BITS Pilani
Pilani Campus

Mechatronics
(Merged - DEZG516/DMZG511/ESZG511)

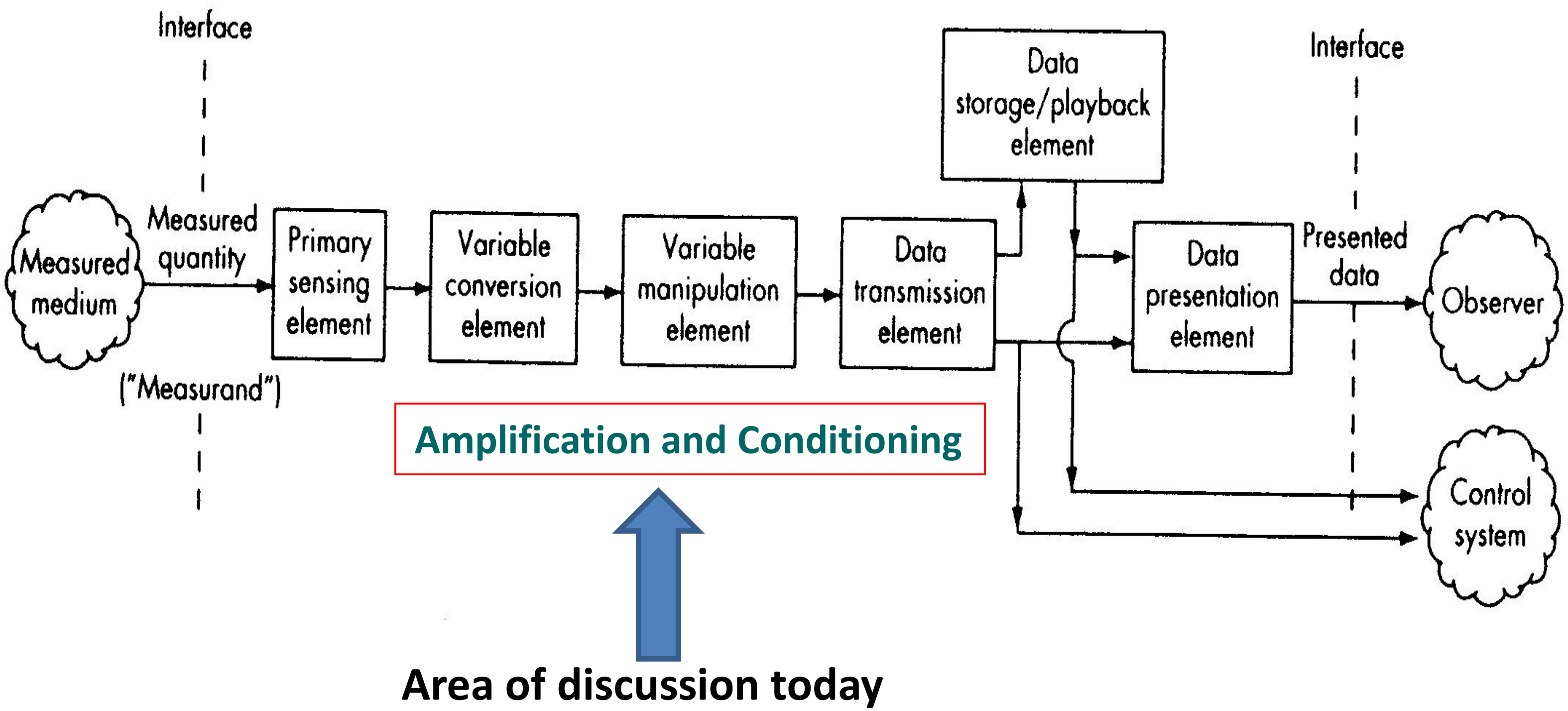
Lecture 4

Session 4

Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Signal conditioning: Need for conditioning, protection, noise elimination Signal conditioning with operational amplifiers: Inverting, non-inverting amplifiers	T1: Chapter 3, T2: Chapter 5
Post CH			Chapter end problems

Basic components in a measurement system

Basic components in a measurement system are shown below:



Output of sensors can be processed as ..

- Input to control system
- Data storage input – digital form
- Data Presentation element
  - Analogue or
  - Digital

The signal may be,

- Too small and have to be amplified.
- Contain interference which has to be removed, be non-linear and require linearization.
- Be analogue and have to be made digital, be digital and have to be made analogue.
- Be a resistance change and have to be made into a current change.
- Be a voltage change and have to be made into a suitable size current change, etc.
- For example, the output from a thermocouple is a small voltage, a few millivolts. A signal conditioning module might then be used to convert this into a suitable size current signal, provide noise rejection, linearization and cold junction compensation (i.e. compensating for the cold junction not being at 0°C).

Signal conditioning

Signal conditioning

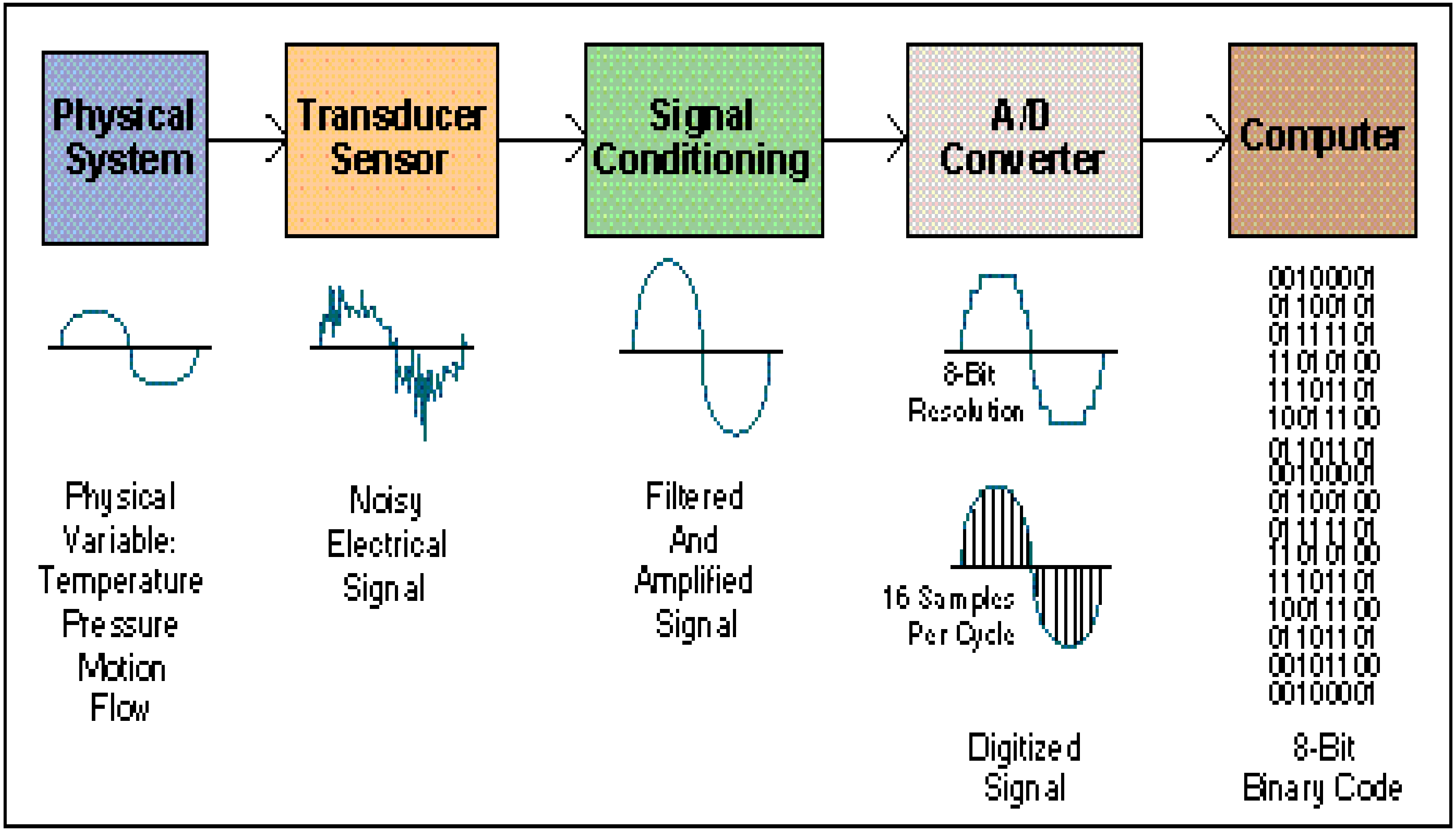
Signal conditioning circuits are used to process the output signal from sensors of a measurement system to be suitable for the next stage of operation

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

Signal Conditioning

- Signal conditioning circuits improve the quality of signals generated by transducers before they are converted into digital signals by the PC's data-acquisition hardware.
- Examples of signal conditioning are
  - signal scaling,
  - amplification,
  - linearization,
  - filtering,
  - excitation, common-mode rejection, and so on.

