Mechatronics (Merged - DEZG516/DMZG511/ESZG511)

BITS Pilani
Pilani Campus

Lecture 5

Session 5

Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Signal conditioning with operational amplifiers: Summing and difference amplifiers Integrating, Differentiating and logarithmic amplifiers	T1: Chapter 3, T2: Chapter 5
Post CH			Chapter end problems

Recap

Resistance Vs Impedance

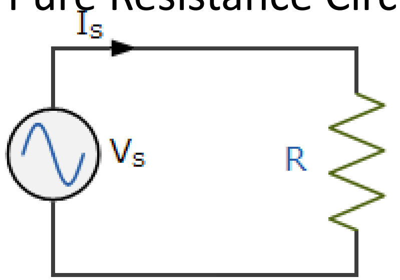
- **Resistance** is simply defined as the opposition to the flow of electric current **in the** circuit.
- **Impedance** is opposition to the flow of AC current because of any three components that is resistive, inductive or capacitive.
- It is a combination of both **resistance** and reactance **in a** circuit.

Resistance Vs Impedance

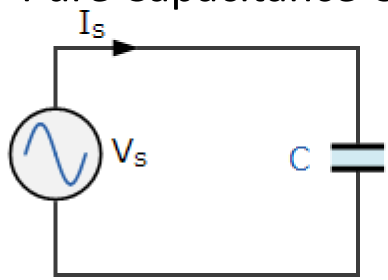
Difference Between Resistance and Impedance	
Resistance	Impedance
It is used in DC circuits	It is used in AC circuits
Resistance can be seen in both AC and DC circuits	Impedance can be seen only in AC circuits
It happens due to resistive elements	It happens due to reactance and resistance
It is represented by letter R	It is represented by letter Z
It is represented using real numbers such as 5.3 ohms	It is represented using real and imaginary values such as R + ik
It does not vary depending upon the frequency of DC current	It varies according to the frequency of AC current.
It does not have a magnitude and phase angle	It does have a phase angle and magnitude
If kept in a electromagnetic field, it only shows the power dissipation	If kept in a electromagnetic field, it shows power dissipation and energy stored

Circuits

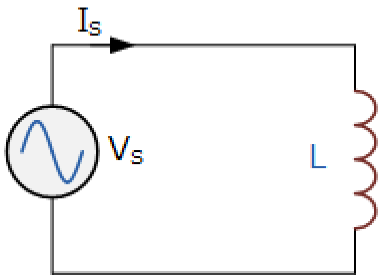
Pure Resistance Circuit



Pure Capacitance Circuit



Pure Inductive Circuit



$$Z = \frac{V_R}{I_R} = R$$

$$X_C = \frac{V_C}{I_C} = \frac{1}{2\pi f C}$$

$$X_L = \frac{V_L}{I_L} = 2\pi f L$$

$$I_S = \frac{V_S}{R}$$

$$I_S = \frac{V_S}{X_C}$$

$$I_S = \frac{V_S}{X_L}$$

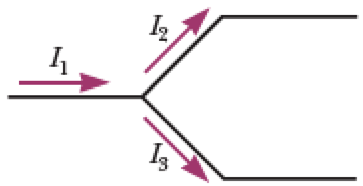
$$I(t) = C\,\frac{dV}{dt}$$

Unlike Resistor which just impedes the current (Constant Ohms), Capacitor and inductor impede currents (Variable ohms) based on frequency of power supply

Kirchhoff's Law

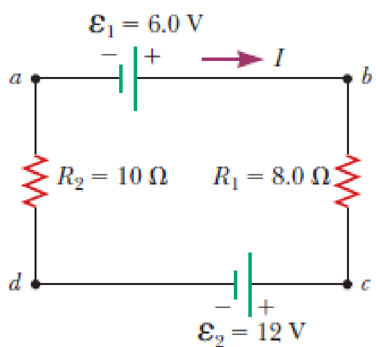
1. Junction rule. At any junction, the sum of the currents must equal zero:

