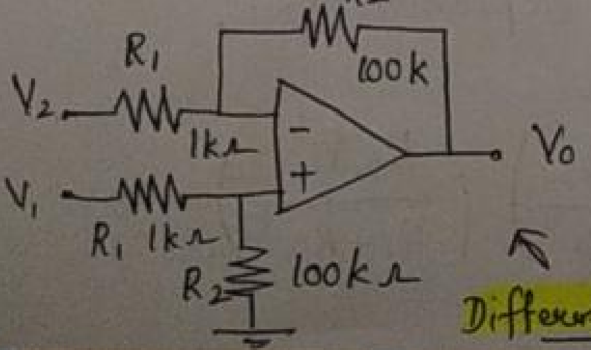
Instrumentation Amplifier:

* For industrial and consumer applications, it is necessary to measure and control physical quantities like temperature, humidity, light intensity, water flow etc.,
* These physical quantities are usually measured with the help of transducers.
* The output of the transducer has to be amplified, so that it can drive the display system. This function is performed by an instrumentation amplifier.

Features of an instrumentation amplifier:

(1) High gain accuracy.
(2) High CMRR.
(3) High gain stability with low temperature co-efficient
(4) Low dc offset
(5) Low output impedance.



Differential Amplifier

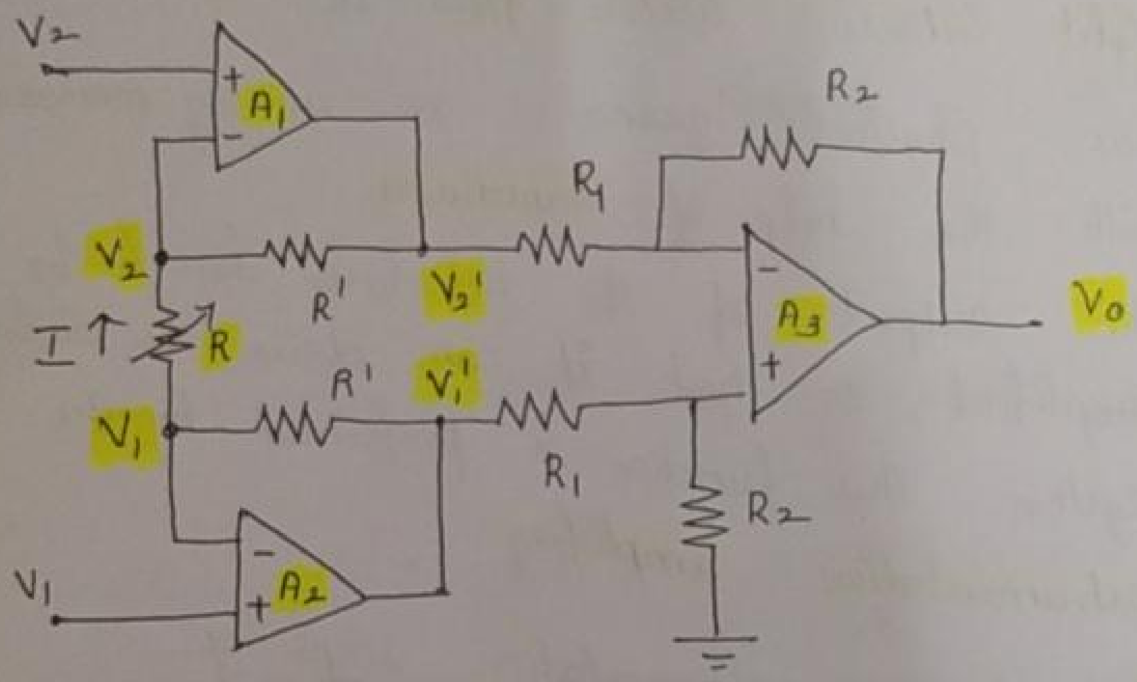
$V_1 \rightarrow$ i/p impedance $\rightarrow (100+1) = 101k\Omega$

$V_2 \rightarrow$ i/p impedance $\rightarrow 1k\Omega = 1k\Omega$

$\Downarrow$ creates

Loading effect

* To avoid this loading effect, high resistance buffer is used proceeding to the differential amplifier, that circuit is called instrumentation amplifier.



