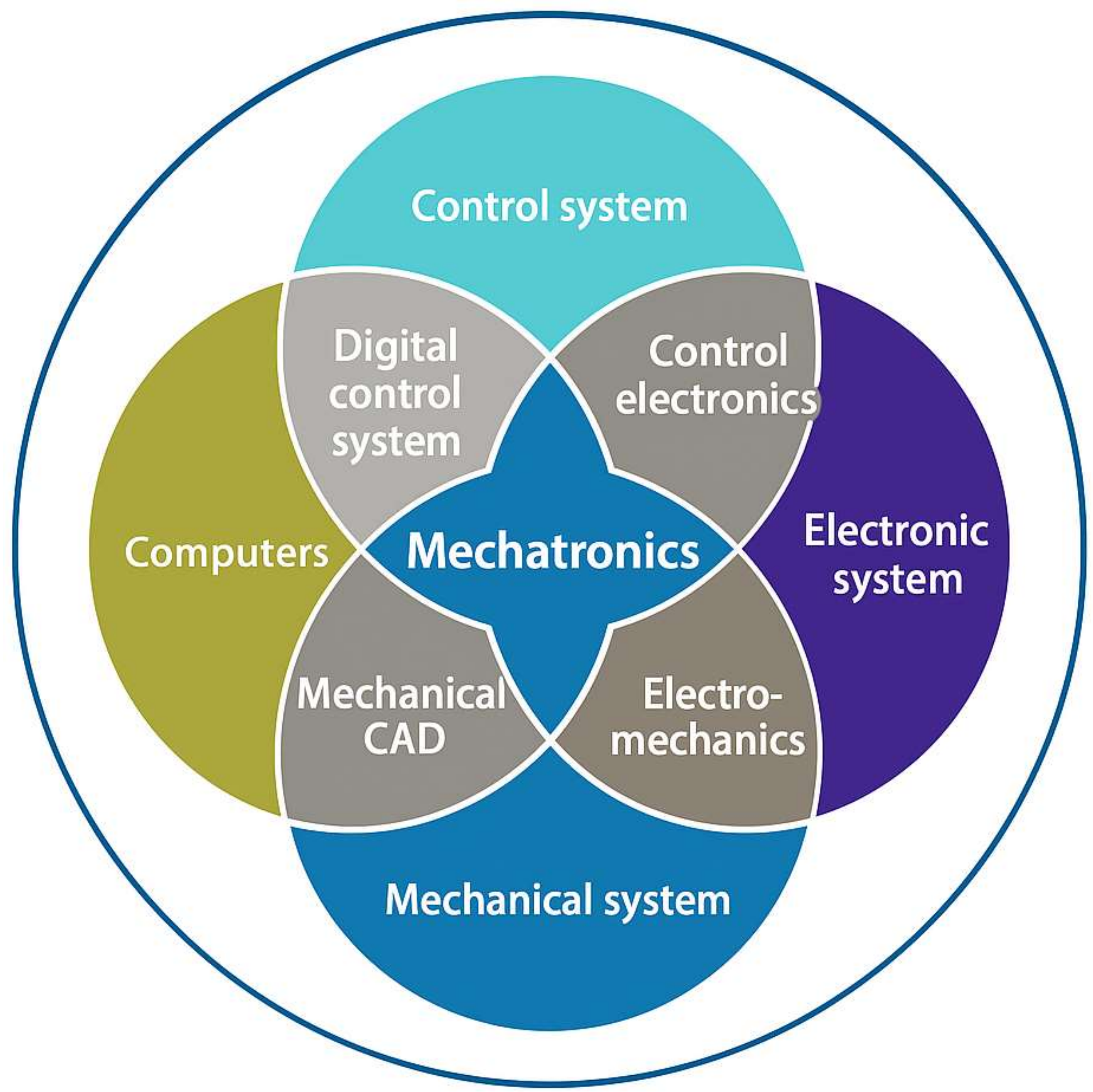
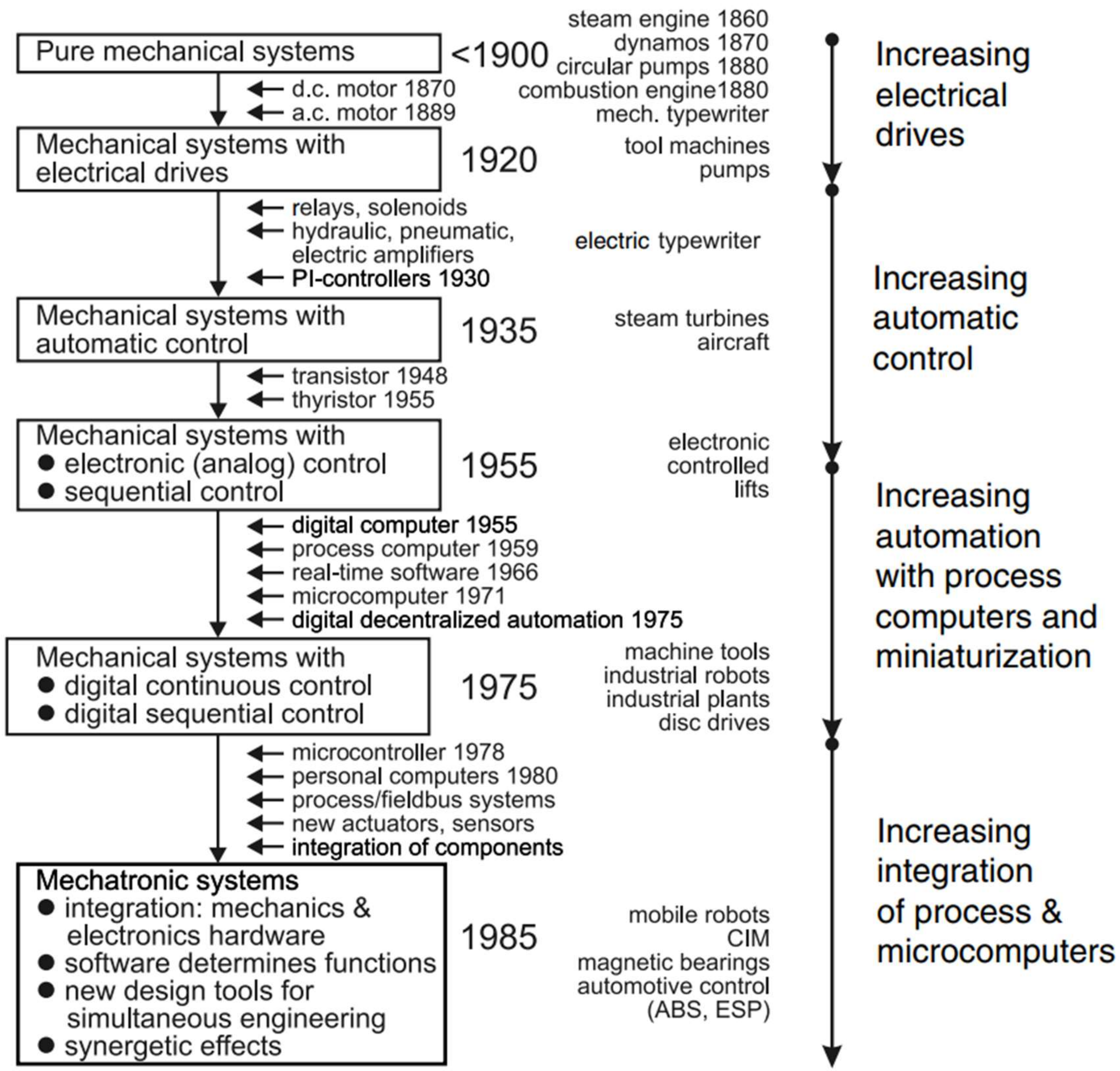
INTRODUCTION TO MECHATRONICS



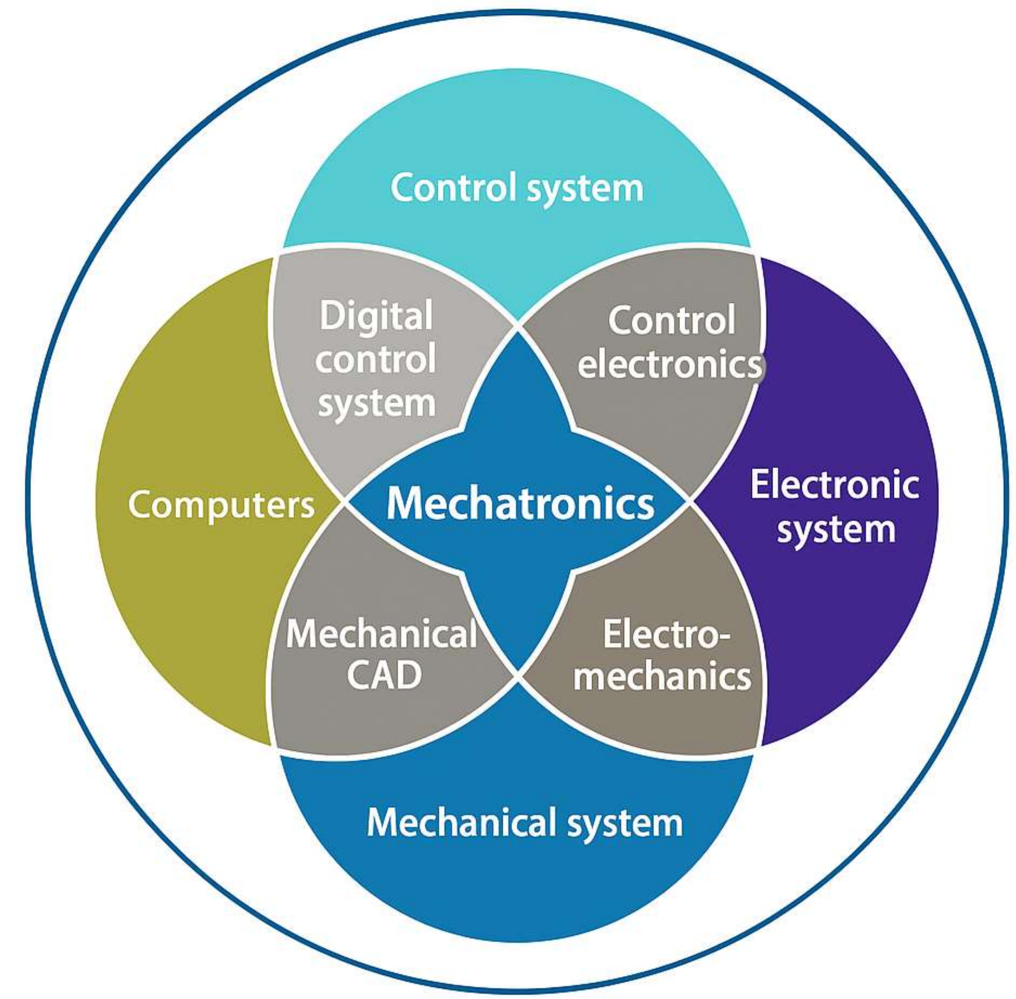
MECHATRONICS



Historical Development of Mechanical, Electrical, and Electronic Systems

MECHATRONICS

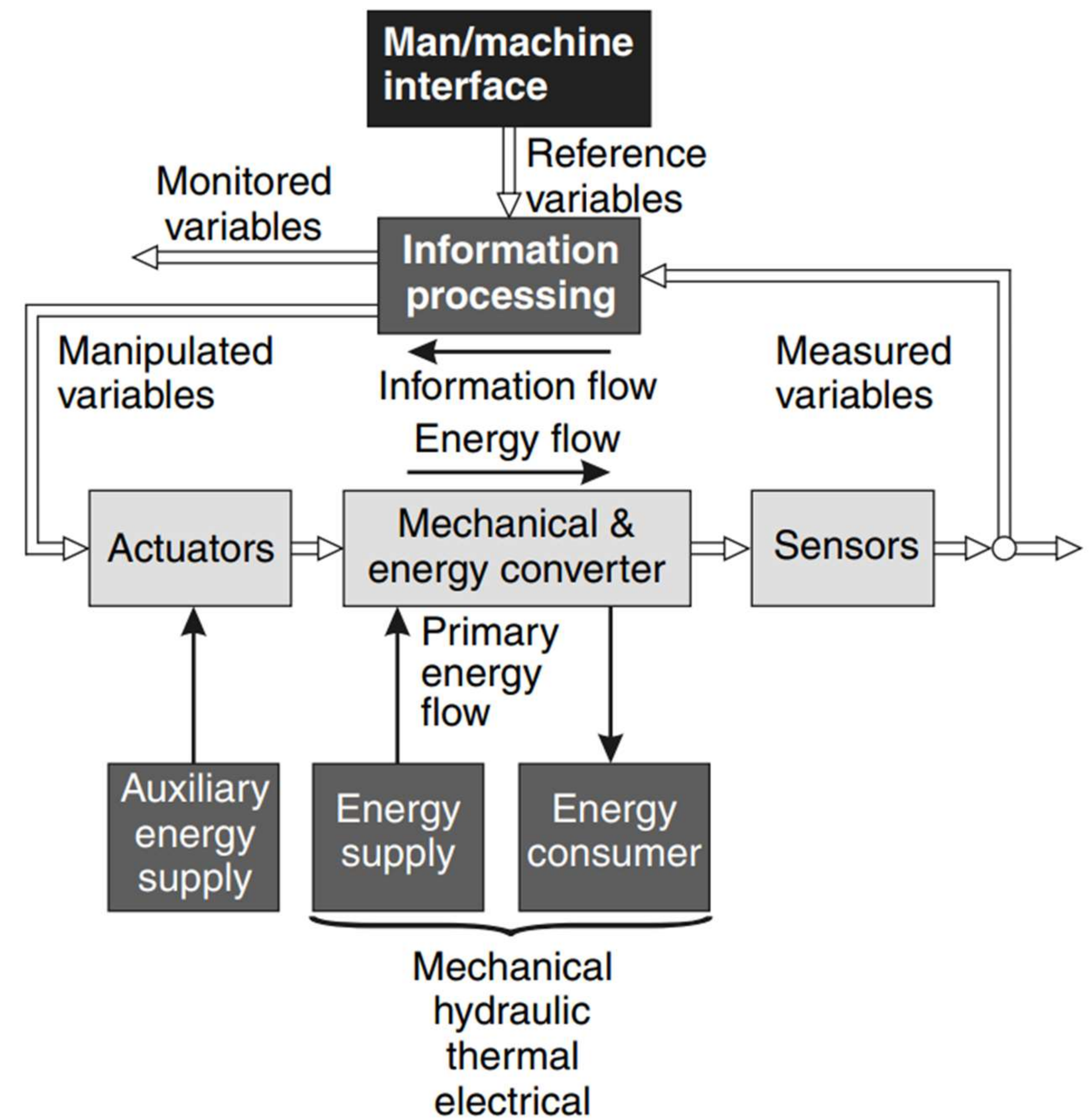
- The term “Mechatronics" was first coined by Tetsuro Mori, an engineer at the Japanese company Yaskawa Electric Corporation, in 1969.
- Originally, it was a combination of “Mechanics" and “Electronics.
- However, over time, the meaning expanded to include other disciplines like Control Systems, Computer Science, and Systems Engineering — forming the modern multidisciplinary field we now know as Mechatronics.
- A synergistic combination of mechanical, electrical, electronics, computer and control systemswhich, when combined, make possible the generation of simple, more economic, and reliable systems.