Data Acquisition System Block Diagram

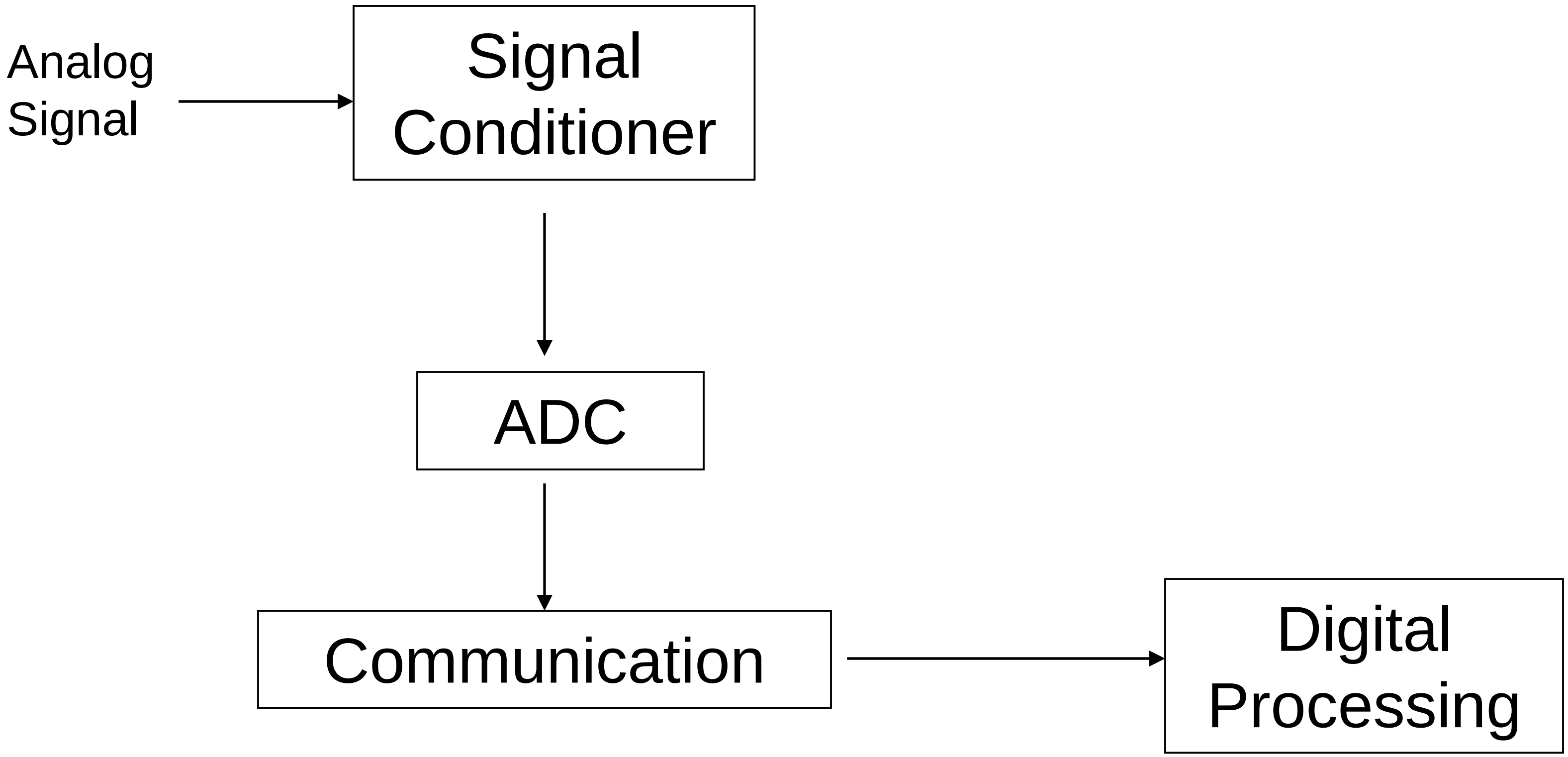


Signal Conditioning

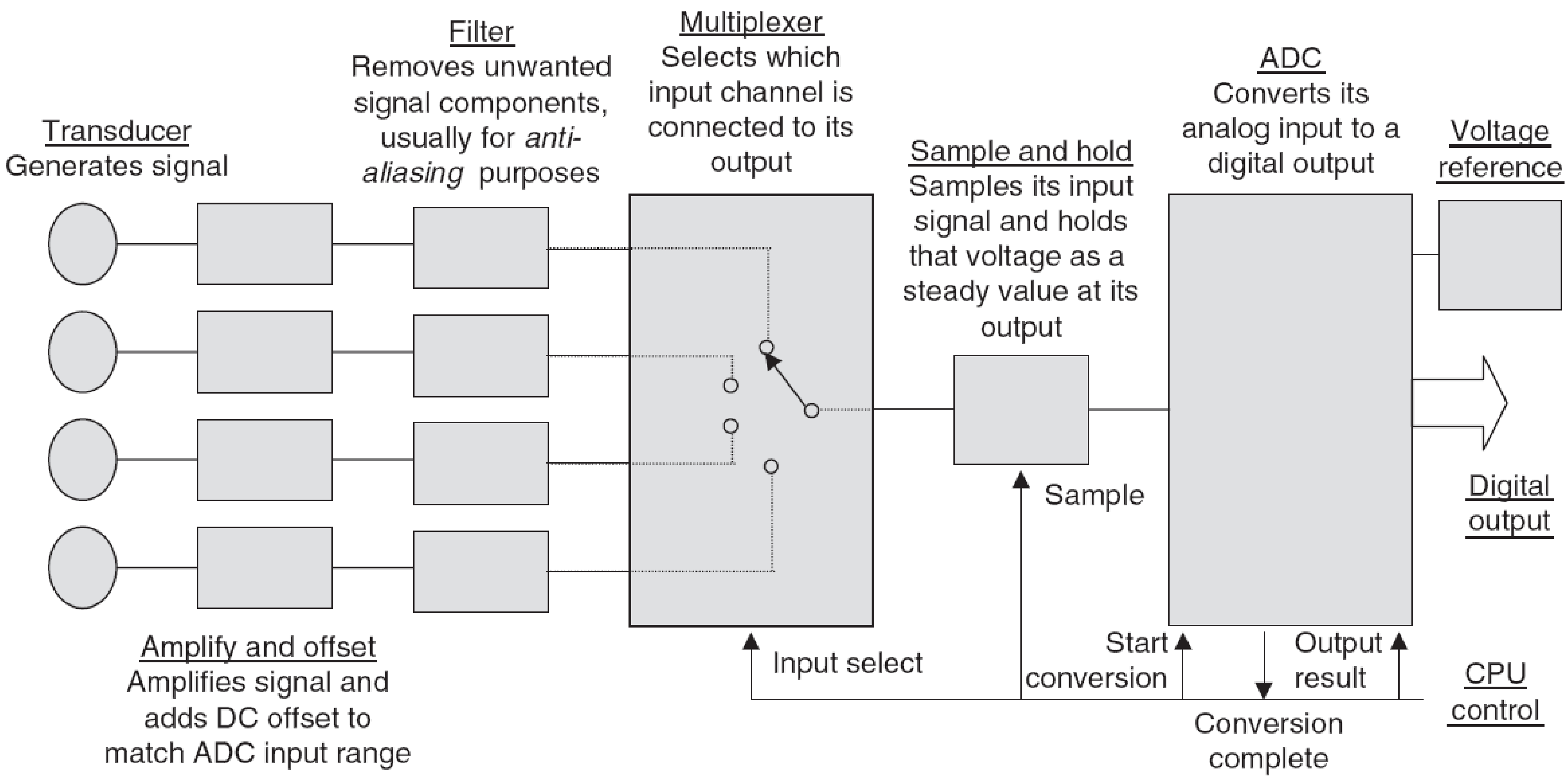
Electrical signals are conditioned so they can be used by an analog input board. The following features may be available:

- Amplification
- Isolation
- Filtering
- Linearization

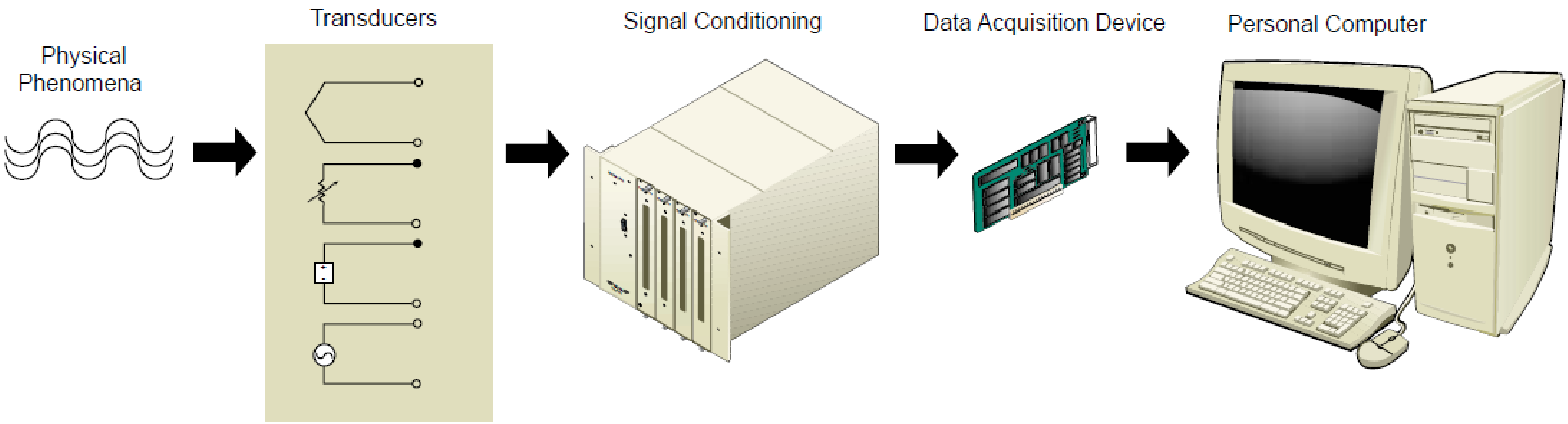
Data Acquisition System



Elements of a data acquisition system



Data Acquisition system



Operational Amplifiers (Op Amps)

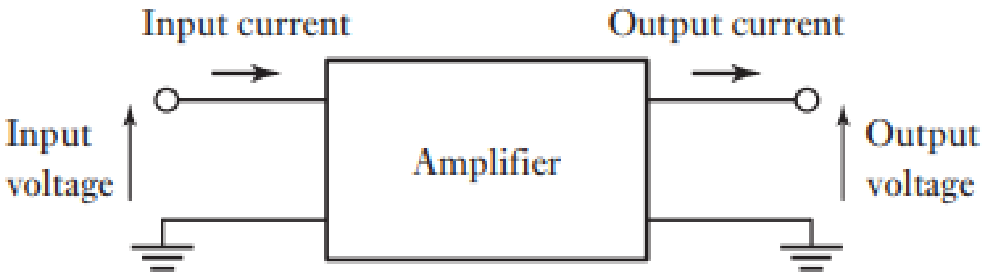


Figure 3.1 Amplifier.

Amplifier

- An amplifier is a device which increases the amplitude of a signal without affecting the phase relationship of different components of signal.
- The voltage gain of the amplifier being the ratio of the output and input voltages when each is measured relative to the earth.
- The input impedance of an amplifier is defined as the input voltage divided by the input current.

Op-Amp

- The output impedance of an amplifier is defined as the output voltage divided by the output current.
- Operational Amplifier or an Op amp is a better and an advanced class of amplifier which amplifies the input signal with little bit operations on them.
  - Comparator
  - Summing
  - Differencing
  - Integrating
  - Differentiation
  - Logarithmic

Op-Amp

- Is supplied as an integrated circuit on a silicon chip.
- High gain DC amplifier.
- Has two inputs, known as the inverting input (-) and the non-inverting input (+)
- An ideal model for an operational amplifier is as an amplifier with an infinite gain, infinite input impedance and zero output impedance, i.e. the output voltage is independent of the load.

Ideal Op Amp

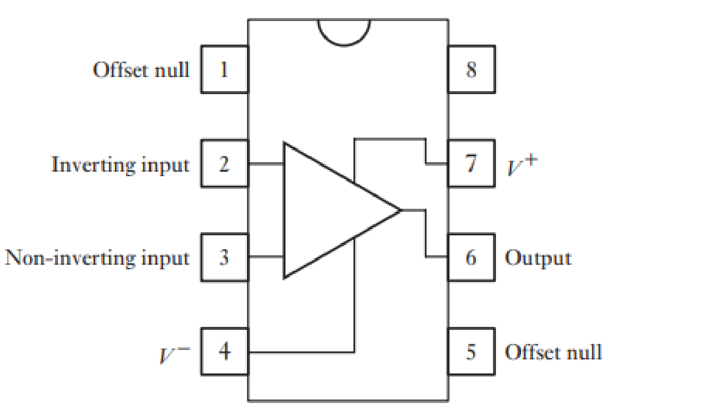
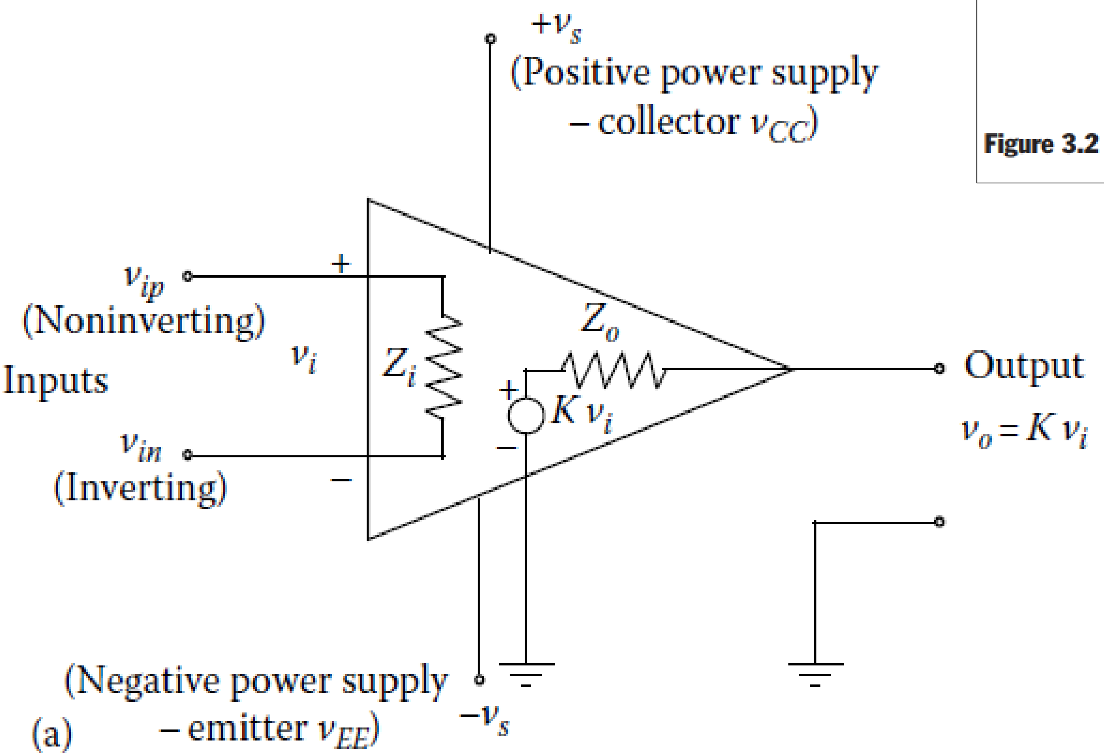


Figure 3.2 Pin connections for a 741 operational amplifier.

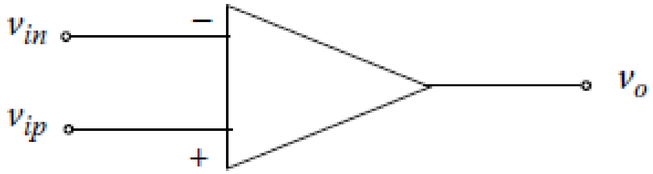


V_i- The difference in voltage between Non Inv and Inv inputs

K- Output gain (10^5 to 10^7)