* For $V_1 = V_2$, under common-mode condition, no current flows through R & R', so A_1 & A_2 act as voltage follower.
* If $V_1 \neq V_2$, current flows in R & R', &

$(V_2' - V_1') > (V_2 - V_1)$.

Let us, Write the output voltage expression (V_o),

$$V_o = -\underbrace{\frac{R_2}{R_1}}_{\text{invt. gain}} \underbrace{V_2'}_{\text{i/p}} + \underbrace{\left(1 + \frac{R_2}{R_1}\right)}_{\text{non-invt. gain}} \underbrace{\left(\frac{R_2 V_1'}{R_1 + R_2}\right)}_{\text{i/p}}.$$

$$\therefore \quad V_o = \frac{-R_2}{R_1} V_2' + \left(\frac{\cancel{R_1+R_2}}{R_1}\right)\left(\frac{R_2 V_1'}{\cancel{R_1+R_2}}\right)$$

$$= \frac{-R_2}{R_1} V_2' + \frac{R_2}{R_1} V_1'$$

$$V_o = \frac{R_2}{R_1}\left(V_1' - V_2'\right) \longrightarrow (1)$$

* The current flows through 'R' expressed as

$$I = \frac{(V_1 - V_2)}{R}$$

$$\therefore \quad V_1' = R'I + V_1 = \frac{R'}{R}(V_1 - V_2) + V_1 \longrightarrow (2)$$

$$V_2' = -R'I + V_2 = -\frac{R'}{R}(V_1 - V_2) + V_2 \longrightarrow (3)$$

Substitute equation (2) and (3) in (1), we get

$$V_o = \frac{R_2}{R_1}\left(V_1' - V_2'\right)$$

$$= \frac{R_2}{R_1}\left[\left(\frac{R'}{R}(V_1 - V_2) + V_1\right) + \left(\frac{R'}{R}(V_1 - V_2) \; V_2\right)\right]$$

$$= \frac{R_2}{R_1}\left[\frac{2R'}{R}(V_1 - V_2) + (V_1 - V_2)\right]$$

$$\boxed{V_o = \frac{R_2}{R_1}(V_1 - V_2)\left[1 + \frac{2R'}{R}\right]} \longrightarrow (4)$$

In equation ④, if we choose

$R_1 = R_2 = 25\,k\Omega$

$R' = 25\,k\Omega$

$R = 50\,\Omega$, then

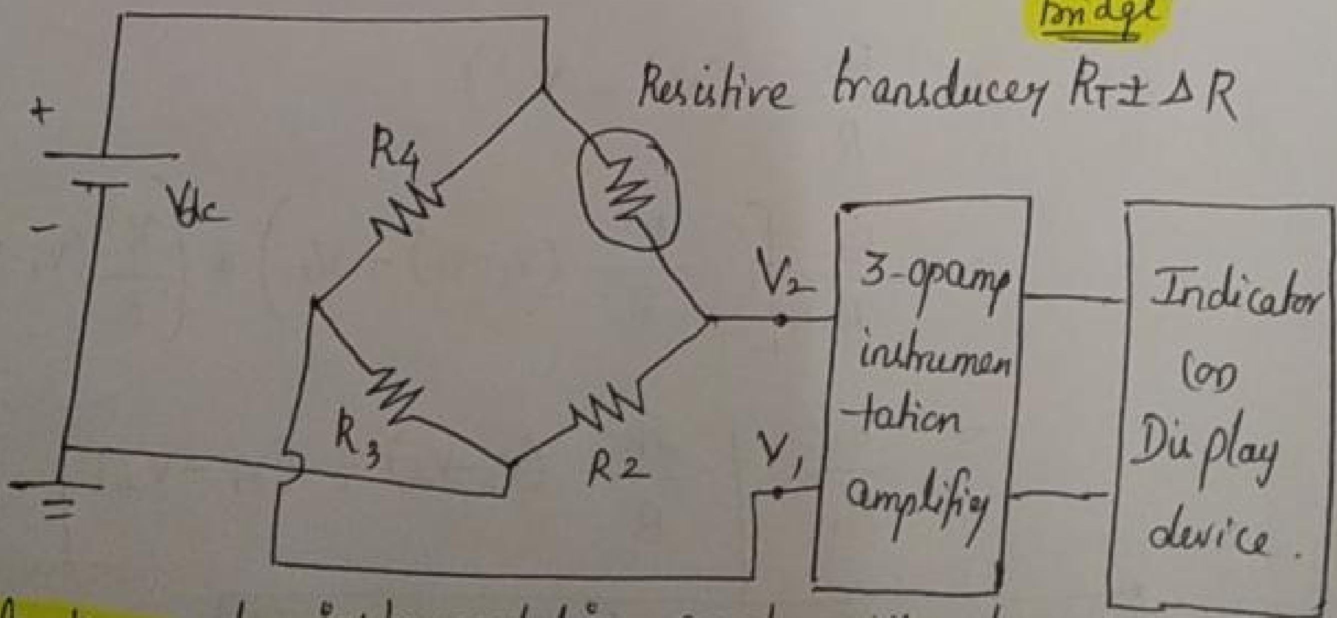
$$\text{Gain} = \frac{V_o}{V_i} = \frac{R_2}{R_1}\left(1 + \frac{2R'}{R}\right) = \frac{25k}{25k}\left(1 + \frac{2(25k)}{50}\right)$$

