**Electronics Instrumentation** (EC0216)

Unit-2

**Asst. Prof. Zalak Patel**

Academic Year 2020

# UNIT- II

- **Analog measurements**

Voltage, Current and Power, Impedance, Resistance, Capacitance, Inductance, Time and Phase, Gain and loss, Frequency, Frequency response, Noise power, Noise figure, Non-linearity, Group Delay, Distortion, Video Measurements

- **Digital measurements**

Jitter, BER, Eye diagram

# Measurement of Resistance

- It is important in many cases to have reasonably accurate information of the magnitude of resistance present in the circuit for analysing its behaviour.
- Measurement of resistance is thus one of the very basic requirements in many working circuits, machines, transformers, and meters.
- Apart from these applications, resistors are used as standards for the measurement of other unknown resistances and for the determination of unknown inductance and capacitance.

# Measurement of Resistance

- From the point of view of measurement, resistances can be classified as follows:

**1. Low Resistances:** All resistances of the order less than 1 Ω may be classified as low resistances. In practice, such resistances can be found in the copper winding in armatures, ammeter shunts, contacts, switches, etc.

**2. Medium Resistances**: Resistances in the range 1 Ω to 100 kΩ may be classified as medium resistances. Most of the electrical apparatus used in practice, electronic circuits, carbon resistance and metalfilm resistors are found to have resistance values lying in this range.

**3. High Resistances:** Resistances higher than 100 kΩ are classified as high resistances. Insulation resistances in electrical equipment are expected to have resistances above this range.