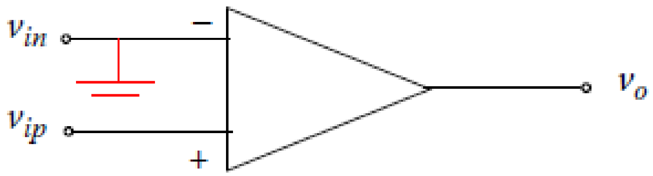
Ideal Op Amp

$$v_o = Kv_i$$

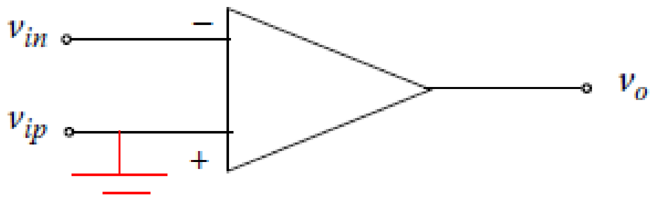


$$v_i = v_{ip} - v_{in}$$

If V_{in} is ground ; $v_o = Kv_{ip}$



If V_{ip} is ground; $v_o = -Kv_{in}$

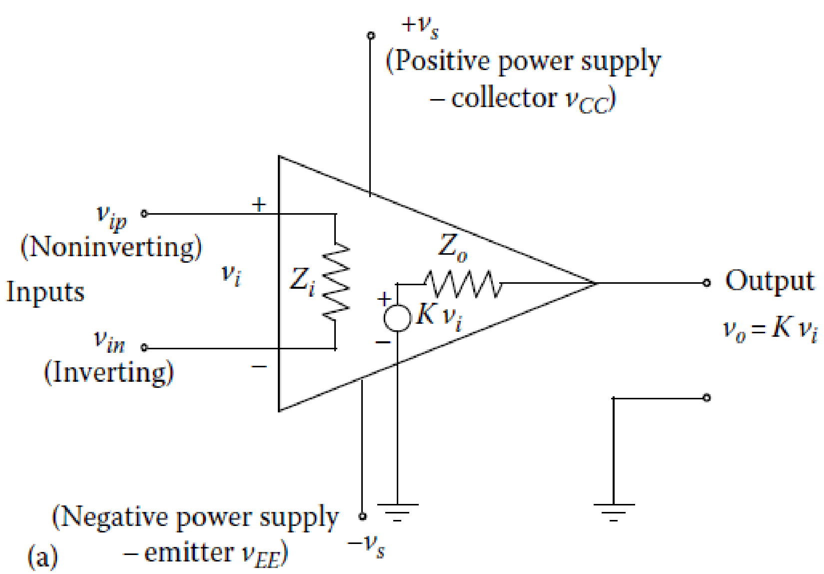


This is why V_{ip} Is called Non- Inverting

and

V_{in} is called Inverting input

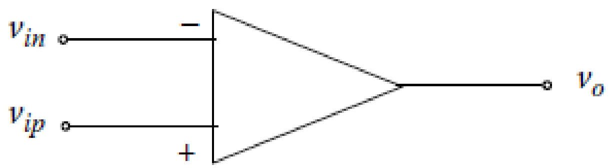
Op-Amp Properties



- It has infinite impedance at input I+ or I- = 0
- It has infinite gain. V+ = V-
- It has zero output impedance.
- Vout does not depend on output current.

Ideal Op Amp

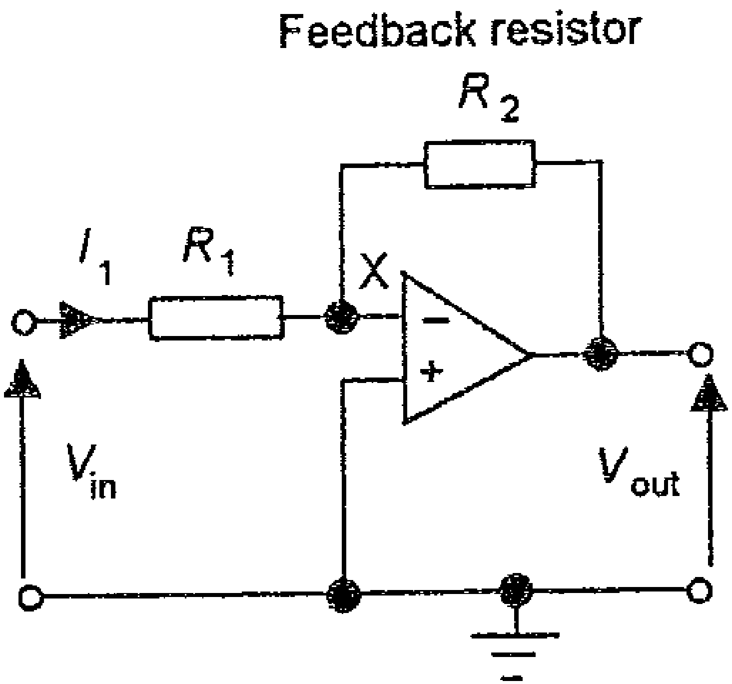
PARAMETER NAME	PARAMETERS SYMBOL	VALUE
Input current	I_{IN}	0
Input offset voltage	V_{OS}	0
Input impedance	Z_{IN}	∞
Output impedance	Z_{OUT}	0
Gain	K	∞



$$v_o = Kv_i$$

Simplified diagram showing only voltage inputs (without external power supply)

Virtual Ground of Op Amp



This assumption of Virtual Ground saves us from lots of algebraic manipulations!!!

\+ terminal is connected to ground

Gain (K) of amplifier is 100,000

Output voltage is say 10 V

Means input voltage is 0.0001.

This can be considered **as Zero!!**

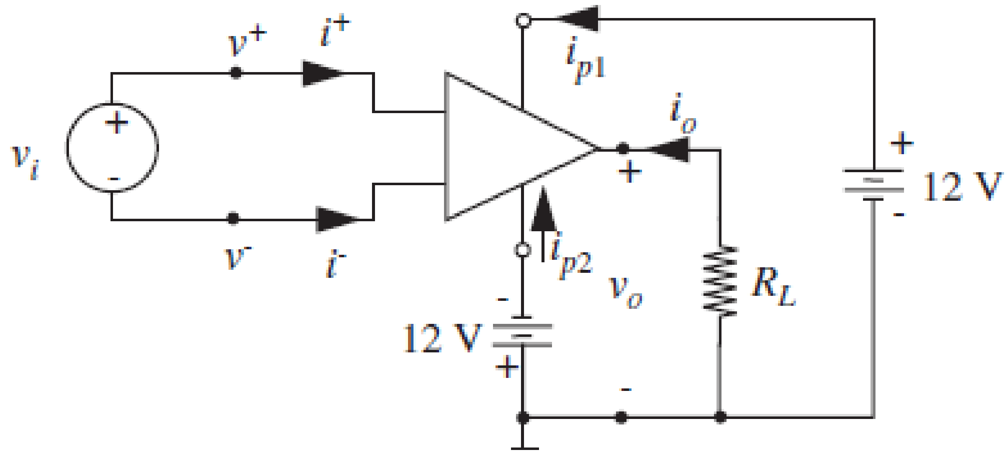
Point X is at "0" Voltage!!

Called Virtual Ground

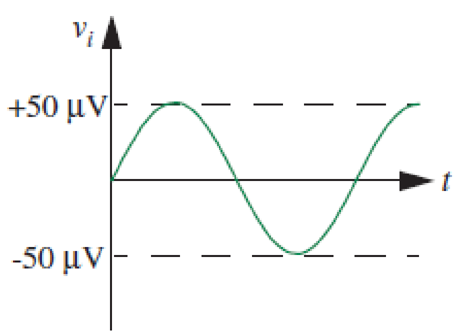
Ideal Op Amp Assumptions(Summarized)

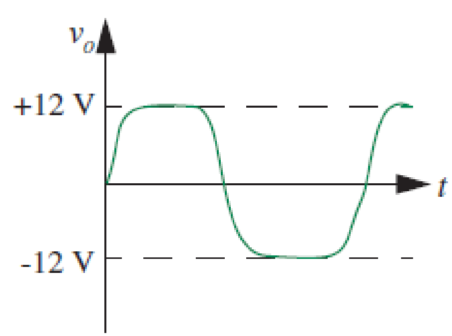
- Input Impedance is Very High (10 Mega Ohms)
- Output Impedance is Very low (10 Ohms)
- No current passes through Op amp
- Virtual ground assumption can be made safely
- Gain is very high (100,000 – 1,000,000)

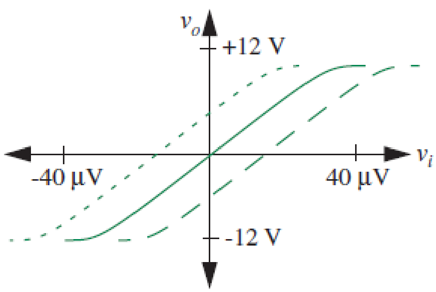
Typical Characteristics of Op amp



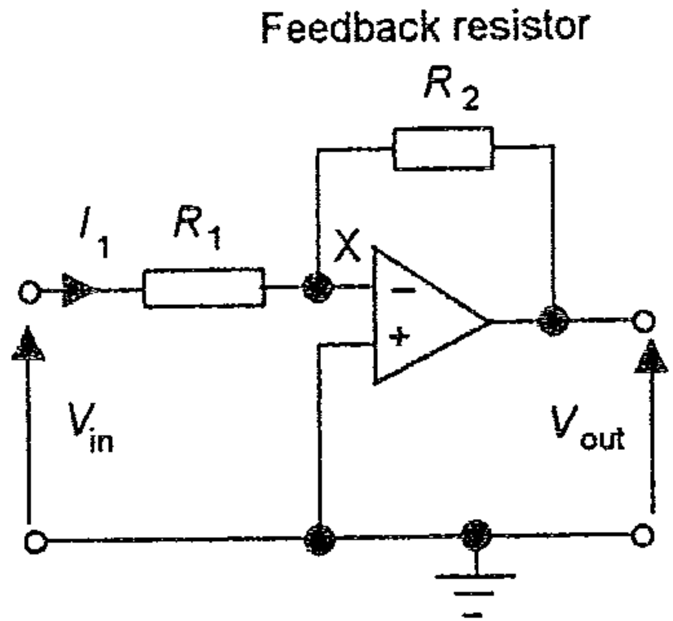
(a)







