Chapter3: Signal conditioning

Signal conditioning circuits are used to process the output signal from sensors of a measurement system to be suitable for the next stage of operation

The function of the signal conditioning circuits include the following items: Signal amplification (opamp), Filtering (opamp), Interfacing with μP (ADC), Protection (Zener & photo isolation), Linearization, Current – voltage change circuits, resistance change circuits (Wheatstone bridge), error compensation

Operational Amplifiers

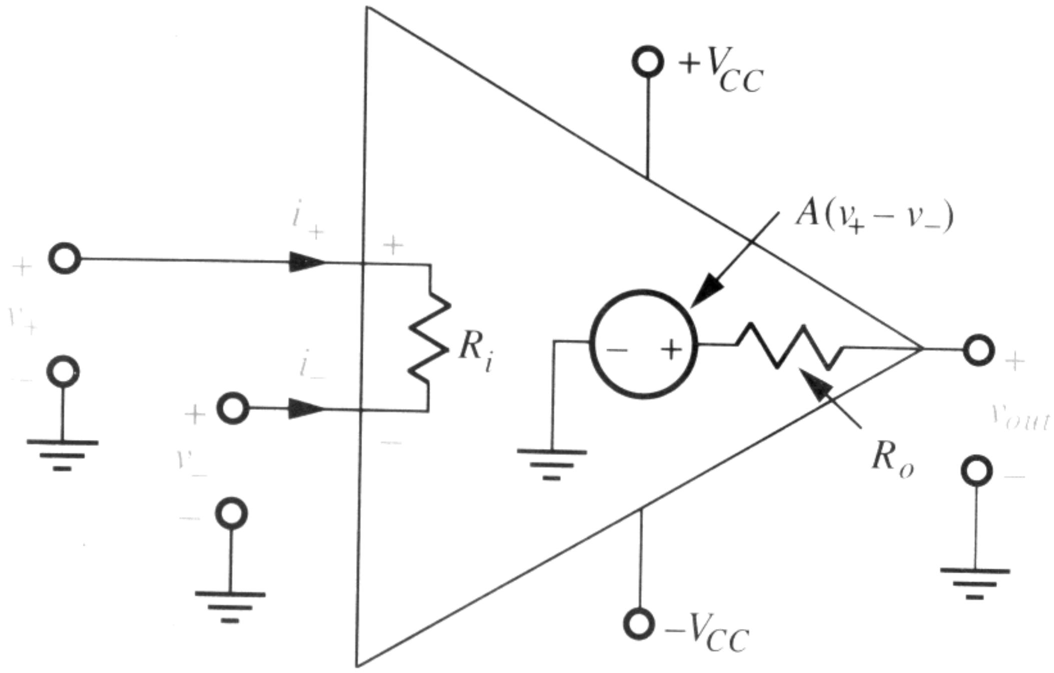
Operational amplifiers are the basic element of many signal conditioning modules

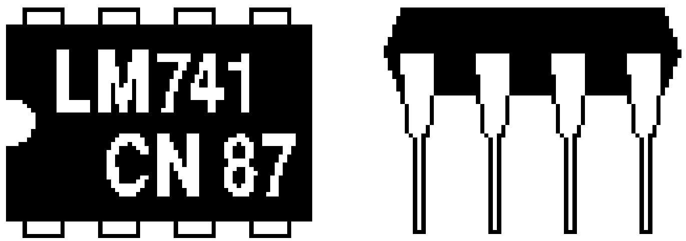
- **Generally the opamp has the following properties:**

  Gain: being of the order greater than 100000, ideally = infinite

  Input impedance: ideally infinite

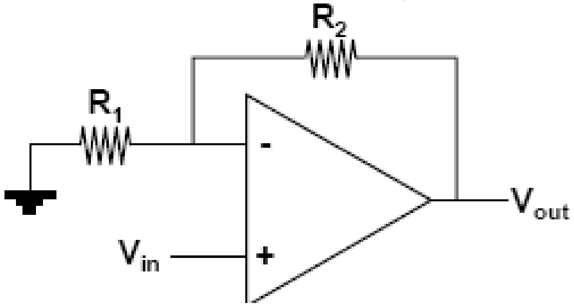
  output impedance: ideally zero; practical values 20-100Ω





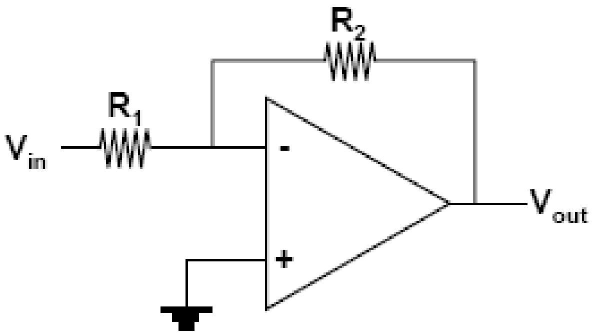
Opamp Circuit Configurations (1)

Non-Inverting Amp



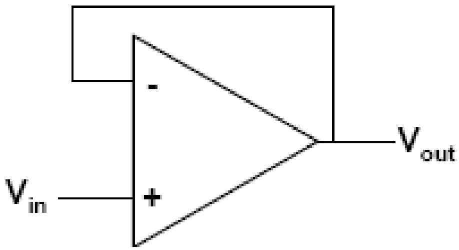
$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

Inverting Amp



$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

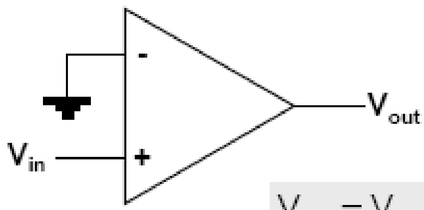
Voltage Follower



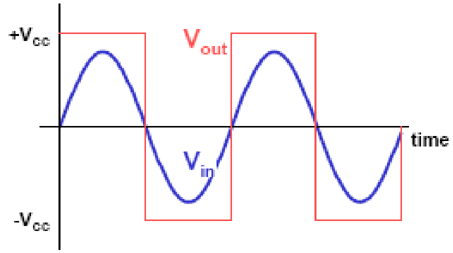
$$V_{out} = V_{in}$$

Voltage Comparator

– digitize input



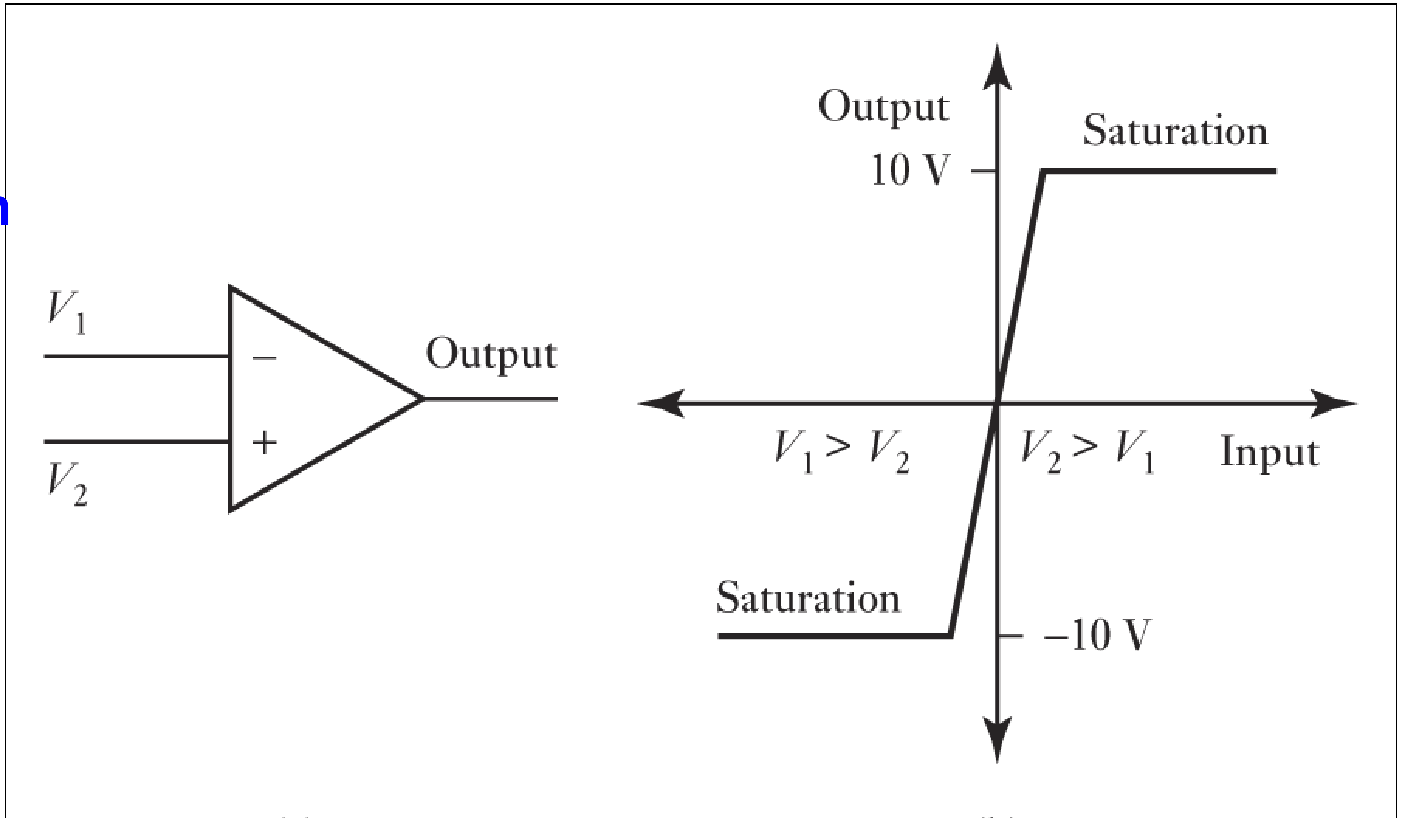
$$V_{out} = V_{CC}\,\mathrm{sign}(V_{in})$$