$$\sum_{\text{junction}} I = 0 \qquad \textbf{(28.9)}$$



2. Loop rule. The sum of the potential differences across all elements around any closed circuit loop must be zero:

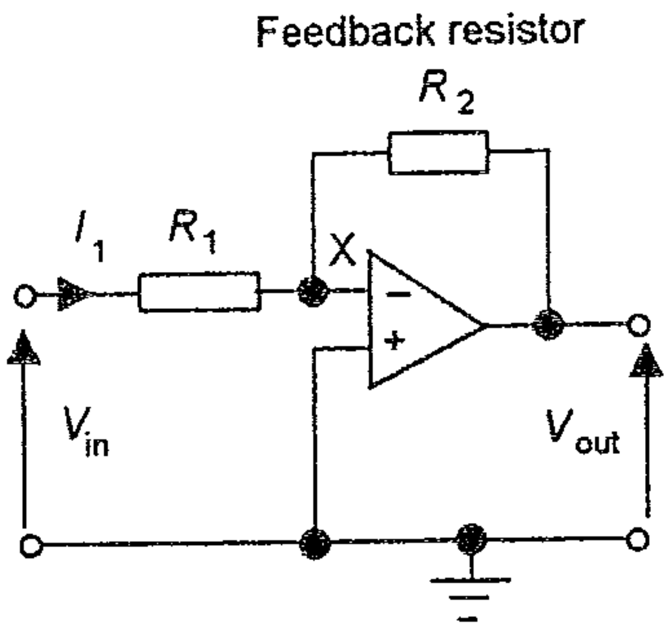
$$\sum_{\text{closed loop}} \Delta V = 0 \qquad \textbf{(28.10)}$$



$$\sum \Delta V = 0 \ \rightarrow \ \mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0$$

$$(1) \quad I = \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2} = \frac{6.0\text{ V} - 12\text{ V}}{8.0\ \Omega + 10\ \Omega} = \boxed{-0.33\text{ A}}$$

Inverting amplifier



Potential difference across R1 is

$Vin - Vx = I_1 \times R_1$

Potential difference across R2 is

$Vx - Vout = I_2 \times R_2$

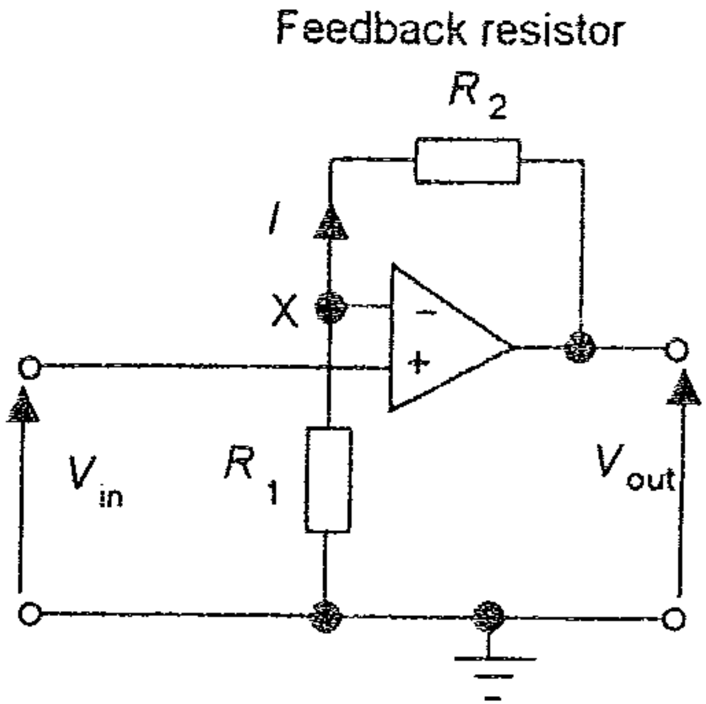
No current can flow through X into Op Amp (Refer our assumptions)

Means $I_1 = I_2$

Again $Vx = 0$ (based on virtual ground)

$$\text{Voltage gain of circuit} = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Non – Inverting amplifier



This is voltage divider circuit

R2 and R1 are in series with X in between.