# Measurement Of Medium Resistances

The different methods for measurement of medium range resistances are

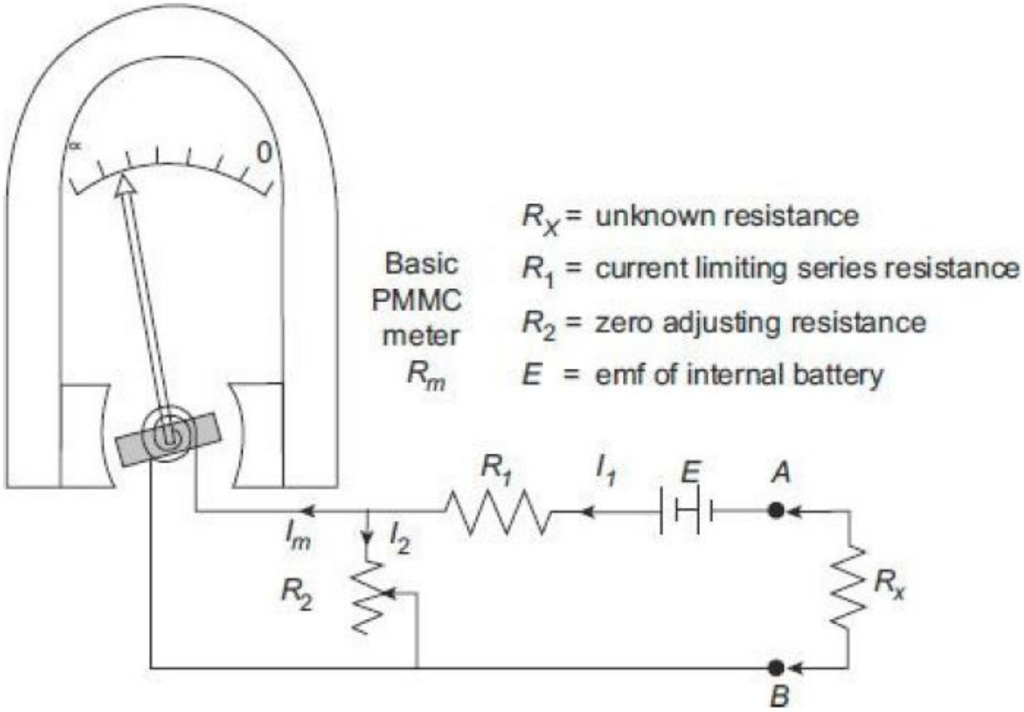
(i) ohmmeter method

(ii) voltmeter–ammeter method

(iii) substitution method

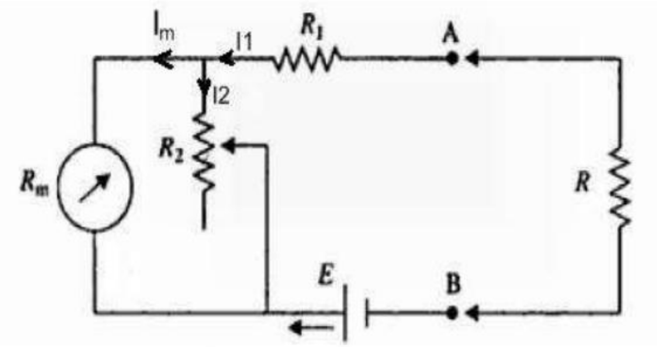
(iv) Wheatstone bridge method

# Ohmmeter Method for Measuring Resistance



# Series Type Ohmmeters

- It consists of basic d'Arsonval movement meter connected in parallel with a shunting resistor R2 .
- This parallel circuit is in series with resistance R1 and a battery of emf E.
- The series circuit is connected to the terminals A and B of unknown resistor Rx.