Opamp as comparator (1)

The output indicates which of the two voltages is high (V1 or V2). When used with no feedback connection

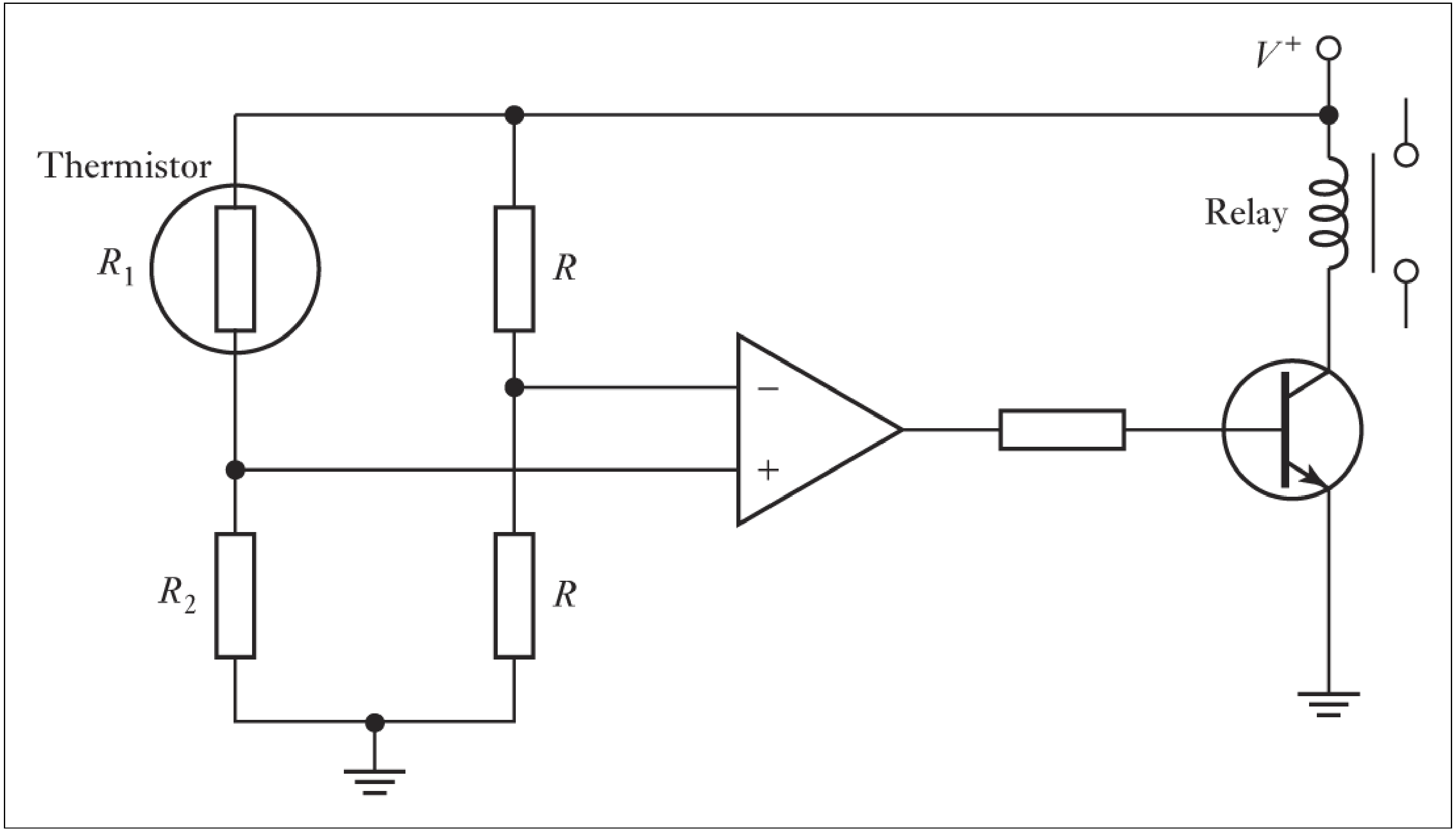
If the voltage applied to v1 is greater than V2 then the output is constant voltage equal to (-10V) if (V2>V1) then the output is constant voltage =(+10V). This can be used in the following example:



(a) (b)

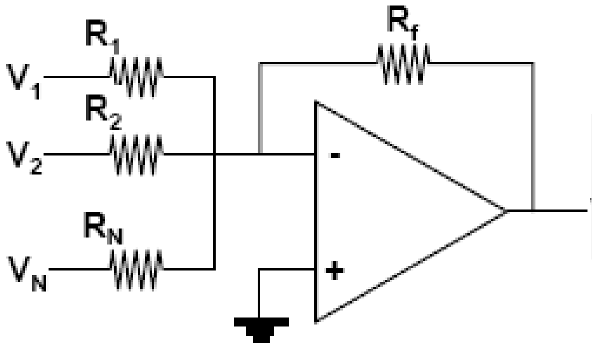
Opamp as comparator (2)

The circuit is designed to control temperature with a certain range. When the temp. is below certain value, the thermistor R1 is more than R2 and the bridge is out of balance, it gives an output at its lower saturation limit which keeps the transistor OFF. When temperature rises and R1 falls the opamp switch to +ive saturation value and switch the transistor ON



Opamp Circuit Configurations (2)

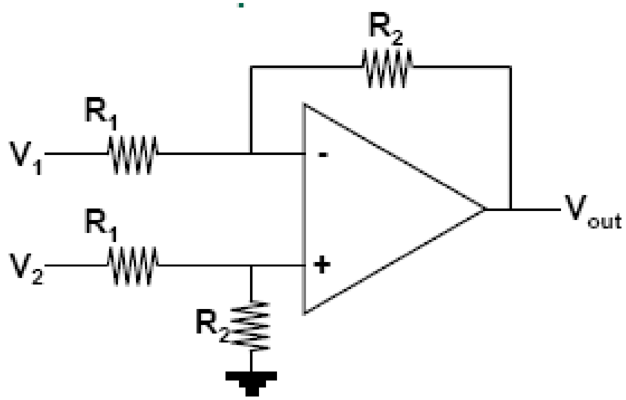
- **Summing Amp**



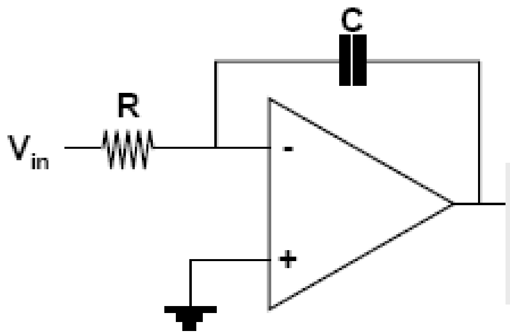
$$V_{out} = -\left(V_1 \frac{R_f}{R_1} + V_2 \frac{R_f}{R_2} + \cdots + V_N \frac{R_f}{R_N} \right)$$