MECHATRONICS

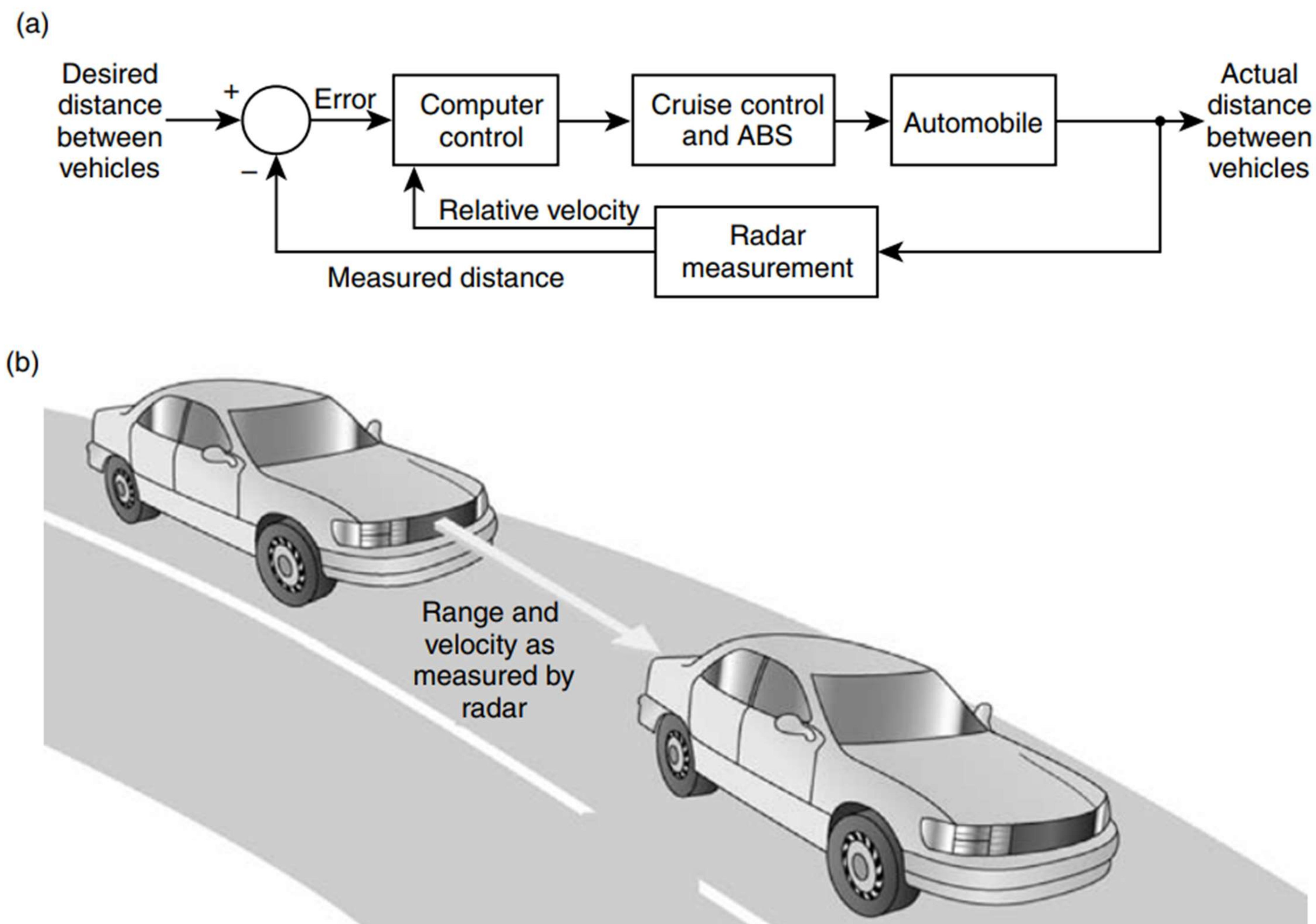
Physically mechatronic system composed of four prime components

- Sensors,
- Actuators,
- Controllers and
- Mechanical/electrical components.



Mechanical process and information processing develop towards mechatronic systems

MECHATRONICS

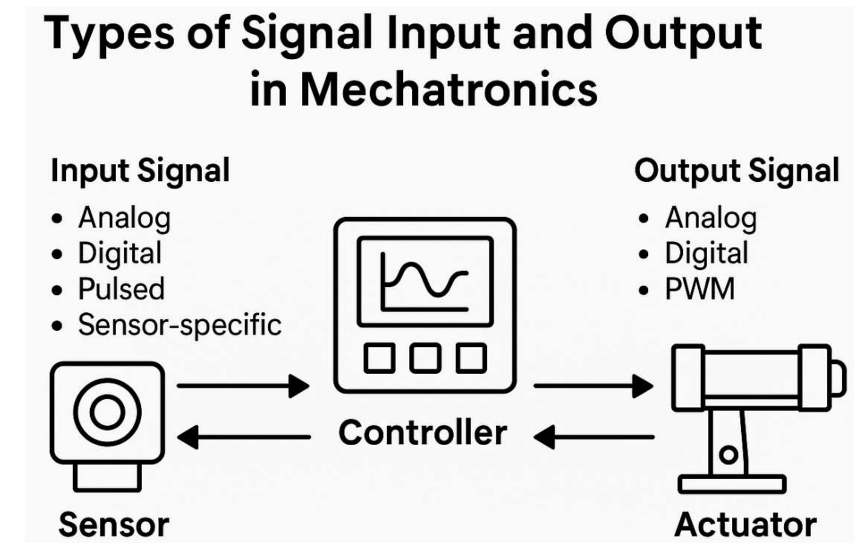


Using a radar to measure distance and velocity to autonomously maintain desired distance between vehicles. (*Modern Control Systems*, 11th edn)

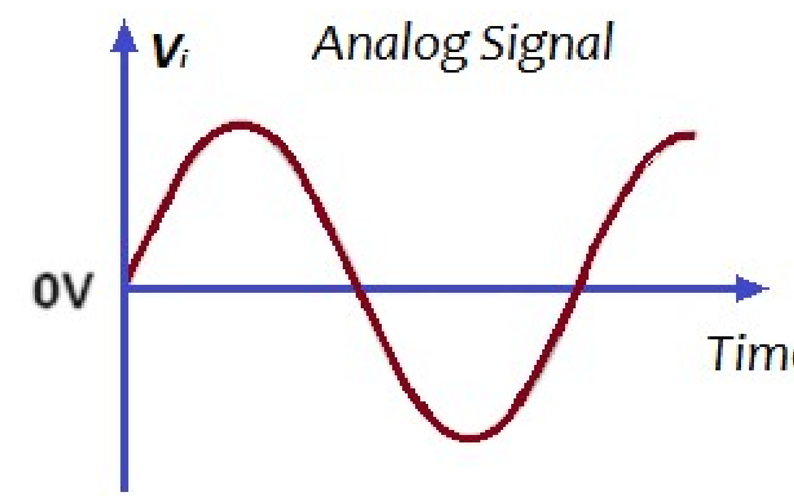
SIGNALS

Signal Type (INPUT/OUTPUT)

These signals are generated by sensors (sent to a controller) or given to an actuator (through the a controller)

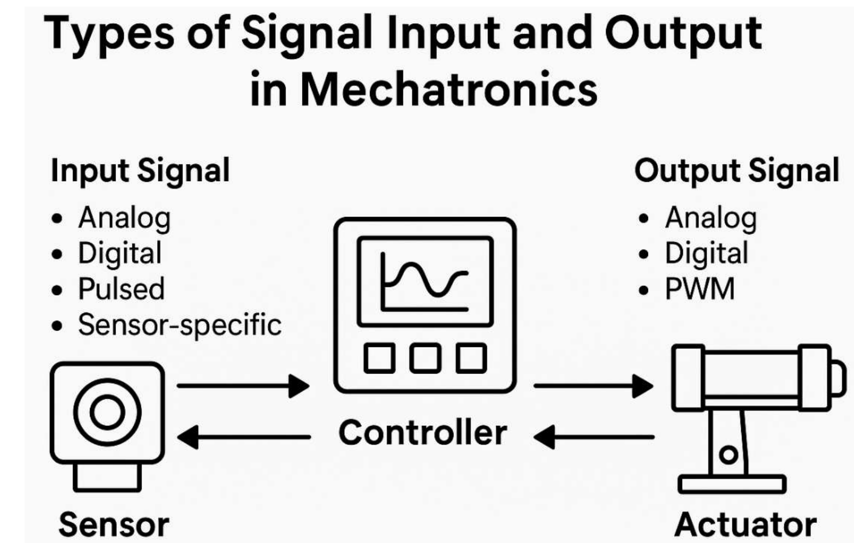


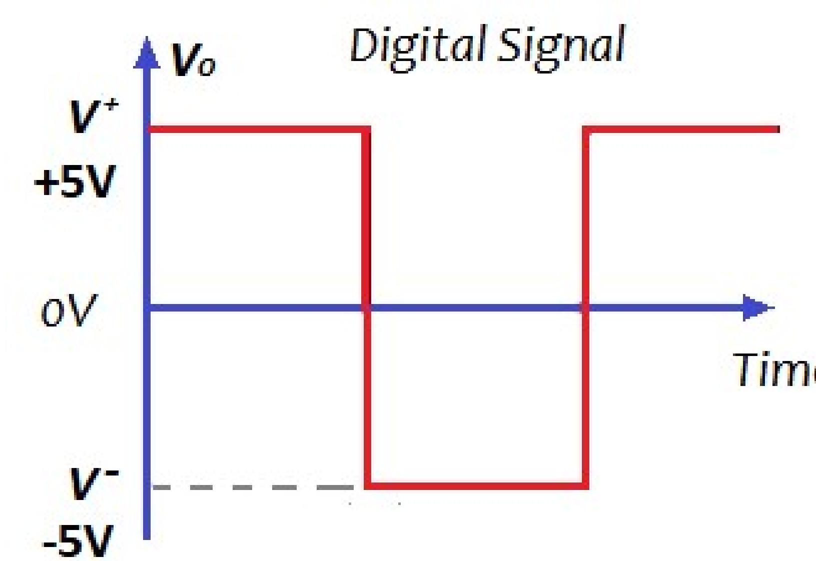
- Analog Signals
  - Continuous values over time.
  - An analog signal is usually in the form of a sine wave.
  - However, it may be also in the form of triangular, sawtooth, or any time-varying form.
  - They are sensitive to noise. The analog signal can catch the noise signal.
  - The noise can affect the accuracy of the analog signals.
  - Example: Temperature from a thermistor, position from a potentiometer, pressure, flow measurements, etc.
  - Analog signals may pick the noise during signal transmission.
  - Analog signals use more power.



Signal Type (INPUT/OUTPUT)

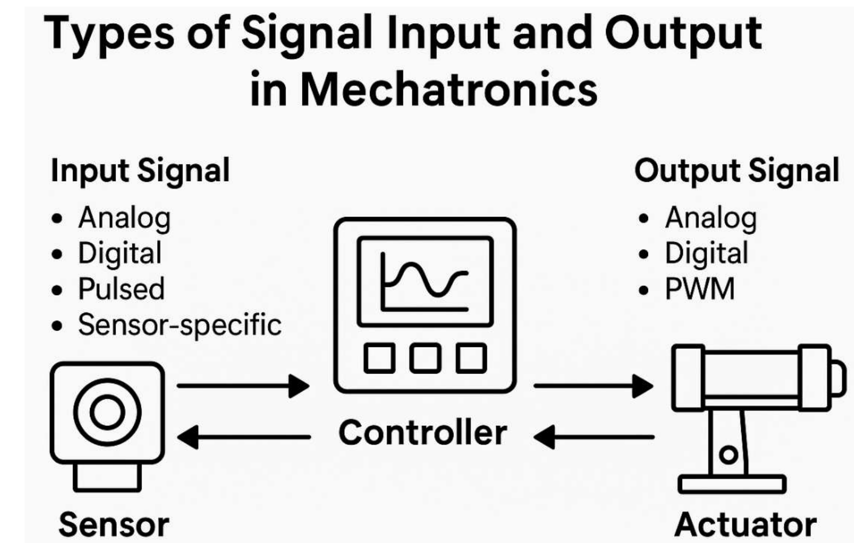
- Digital Signals
  - Binary states: ON/OFF or HIGH/LOW.
  - A digital signal is usually in the form of a square wave that represents two states of the signal.
  - Digital signals are not prone to noise.
  - The noise cannot affect the accuracy of the digital signals.
  - The digital signal does not pick up noise during signal transmission.
  - Digital signals are less power consuming.
  - Example: Push button, proximity switch, valve feedback, motor start/stop, trip.

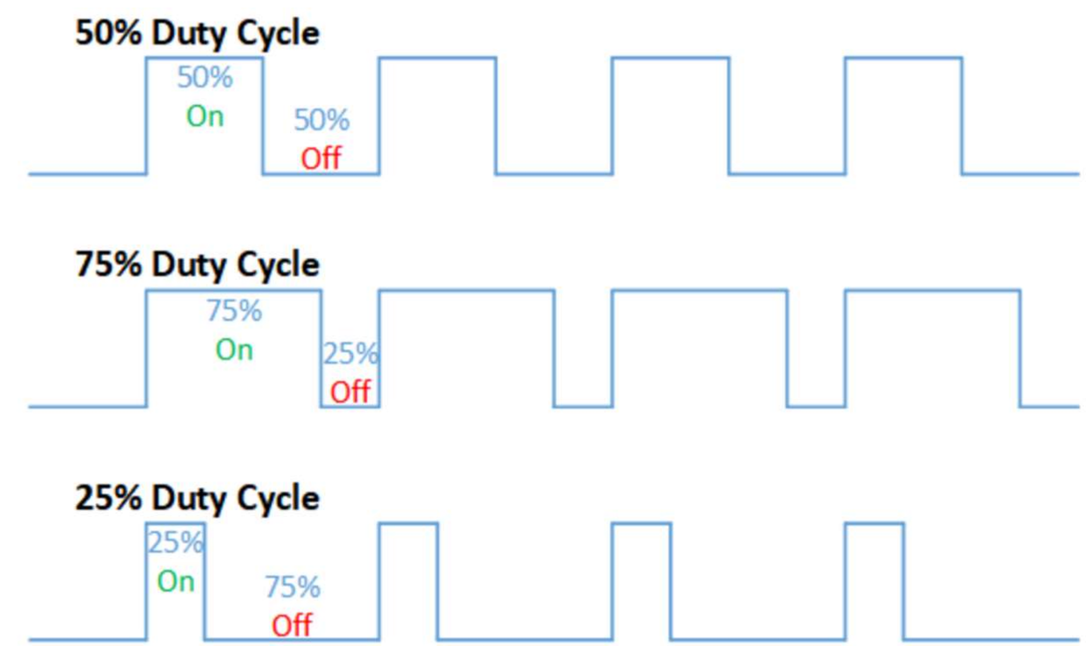




Signal Type (INPUT/OUTPUT)

- Pulsed Signals
  - Repetitive digital pulses used for timing or measurement.
  - When the pulse is in ON state current will be delivered to the device, when signal is in OFF state current will no flow through.
  - When frequency of the pulse is high enough the device will not see any interruption in its power supply at all thereby operates normally while consuming less current.
  - Example: Rotary encoder pulses, step signals.
- Sensor-Specific Signals
  - Protocol-based or current/voltage signals:
  - Voltage-based: 0–10 V
  - Current-based: 4–20 mA loop
  - Serial protocols: I^2C, SPI, UART (for smart sensors)





SIGNAL CONDITIONING

SIGNAL CONDITIONING

The output signal from sensor of a measurement system has to be processed in a suitable form for next stage of operation.

