Islamic University of Technology

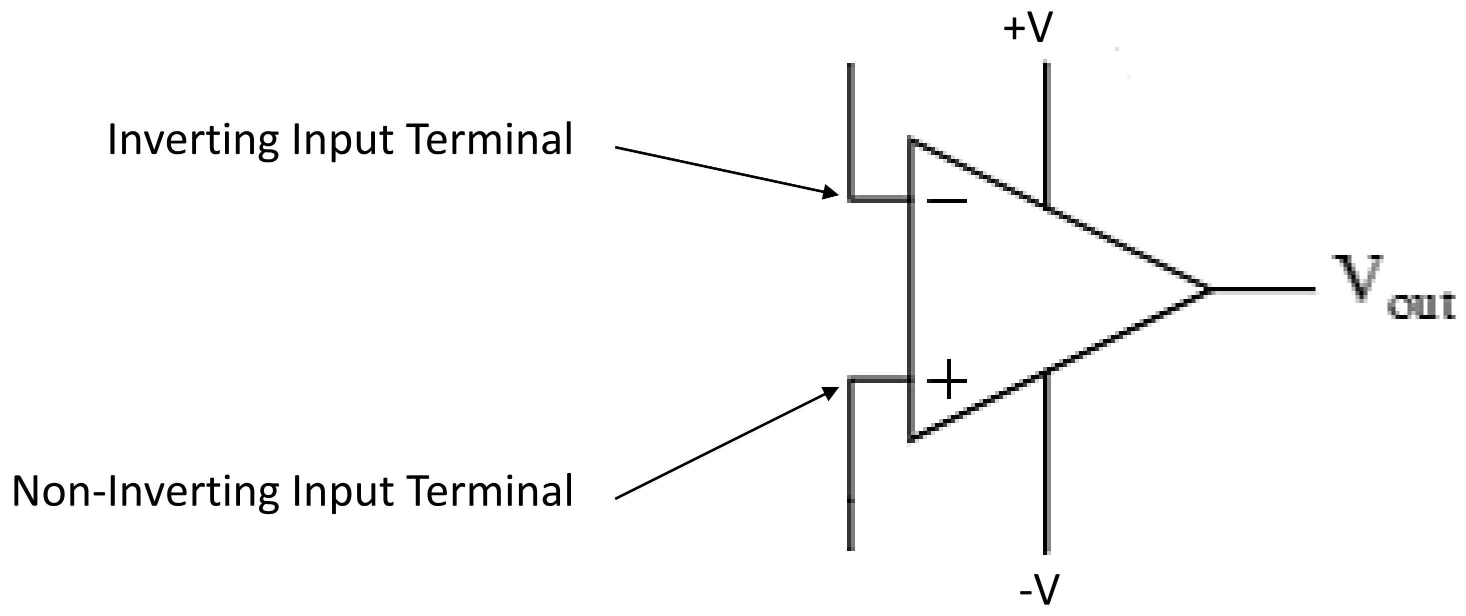
EEE 4483
Digital Electronics & Pulse Techniques