- **Differential Amp**

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

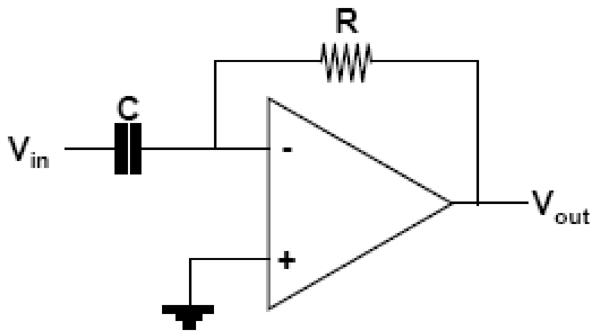


- **Integrating Amp**



$$V_{out} = -\frac{1}{j\omega CR} V_{in} = -\frac{1}{RC} \int V_{in} dt$$

- **Differentiating Amp**



$$V_{out} = -\frac{R}{\frac{1}{j\omega C}} V_{in} = -RC \frac{dV_{in}}{dt}$$

Differential Opamp Circuit Example (3)

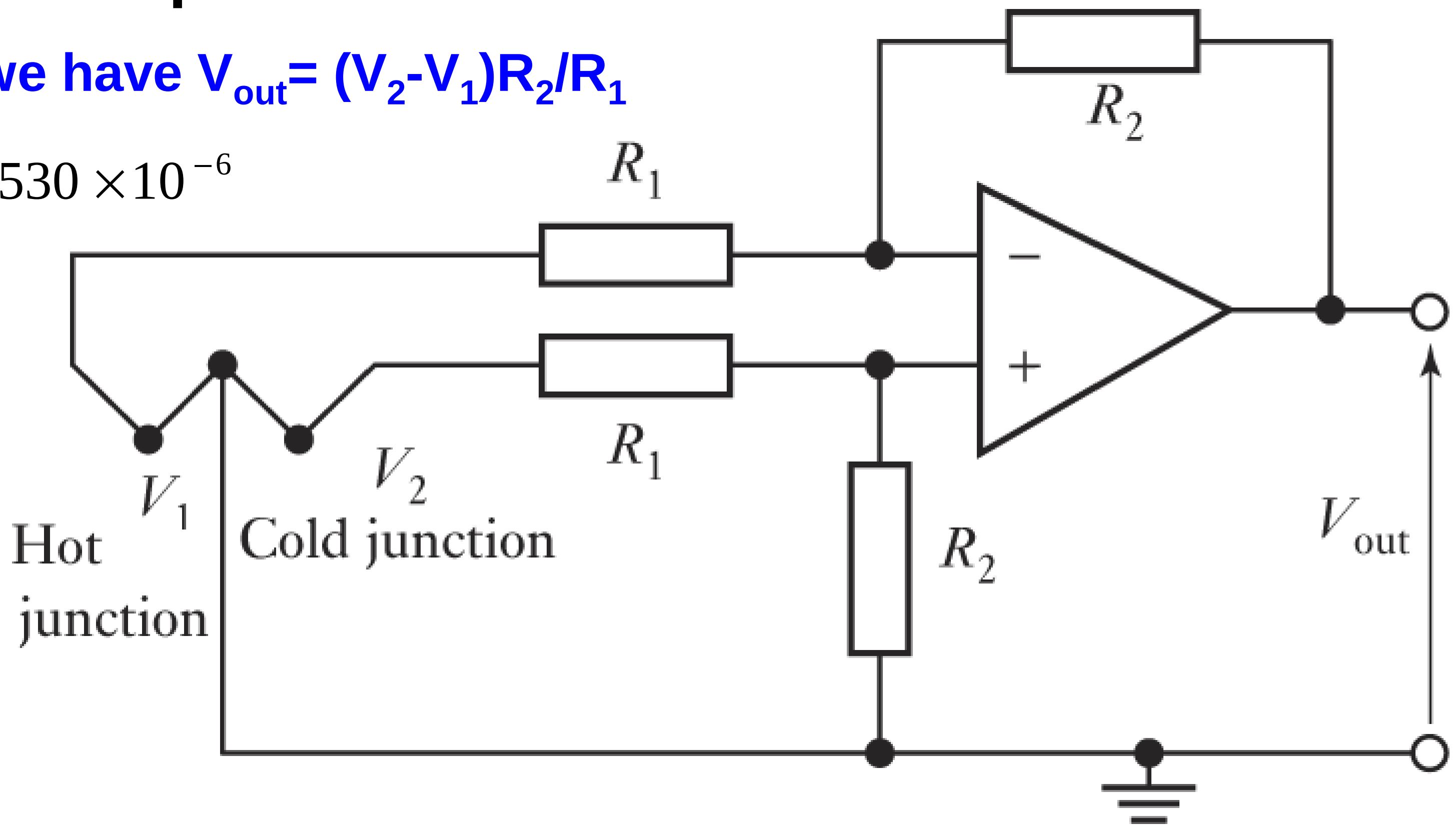
The difference in voltage between the emfs of the two junctions of the thermocouple is being amplified.

If a temperature difference between the thermocouple junctions of 10 ^{0}C produces an emf difference of 530 μV, then the values of R1 and R2 can be chosen to give a circuit with an output of 10mV.

For the circuit we have $V_{out} = (V_2 - V_1) R_2/R_1$

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

$$\frac{R_2}{R_1} = 18.9$$

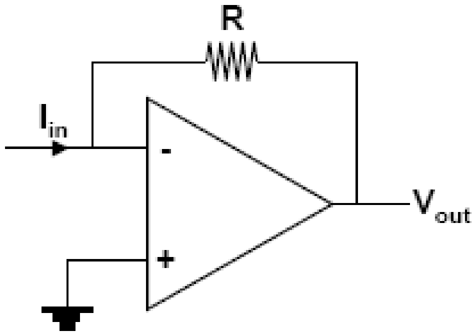


So if we select R1 as 10 k Ohm then

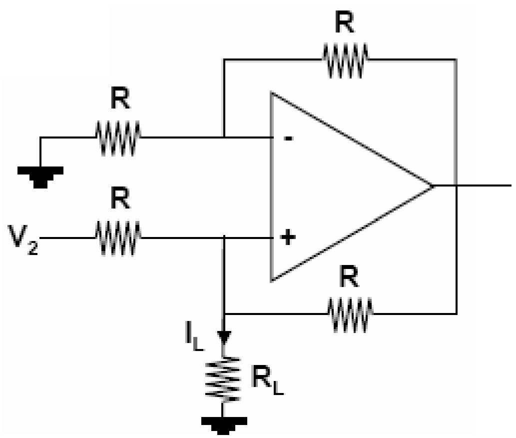
R2=189 k Ohm

Opamp Circuit Configurations (4)