- R1 = current limiting resistor, R2 = zero adjusting resistor, E = emf of internal battery, Rm = internal resistance of d'Arsonval movement




Basic series type ohmmeter.

# Series Type Ohmmeters

- When the unknown resistance Rx = 0 (terminals A and B shorted) maximum current flows through the meter. Under this condition resistor R2 is adjusted until the basic movement meter indicates full scale current I fsd. The full scale current position of the pointer is marked “0Ω” on the scale.

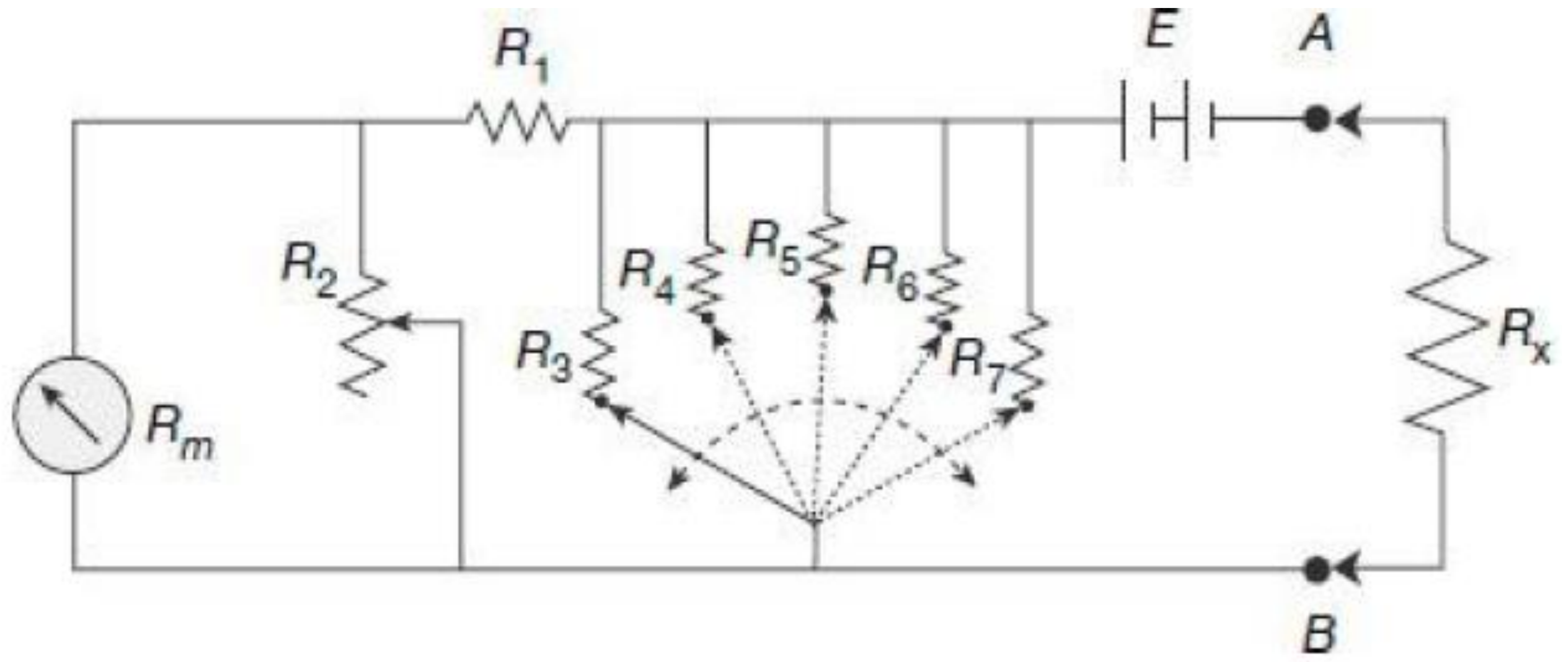
- Similarly when Rx is removed from circuit Rx = ∞ (that is when terminal A and B are open), the current in the meter drops to the zero and the movement indicates zero current which is the marked “∞”.