Lecture-2

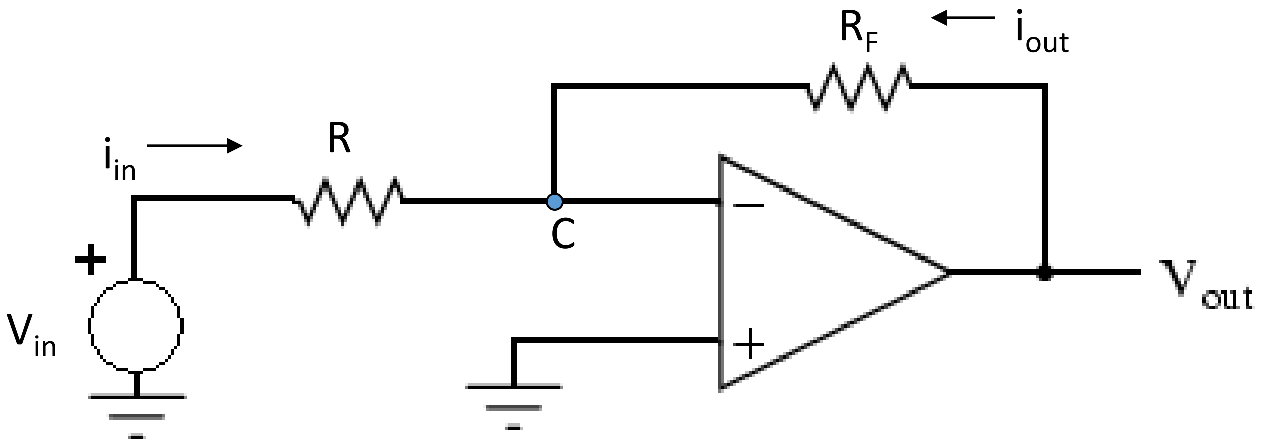
Operational Amplifiers

- An operational amplifier (called op-amp) is a specially-designed amplifier in bipolar or CMOS with the following typical characteristics:
    - Very high gain (10,000 to 1,000,000)
    - Differential input
    - Very high (assumed infinite) input impedance
    - Single ended output
    - Very low output impedance