Current-to-Voltage

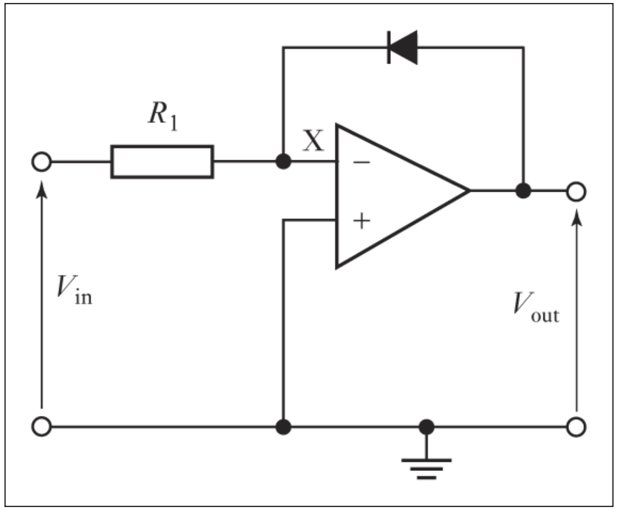


$$V_{out} = -I_{in}R$$



$$I_L = \frac{V_{in}}{R}$$

Voltage-to-Current



Logarithmic amplifier

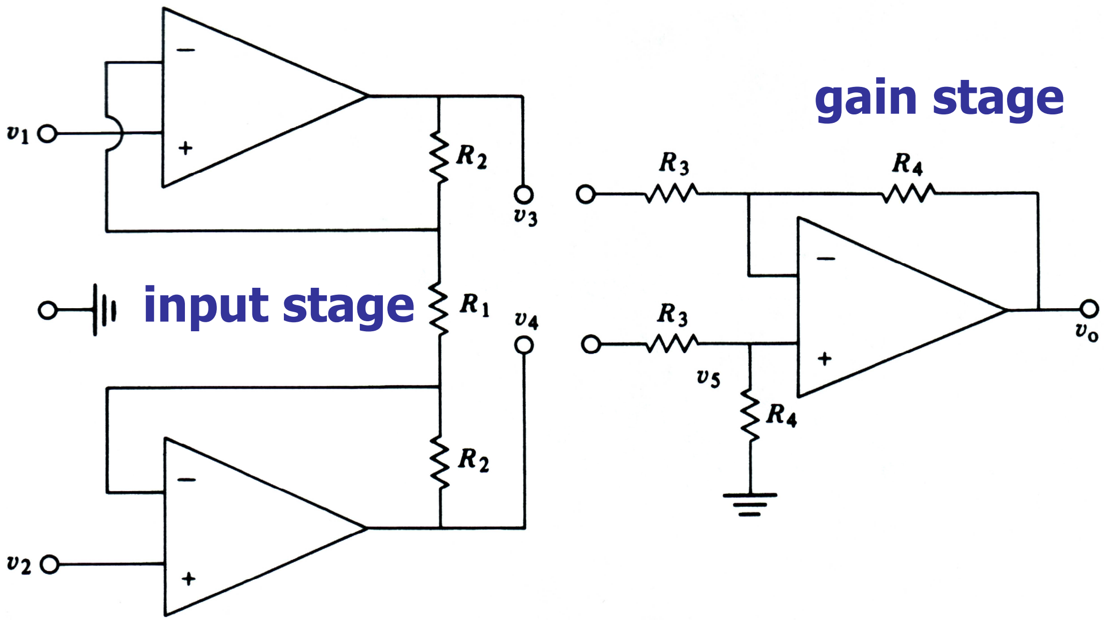
$V_{out} = k \ln (V_{in})$

The voltage- current relationship can be approximated by:

$V=C\ln(I) = C\ln(V_{in}/R) = k\ln(V_{in})$; so if $V_{in}=A\exp(at)$ then

$V_{out} = K \ln(A\exp(at)) = k\ln A + at$ which is linear relationship

Instrumentation Amplifier



- It is available as single IC is designed to have:

  -**high input impedance (300M ohm)**

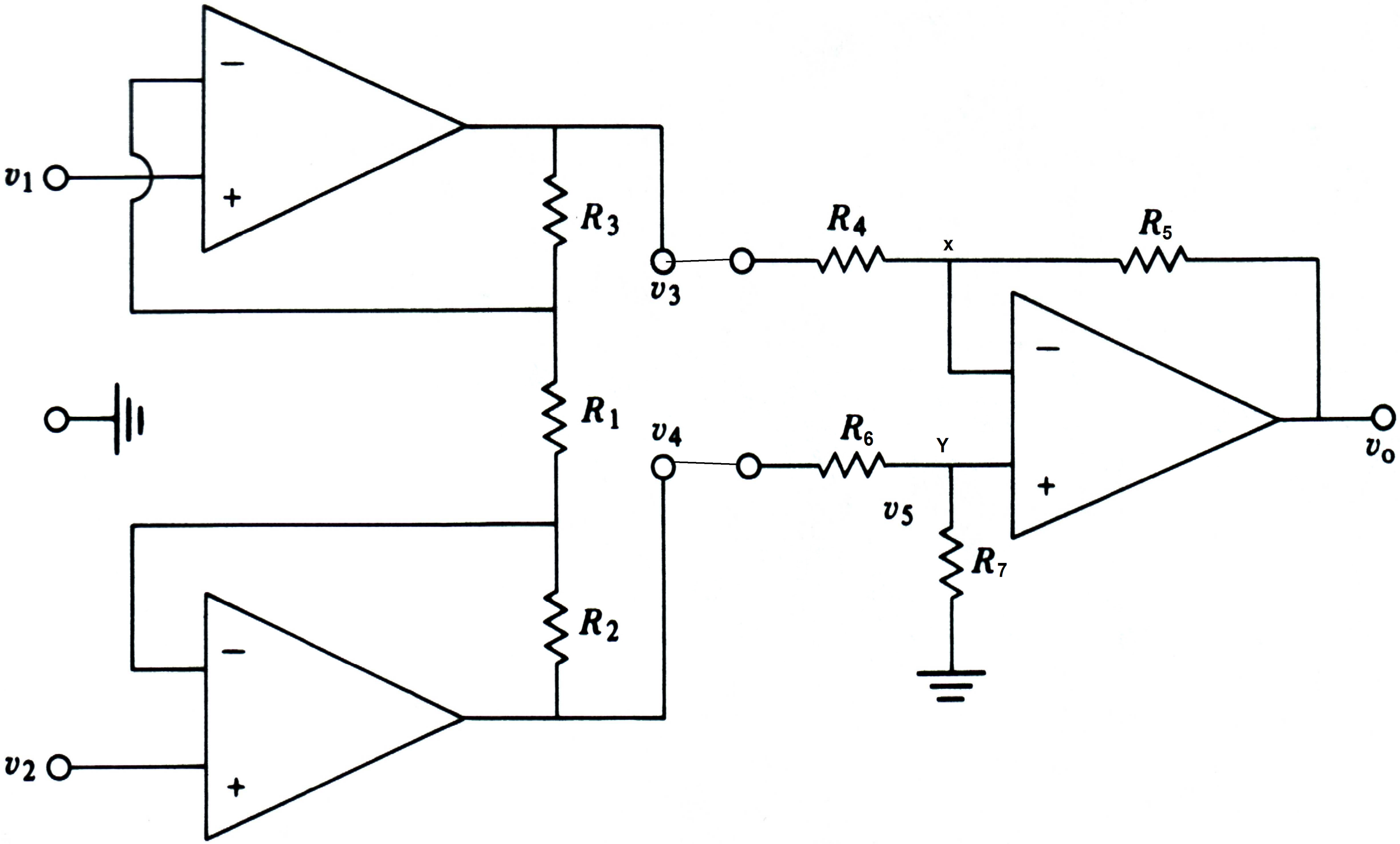
  – **High common mode rejection gain (more than 100 dB)**

  – **High voltage gain**

total differential gain

$$G_d = \frac{2R_2 + R_1}{R_1}\left(\frac{R_4}{R_3}\right)$$

Instrumentation Amplifier



By selection suitable resistance ratios show that this circuit is capable of rejecting common mode noise.???

See Mechatronics, Bolton

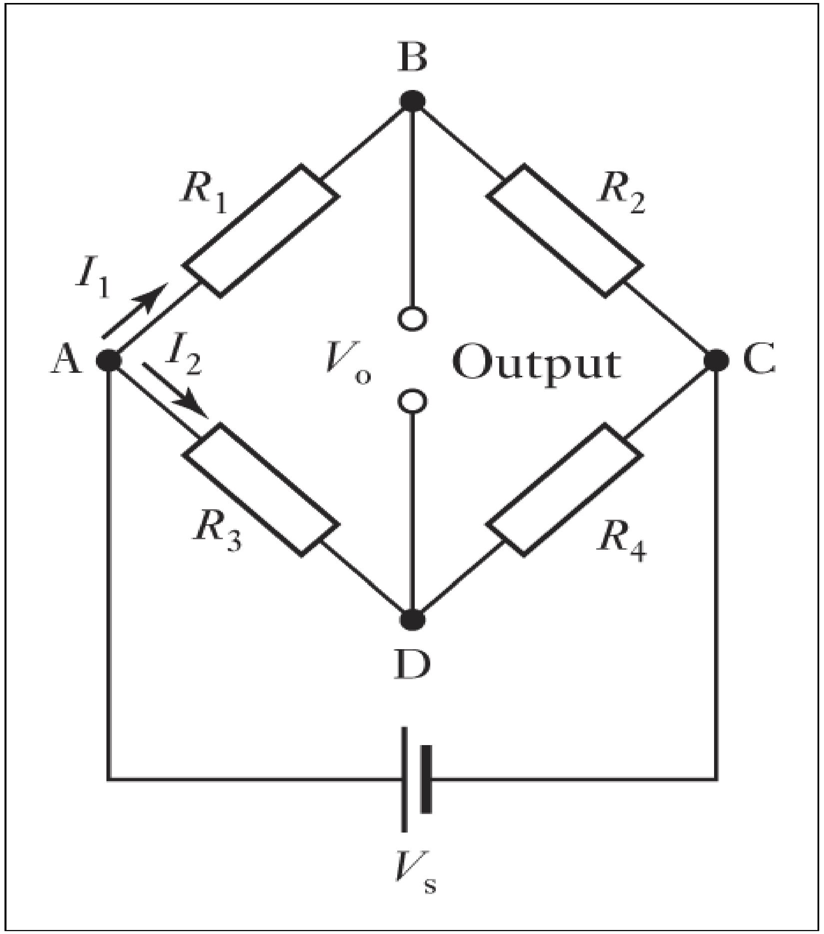
Signal conditioning: Wheatstone Bridge

- **One of the most used signal conditioning circuit. It can be used to convert a resistance change to a voltage change as in the following example:**

At balanced condition V_0 =0 and in result $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

When not balanced V_{BD} =

$$V_{BD} = V_0 = V_s\left(\frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right)$$



$$V_0 + \delta V_0 = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right)$$

$$\delta V_0 = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_1}{R_1 + R_2}\right)$$

if δR_1 *is much smaller than* R_1

then we can write $\delta V_0 = \frac{\delta R_1}{R_1 + R_2} V_s$

Signal conditioning: Wheatstone Bridge

Eg. A platinum resistance temperature sensor has a resistance of 100 ohm at 0 ^{0}C is placed in one arm of a Wheatstone bridge with each of the other arms also being 100 ohm. If the resistance temperature coefficient of the platinum is 0.0039/K, find the output voltage from the bridge per degree change in temp. if the load across the output can be assumed to be infinite. V_s=6.0 volt.