- Thus the meter will read infinite resistance at the zero current position and zero resistance at full scale current position. Since zero resistance is indicated when current in the meter is the maximum and hence the pointer goes to the top mark.

- When the unknown resistance is inserted at terminal A, B the current through the meter is reduced and hence pointer drops lower on the scale. Therefore the meter has “0” at extreme right and “∞” at the extreme left.

- Intermediate scale marking may be placed on the scale by different known values of the resistance Rx to the instrument.

# Multi-range Series Ohmmeter



# Multi-range Series Ohmmeter

1 mΩ - 1000mΩ

1Ω - 10Ω

10Ω — 100Ω

100Ω - 1kΩ

1kΩ - 10kΩ

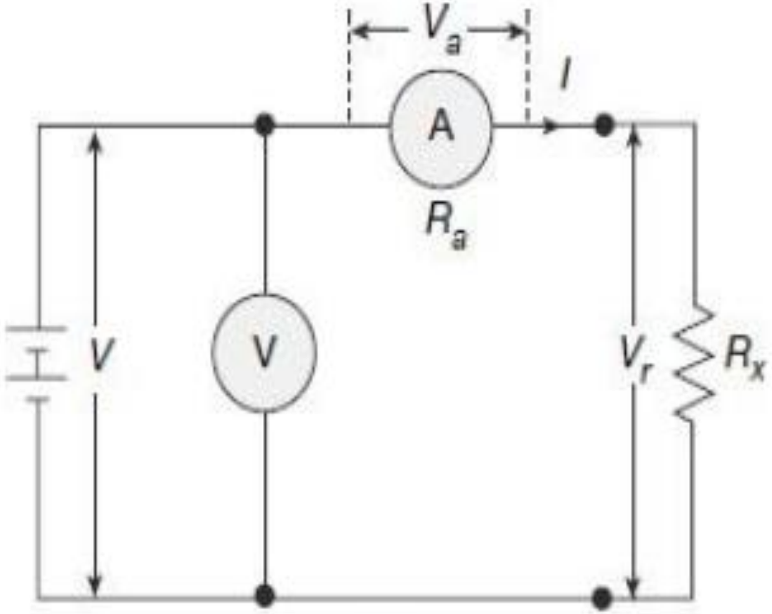
ohms

250 Ω

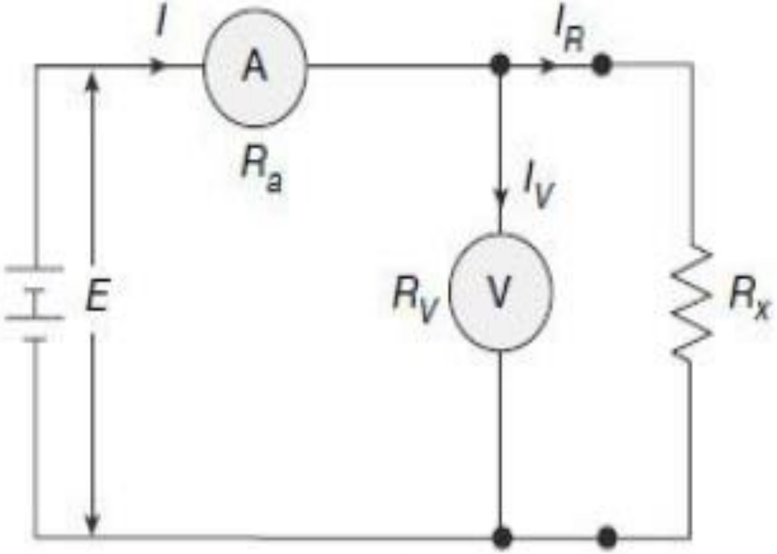
# Voltmeter–Ammeter Method

- The voltmeter–ammeter method is a direct application of ohm's law in which the unknown resistance is estimated by measurement of current (I) flowing through it and the voltage drop (V) across it.
- This method is very simple and popular since the instruments required for measurement are usually easily available in the laboratory.
- Two types of connections are employed for voltmeter–ammeter method.
- **Case A**-the voltmeter is connected in the supply side and ammeter connected directly in series with unknown resistance.
- **Case B**- the voltmeter is put across the resistance and the ammeter connected in series with the supply.
- In both the cases, the reading of Voltmeter and Ammeter is taken. If the Voltmeter reading is V and Ammeter reading is I then the measured Resistance will be
- $R_m = V/I$
- **This measured Resistance Rm will be the true value of the Resistance if and only if the Resistance of Ammeter is zero and that of Voltmeter is infinite.** But actually this is not possible to achieve zero resistance Ammeter and infinite Resistance Voltmeter. Therefore measured value of resistance Rm will deviate from the true value Rx (Say).

# Voltmeter–Ammeter Method




Case A




Case B

# Voltmeter–Ammeter Method (Case-A)

- Let, voltmeter reading = V
- And, ammeter reading = I
- So, measured value of resistance= Rm= V/I
- However, V = Va + Vr  (Kirchoff's volatge Law)
- or, V = I × Ra + I × Rx = I × (Ra + Rx)
- So. V/I = Rm= (Ra + Rx)
- Relative Error in measurement e = Rm-Rx/Rx= Ra/Rx

**Therefore, Relative Error will be less if the true value of unknown Resistance to be measured is high as compared to the internal Resistance of Ammeter. That's why this method should be adopted when measuring high Resistance but it should be under Medium Resistance category.**

# Voltmeter–Ammeter Method (Case-B)

Let, voltmeter reading = $V$

And, ammeter reading = $I$

Thus, $V = I_R \times R_X = I_V \times R_V$

However, $I = I_V + I_R$

∴ measured value of resistance

$$= R_m = \frac{V}{I} = \frac{V}{I_V + I_R} = \frac{V}{\frac{V}{R_V} + \frac{V}{R_x}} = \frac{R_V R_x}{R_V + R_x} = \frac{R_x}{1 + \frac{R_x}{R_V}}$$

- Therefore, true value of Resistance Rx = RmRv/(Rv-Rm)

  = Rm/(1-Rm/Rv)

- Therefore, true value of Resistance will only be equal to measured value if the value of Voltmeter resistance Rv is infinite.