Symbol for an Op-Amp



Inverting Amplifier

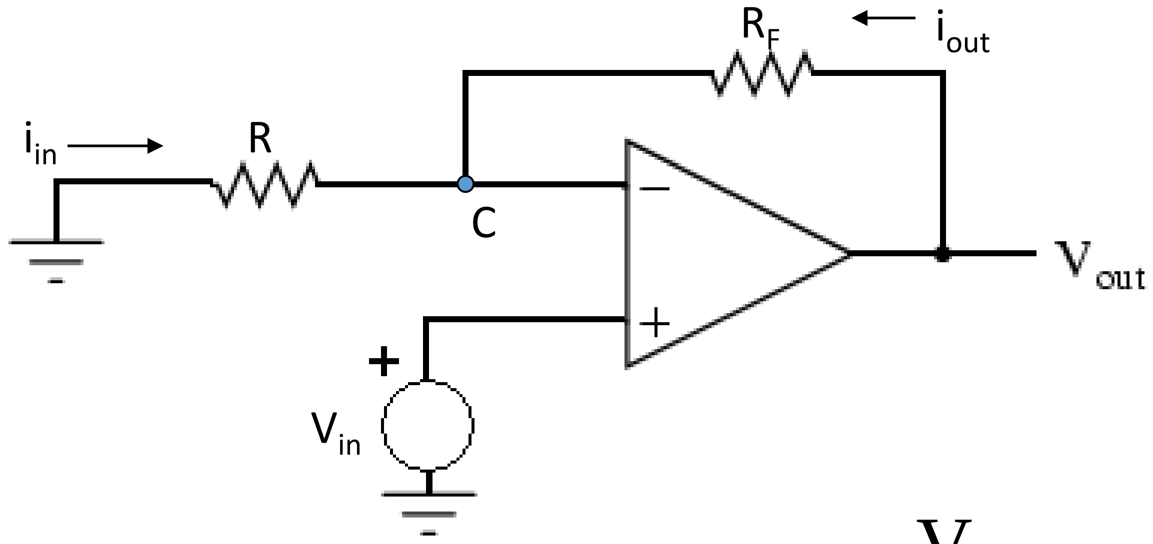


$$\frac{V_{out}}{V_{in}} = -\frac{R_F}{R}$$

$$Z_{in} = R_1$$

$$Z_{out} = 0$$

Non-Inverting Amplifier

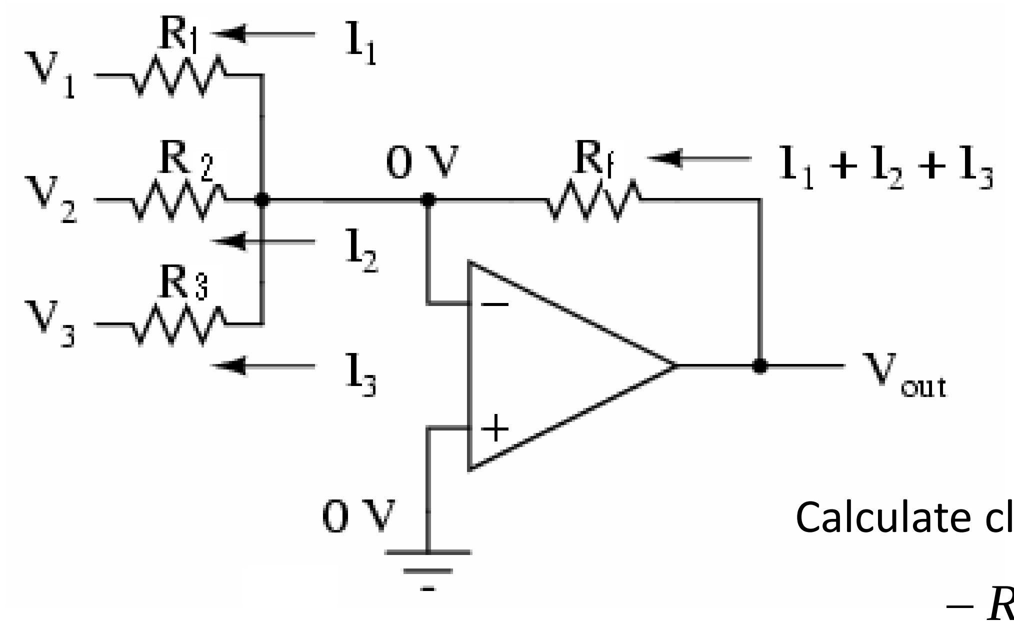


$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R}$$

$$Z_{in} = \infty$$

$$Z_{out} = 0$$

Summing Circuits



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

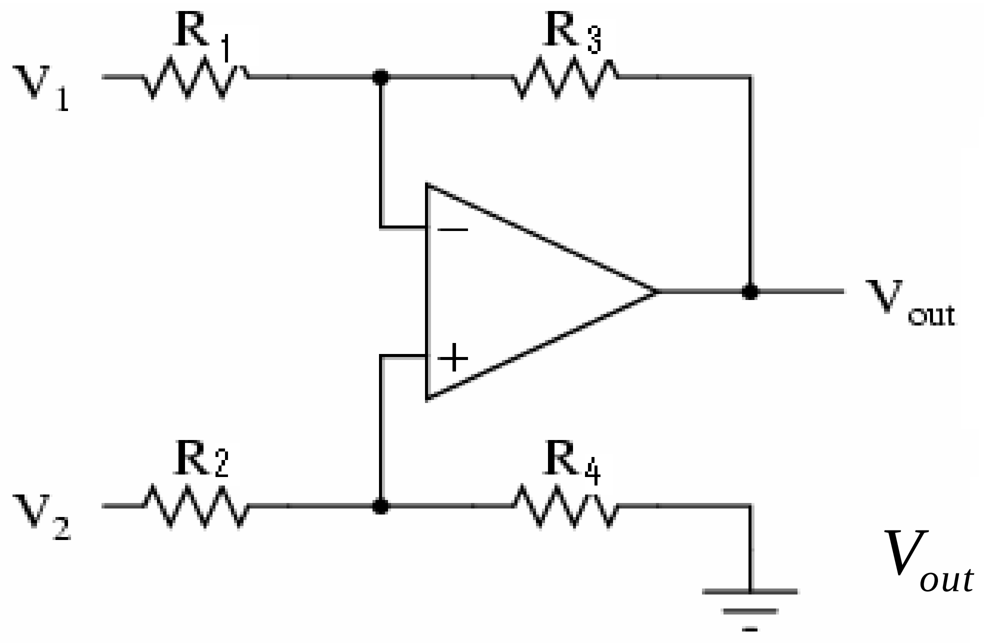
Calculate closed loop gain for each input