The variation of the resistance of the platinum with temperature can be represented as $R_t = R_0 (1+\alpha T)$

Sol.

Change in resistance= $R_t - R_0 = R_0 \alpha T$

=100x0.0039x1=0.39 ohm/k

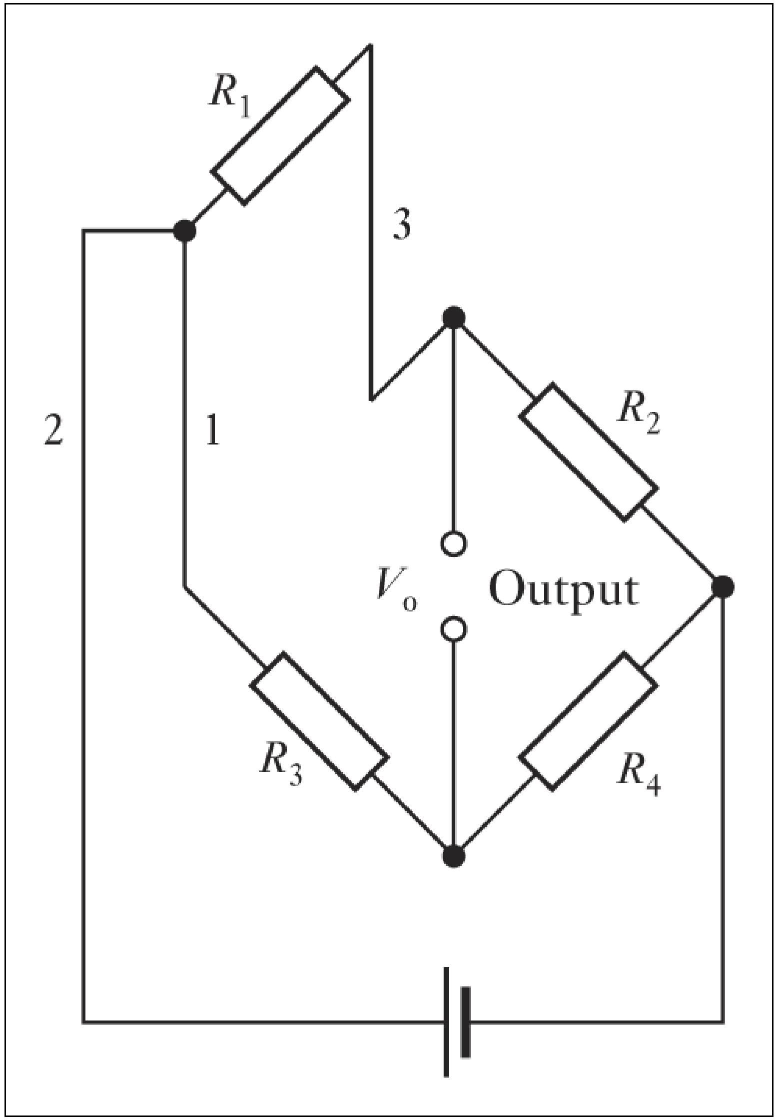
Since the resistance change is small compared to the 100 ohm, the approximate equation can be used. Hence:

$$\delta V_0 = \frac{\delta R_1}{R_1 + R_2} V_s = \frac{0.39 \times 6.0}{100 + 100} = 0.012 V / \deg ree\ K$$

Signal conditioning: Wheatstone Bridge

Compensation for leads

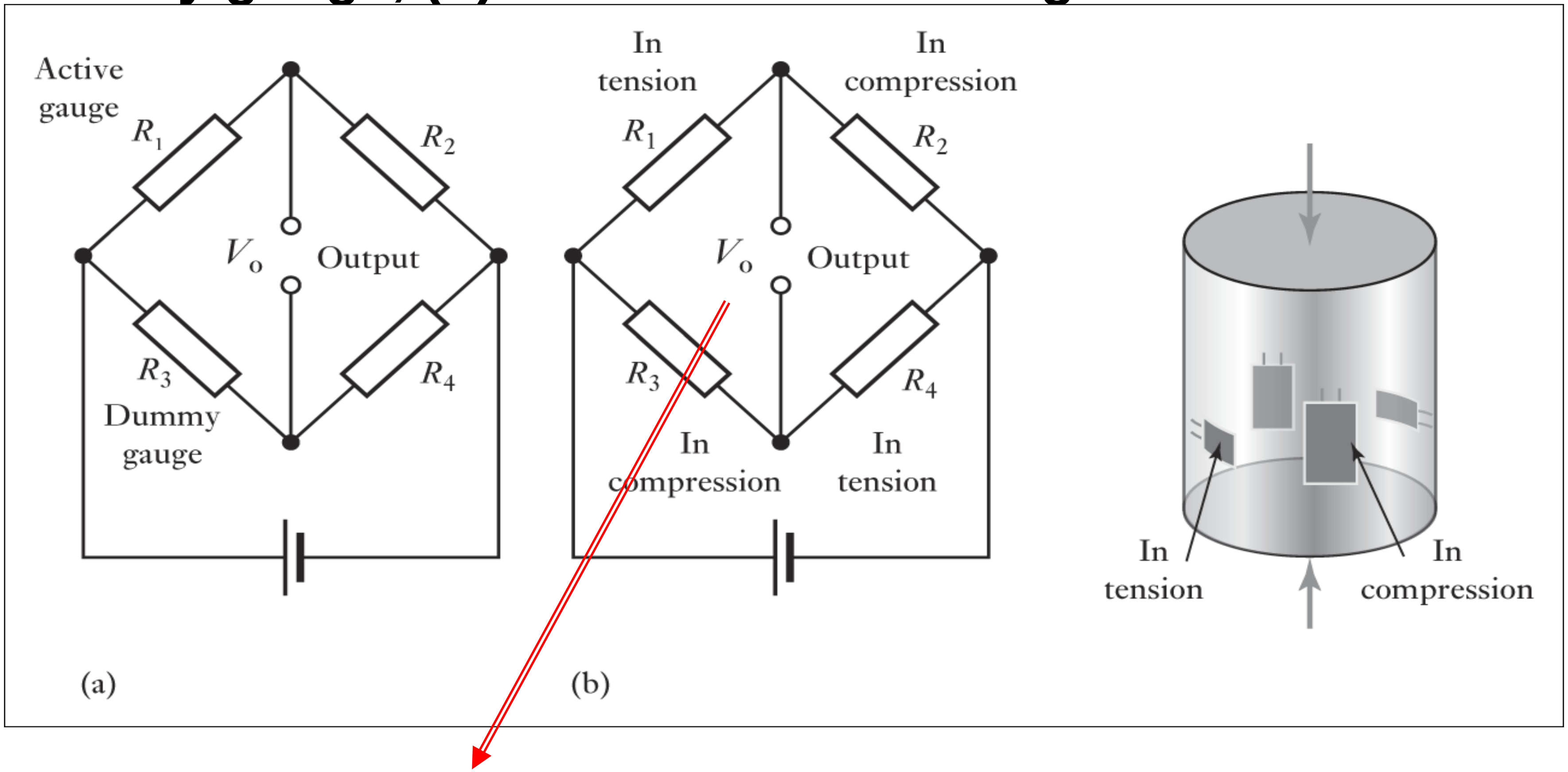
In many measurement system involving a resistive sensor, the actual sensing element may be affected by the connecting leads. so to compensate for such effects Wheatstone bridge may be used as arranged in the figure



Connecting Lead 1 to R3 and Lead 3 to R1 (the sensor) and so if R1 is equal to R3 and of the same size and type then the leads effect can be canceled out.