Example:

Too small	Amplified
Interference	Removed
Non- linear	Linearization
Analog	Digital
Digital	Analog
Voltage change	Suitable current change

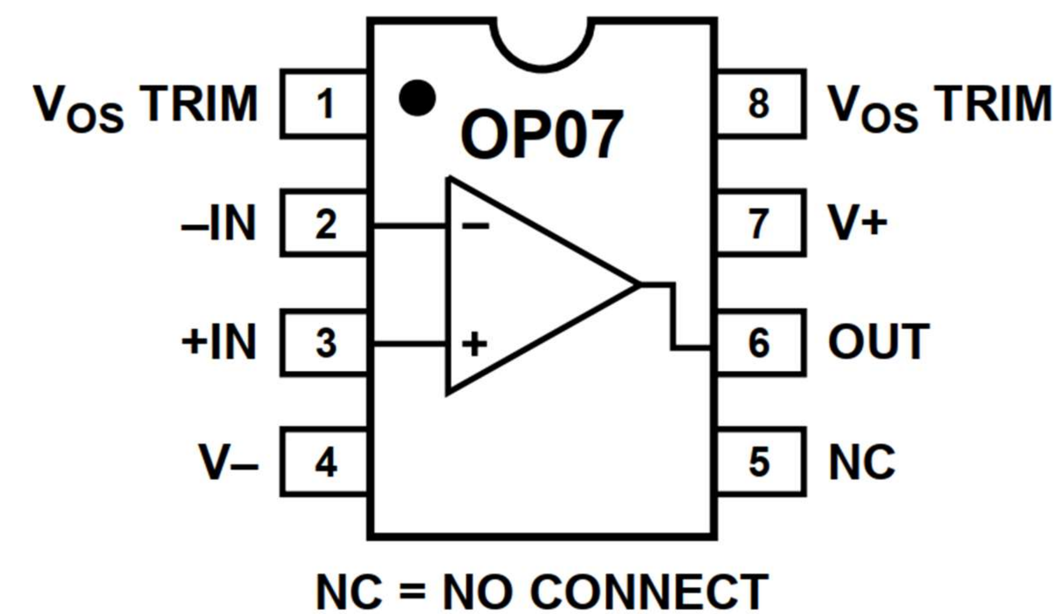
Output from thermocouple is small voltage (few millivolts) – a signal conditioning module is used to convert into suitable size signal Interfacing with Microprocessor.

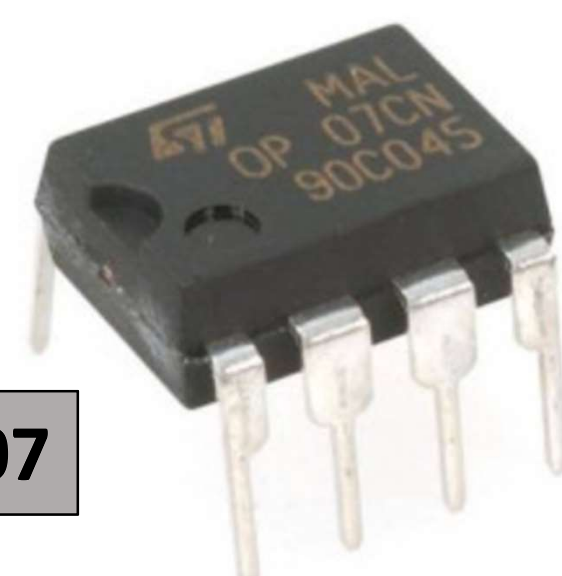
OPERATIONAL AMPLIFIER

OPERATIONAL AMPLIFIER (OP)

The term “**Operational Amplifier**” (Op-Amp) originated in the field of analog computers, since these types of amplifiers were used to achieve mathematical operations such as addition, integration etc. Although Op-Amps are now used for a wide range of applications, the original term is retained.

PIN CONFIGURATION





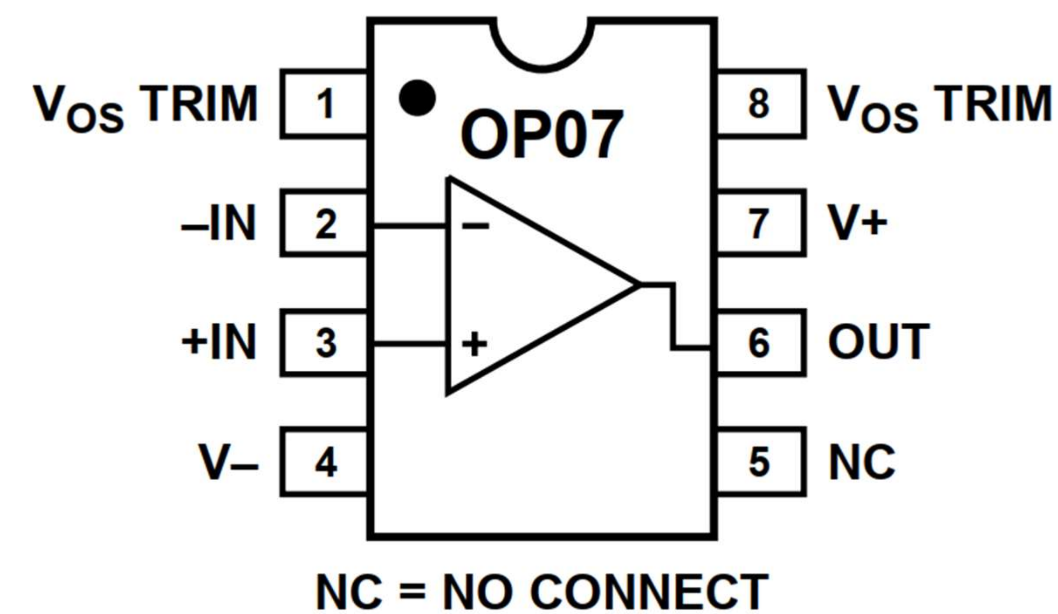
OP07

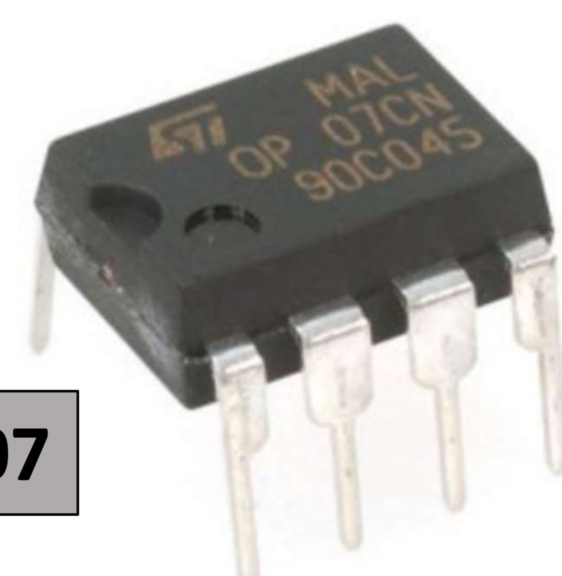
OPERATIONAL AMPLIFIER (OP)

The Op-Amp is a high gain DC amplifier. Ideally it would have the following characteristics:

- Infinite gain
- Infinite bandwidth
- Infinite input impedance
- Zero output impedance

PIN CONFIGURATION





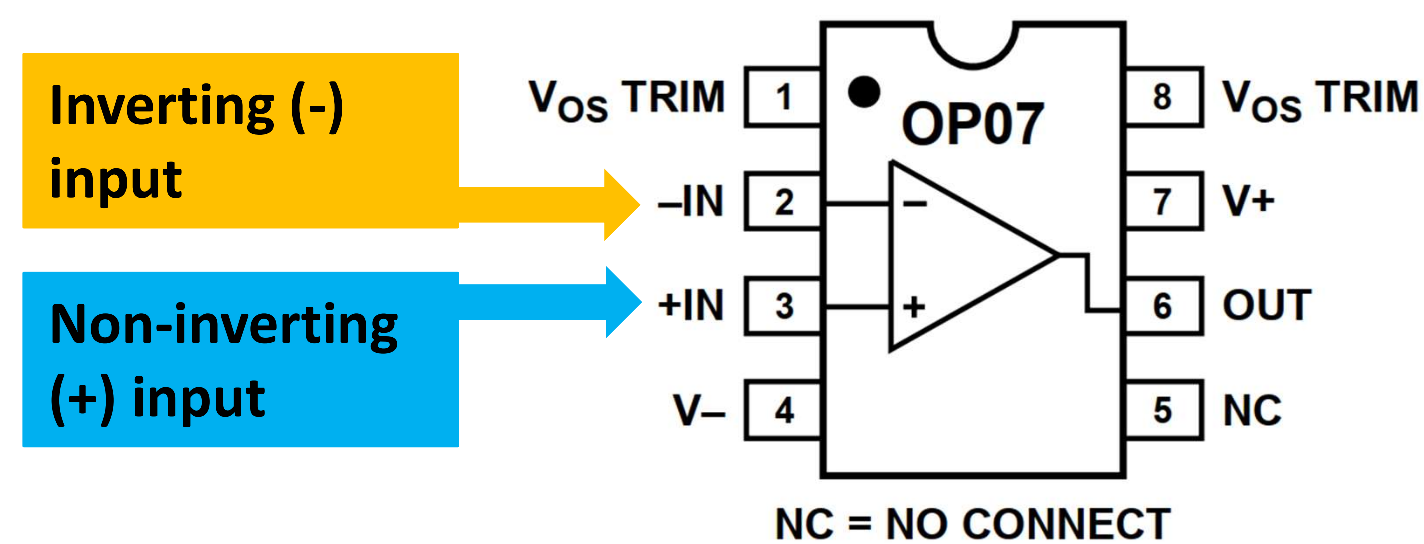
OP07

OPERATIONAL AMPLIFIER (OP)

However, in practice, it falls somewhat short of these ideal conditions, *i.e.*,

- Gain up to 10^6
- Bandwidth up to Mega Hertz range
- Input impedance up to Mega Ohm range
- Output impedance up to few Ohms

PIN CONFIGURATION



As shown in figure, the Op-Amp has two inputs

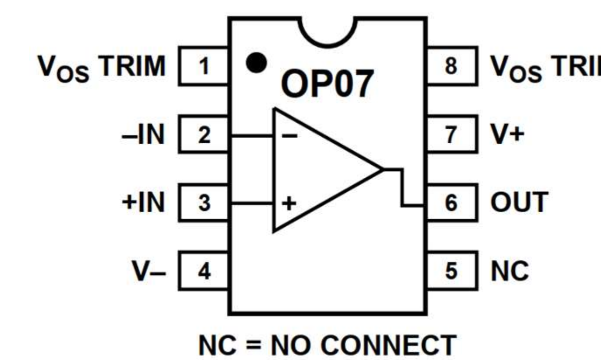
- Non-inverting (+) input
- Inverting (–) input

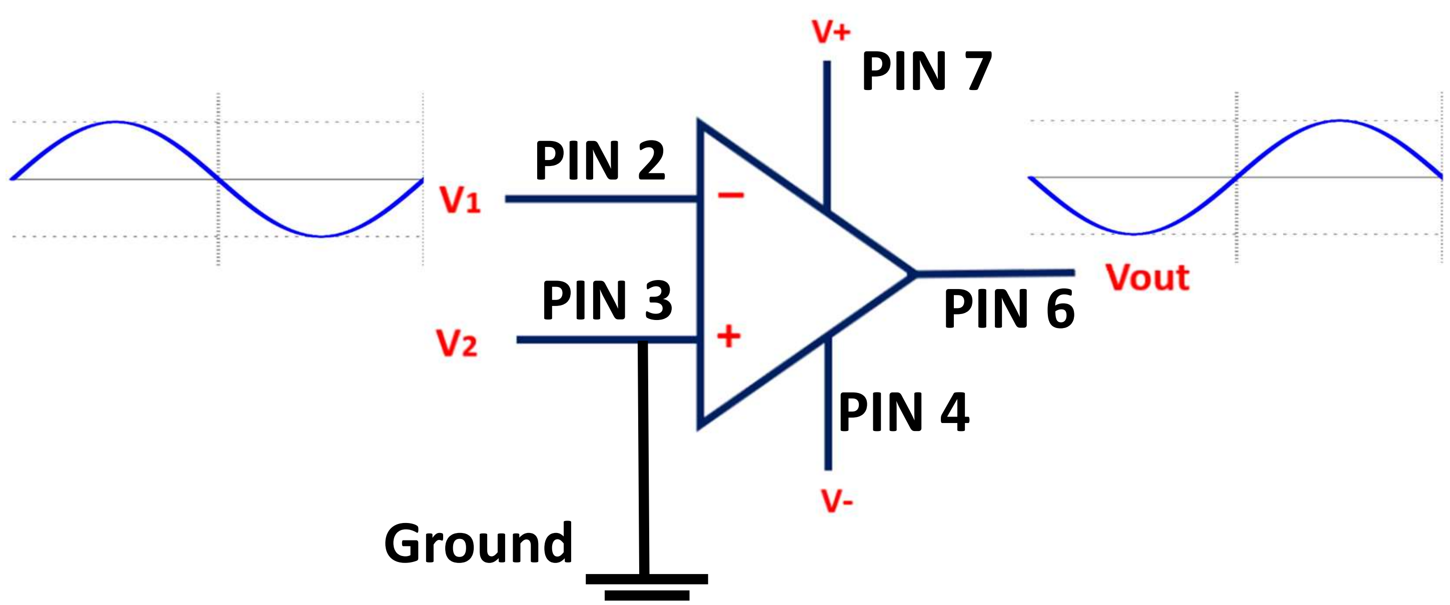
and one output. Normally the Op-Amp is powered by ±5 to ±15 Volts DC.