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

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

If all resistors are equal in value: $$V_o = -(V_1 + V_2 + V_3)$$

Difference Circuit

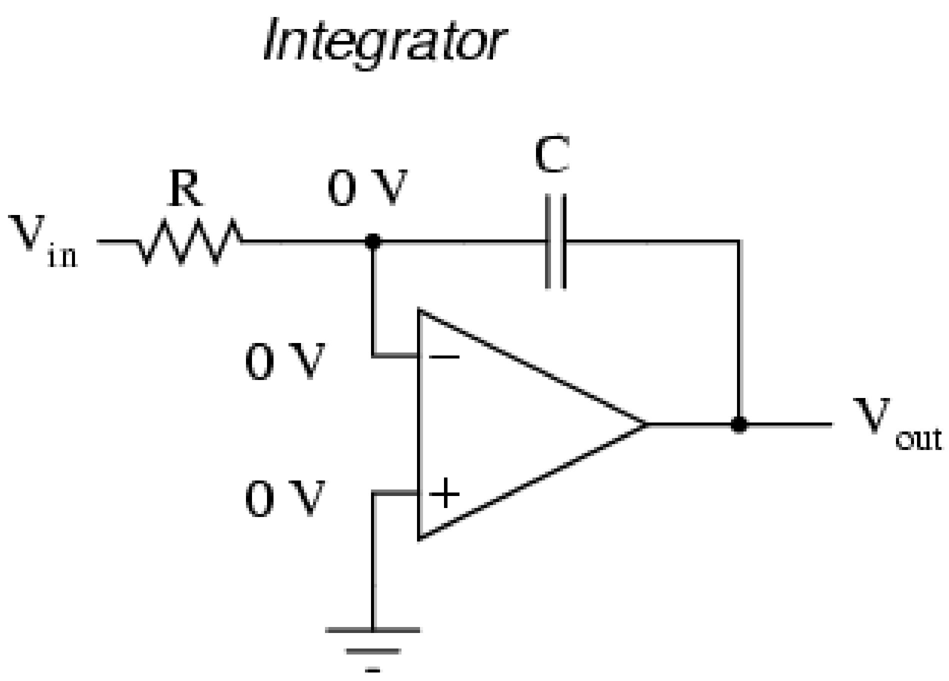


- Used to subtract analog signals
- Output signal is proportional to difference between two inputs