Signal conditioning: Wheatstone Bridge

Temperature compensation with strain gauges: (a) use of dummy gauge, (b) four active arm bridge



$$V_0 = \frac{V_s R_1 R_4}{(R_1 + R_2)(R_3 + R_4)} = \left(\frac{\delta R_1}{R_1} - \frac{\delta R_2}{R_2} - \frac{\delta R_3}{R_3} + \frac{\delta R_4}{R_4}\right) V_s$$

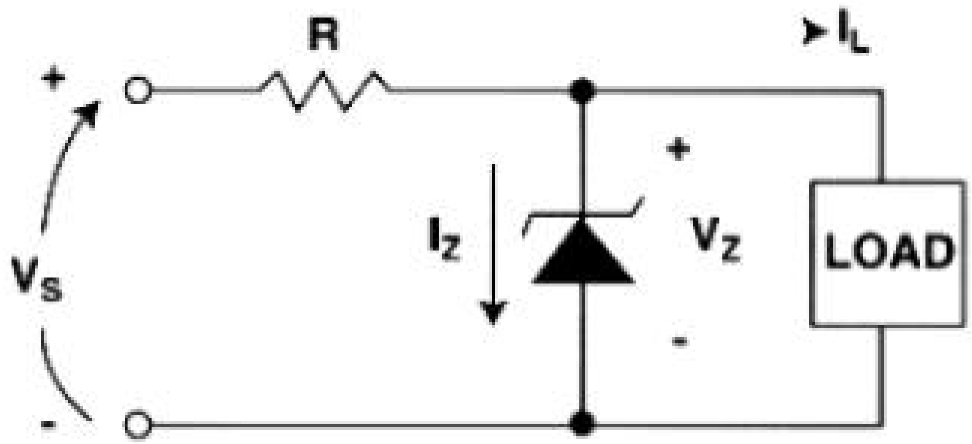
Strain gauge in tension increase resistance , in compression decrease resistance which increase the output voltage

Signal conditioning: PROTECTION

- Normally protection is provided against high current and high voltage which may damage the important components.
- **Examples of protection in mechatronics:**
- Series resistor to limit line current
- Fuse to break if the current does exceed a safe level
- Zener diode circuit to protect against high voltage and wrong polarity.
- Optoisolator to isolate circuits completely

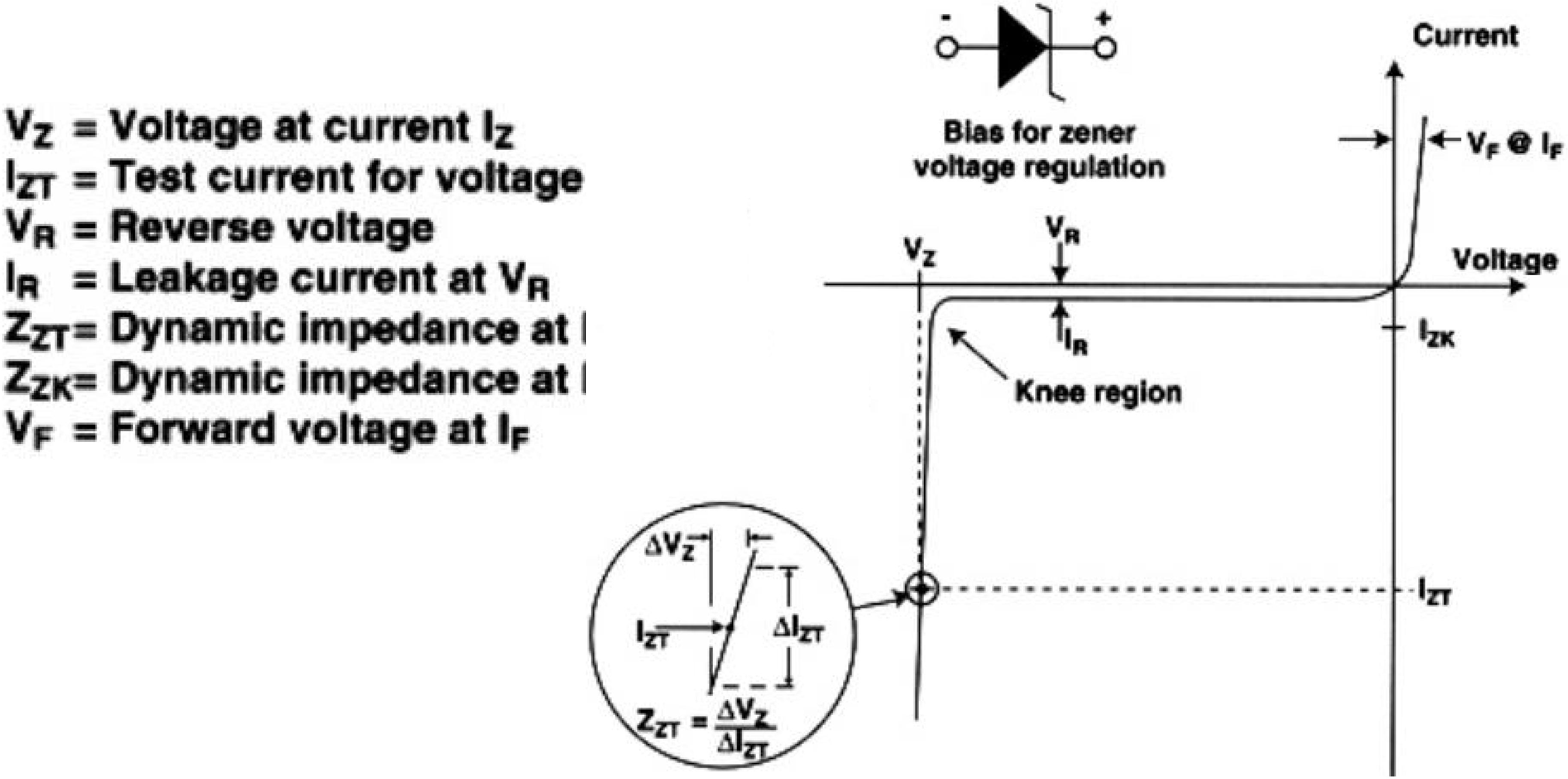
Protection: Zener Diode

- Zener diodes operate in the breakdown region.
- Zener diodes have a specified voltage drop when they are used in reverse bias. So normally used for voltage regulation in reverse bias
- Zener has the ability to maintain a nearly constant voltage under conditions of widely varying current.



$V_S > V_Z$ to permit zener regulation

Zener Diode characteristics



When **the reverse voltage V_R is increased, the leakage current remains essentially constant until the breakdown voltage V_Z (Zener voltage) is reached.**

Optoisolator Background

- Operation similar to relays
- Used to control high voltage devices
- Excellent noise isolation because switching circuits are electrically isolated
- Coupling of two systems with transmission of photons eliminates the need for a common ground