$$= \left(1 + \frac{50k}{50\Omega}\right)$$

$$\boxed{\text{Gain} = 1001}$$

* The differential gain of this instrumentation amplifier is varied by replacing the resistance 'R' by a potentiometer.

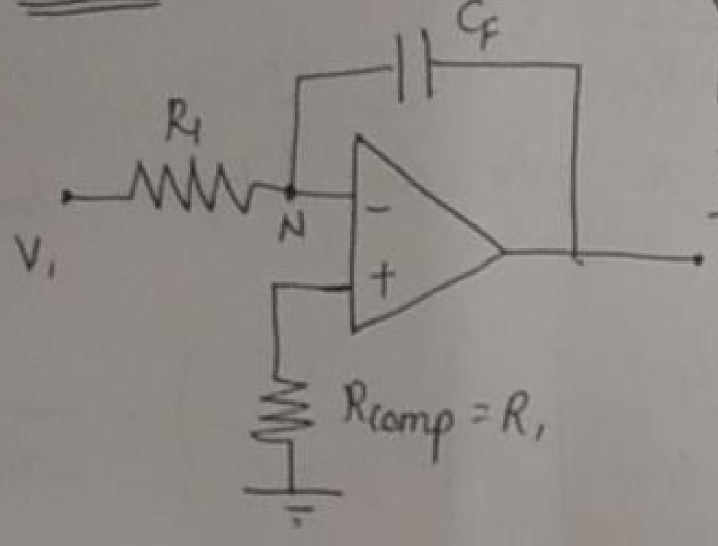
Instrumentation amplifier using transducer bridge



Applications of instrumentation ampl. with transducer bridge:

Temperature indicator, Temperature controller, light intensity meter, Analog weighing scale, Measurement of flow of electricity & thermal conductivity

Integrator: (Low pass filter) → It provides an o/p voltage which is proportional to the time integral of the i/p and R_1C_F is the time constant of the integrator.



* The Nodal equation at node N, is

$$\frac{V_i}{R_1} + C_F \frac{dv_o}{dt} = 0$$

$$\frac{dv_o}{dt} = -\frac{1}{R_1C_F} V_i$$

$\int$ing both sides, we get

$$\int_0^t \frac{dv_o}{dt} = -\frac{1}{R_1C_F} \int_0^t V_i \, dt$$

$$V_o(t) = -\frac{1}{R_1C_F} \int_0^t V_i(t)\, dt + \underbrace{V_o(0)}_{\text{initial o/p voltage}}$$