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

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

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

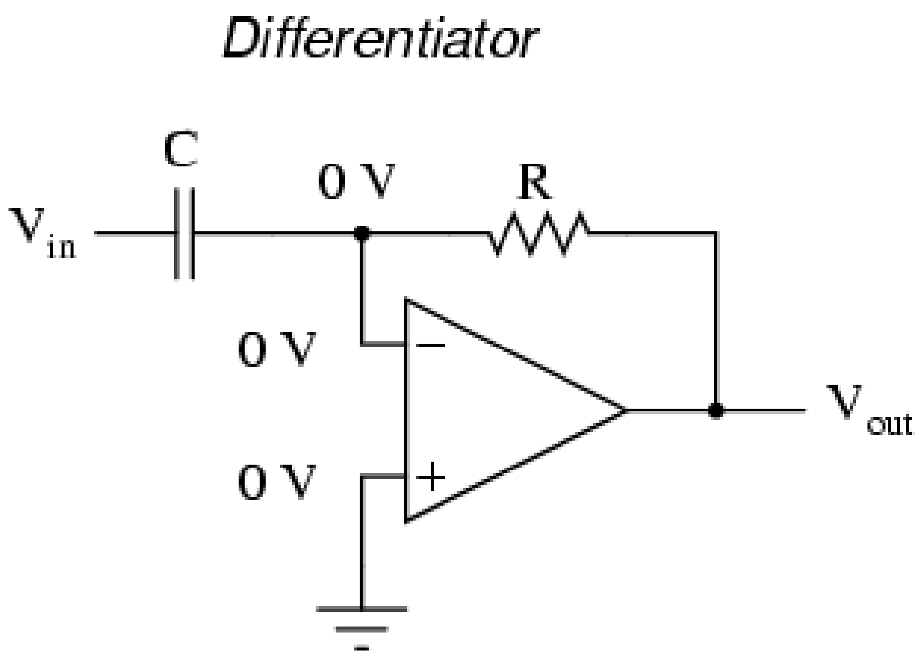
or

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

Where,

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

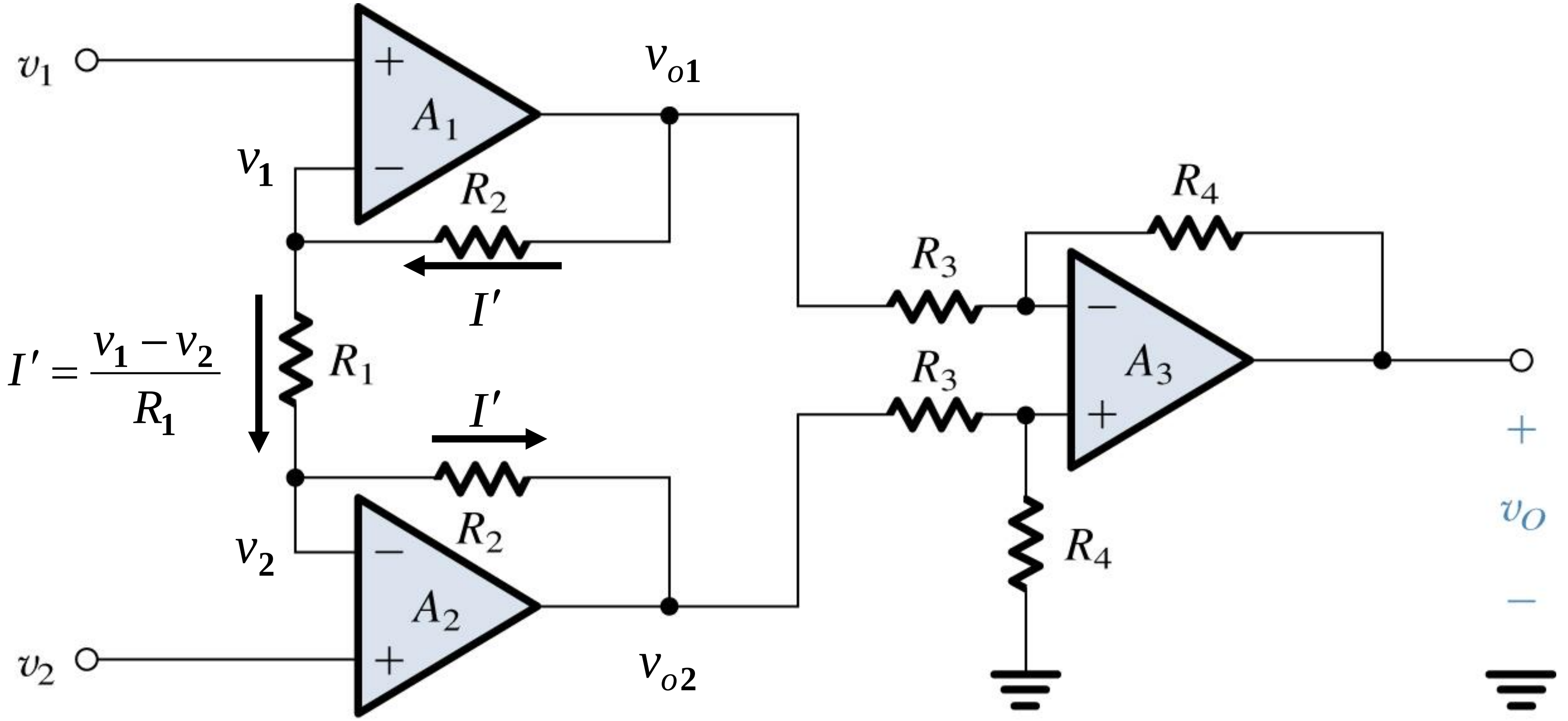
Differentiating Circuit



- 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

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

Instrumentation Amplifier



Instrumentation Amplifier : continuing ..