Ideal for applications requiring High isolation surge voltage

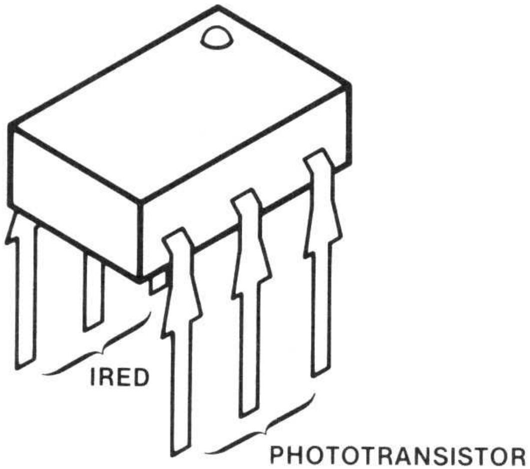
Noise isolation

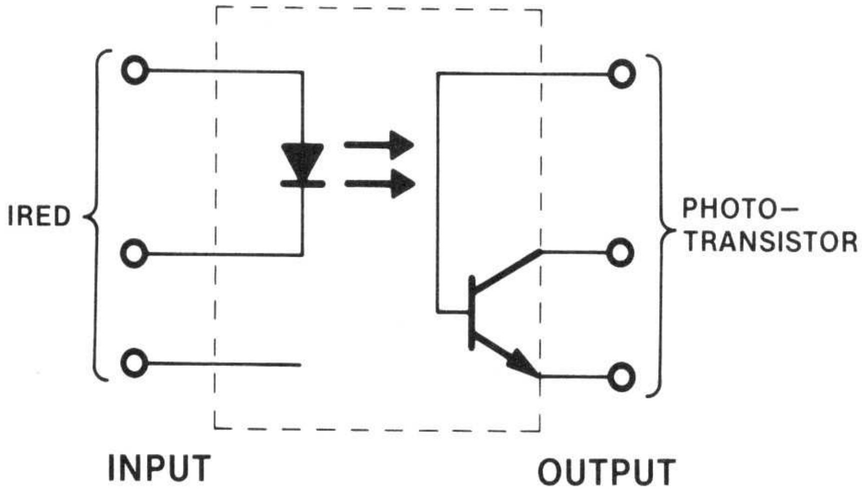
Small size

Signal cannot travel in opposite direction

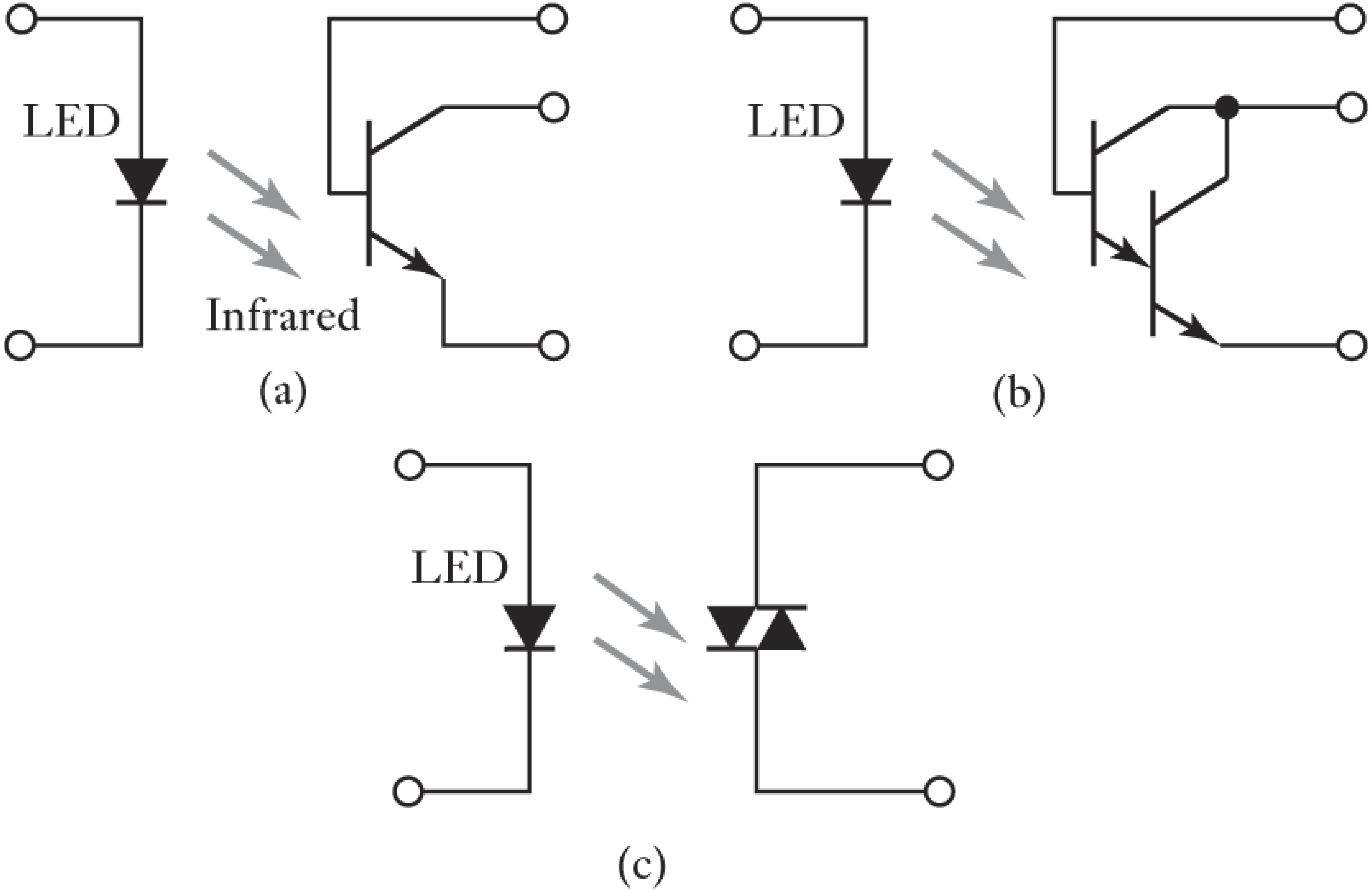
Used to control motors, solenoids, etc.

Optoisolator Schematic



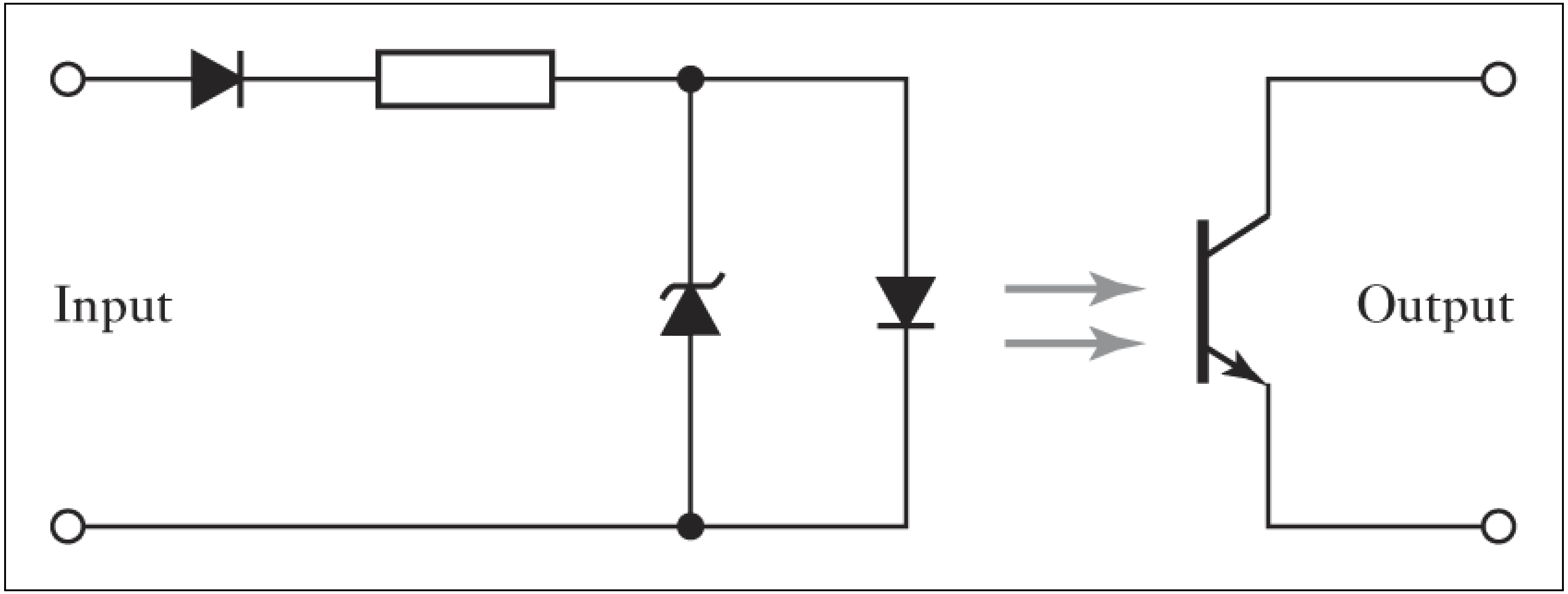


- Input Stage = infrared emitting diode (IRED)
- Output Stage = silicon NPN phototransistor



Optoisolators: (a) transistor, (b) Darlington, (c) triac

(see Bolton Mechatronics)



Protection circuit

Signal conditioning: Filtering (1)