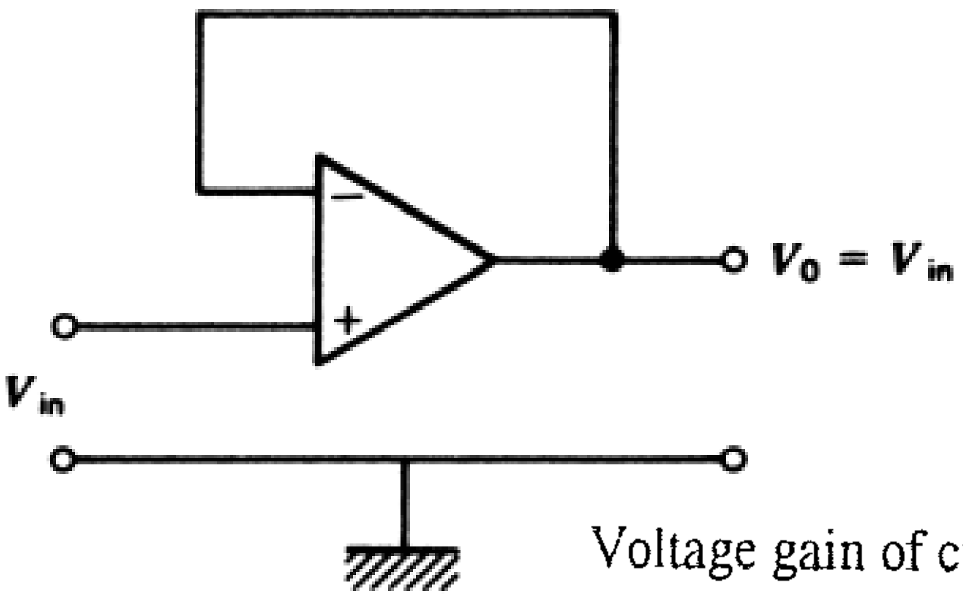
$$V_X = \frac{R_1}{R_1 + R_2} V_{out}$$

Again Vx = Vin (No current flows through Op Amp)

$$\text{Voltage gain of circuit} = \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

Voltage Follower

Non Inverting amplifier without resistors is a follower



a) Used in voltage divider circuit

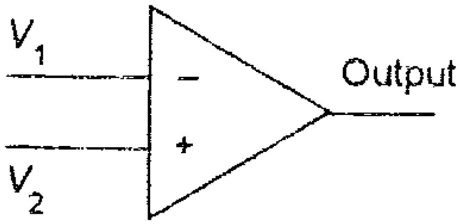
b) As isolators

c) R2 = 0

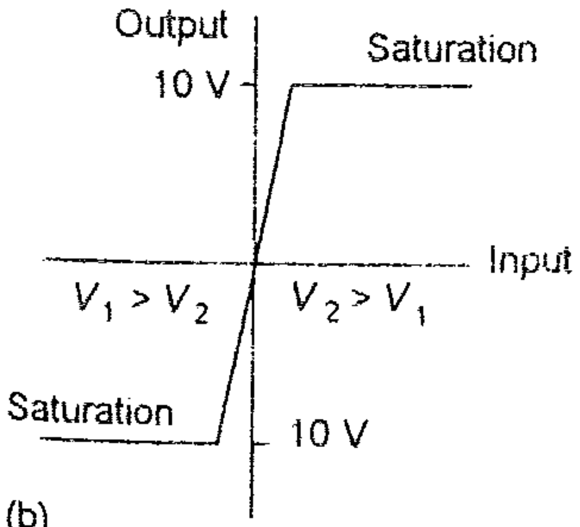
$$\text{Voltage gain of circuit} = \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

- **An op amp circuit with unity gain and very high input impedance.**
- **The unity gain voltage follower is essentially an impedance transformer in the sense of converting a voltage at high impedance to the same voltage at low impedance.**