$$v_{o1} - v_{o2} = \frac{v_1 - v_2}{R_1} R_2 + v_1 - v_2 + \frac{v_1 - v_2}{R_1} R_2$$

$$= (v_1 - v_2)\left[\frac{R_2}{R_1} + 1 + \frac{R_2}{R_1}\right]$$

$$= (v_1 - v_2)\left[1 + \frac{2R_2}{R_1}\right]$$

Instrumentation Amplifier : continuing ..

- Using superposition, the output is due to an inverting amplifier and non-inverting amplifier.

The Difference Amplifier

- The inverting amplifier produces

$$v_{oi} = -v_{o1}\left[\frac{R_4}{R_3}\right]$$

- The non-inverting amplifier produces

$$v_{on} = v_{o2}\left[\frac{R_4}{R_3 + R_4}\right]\left[1 + \frac{R_4}{R_3}\right]$$

Instrumentation Amplifier : continuing ..

- The output is the sum of the outputs produced by each input.

$$v_{out} = v_{oi} + v_{on} = v_{o2}\left[\frac{R_4}{R_3 + R_4}\right]\left[\mathbf{1} + \frac{R_4}{R_3}\right] - v_{o1}\left[\frac{R_4}{R_3}\right]$$

$$= v_{o2}\left[\frac{R_4}{R_3 + R_4}\right]\left[\frac{R_3}{R_3} + \frac{R_4}{R_3}\right] - v_{o1}\left[\frac{R_4}{R_3}\right]$$

Instrumentation Amplifier : continuing ..

$$v_{out} = v_{o2}\left[\frac{R_4}{R_3+R_4}\right]\left[\frac{R_3+R_4}{R_3}\right] - v_{o1}\left[\frac{R_4}{R_3}\right]$$

$$= v_{o2}\left[\frac{R_4}{R_3}\right] - v_{o1}\left[\frac{R_4}{R_3}\right] = \left(v_{o2} - v_{o1}\right)\left[\frac{R_4}{R_3}\right]$$

$$= -\left(v_1 - v_2\right)\left[\mathbf{1} + \frac{R_2}{R_1}\right]\left[\frac{R_4}{R_3}\right] = \left(v_2 - v_1\right)\left[\mathbf{1} + \frac{R_2}{R_1}\right]\left[\frac{R_4}{R_3}\right]$$

Instrumentation Amplifier : continuing ..

- For R_2=R_3=R_4,

$$v_{out} = \left(v_2 - v_1\right)\left[1 + \frac{R_2}{R_1}\right]$$

  - Quite often, R_1 is a variable resistor that is used to set the gain and is denoted as R_g.

CMRR and CMR

- Common-Mode Rejection Ratio is defined as the ratio of the differential gain to the common-mode gain

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

- CMR is defined as follows:

$$CMR(dB) = 20\log_{10}(CMRR)$$

- CMR and CMRR are often used interchangeably

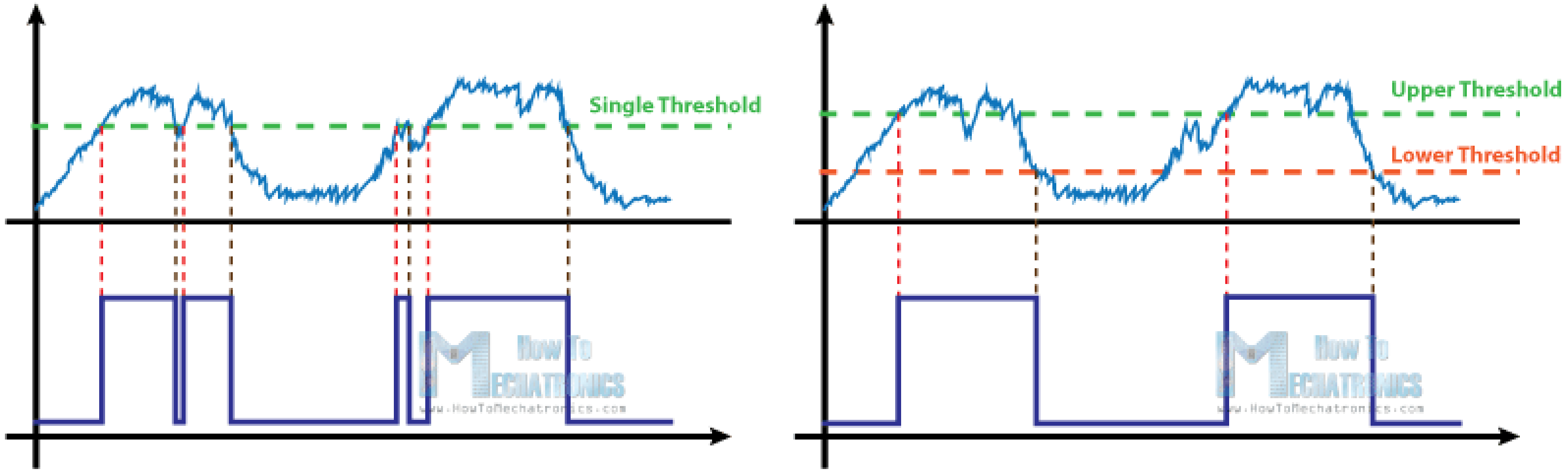
CMRR : continuing

CMRR actually rejects this common mode signal (common signal to both input) which is unwanted. Without an excellent CMRR, we can not have output significant.

Schmitt Trigger

A the simple comparator circuit using either an ordinary operational amplifier. However if the input waveform is slow or has noise on it, then there is the possibility that the output will switch back and forth several times during the switch over phase as only small levels of noise on the input will cause the output to change.

This may not be a problem in some circumstances, but if the *output from the operational amplifier comparator is being fed into fast logic circuitry, then it can often give rise to problems*.



Schmitt Trigger: continued

Problem: Design a voltage level detector with noise immunity that indicates when an input signal crosses the nominal threshold of – 2.5 V. The output is to switch from high to low when the signal crosses the threshold in the positive direction, and vice versa. Noise level expected is 0.2 V_{PP} , maximum. Assume the output levels are V_H = 10 V and V_L = 0V.

Schmitt Trigger: continued..

Schmitt trigger applications

A Schmitt trigger is used in most applications where a level needs to be sensed. Even if only a small amount of hysteresis is used, it reduces the multiple transitions that can occur around.

As such the Schmitt trigger applications include many different areas of electronics.

Digital to analogue conversion: The Schmitt trigger is effectively a one bit digital to analogue converter. When the signal reaches a given level it switches from its low to high state.

Level detection: The Schmitt trigger circuit is able to provide level detection. When undertaking this application, it is necessary that the hysteresis voltage is taken into account so that the circuit switches on the required voltage.

Line reception: When running a data line that may have picked up noise into a logic gate it is necessary to ensure that a logic output level is only changed as the data changed and not as a result of spurious noise that may have been picked up. Using a **Schmitt trigger** broadly enables the peak to peak noise to reach the level of the hysteresis before spurious triggering may occur.

Astable Multivibrator

- The **Op-amp Multivibrator** is an astable oscillator circuit that generates a rectangular output waveform using an RC timing network connected to the inverting input of the operational amplifier and a voltage divider network connected to the other non-inverting input.
- Astable multivibrator is a kind of self-oscillation circuit . When power is applied It can generate rectangle pulse which has a certain frequency and amplitude.
- Because of the abundant high-order resonance wave ponderance, it named astable multivibrator.
- It consists of switch device, feedback network, and delay device.