In frequency domain,

$$V_o(s) = -\frac{1}{sR_1C_F} V_i(s)$$

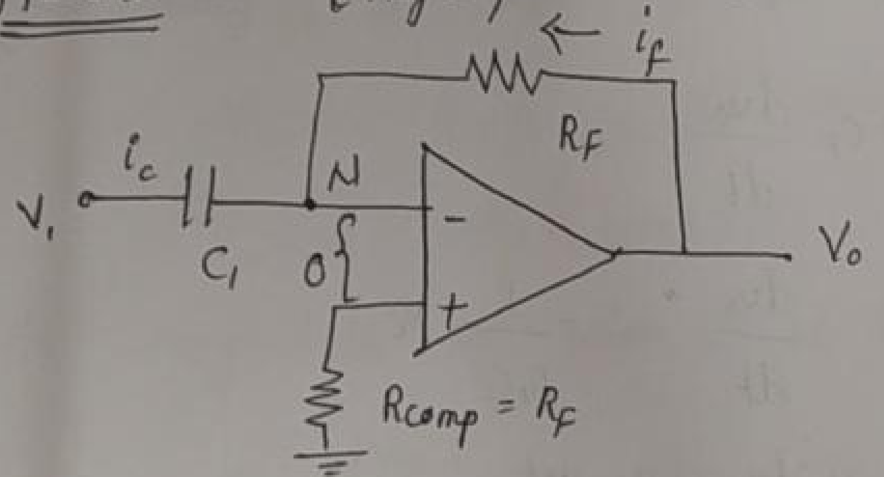
In steady state, put $s = j\omega$,

$$V_o(j\omega) = -\frac{1}{j\omega R_1 C_F} V_1(j\omega)$$

The magnitude of the gain (or) Integrator transfer function is,

$$|A| = \left| \frac{V_o(j\omega)}{V_i(j\omega)} \right| = \left| -\frac{1}{j\omega R_1 C_F} \right| = \frac{1}{\omega R_1 C_F}$$

Differentiator:- (High pass filter)



The O/P voltage v_0 is a constant $(-R_F C_1)$ times the derivate of the input voltage v_i & the circuit is a differentiator.

Analysis:-

The node N is at virtual ground $v_N = 0$.
The current i_c through the capacitor is,

$$i_c = C_1 \frac{d}{dt}(v_i - v_N) = C_1 \frac{dv_i}{dt}$$

The nodal equation at node N,

$$C_1 \frac{dv_i}{dt} + \frac{v_o}{R_F} = 0.$$

$$\boxed{\therefore V_o = -R_F C_1 \frac{dv_i}{dt}}$$

In frequency domain,

$$V_o(s) = -R_F C_1 s V_i(s)$$

In steady state, put $s = j\omega$, then

$$V_o(s) = -R_F C_1 s V_i(s) \quad \text{becomes}$$

$$V_o(j\omega) = -R_F C_1 (j\omega) V_i(j\omega).$$

The magnitude of gain A of the differentiator is

$$|A| = \left|\frac{V_o}{V_i}\right| = -j\omega R_F C_1 = \omega R_F C_1.$$

In the frequency response of the op-amp, the frequency can be written as

$$f_a = \frac{1}{2\pi R_F C_1}$$

Inverting Summing Amplifier

A typical summing amplifier with three input voltages V_1, V_2 and V_3, three input resistors R_1, R_2, R_3 and a feedback resistor R_f is shown in Fig. 4.2 (a). The following analysis is carried out assuming that the op-amp is an ideal one, that is, $A_{OL} = \infty$ and $R_i = \infty$. Since the input bias current is assumed to be zero, there is no voltage drop across the resistor R_{comp} and hence the non-inverting input terminal is at ground potential.