Voltage Comparator

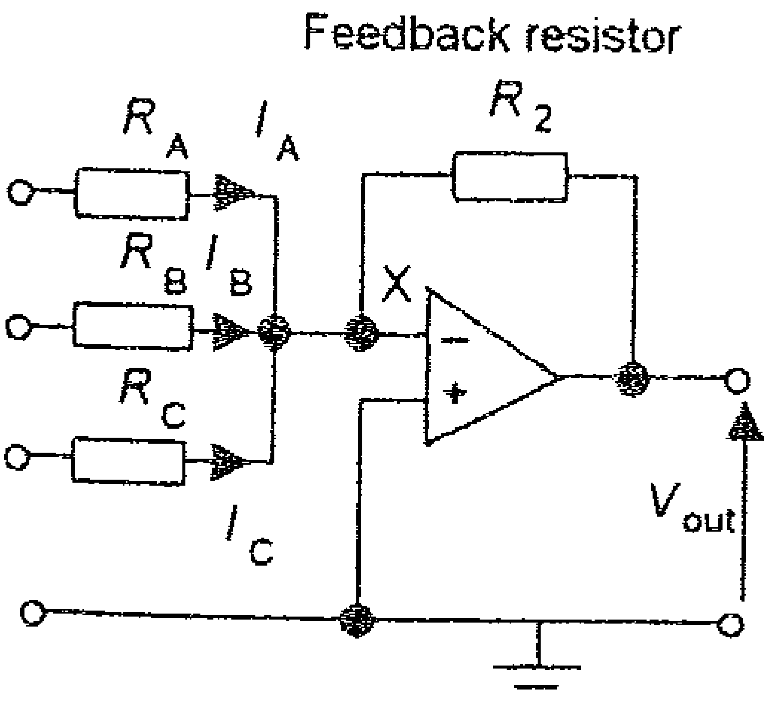


(a)



(b)

Summing Amplifier



$$I = I_A + I_B + I_C$$

$$-\frac{V_{out}}{R_2} = \frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_C}{R_C}$$

$$V_{out} = -\left(\frac{R_2}{R_A}V_A + \frac{R_2}{R_B}V_B + \frac{R_2}{R_C}V_C\right)$$

If $R_A = R_B = R_C = R_1$ then

$$V_{out} = -\frac{R_2}{R_1}(V_A + V_B + V_C)$$

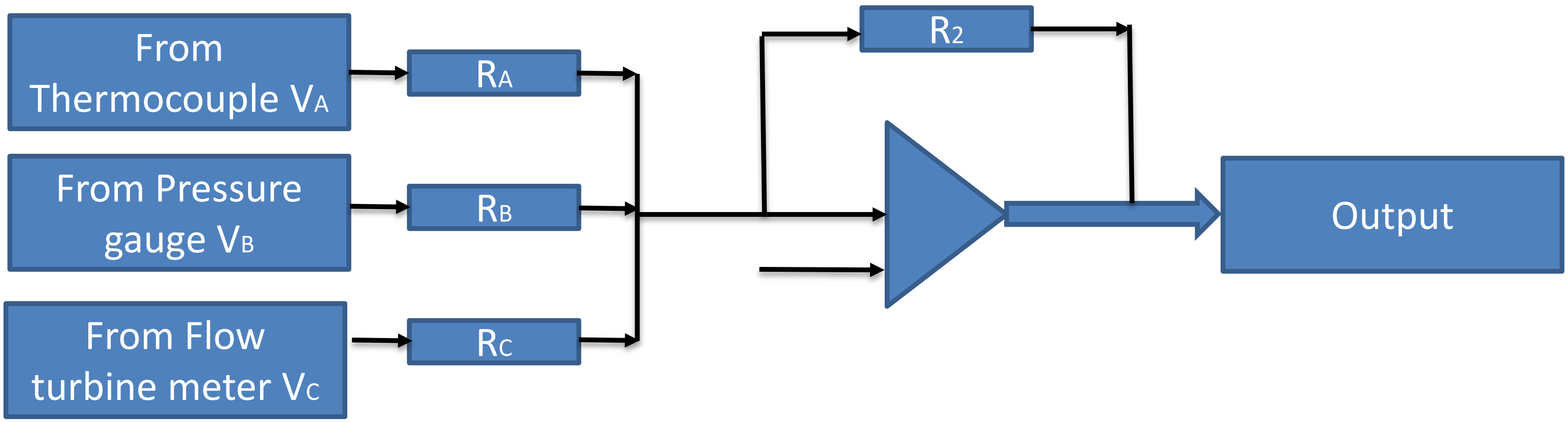
$$V_{\text{out}} = -\frac{R_2}{R_1}(V_{\text{A}} + V_{\text{B}} + V_{\text{C}})$$