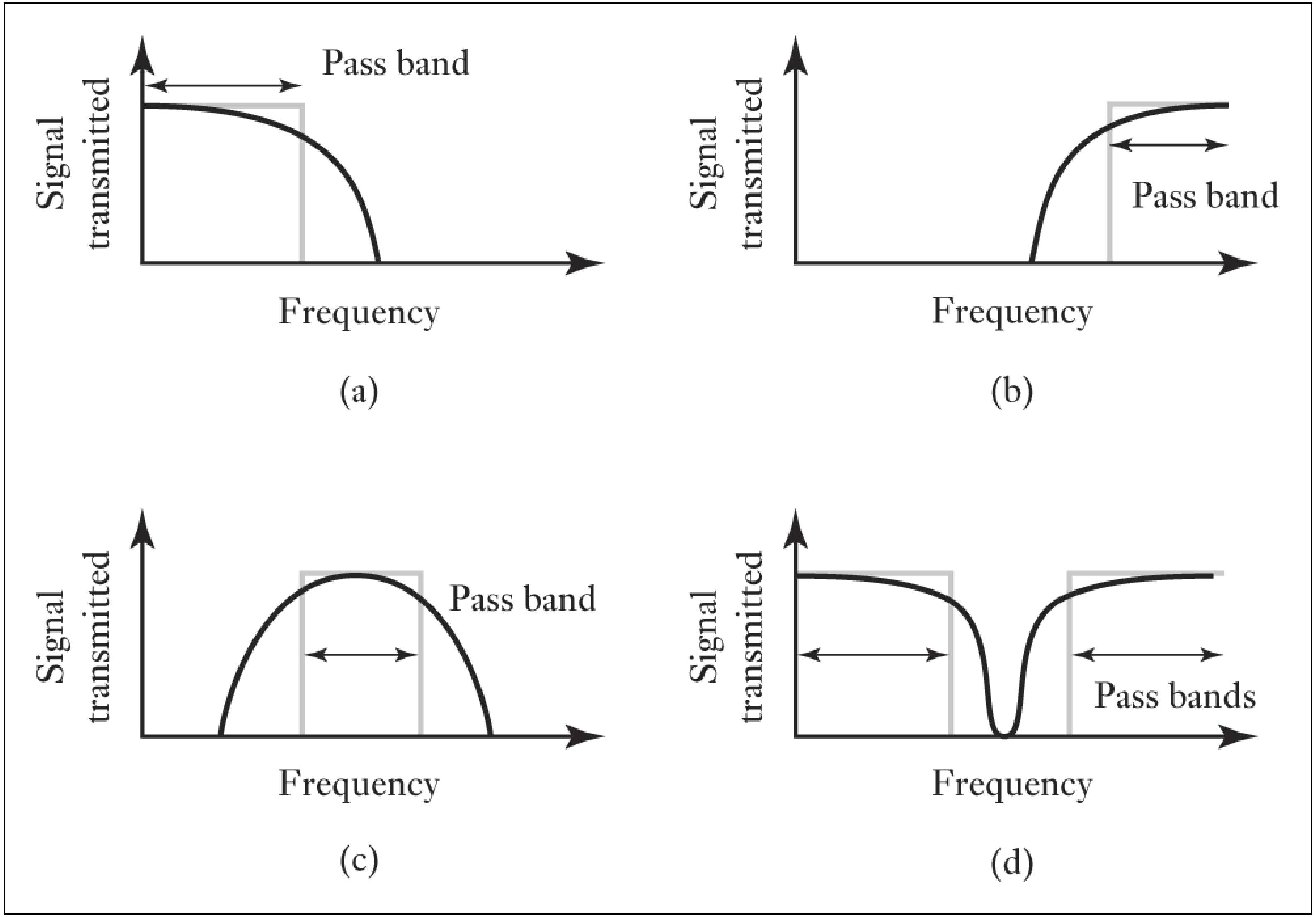
- **Filtering is the process of removing a certain band of frequencies from a signal and permitting others to be transmitted.**
- **The Pass Band: the range of frequencies passed by the filter**
- **The Stop Band: the range not passed by the filter.**
- **CUT OFF frequency: the boundary between stopping and passing**

Technically CUTOFF frequency is defined as the frequency at which the output voltage is 70.7% of that in the pass band.

Attenuation dB (decibels)= $10\log\frac{P_{out}}{P_{in}} = 20\log\frac{V_{out}}{V_{in}}$

The output voltage of 70.7% of that in the pass band is thus an attenuation of 3dB=20 log (0.707)

Signal conditioning: Filtering (2)

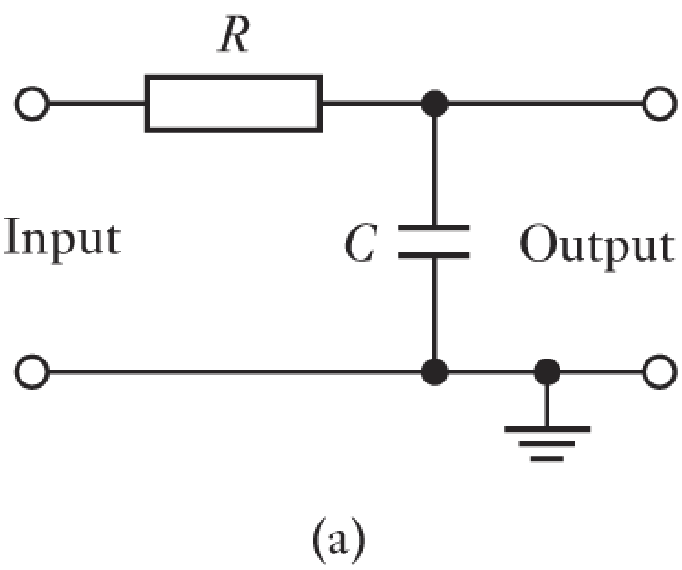


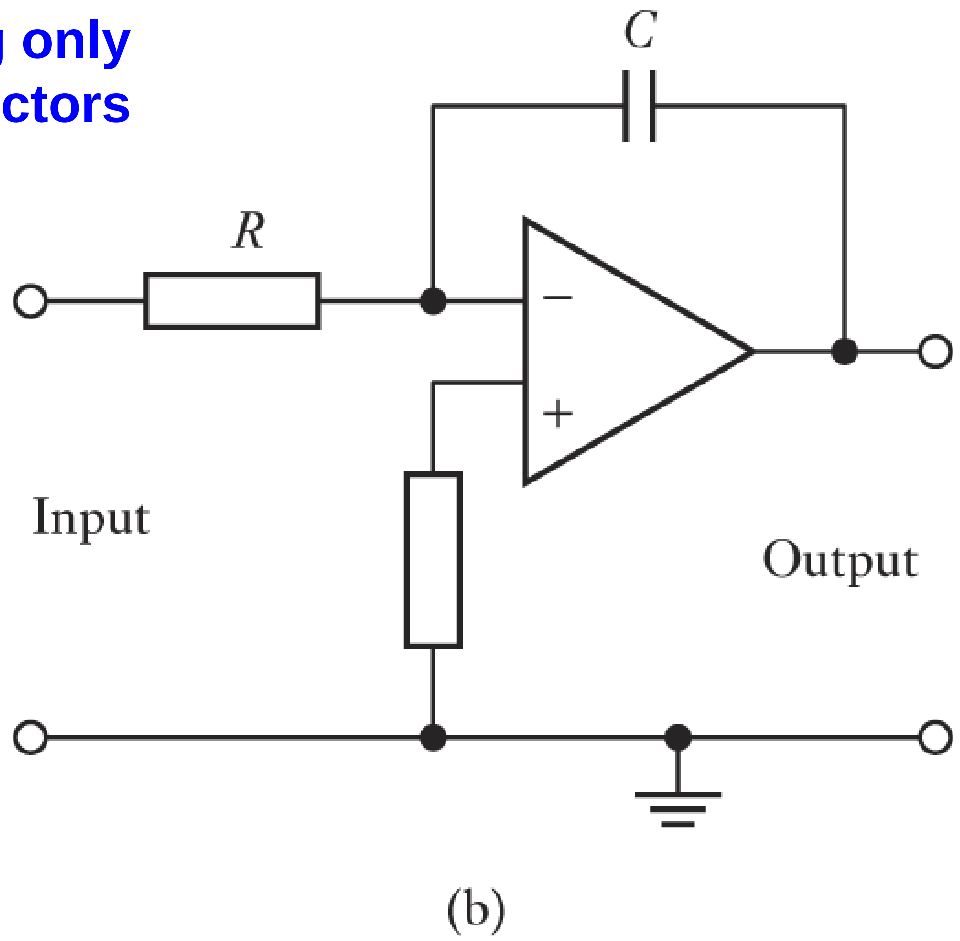
Characteristics of ideal filters: (a) low-pass filter, (b) high-pass filter, (c) band-pass filter, (d) band-stop filter

Signal conditioning: Filtering (3)

Passive Filters made up using only resistors, capacitors and inductors

Active filters involve an operational amplifier





Low-pass filter: (a) passive, (b) active using an operational amplifier