Inverting amplifier



Potential difference across R1 is

$Vin - Vx = I_1 \text{ x } R_1$

Potential difference across R2 is

$Vx - Vout = I_2 \text{ x } R_2$

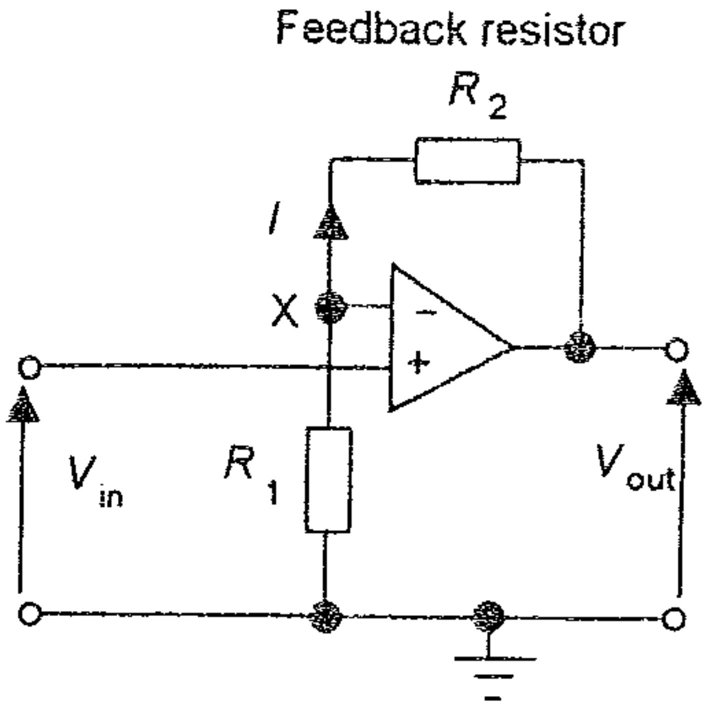
No current can flow through X into Op Amp (Refer our assumptions)

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.

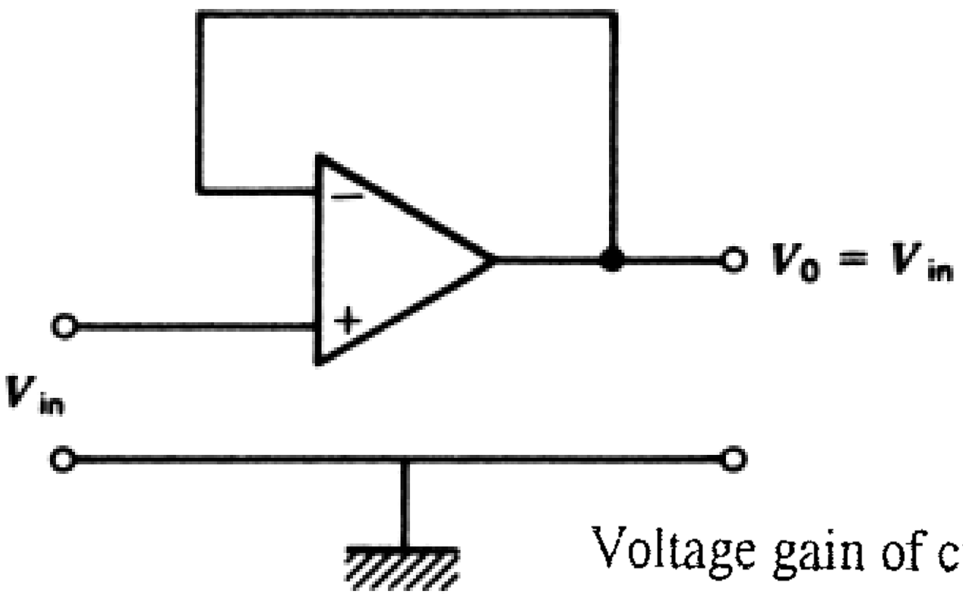
$$V_X = \frac{R_1}{R_1 + R_2} V_{out}$$

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

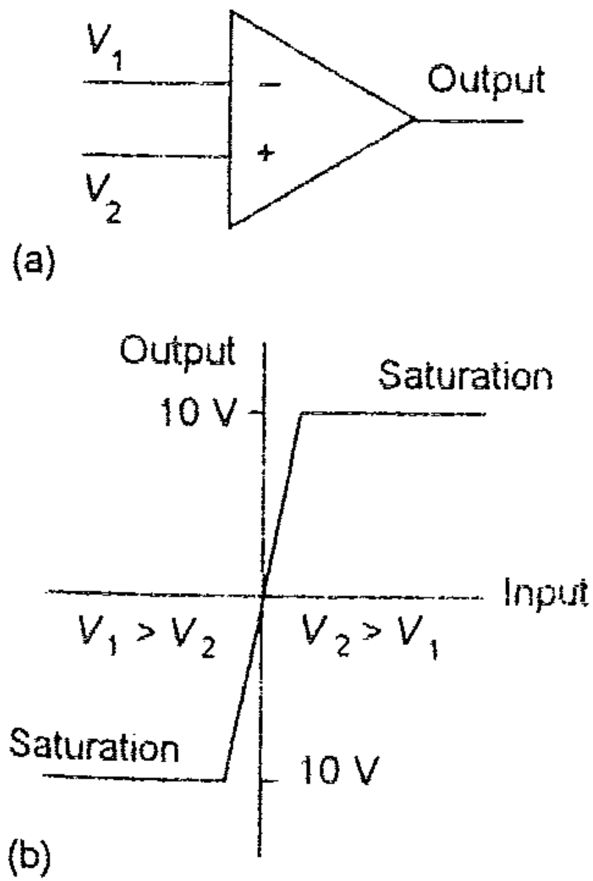
b) As isolators

c) R2 = 0

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

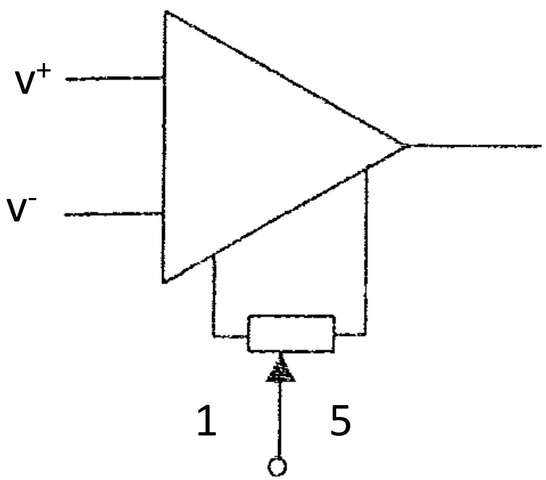
- **An op amp circuit with unity gain and very high input impedance.**
- **The unity gain voltage follower is essentially an impedance transformer in the sense of converting a voltage at high impedance to the same voltage at low impedance.**

Voltage Comparator



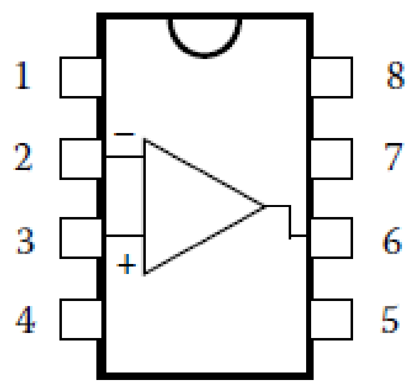
- When the two inputs are equal there is no output.
- When the non-inverting input V2 is greater than the inverting input by more than a small fraction of a volt then the output jumps to a steady positive saturation voltage of typically +10 V
- When the inverting input V1 is greater than the non-inverting input then the output jumps to a steady negative saturation voltage of typically -10 V.