Summing Amplifier

$$V_{\text{out}} = -\frac{R_1}{R_2}(V_A + V_B + V_C)$$

- To illustrate the above, consider the design of a circuit that can be used to produce an output voltage which is the average of the input voltages from three sensors.
- Each of the three inputs must be scaled to 1/3 to give an output of the average. Thus a voltage gain of the circuit of 1/3 or each of the input signals is required.
- Hence, if the feedback resistance is 4 ohm the resistors in each input arm will be 12 ohm.

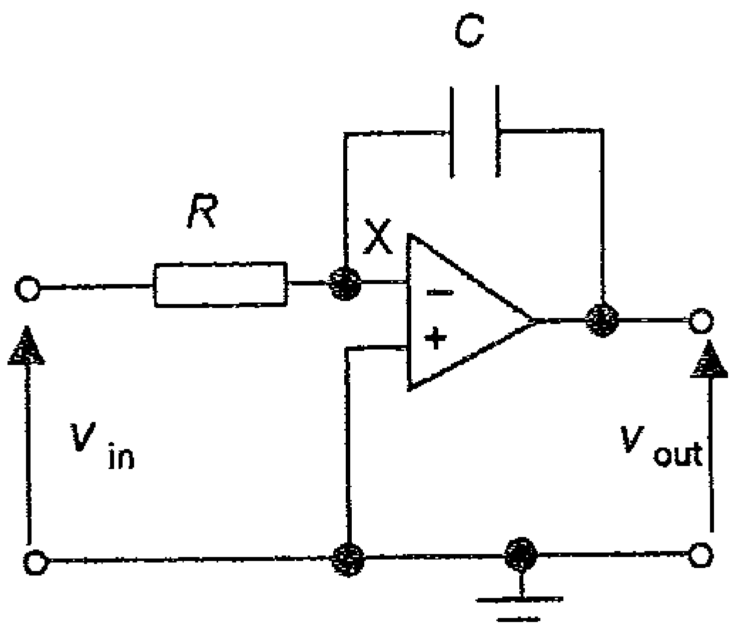
Summing Amplifier



$$V_{out} = -\frac{R_2}{R_1}(V_A + V_B + V_C)$$

Integrating Amplifier

Replace resistor R2 in inverting amplifier with a capacitor



Charge

$$q = Cv,$$

$$i = \mathrm{d}q/\mathrm{d}t = C\,\mathrm{d}v/\mathrm{d}t.$$

$$\frac{v_{in}}{R} = -C\frac{\mathrm{d}v_{out}}{\mathrm{d}t}$$

Rearranging this gives

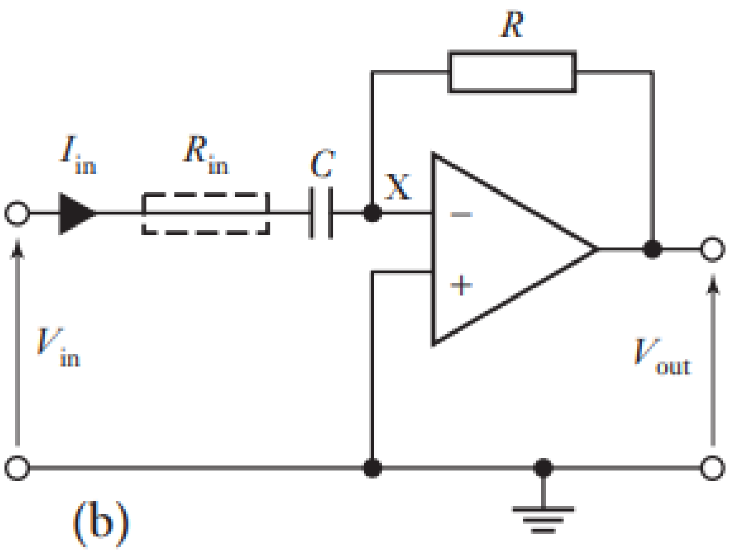
$$\mathrm{d}v_{out} = -\left(\frac{1}{RC}\right)v_{in}\,\mathrm{d}t$$