Inverting vs Non-inverting input

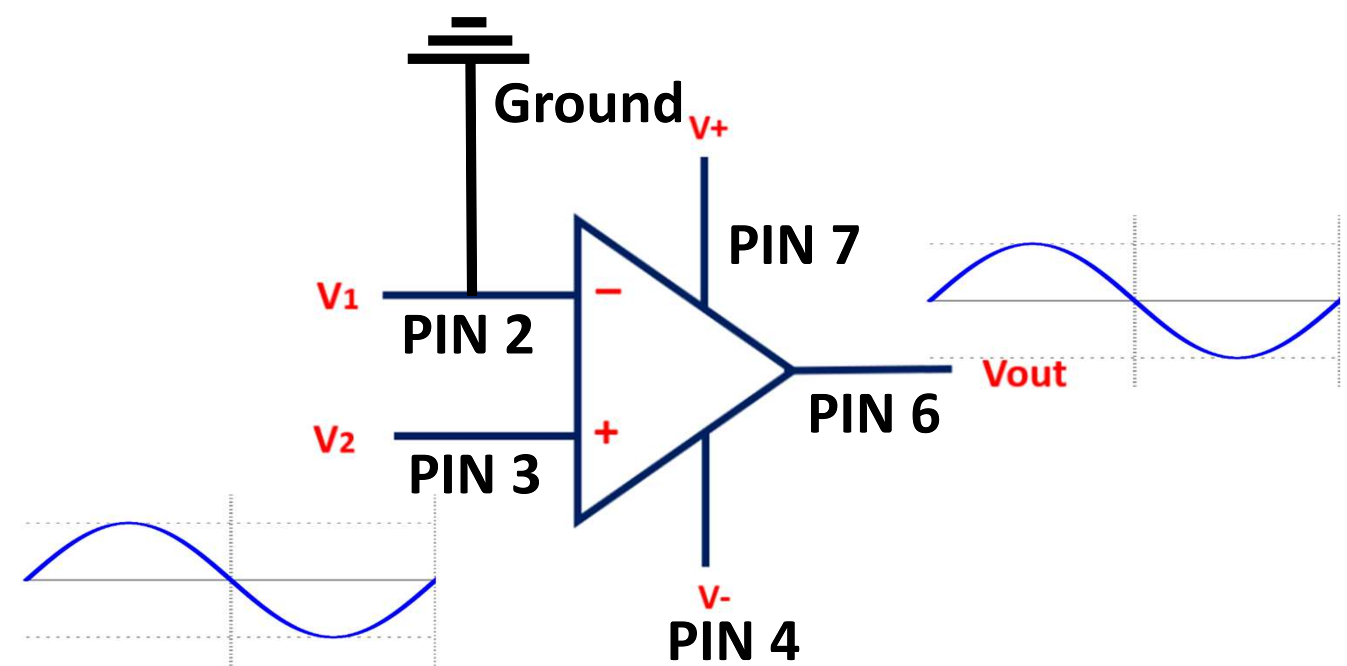
- If a signal is applied to the non-inverting input of an Op-Amp, the output will be in phase with the input
- If a signal is applied to the inverting input of an Op-Amp, the output will be out of phase by 180° with the input

PIN CONFIGURATION





Inverting



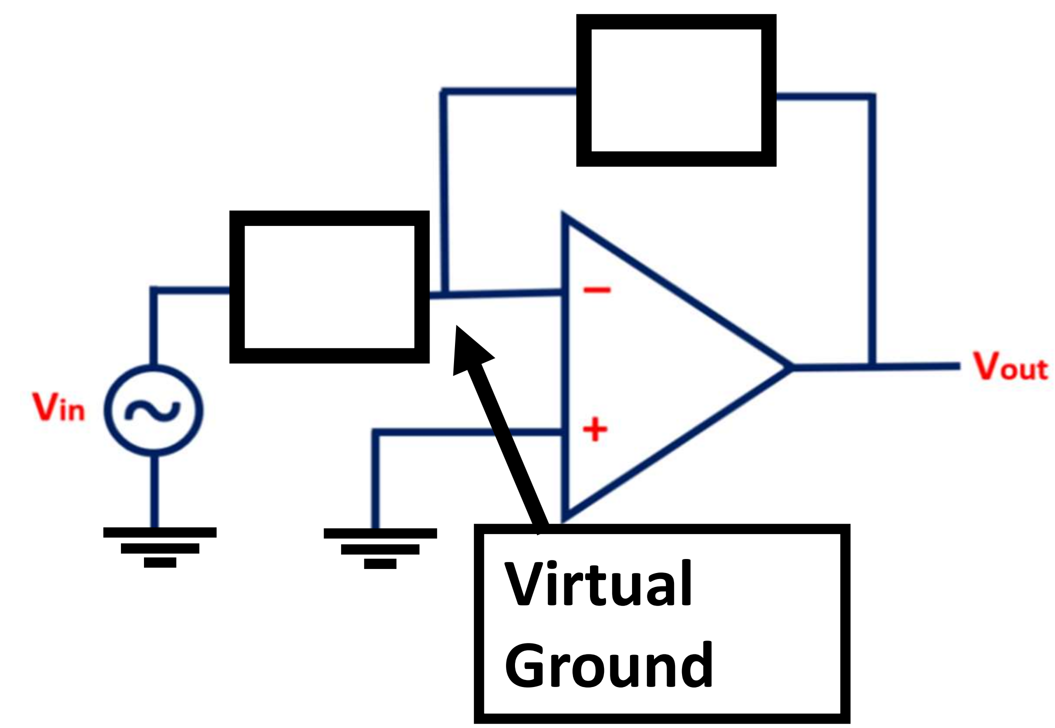
Non-inverting

Negative Feedback

The immediate consequence of the extremely high gain of an Op-Amp is that

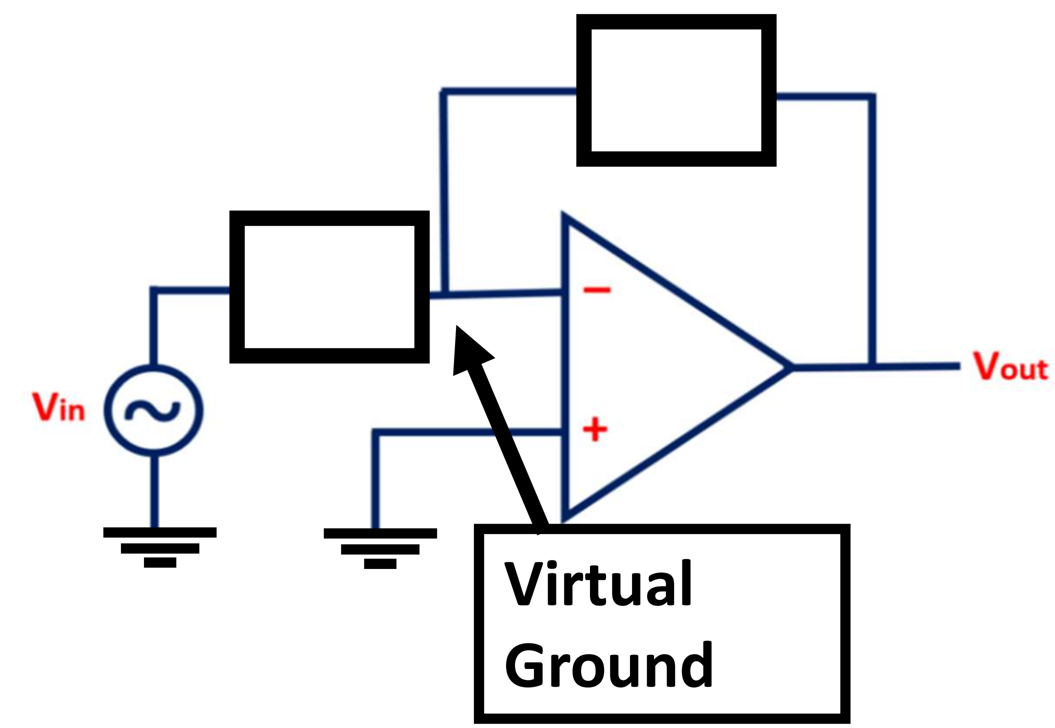
- Even a small change in the supply voltage, temperature *etc.*, will cause the amplifier output saturation or to behave highly abnormally, rendering it useless for most practical purposes.

Hence some device must be employed to stabilize its gain so that the Op-Amp could be employed in practical circuits. The device utilized to stabilize the gain is negative feedback. With the application of negative feedback the gain is stabilized and reduces in magnitude.



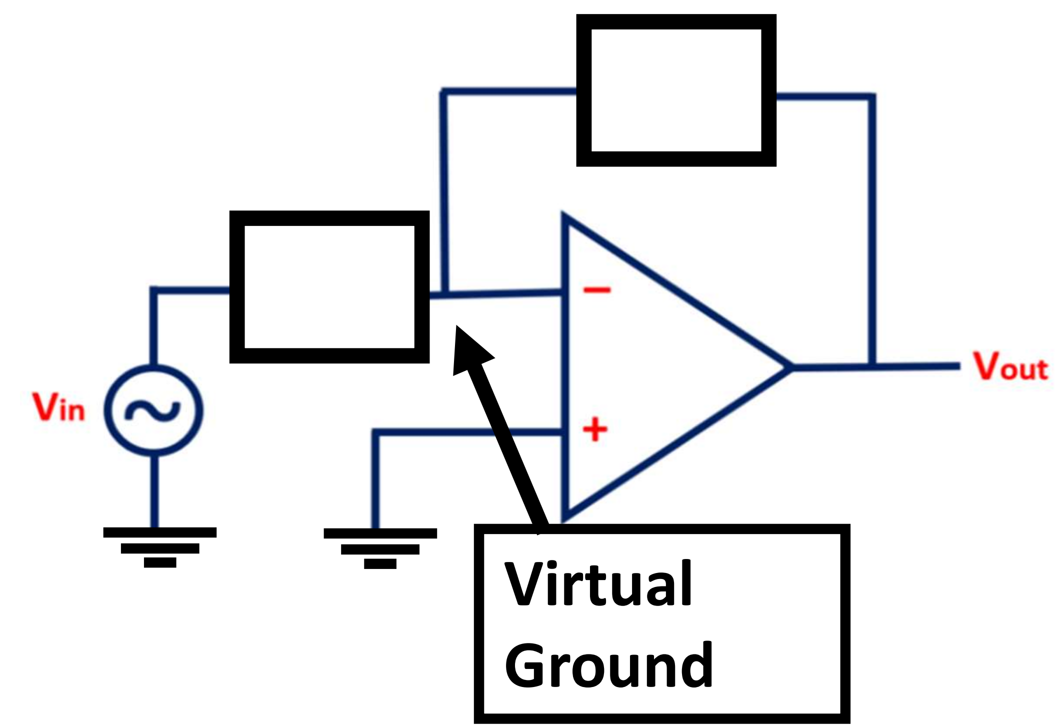
Negative Feedback

- The gain of an amplifier without feedback is called open loop gain and that with feedback is called closed loop gain.
- The open loop gain of an Op-Amp is extremely high, but its closed loop gain can be as high as 10^4.



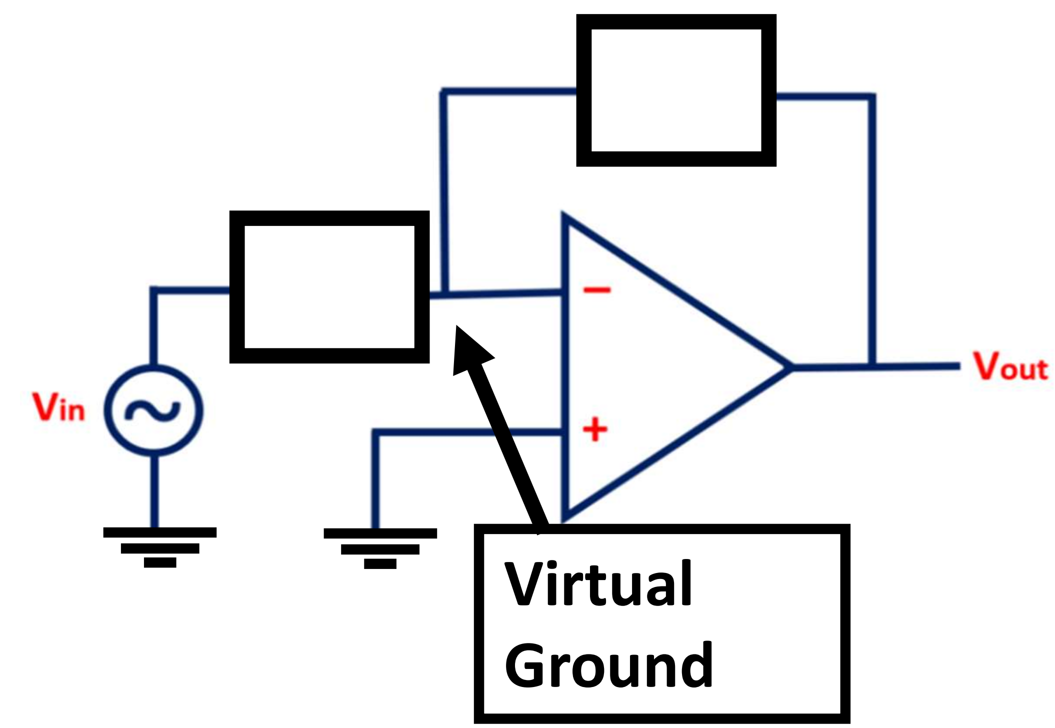
Virtual ground

- As the gain of an Op-Amp is extremely high the input voltage required between two input for all amplifications purpose is very low (as low as 1 milli volt) and may be neglected.
- So there will be practically no voltage drop between the two inputs (+ and −).



Virtual ground

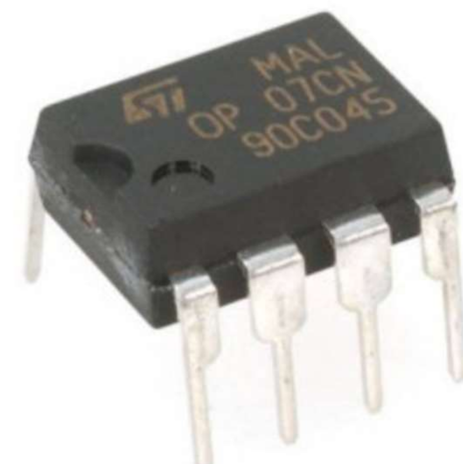
- The non-inverting (+ input) of the Op-Amp is grounded or at 0 potential (0 volts).
- So the inverting (– input) will be at the same potential i.e. ground potential (0 volts) with high input impedance and this differs from the real ground (because real ground will pose ground potential with 0 resistance) and hence called virtual ground.



OP07: FEATURES AND APPLICATIONS

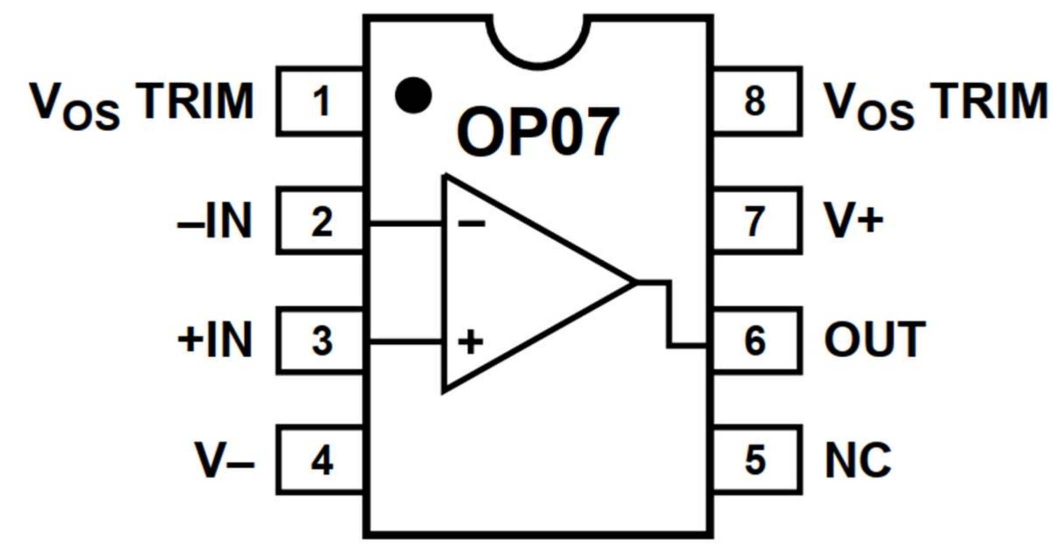
FEATURES

- Low VOS: 75 µV maximum
- Low VOS drift: 1.3 µV/°C maximum
- Ultrastable vs. time: 1.5 µV per month ma
- Low noise: 0.6 µV p-p maximum
- Wide input voltage range: ±14 V typical
- Wide supply voltage range: ±3 V to ±18 V
- 125°C temperature-tested dice