# Voltmeter–Ammeter Method (Case-B)

- Relative Error in Measurement = (Rm-Rx)/Rx

  = -Rx/Rv

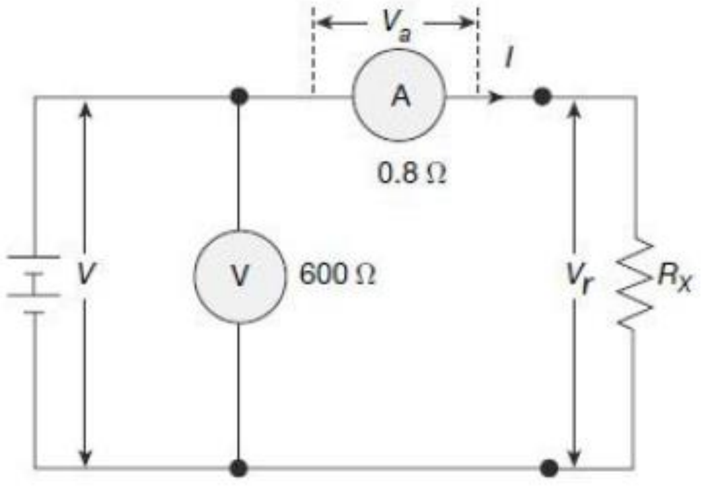
- **Therefore, it is clear from the expression of Relative Error that, error in measurement will be low if the value of Resistance under measurement is very less as compared to the internal Resistance of Voltmeter.**
- This is the reason; this method is used for the Contact Resistance Measurement. As the value of Contact Resistance is of the order of 20 micro Ohm which is very less as compared to the internal Resistance of Voltmeter.
- However this method is very useful where high accuracy is not required. The suitability of Case1 or Case2 depends on the value of Resistance to be measured. The division point between the two methods is at the Resistance for which both the method give same Relative Error.
- So, Ra/Rx = Rx/Rv

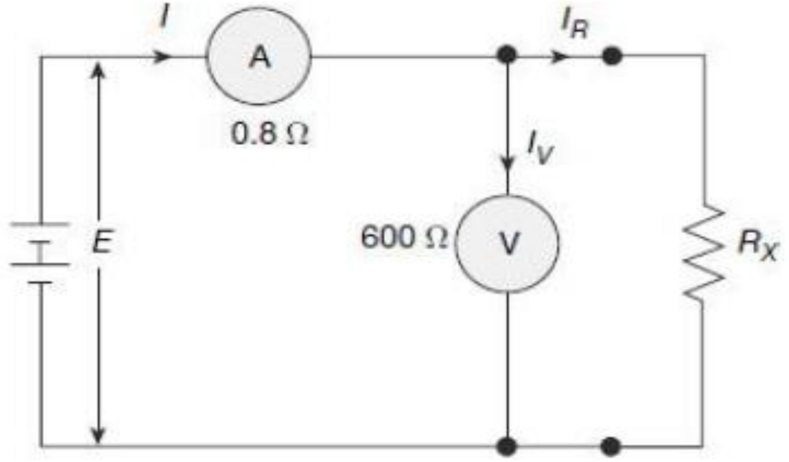
$$R_x = \sqrt{R_a}\sqrt{R_v}$$

- For the Resistance greater than the value given above, Case A is used while for the value of Resistance lower than Rx given above Case B is used.

# Example

A voltmeter of 600 Ω resistance and a milliammeter of 0.8 Ω resistance are used to measure two unknown resistances by voltmeter–ammeter method. If the voltmeter reads 40 V and milliammeter reads 120 mA in both the cases, calculate the percentage error in the values of measured resistances if (a) in the first case, the voltmeter is connected in the supply side and milliammeter connected directly in series with the resistance. and (b) in the second case, the voltmeter is put across the resistance and the milliammeter connected in series with the supply



# Solution –Case A

∴ measured resistance from voltmeter and ammeter readings is given by

$$= R_m = \frac{V}{I} = \frac{40}{120 \times 10^{-3}} = 333\ \Omega$$

Voltmeter reads the voltage drop $V_r$ across the resistance $R_x$ and also the voltage drop $V_a$ across the ammeter resistance $R_a$.

Thus, $V = V_a + V_r$

Voltage drop across ammeter

$$V_a = I \times R_a = 120 \times 10^{-3} \times 0.8 = 0.096\ \text{V}$$

∴ true voltage drop across the resistance

$$V_r = V - V_a = 40 - 0.096 \times 39.904\ \text{V}$$

∴ true value of resistance $= R_x = \frac{V_r}{I} = \frac{39.904}{120 \times 10^{-3}} = 332.53\ \Omega$

Percentage error in measurement is $\varepsilon = \frac{333 - 332.53}{332.53} \times 100\% = 0.14\%$

# Solution- Case B

Voltmeter reading $V = 40$ V

Ammeter reading $I = 120$ mA

∴ measured resistance from voltmeter and $I$

ammeter readings is given by

$$= R_m = \frac{V}{I} = \frac{40}{120 \times 10^{-3}} = 333\ \Omega$$

The ammeter reads the current flowing $I_R$ through the resistance $R_x$ and also the current $I_V$ through the voltmeter resistance $R_V$.