Integrating both sides gives

$$v_{out}(t_2) - v_{out}(t_1) = -\frac{1}{RC}\int_{t_1}^{t_2} v_{in}\,\mathrm{d}t$$

Interchange the capacitor and Resistor positions you get Differentiating Amplifier – Verify!!!!

Differentiating amplifiers



$$q = Cv,$$

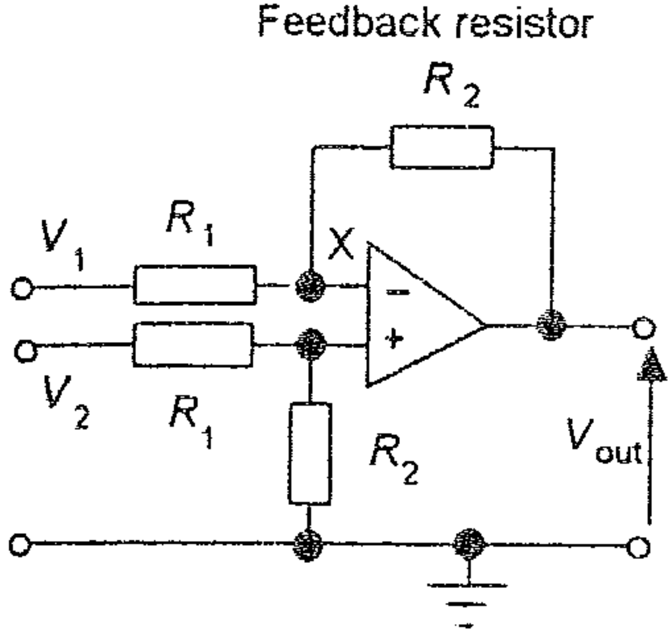
$$i = dq/dt = C\, dv/dt.$$

$$\frac{v_{out}}{R} = -C\frac{dv_{in}}{dt}$$

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

At high frequencies the differentiator circuit is susceptible to stability and noise problems. A solution is to add an input resistor Rin to limit the gain at high frequencies and so reduce the problem.

Differencing amplifier

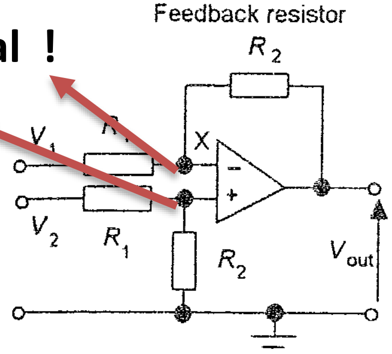


$$\frac{V_X}{V_2} = \frac{R_2}{R_1 + R_2}$$

$$\frac{V_1 - V_X}{R_1} = \frac{V_X - V_{out}}{R_2}$$

$$\frac{V_{out}}{R_2} = V_X\left(\frac{1}{R_2} + \frac{1}{R_1}\right) - \frac{V_1}{R_1}$$

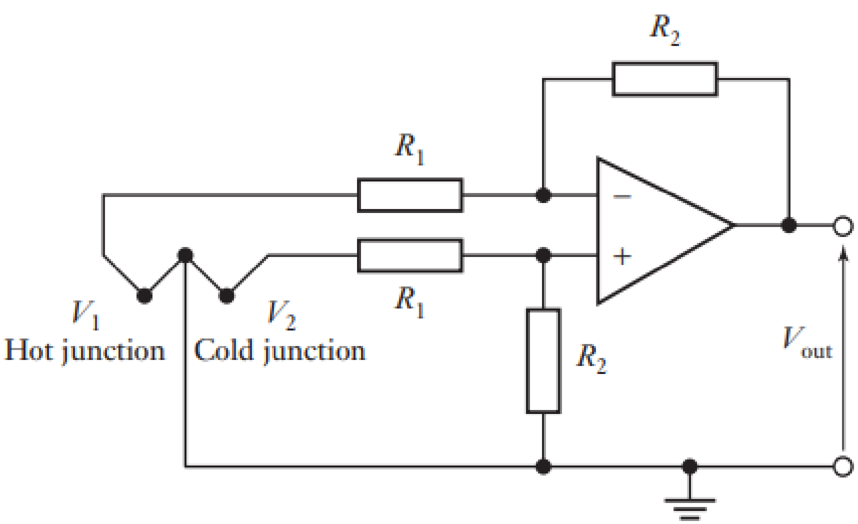
At same Potential !