OP07

PIN CONFIGURATION



NC = NO CONNECT

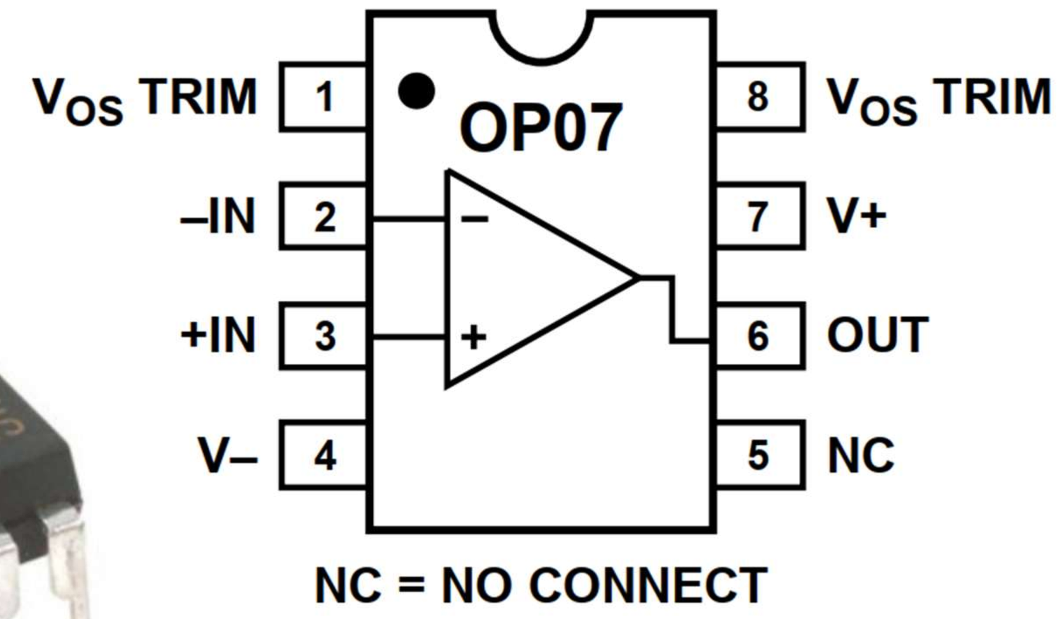
APPLICATIONS

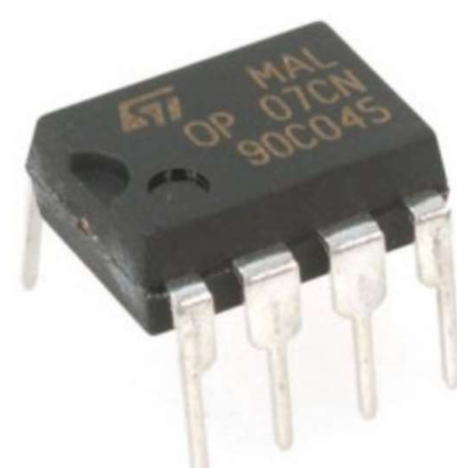
Wireless base station control circuits, Optical network control circuits, Instrumentation, Sensors and controls, Thermocouples, Resistor thermal detectors (RTDs), Strain bridges, Shunt current measurements, Precision filters

OP07: TYPICAL APPLICATIONS

- **D.C. condition of the Op-Amp circuit.**
- Op-Amp as Inverting Amplifier.
- Op-Amp as Non-Inverting Amplifier.
- Op-Amp as Voltage Follower.
- Op-Amp as Summing Amplifier.
- Op-Amp as Subtractor Amplifier.
- **Op-Amp as Schmitt Trigger.**
- Op-Amp as Differentiator.
- Op-Amp as Integrator.

PIN CONFIGURATION

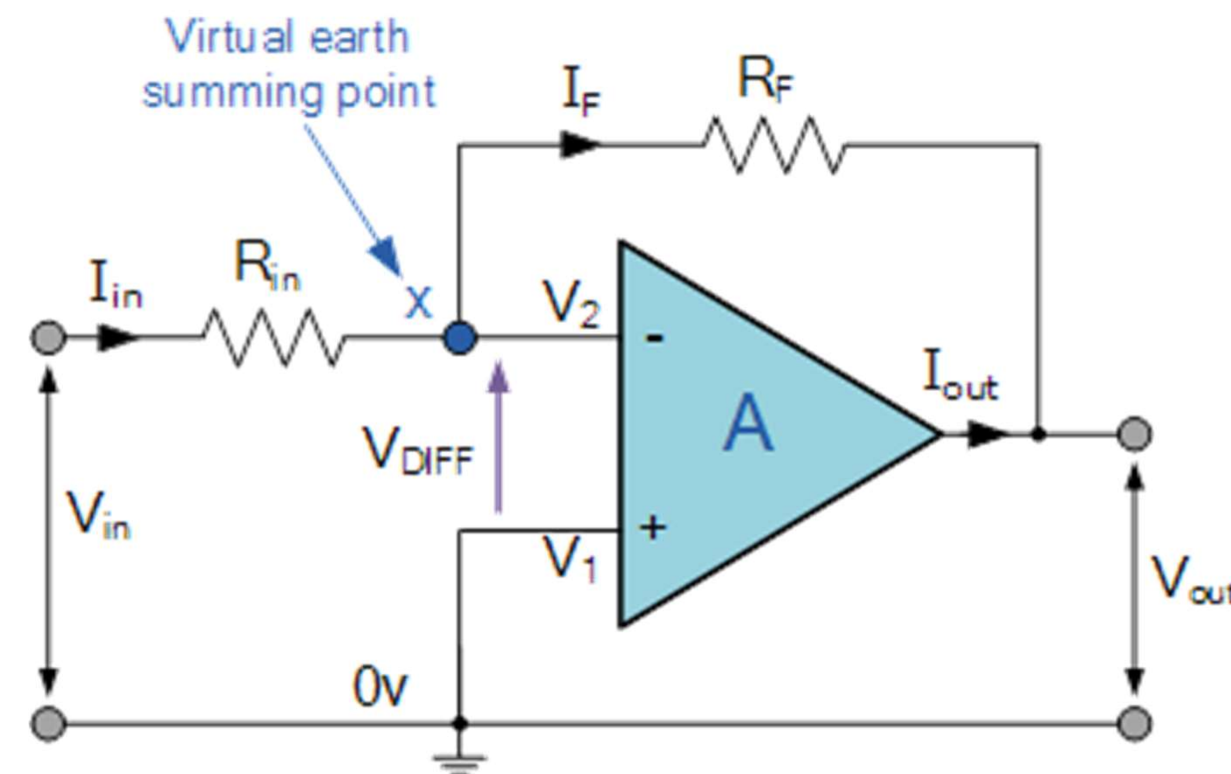




OP07

Inverting Amplifier

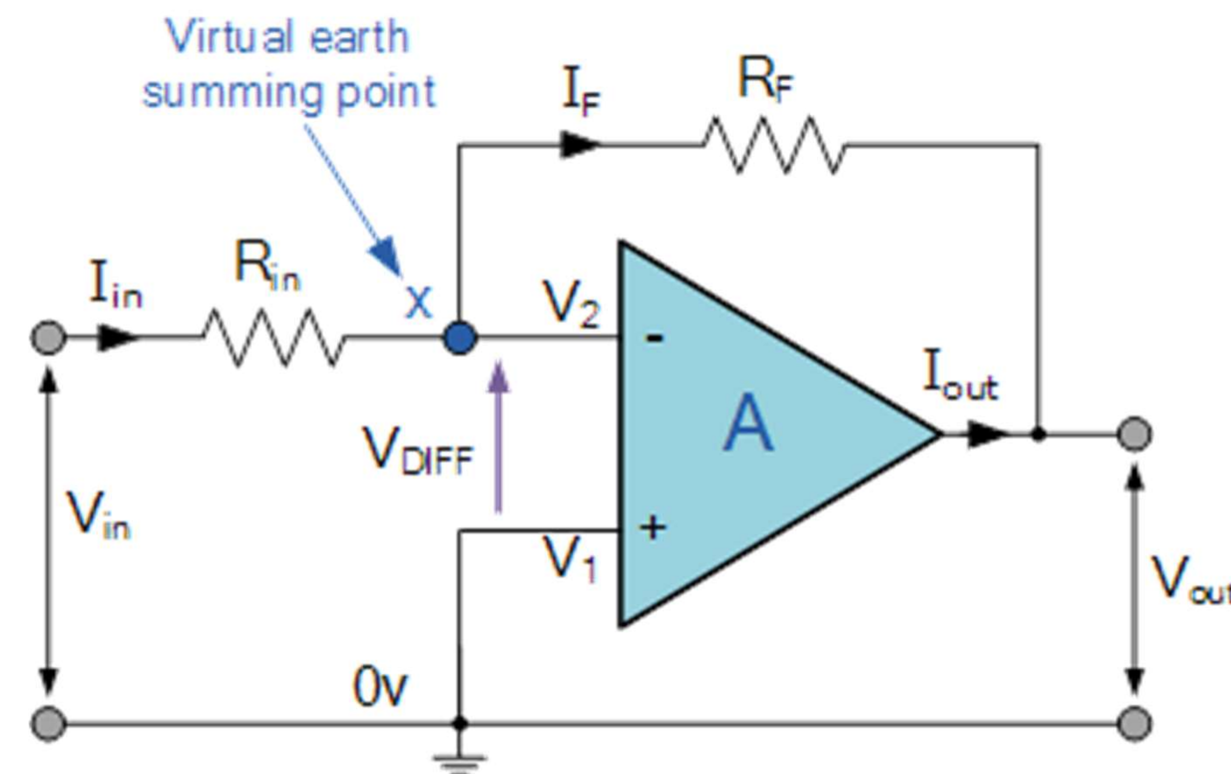
- The inverting operational amplifier is basically a constant or fixed-gain amplifier producing a negative output voltage as its gain is always negative.
- Negative Feedback is the process of "feeding back" a fraction of the output signal back to the input.
- To make the feedback negative, we must feed it back to the negative or "inverting input" terminal of the op-amp using an external Feedback Resistor called R_F



Inverting Amplifier

Inverting Amplifier

- This feedback connection between the output and the inverting input terminal forces the differential input voltage V_{DIFF} towards zero.
- This effect produces a closed loop circuit to the amplifier resulting in the gain of the amplifier now being called its Closed-loop Gain.

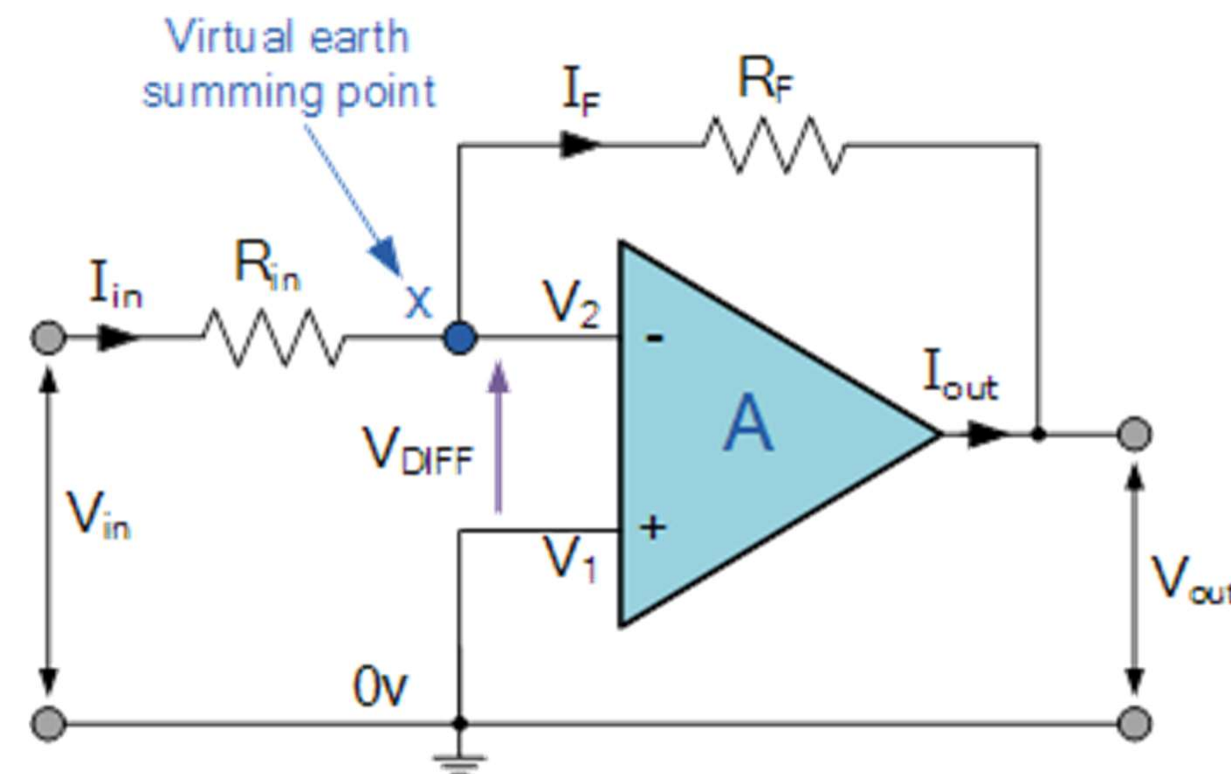


Inverting Amplifier

Inverting Amplifier

There are two very important rules to remember about Inverting Amplifiers or any operational amplifier for that matter such as:

- No Current Flows into the Input Terminals
- The Differential Input Voltage V_{DIFF} is Zero as $V_1 = V_2 = 0$ (Virtual Earth)



Inverting Amplifier

Using these two rules we can derive the equation for calculating the closed-loop gain of an inverting amplifier, using first principles.