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

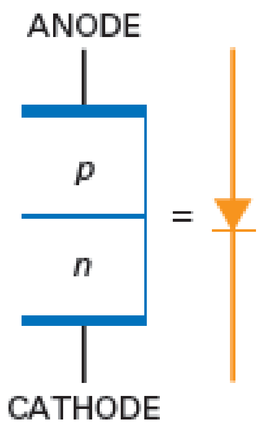


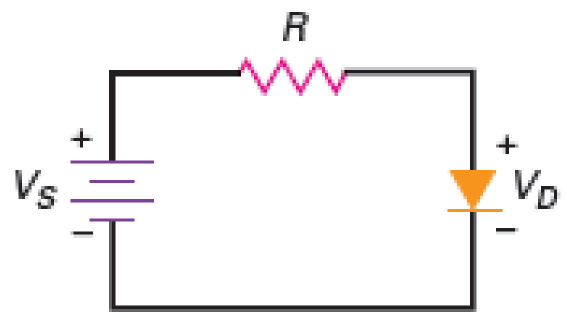
Pin designations:

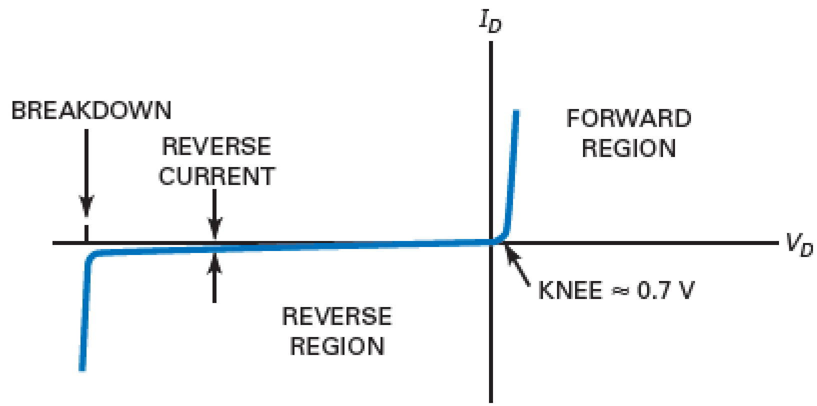
1 Offset null
2 Inverting input
3 Noninverting input
4 Negative power supply v_{EE}
5 Offset null
6 Output
7 Positive power supply v_{CC}
8 NC (not connected)

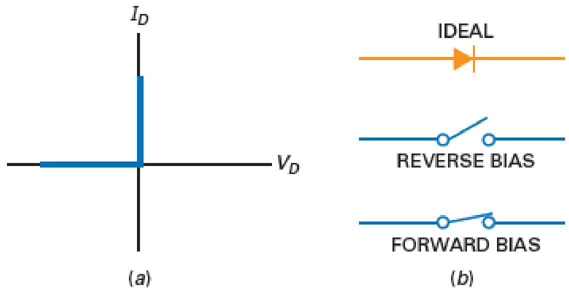
Protectors

Diodes – (Electronic check valve) Unidirectional Current flow







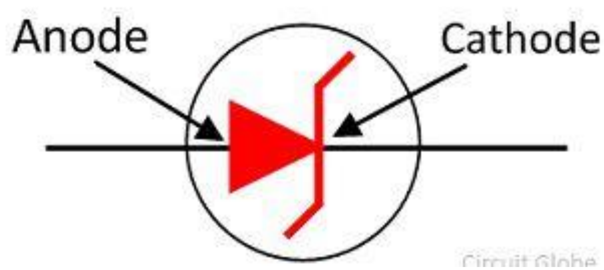


Zener Diode (Voltage Regulator)

Power Supply
1V to 5V

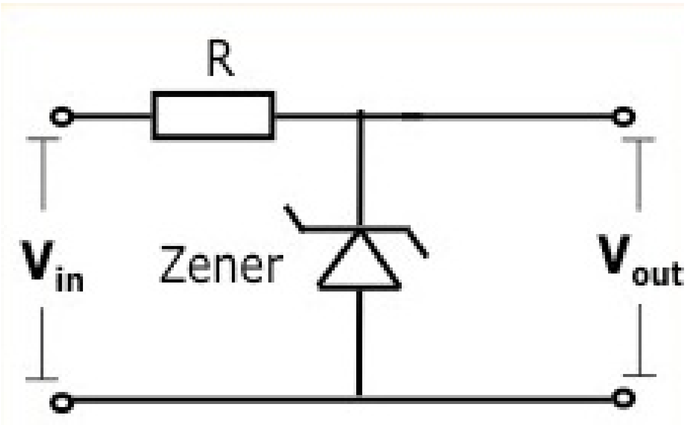
Continuous Vs<2V supply

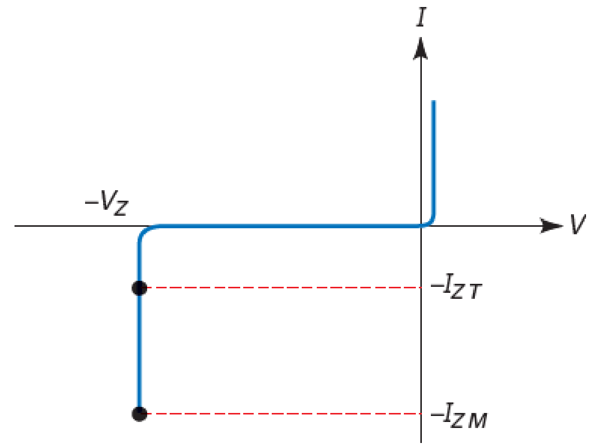
LED
Vs<2V

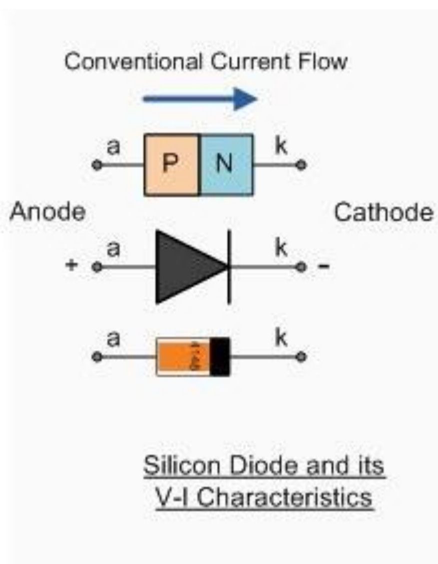


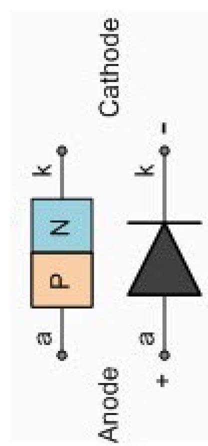
Reverse bias

Zener Diode (Voltage Regulator)



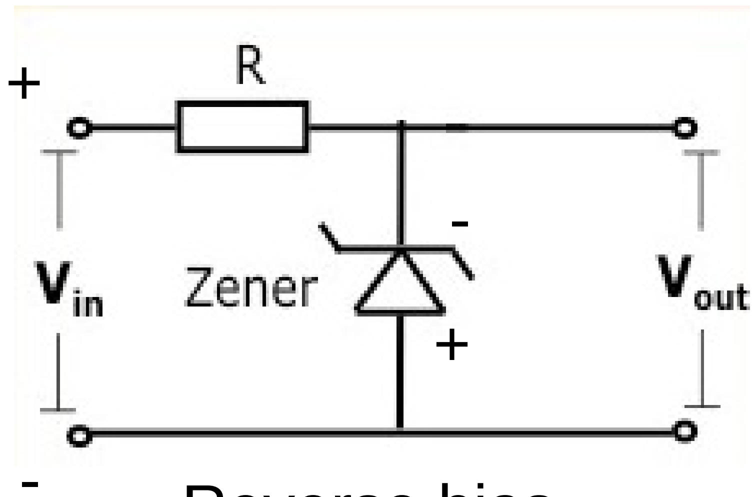




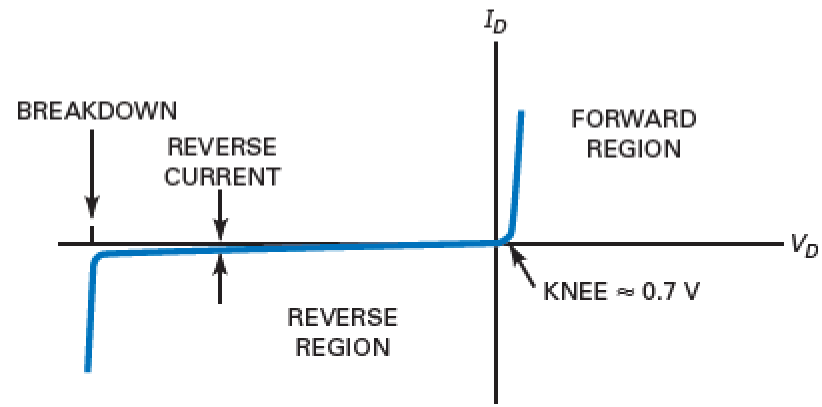


Reversed biases Heavily doped diode – More you dope, more are the impurities -smaller is the depletion region