Hence substituting for V_X using the earlier equation,

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

Eg. Difference amplifier with a thermocouple



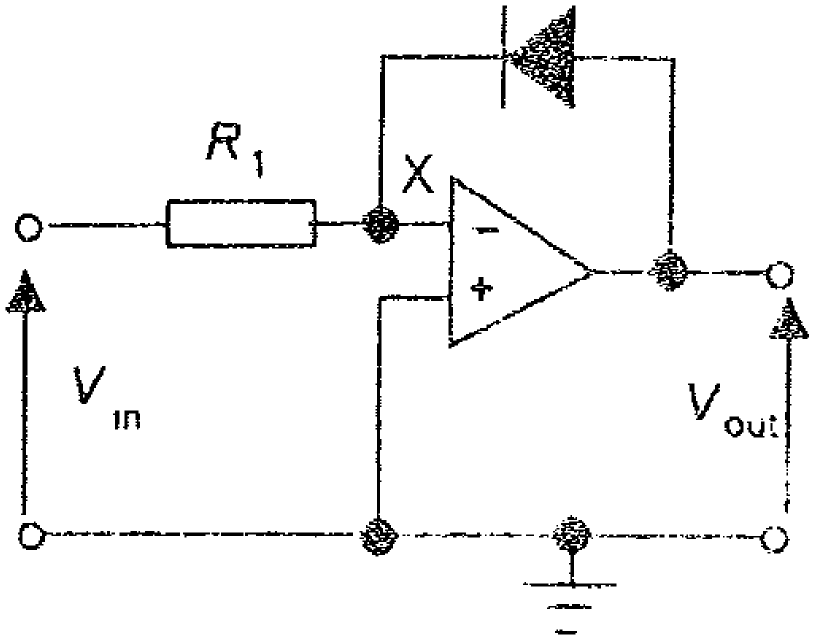
The difference in voltage between the e.m.f.s of the two junctions of the thermocouple is being amplified. The values of R1 and R2 can, for example, be chosen to give a circuit with an output of 10 mV for a temperature difference between the thermocouple junctions of 10°C if such a temperature difference produces an e.m.f. difference between the junctions of 530 μV.

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

$$10 \times 10^{-3} = \frac{R_2}{R_1} \times 530 \times 10^{-6}$$

Hence $R_2/R_1 = 18.9$. Thus if we take for R_1 a resistance of 10 kΩ then R_2 must be 189 kΩ.

Logarithmic amplifier



Feedback loop contains a diode
The diode has non linear characteristics represented by ---

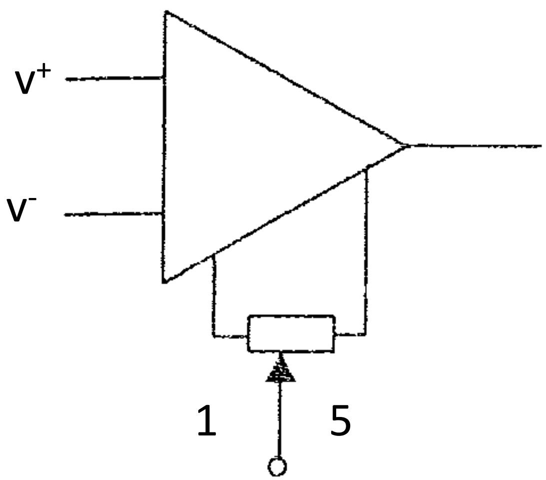
V = C ln (I)