Inverting Amplifier

$$I_{in} = i = \frac{V_{in} - V_2}{R_{in}} = \frac{V_2 - V_{out}}{R_F}$$

where $V_2 = 0$

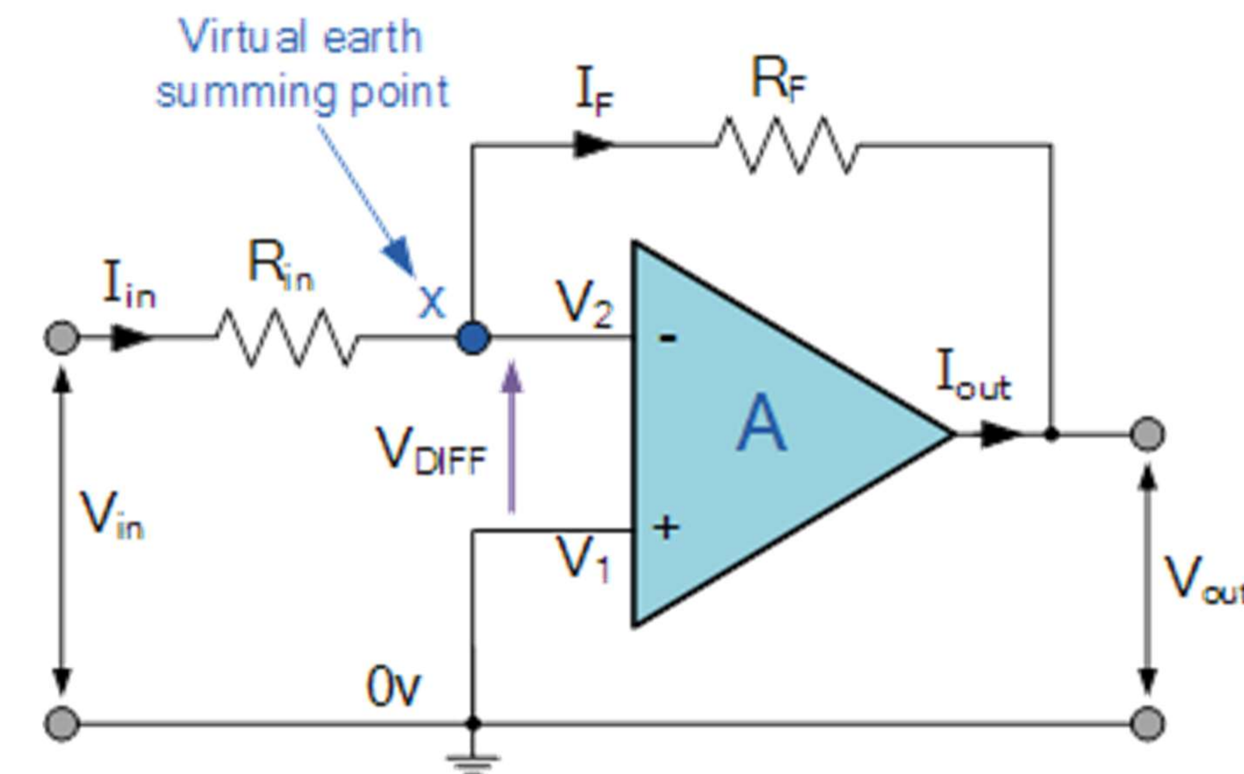
$$I_{in} = i = \frac{V_{in}}{R_{in}} = \frac{-V_{out}}{R_F}$$

$$\Rightarrow \frac{V_{in}}{V_{out}} = \frac{-R_{in}}{R_F}$$

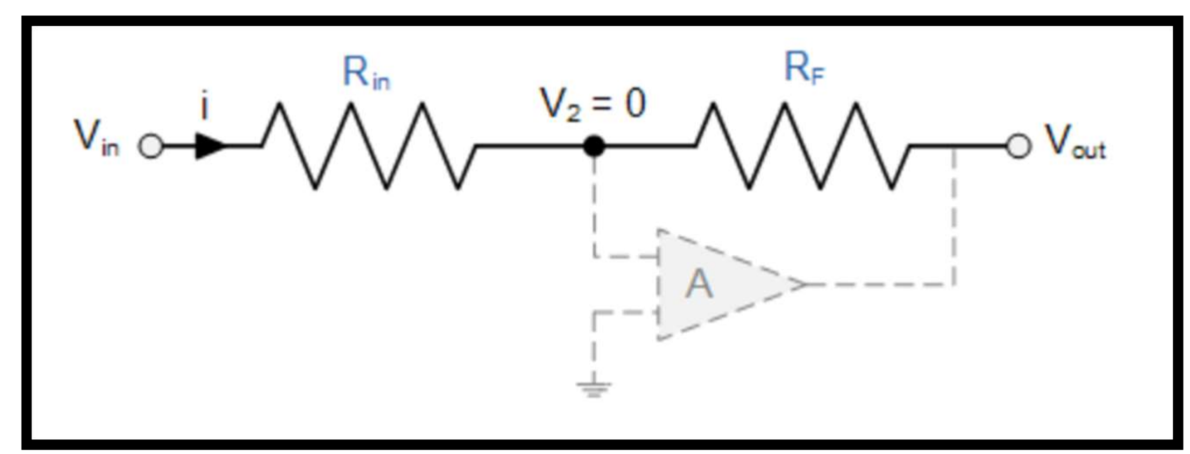
$$\Rightarrow V_{out} = -\left[\frac{R_F}{R_{in}}\right] V_{in} = \boldsymbol{A_v}\, V_{in}$$

Inverting the input signal
Negative Sign

A_v = Gain

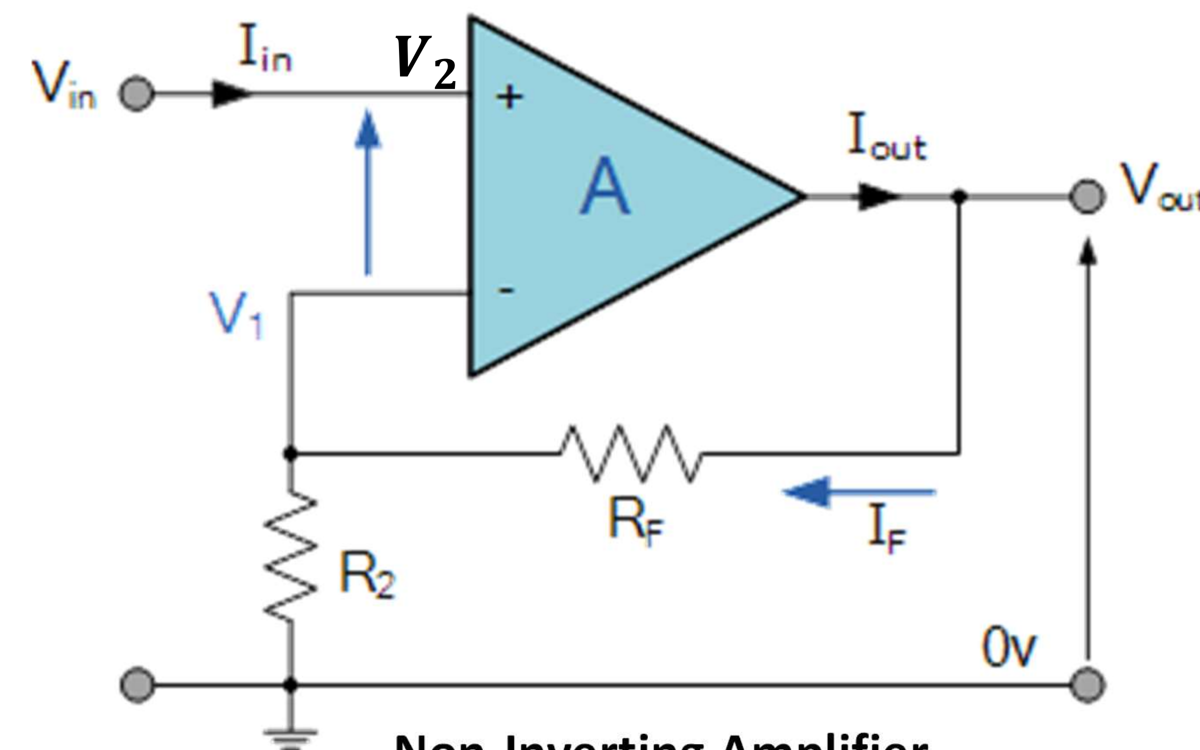


Inverting Amplifier



Non-Inverting Amplifier

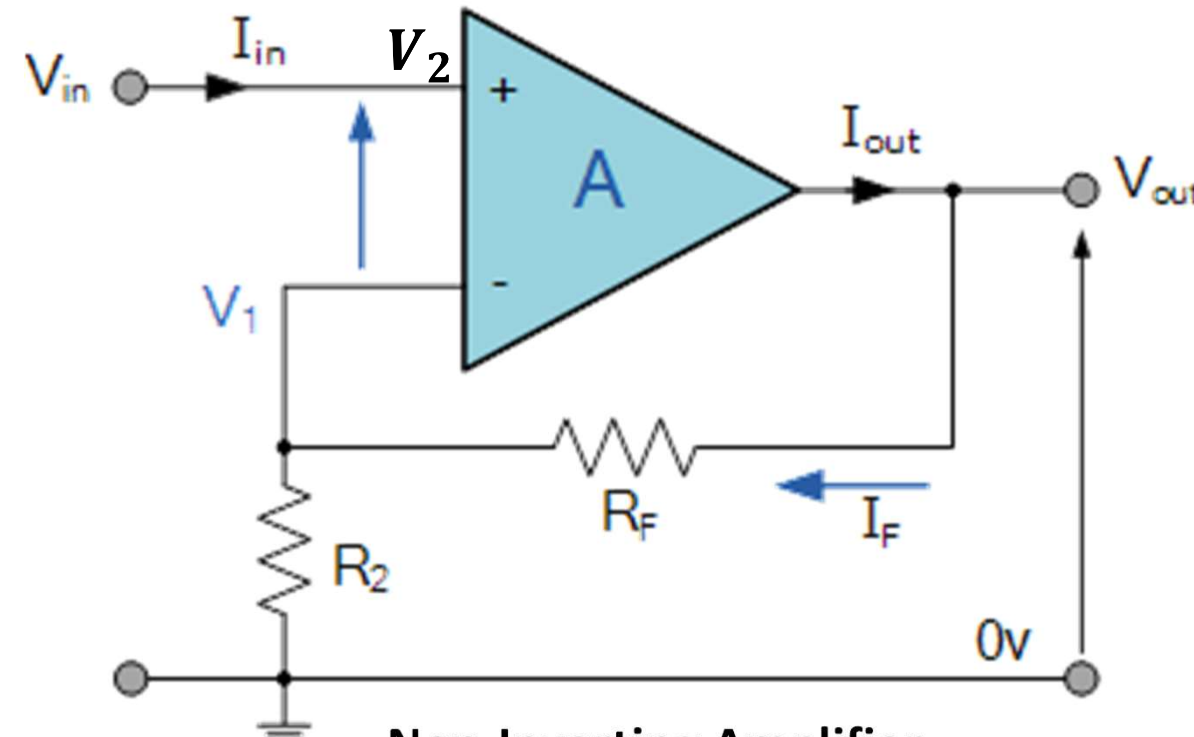
- Input voltage signal, V_{in} is applied directly to the non-inverting (+) input terminal
- The output gain of the amplifier becomes "Positive"
- The output signal is "in-phase" with the input signal.
- Feedback control is achieved by applying a small part of the output voltage signal back to the inverting (–) input terminal via a $R_F - R_2$ voltage divider network, again producing negative feedback.



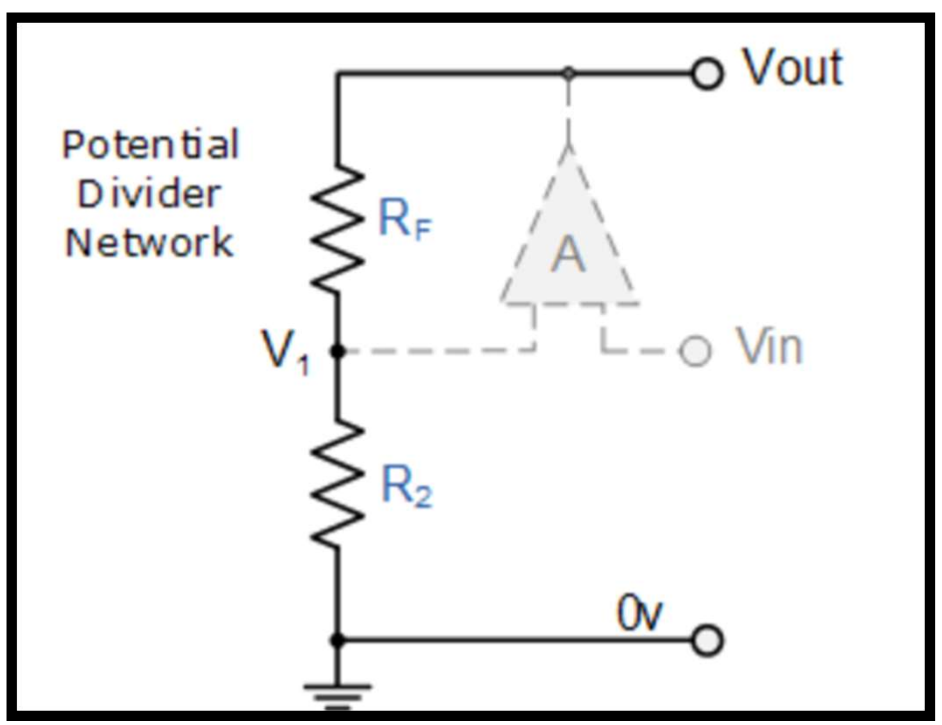
Non-Inverting Amplifier

Non-Inverting Amplifier

- "No current flows into the input terminal" of the amplifier .
- "V_1 always equals V_2". This is because the junction of the input and feedback signal (V_2) are at the same potential.



Non-Inverting Amplifier



$$V_1 = V_2 = V_{in}$$

$$I_F = \frac{V_1}{R_2} = \frac{V_{out}}{R_2 + R_F}$$

$$\Rightarrow \frac{V_{in}}{R_2} = \frac{V_{out}}{R_2 + R_F} \Rightarrow V_{out} = \left[1 + \frac{R_F}{R_2}\right] V_{in} = \boldsymbol{A_v}\, V_{in}$$

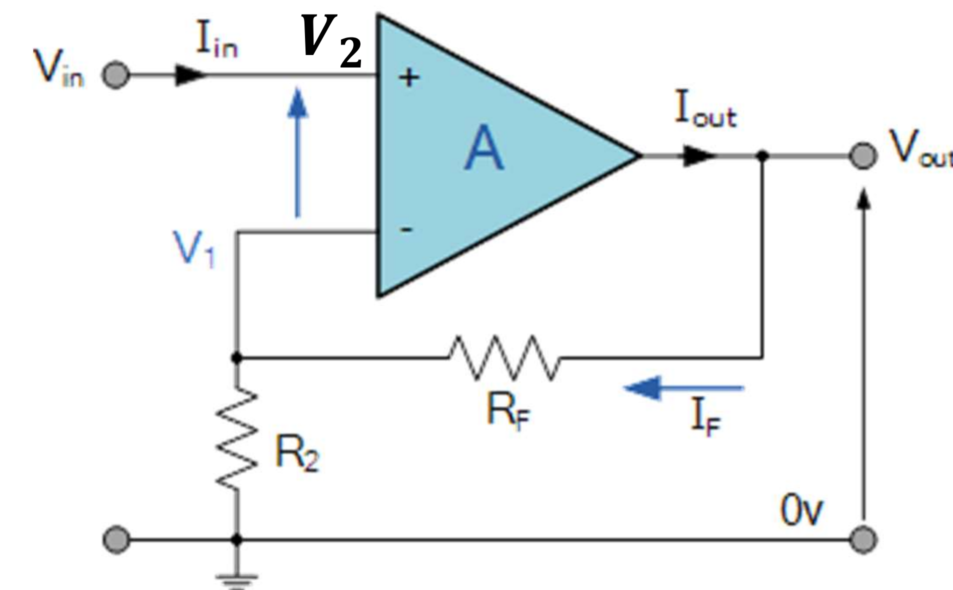
A_v = Gain, Positive

Voltage Follower (Unity Gain Buffer)

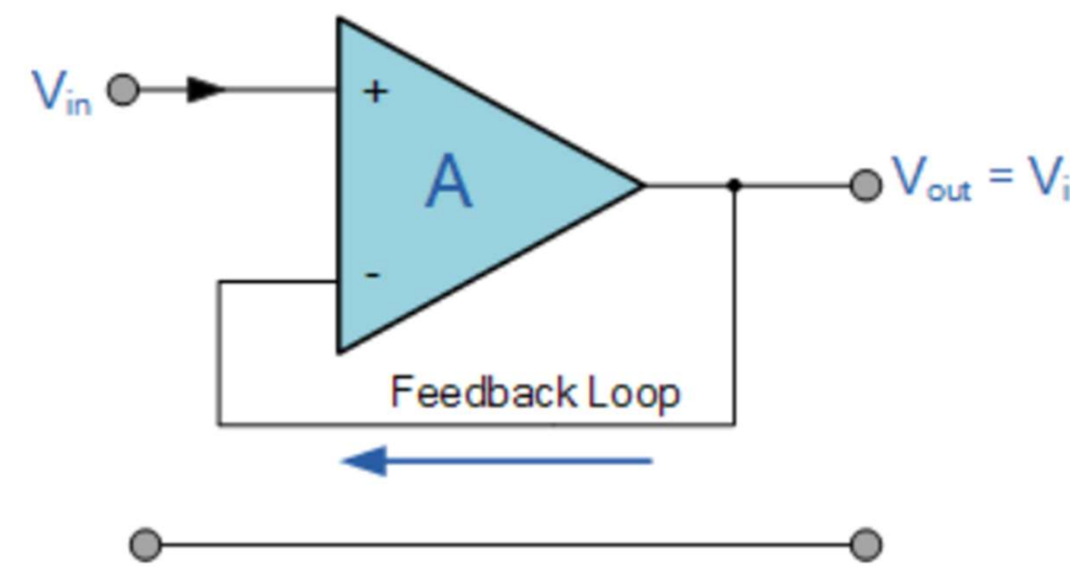
- Making the feedback resistor, $R_F = 0$ and resistor $R_2 \to \infty$, the resulting circuit would have a fixed gain of "1" (unity)
- As all the output voltage is fed back to the inverting input terminal (negative feedback).
- This configuration would produce a special type of the non-inverting amplifier circuit called a Voltage Follower, also known as a "unity gain buffer".