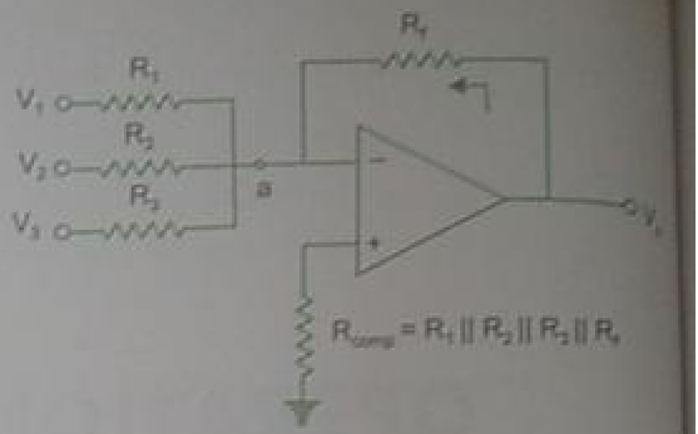


Fig. 4.2 (a) Inverting summing amplifier

The voltage at node 'a' is zero as the non-inverting input terminal is grounded. The nodal equation by KCL at node 'a' is

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_f} = 0$$

or,

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right) \tag{4.1}$$

Thus the output is an inverted, weighted sum of the inputs. In the special case, when $R_1 = R_2 = R_3 = R_f$, we have

$$V_o = -(V_1 + V_2 + V_3) \tag{4.2}$$

in which case the output V_o is the inverted sum of the input signals. We may also set

$$R_1 = R_2 = R_3 = 3R_f$$

in which case

$$V_o = -\left(\frac{V_1 + V_2 + V_3}{3}\right) \tag{4.3}$$

Thus the output is the average of the input signals (inverted). In a practical circuit, input bias current compensating resistor R_{comp} should be provided as discussed in Sec. 3.2.1. To find R_{comp}, make all inputs $V_1 = V_2 = V_3 = 0$. So the effective input resistance $R_i = R_1 \| R_2 \| R_3$. Therefore, $R_{comp} = R_i \| R_f = R_1 \| R_2 \| R_3 \| R_f$.

Example 4.1

Design an adder circuit using an op-amp to get the output expression as

$$V_o = -(0.1\,V_1 + V_2 + 10\,V_3)$$

where V_1, V_2, and V_3 are the inputs.

Solution

The output in Fig. 4.2 (a) is

$$V_o = -[(R_f/R_1)V_1 + (R_f/R_2)V_2 + (R_f/R_3)V_3]$$

say $$R_f = 10\ \text{k}\Omega,\ R_1 = 100\ \text{k}\Omega,\ R_2 = 10\ \text{k}\Omega,\ R_3 = 1\ \text{k}\Omega$$

Then the desired output expression is obtained.

Non-inverting Summing Amplifier

A summer that gives a non-inverted sum is the non-inverting summing amplifier of Fig. 4.2 (b). Let the voltage at the (–) input terminal be V_a. The voltage at (+) input terminal will also be V_a. The nodal equation at node 'a' is given by

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

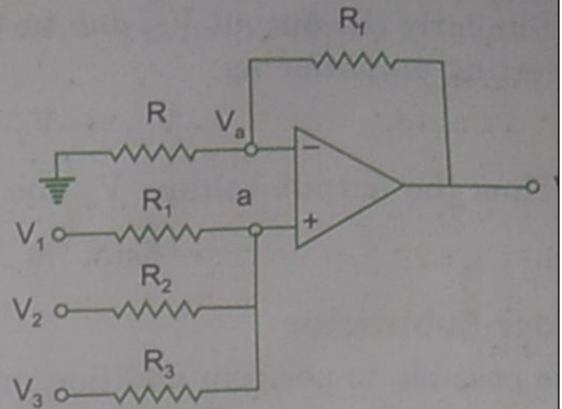


Fig. 4.2 (b) Non-inverting summing amplifie

from which we have,

$$V_a = \frac{\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}} \quad (4$$

The op-amp and two resistors R_f and R constitute a non-inverting amplifier with

$$V_o = \left(1 + \frac{R_f}{R}\right) V_a \quad (4$$

Therefore, the output voltage is,

$$V_o = \left(1 + \frac{R_f}{R}\right) \frac{\left(\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}\right)}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}} \quad (4$$

which is a non-inverted weighted sum of inputs.

Let $R_1 = R_2 = R_3 = R = R_f/2$, then $V_o = V_1 + V_2 + V_3$