Vout = -C ln (Vin / R)

Vout = -C/R ln (Vin)

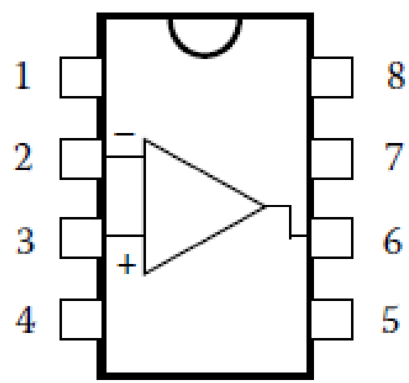
Vout = K ln (Vin)

Amplifier errors



Offset voltage: Presence of output even if v^+ and v^- are shorted

Sliding contact of the potentiometer to a negative supply, so that Vout is zero, when V+ and V- are equal

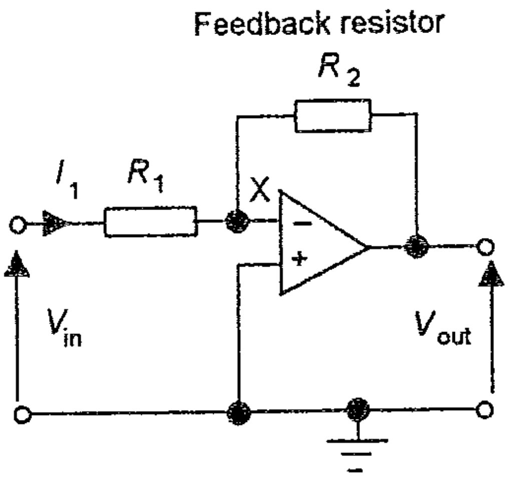


Pin designations:

1 Offset null
2 Inverting input
3 Noninverting input
4 Negative power supply v_{EE}
5 Offset null
6 Output
7 Positive power supply v_{CC}
8 NC (not connected)

Numerical

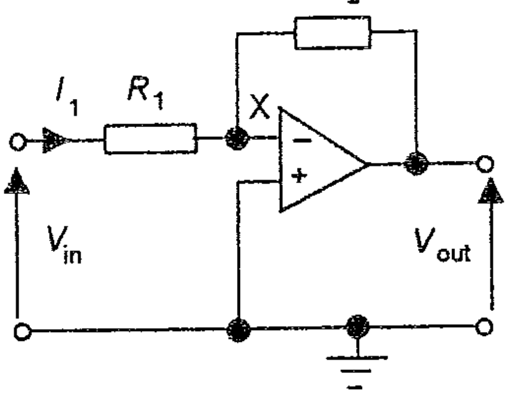
- Design an operational amplifier circuit that can be used to produce an output that ranges from 0 to -5 V when the input goes from 0 to 100 mV.



$$\text{Voltage gain of circuit} = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Numerical

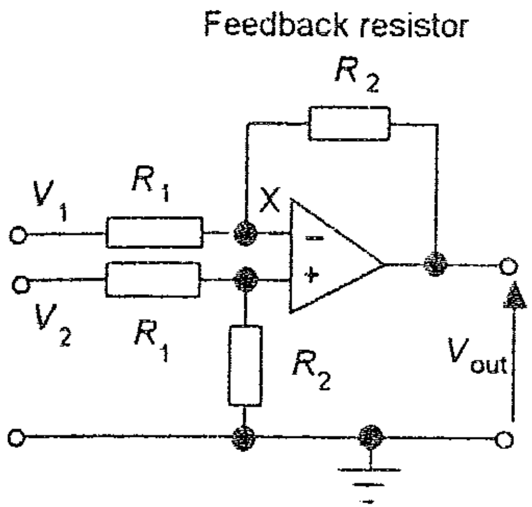
- An inverting amplifier has an input resistance of 2 kΩ. Determine the feedback resistance needed to give a voltage gain of 100.



$$\text{Voltage gain of circuit} = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Numerical

- A differencing amplifier is to have a voltage gain of 100. What will be the feedback resistance required if the input resistances are both 1 kΩ?



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

Thank you