$$\Rightarrow V_{out} = \left[1 + \frac{R_F}{R_2}\right] V_{in} = \boldsymbol{A_v}\, V_{in}$$

$$\Rightarrow V_{out} = V_{in} = \boldsymbol{A_v}\, V_{in}$$



Non-Inverting Amplifier



Voltage Follower

Summing Amplifier

- An summing amplifier sums multiple input signals.
- Uses the inverting configuration of an op-amp.
- Output is the inverted sum of the input voltages.
- Frequently used in analog computing and audio mixing.

$$I_1 = \frac{V_1}{R_{in}}$$

$$I_2 = \frac{V_2}{R_{in}}$$

$$I_3 = \frac{V_3}{R_{in}}$$

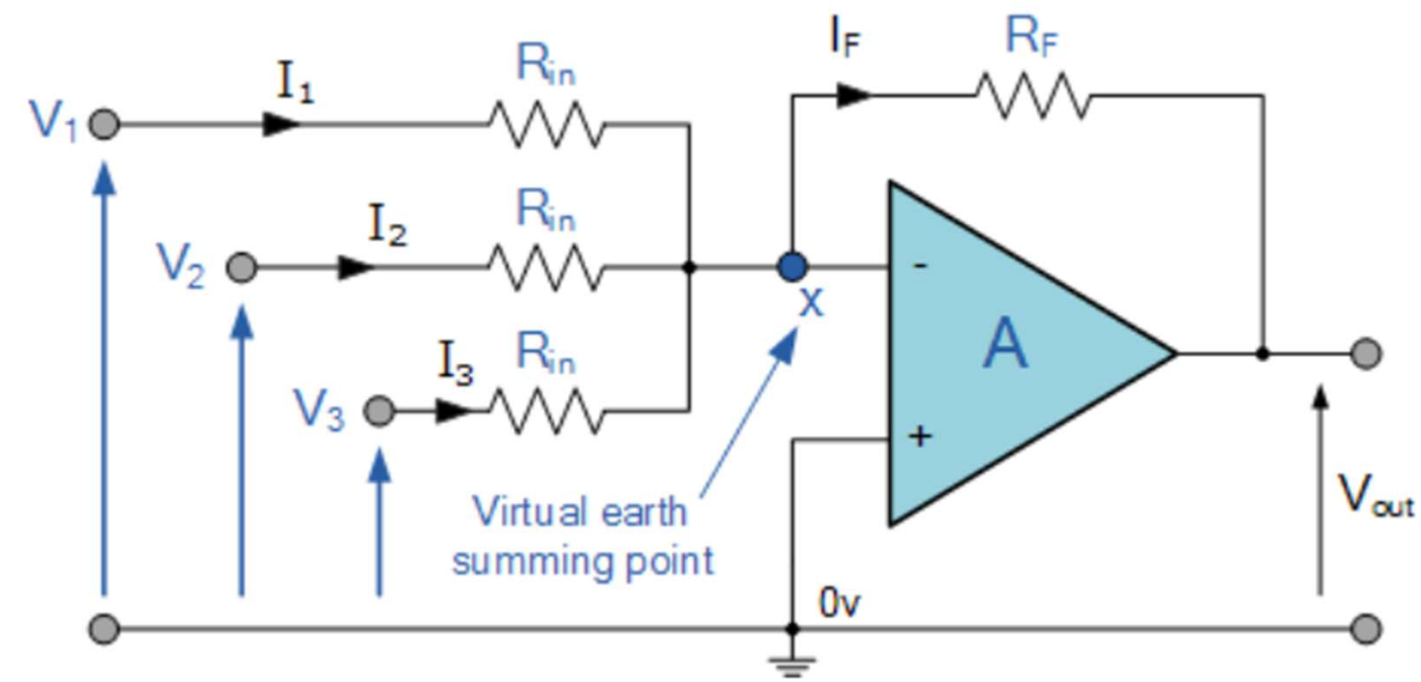
$$I_F = \frac{V_- - V_{out}}{R_F}$$

$$(V_- = 0)$$

$$I_F = I_1 + I_2 + I_3$$

$$\Rightarrow I_F = \frac{V_1 + V_2 + V_3}{R_{in}}$$

$$\Rightarrow V_{out} = -\left[\frac{R_F}{R_{in}}\right](V_1 + V_2 + V_3)$$



Summing Amplifier

Subtractor/Differential Amplifier

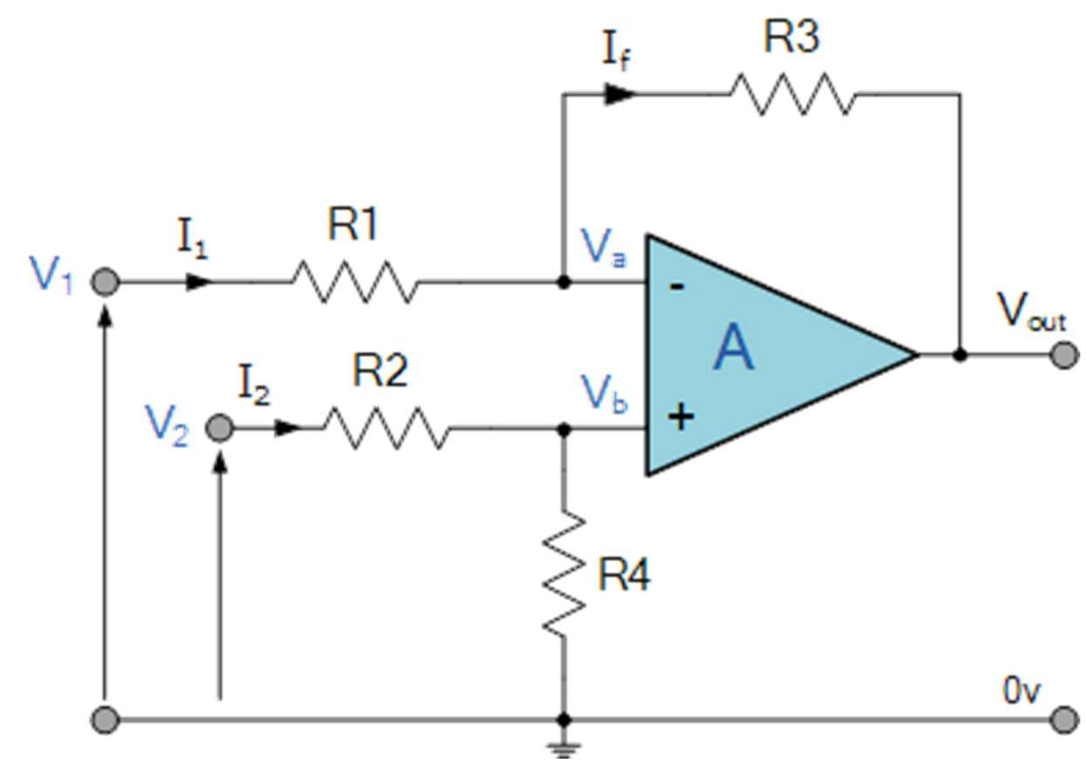
The differential amplifier is a voltage subtractor circuit which produces an output voltage proportional to the voltage difference of two input signals applied to the inputs of the inverting and non-inverting terminals of an operational amplifier.

$$I_2 = \frac{V_2 - V_b}{R_2} = \frac{V_b}{R_4} \Rightarrow V_b = V_2\left[\frac{R_4}{R_2 + R_4}\right]$$

$$I_1 = \frac{V_1 - V_a}{R_1}$$

$$I_F = \frac{V_a - V_{out}}{R_F}$$

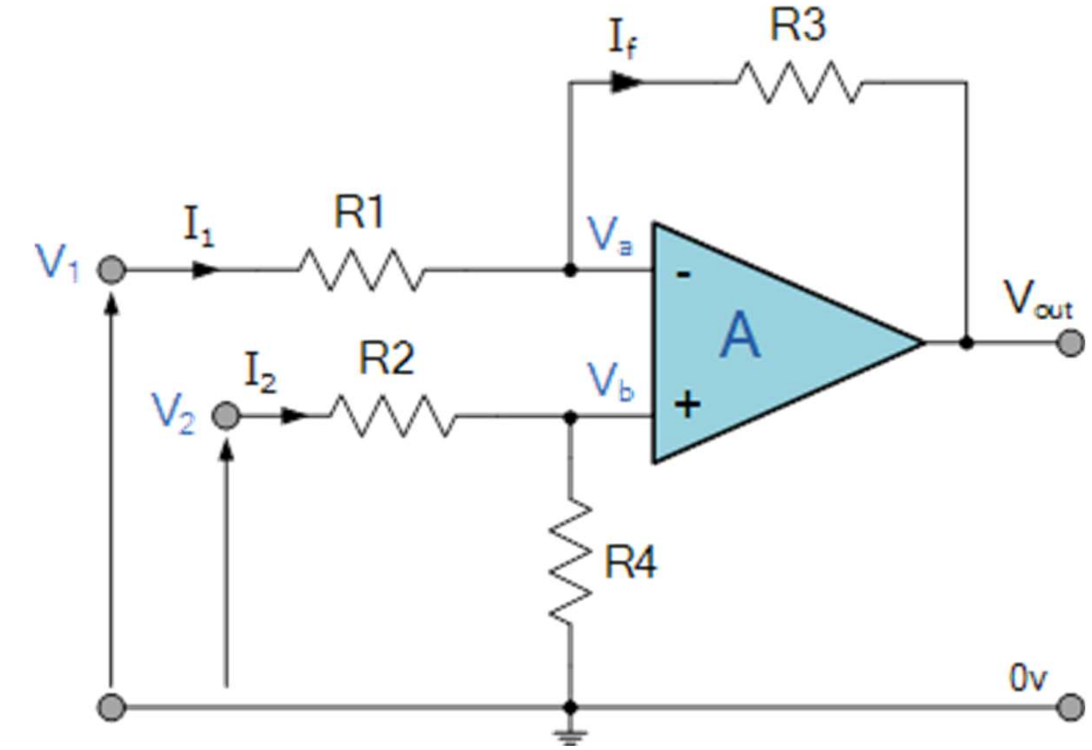
$$V_a = V_b$$



Subtractor/Differential Amplifier

If $V_2 = 0$, then $$V_{out(a)} = -V_1\left[\frac{R_3}{R_1}\right]$$

If $V_1 = 0$, then $$V_b = V_2\left[\frac{R_4}{R_2+R_4}\right]$$ and $$V_a = V_b$$



Considering the flow of current in the negative feedback circuit one gets

$$V_{out(b)} = V_b\left[\frac{R_1+R_3}{R_1}\right] = V_2\left[\frac{R_4}{R_2+R_4}\right]\left[\frac{R_1+R_3}{R_1}\right]$$

The net voltage generated due to both the sources is

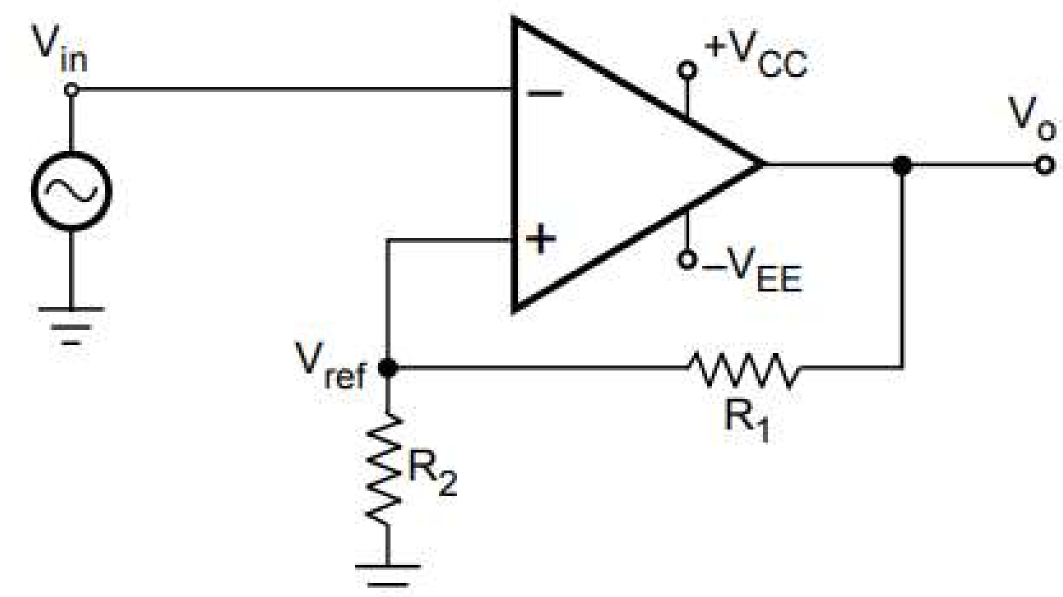
$$V_{out} = V_{out(a)} + V_{out(b)} = -V_1\left[\frac{R_3}{R_1}\right] + V_2\left[\frac{R_4}{R_2+R_4}\right]\left[\frac{R_1+R_3}{R_1}\right]$$

Considering all the resistances of same value one gets

$$V_{out} = V_2 - V_1$$

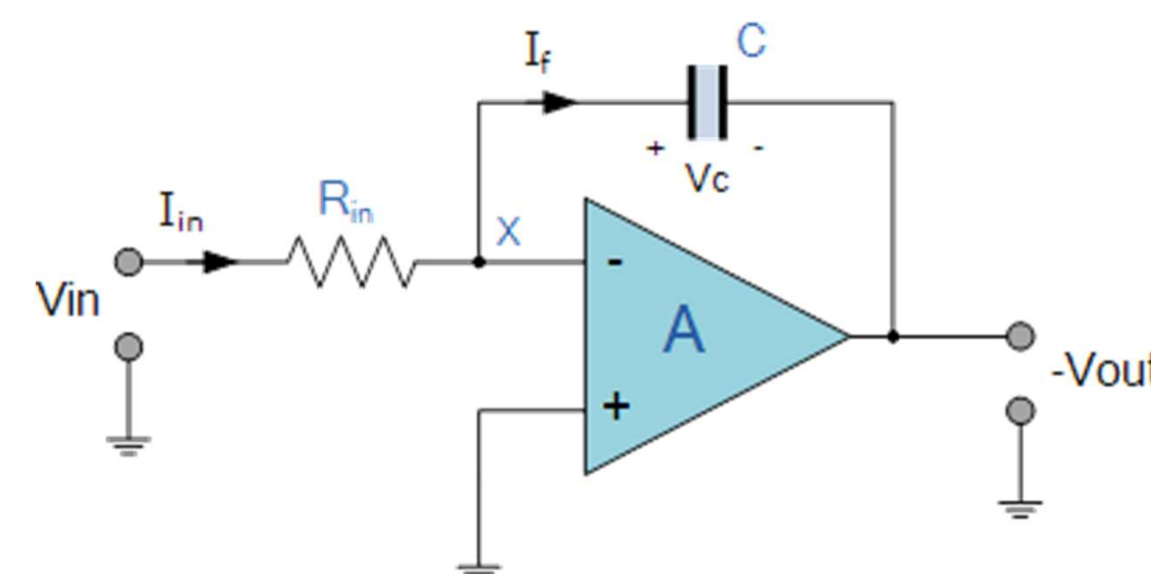
Schmitt Trigger

- A comparator with hysteresis.
- Converts analog input into digital output.
- Introduces two threshold voltages:
- Upper Threshold (VUT)
- Lower Threshold (VLT)
- Useful for removing noise from signals.