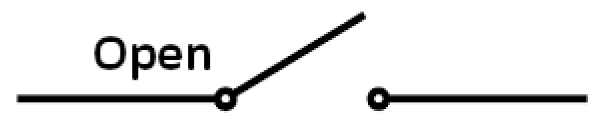
Zener Diode (Voltage Regulator)



Reverse bias

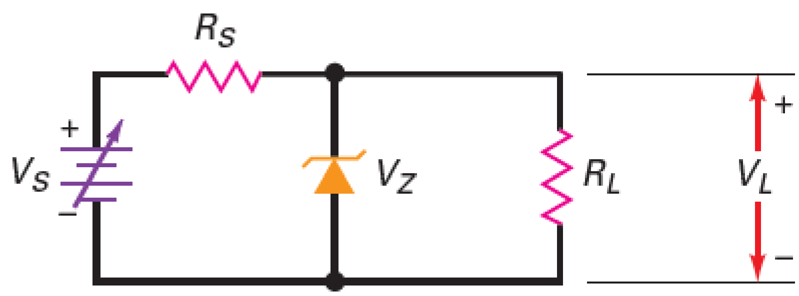


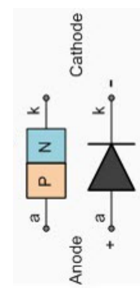
If Vin < Vz it acts as open loop



If Vin >= Vz it acts as closed loop and causes short circuit. To avoid this resistor is series is added.

Zener circuit design calculation





Given,

Vs = 20 Volt to 24Volt
V_L= 12 Volt
R_L = 24 Ohms

Select **Zener**
V_Z = ? I_Z = ? Power =??

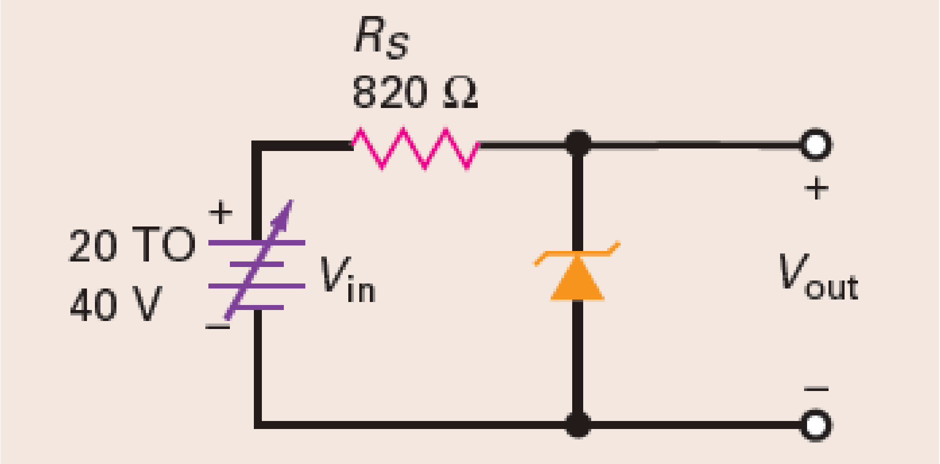
Zener voltage V_Z should be 12 Volts
Load current = V_L/R_L= 12/24 = 500 mA
R_S= (V_S – V_Z)/ I_L = (20- 12)/500 mA = 16 Ohms

Load current through resistor
I_S (max) = (24-12) / 16 = 750 mA
I_S (min) = (20-12) / 16 = 500 mA
$I_S = I_Z + I_L$
750 = I_Z + 500 mA
I_z= 250 mA
Power of Zener = 12V *250 mA = 3 Watts
P = VI

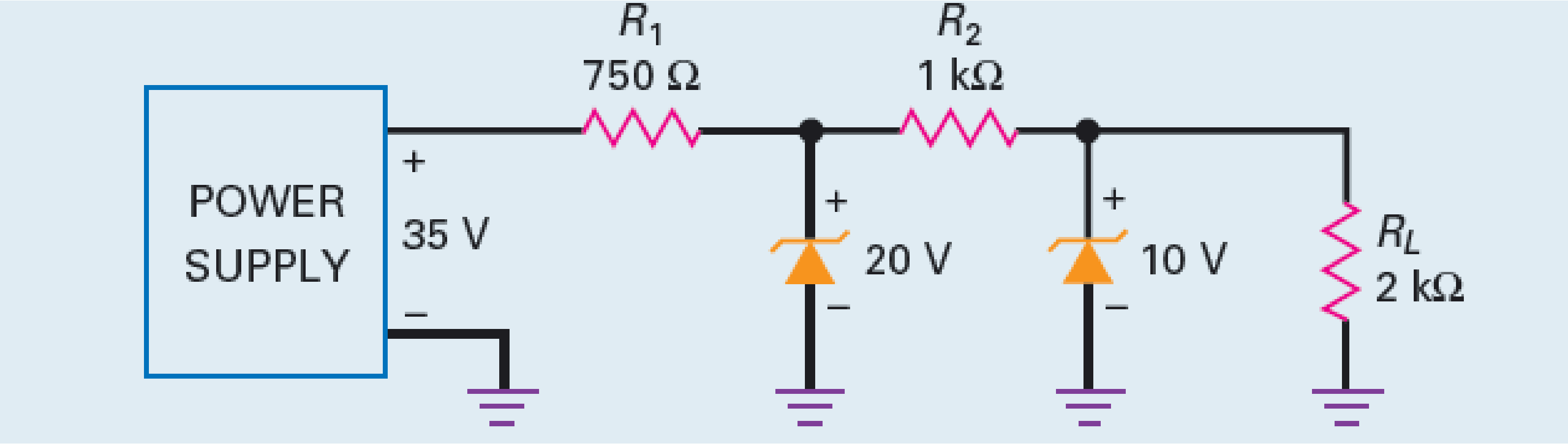
Suppose by chance voltage at source drops to 19 Volts, what will happen? Think and Home work.

Zener Calculation (Home work)

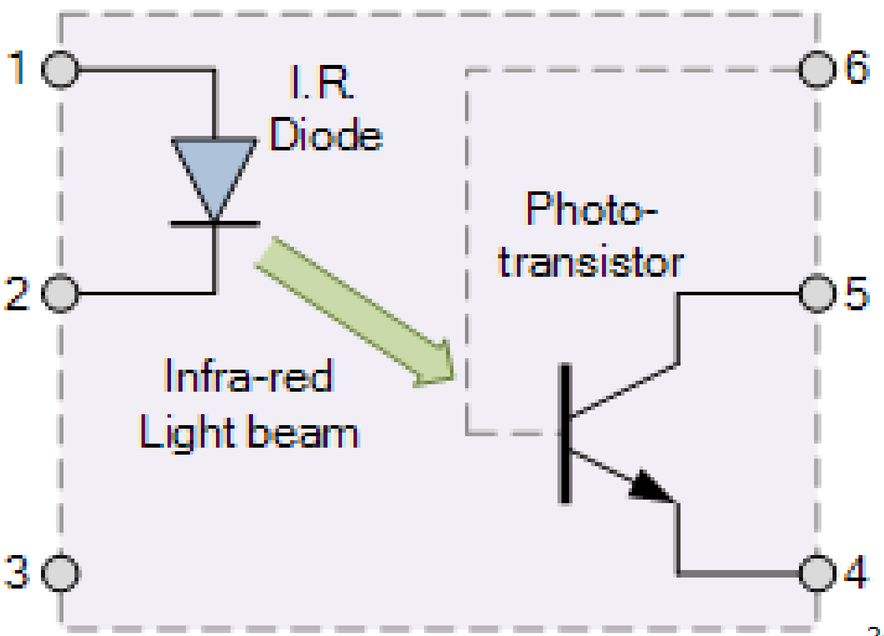
If the Zener diode below is of 10 V breakdown then, what is Vout and Max Zener, min Zener currents



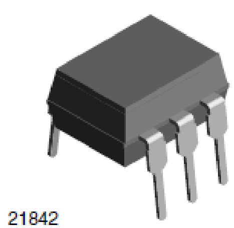
Zener Circuit (Home work)

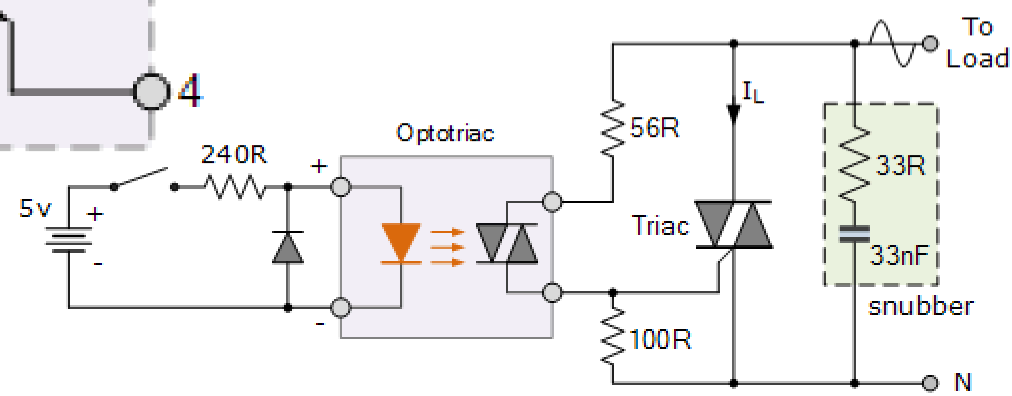


Opto Isolator (Opto Coupler/ photo coupler)



Current from the source signal passes through the input LED which emits an infra-red light whose intensity is proportional to the electrical signal.

