loop mode with typical DC gains of well over 100,000 or 100dB.

- • The basic Op-amp construction is of a 3-terminal device, with 2-inputs and 1-output, (excluding power connections).

- • An Operational Amplifier operates from either a dual positive (+V) and an corresponding negative (-V) supply, or they can operate from a single DC supply voltage.

- • The two main laws associated with the operational amplifier are that it has an infinite input impedance, ($Z = \infty$) resulting in “No current flowing into either of its two inputs” and zero input offset voltage $V1 = V2$.

Summary Op-amp

An operational amplifier also has zero output impedance, (Z = 0).

- Op-amps sense the difference between the voltage signals applied to their two input terminals and then multiply it by some pre-determined Gain, (A).
- This Gain, (A) is often referred to as the amplifiers “Open-loop Gain”.
- Closing the open loop by connecting a resistive or reactive component between the output and one input terminal of the op-amp greatly reduces and controls this open-loop gain.
- Op-amps can be connected into two basic configurations, Inverting and Non-inverting.

Quick Quiz (Poll 1)

- Find the output voltage of an ideal op-amp. If V_1 and V_2 are the two input voltages
-

  a) $V_O = V_1 - V_2$
  b) $V_O = A \times (V_1 - V_2)$
  c) $V_O = A \times (V_1 + V_2)$
  d) $V_O = V_1 \times V_2$

Quick Quiz (Poll 2)

- **Which concept states that if one input terminal of an op-amp is at zero potential, then the other one also will be at zero potential?**

- **a.** Virtual short
  b. Virtual ground
  c. Zero input current
  d. None of the above

Quick Quiz (Poll 3)

- **Which among the following is/are the feature/s characteristic/s of an integrated op-amp?**

- **a.** Small size
  b. High reliability
  c. Low cost & less power consumption
  d. All of the above