Integrator Amplifier

- Operational amplifiers can be used as part of a positive or negative feedback amplifier or as an adder or subtractor type circuit using just pure resistances in both the input and the feedback loop.
- By replacing this feedback resistance with a capacitor we now have an RC Network connected across the operational amplifiers feedback path producing another type of operational amplifier circuit commonly called an Op-amp Integrator circuit as shown below.
- It performs the mathematical operation of Integration.
- The output respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage.



Integrator Amplifier

- The voltage on the plates of a capacitor is equal to the charge on the capacitor divided by its capacitance.

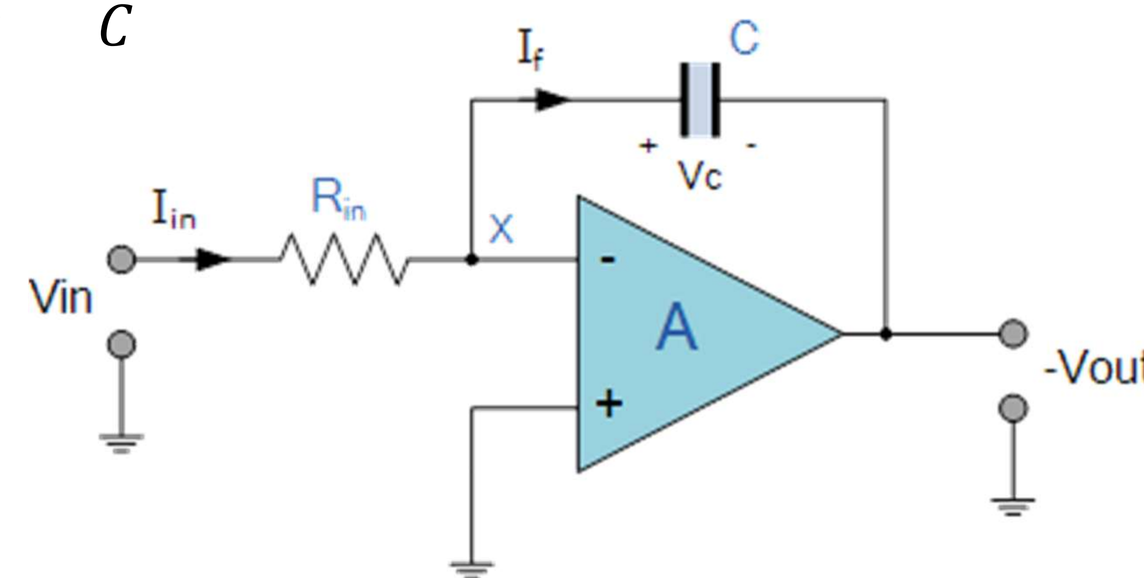
$$V_c = \frac{Q}{C} = V_x - V_{out} = 0 - V_{out} \qquad \Rightarrow -\frac{dV_{out}}{dt} = \frac{1}{C}\frac{dQ}{dt} = \frac{I_F}{C}$$

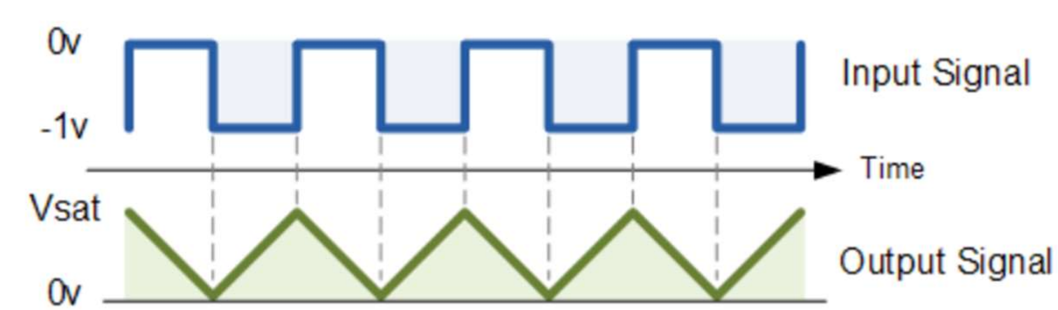
One can further write $\quad I_F = -C\frac{dV_{out}}{dt} = I_{in} = \frac{V_{in}}{R_{in}}$

$$V_{out} = \frac{-1}{C\,R_{in}}\int V_{in}(t)\,dt$$

For a sinusoidal input

$$V_{out} = \frac{1}{\omega\,C\,R_{in}} V_{in} \qquad \omega = 2\pi f$$



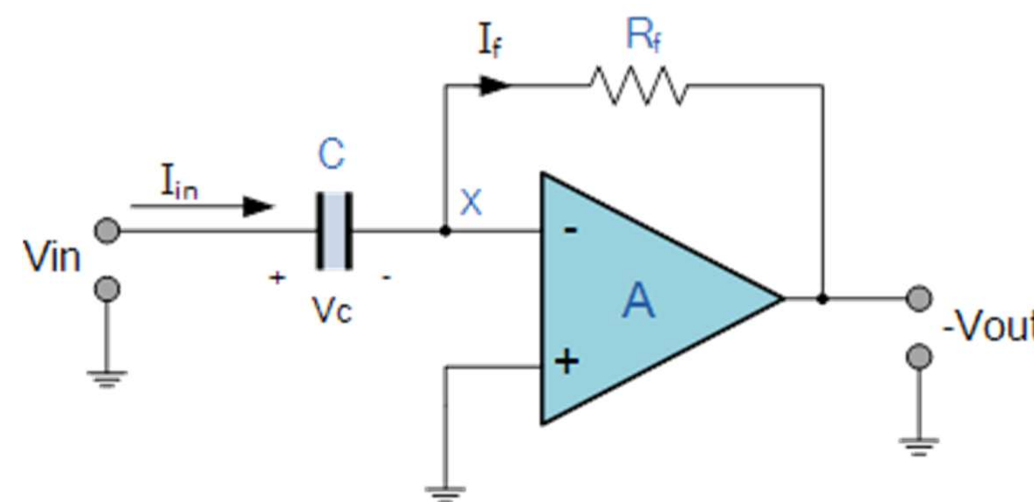


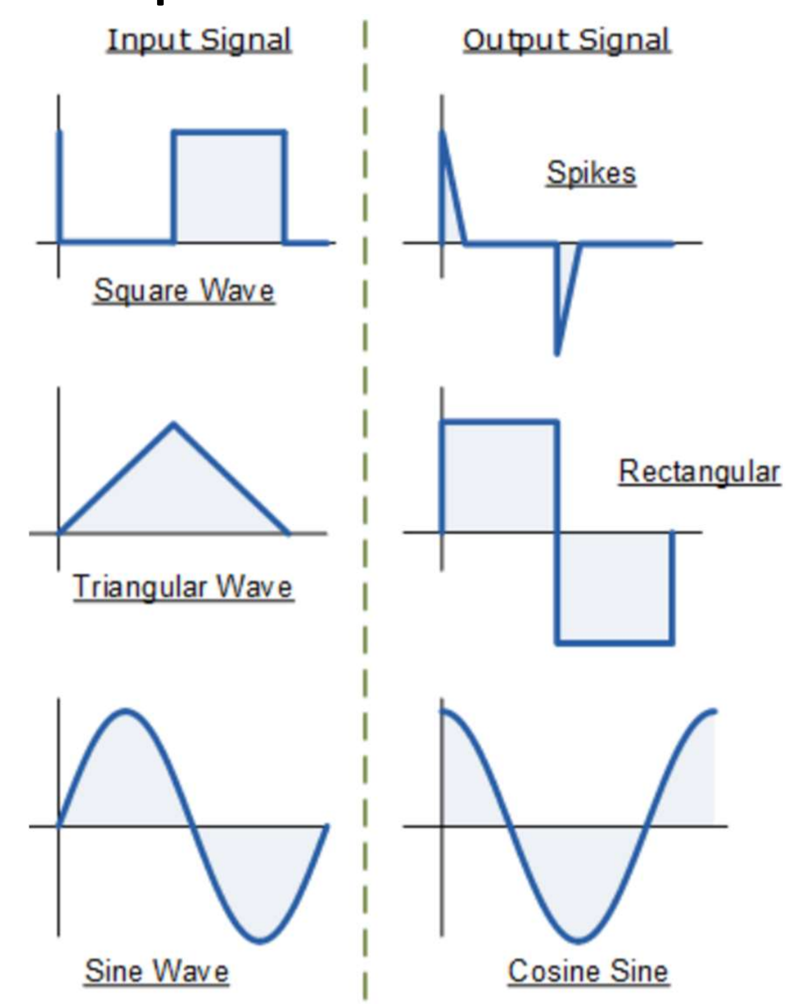
"Low Pass Filter", passing low frequency signals while attenuating the high frequencies.

Differentiator Amplifier

- The position of the capacitor and resistor have been reversed and now the reactance, X_c is connected to the input terminal of the inverting amplifier while the resistor, R_F forms the negative feedback element across the operational amplifier as normal.

$$V_{out} = -R_F\, C\,\frac{dV_{in}}{dt}$$





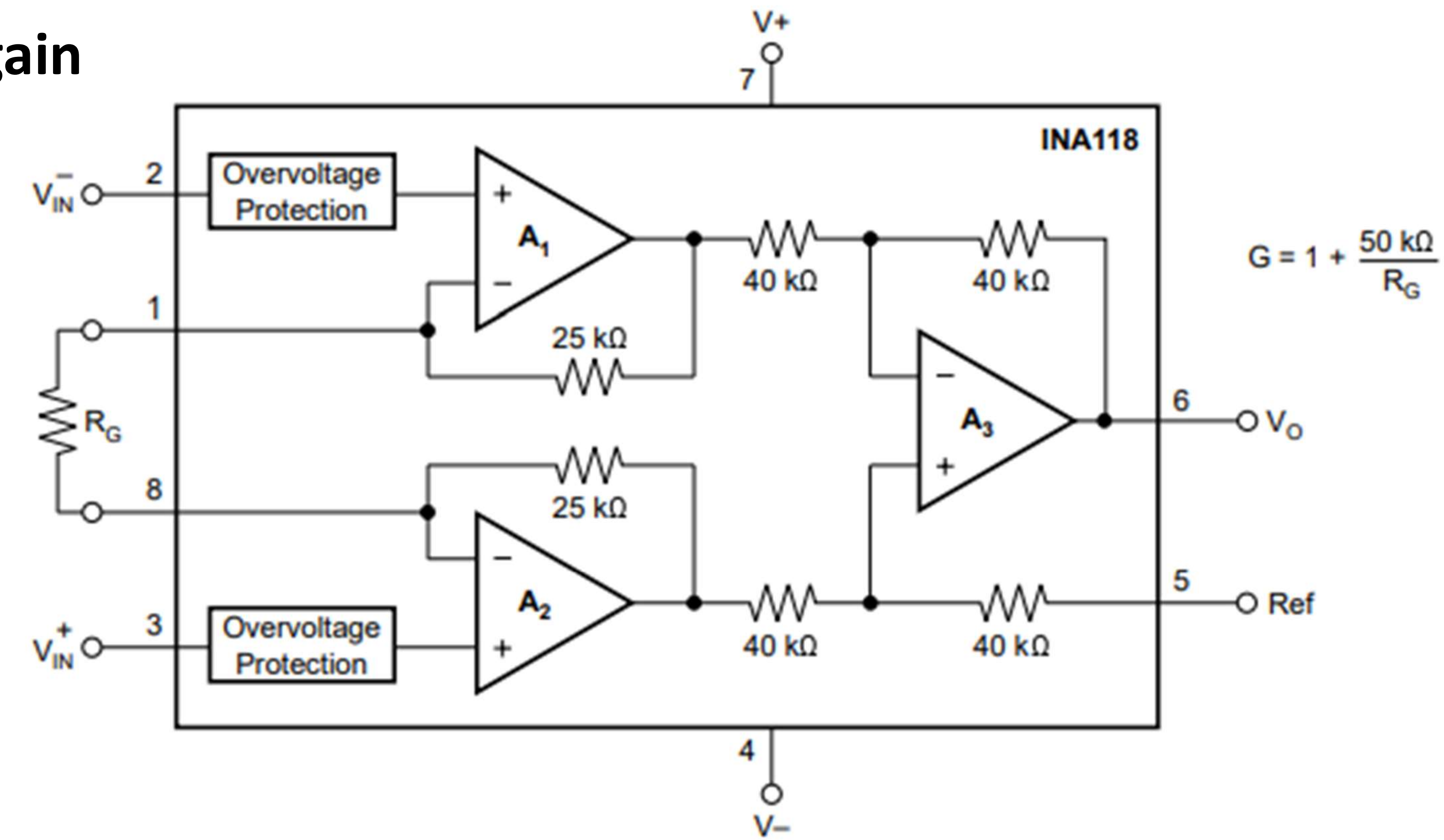
For a sinusoidal input

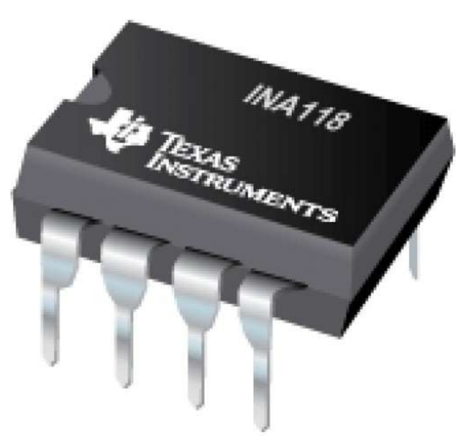
$$V_{out} = \omega\, C\, R_F V_{in} \qquad \omega = 2\pi f$$

"High Pass Filter", passing high frequency signals while attenuating the low frequencies.

Instrumentation Amplifiers (INA 118)

- A single external resistor sets any gain from 1 to 10000.
- Low offset voltage: 50 μV
- Low drift: 0.5 μV/°C
- Low input bias current: 5 nA
- Inputs protected to ±40 V
- Wide supply range: ±2.25 to ±18 V





Instrumentation Amplifiers (INA 125)

- A single external resistor sets any gain from 4 to 10000.
- PRECISION VOLTAGE REFERENCE:

  1.24V, 2.5V, 5V or 10V
- LOW OFFSET VOLTAGE: 250µV
- LOW OFFSET DRIFT: 2µV/°C
- INPUT PROTECTION TO ±40V
- WIDE SUPPLY RANGE

  Single Supply: 2.7V to 36V

  Dual Supply: ±1.35V to ±18V