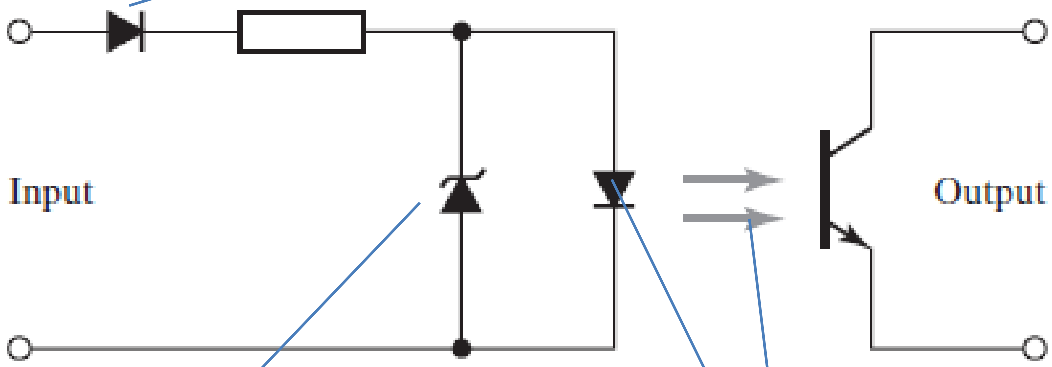




- Isolation test voltage 5000 V_{RMS}

Protection Circuit

Diode To ensure only DC



Zener diode to ensure Voltage regulation

Opto isolator for isolation purposes

Filters and protection

Filters

- The term filtering is used to describe the process of removing a certain band of frequencies from a signal and permitting others to be transmitted.
- The range of frequencies passed by a filter is known as the pass band.
- The range not passed as the stop band.
- the boundary between stopping and passing as the cut-off frequency.

Types of filters

- Passive LPF – Consists of resistance, capacitors and inductors as main components.
  - RC LPF
  - RL LPF
  - RCL LPF

  - Passive filters have the disadvantage that the current that is drawn by the item that follows can change the frequency characteristic of the filter. This problem does not occur with an active filter.
- Active LPF – Consists of op amp and transistor as main component.

Active Frequency Pass filters configurations

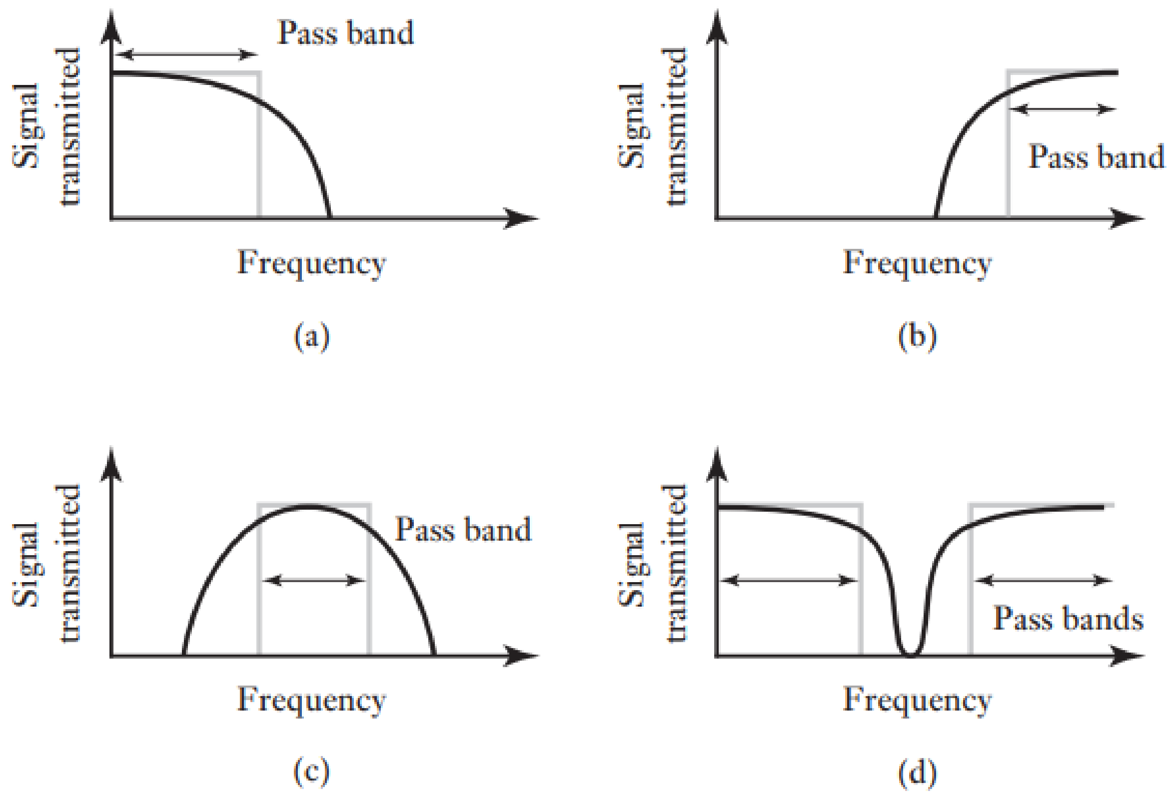
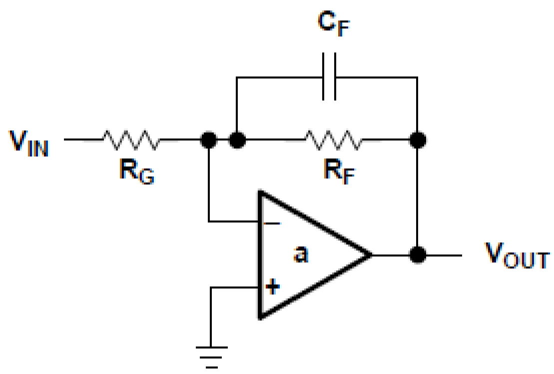


Fig. 3.19 Characteristics of ideal filters: (a) low pass, (b) high pass, (c) band pass, (d) band stop

Low pass filters

$X_C = 1/2\pi fC$. Capacitive resistance



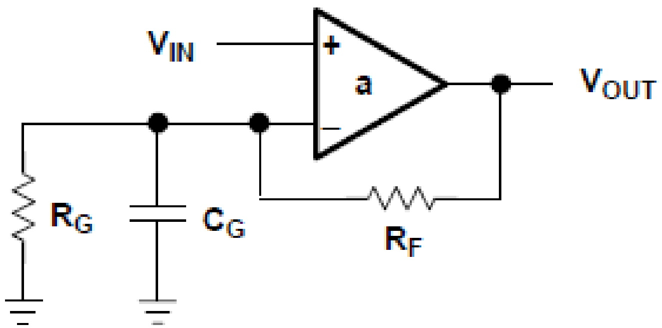
$$\frac{V_{OUT}}{V_{IN}} = -\frac{X_C \parallel R_F}{R_G}$$

At very low frequencies $X_C \rightarrow$ infinity so R_F dominates the parallel combination in Equation and the capacitor has no effect. The gain at low frequencies is $-R_F/R_G$.

At very high frequencies $X_C \rightarrow 0$, so the feedback resistor is shorted out, thus reducing the circuit gain to zero (*The current flows through least resistance path, thereby offering making R_F redundant*)

High Pass filters

$X_C = 1/2\pi fC.$ Capacitive resistance



$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{X_C \parallel R_G}$$

At very low frequencies $X_C \Rightarrow \infty$, so R_G dominates the parallel combination and the capacitor has no effect. The gain at low frequencies is $1+R_F/R_G$. At very high frequencies $X_C \Rightarrow 0$, so the gain setting resistor is shorted out thus increasing the circuit gain to maximum.

Thank you