Thus, $$I = I_V + I_R$$

Now, the voltmeter and the resistance $R_x$ being in parallel, the voltmeter reading is given by

$$V = I_R \times R_X = I_V \times R_V$$

# Solution- Case B

Current through voltmeter

$$I_V = \frac{V}{R_V} = \frac{40}{600} = 66.67 \text{ mA}$$

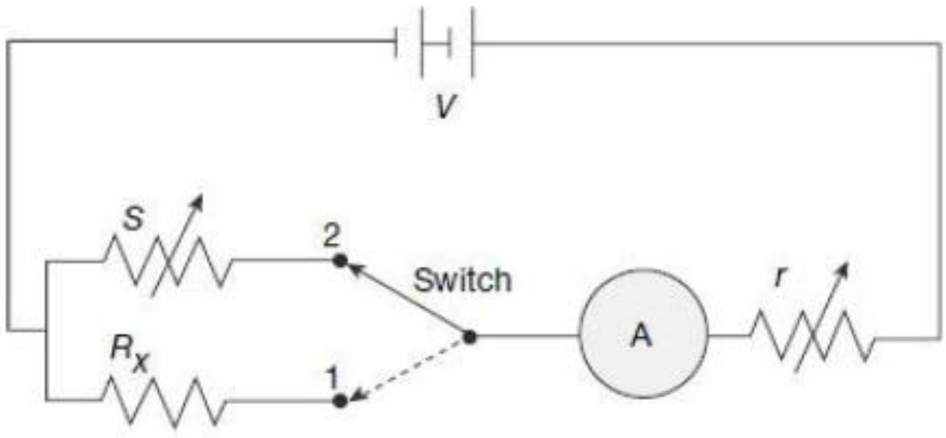
∴ true current throught resistance $I_R = I - I_V = 120\text{-}66.67 = 55.33$ mA

∴ true value of resistance $= R_x = \frac{V}{I_R} = \frac{40}{53.33\times10^{-3}} = 750\ \Omega$

Thus, percentage error $\varepsilon = \frac{R_m - R_x}{R_x} = \frac{333-750}{750}\times100\% = 55.5\%$

# Substitution Method for Measuring Resistance

- The copnnection diagram for substitution method is as shown in figure.
- Here, Rx is the unknown Resistance, S is the Standard variable Resistance, A is Ammeter and r is Regulating Resistance.

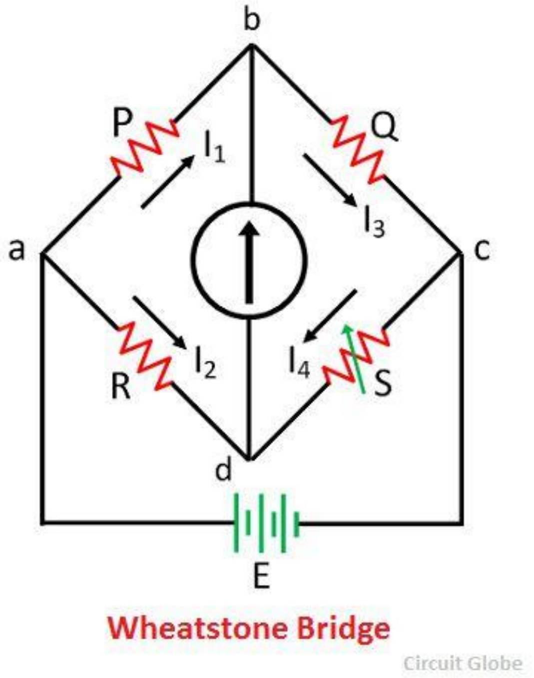


# Substitution Method for Measuring Resistance

- First the switch is placed at position 1 and the ammeter is made to read a certain amount of current by varying regulating resistance r. The value of ammeter reading is noted.
- Now the switch is moved to position 2 and S is varied in order to achieve the same ammeter reading as it read in the initial case.
- The setting of dial of S is read. Since the substitution of one resistance for another has left current unaltered, and provided that EMF of battery and position of Regulating Resistance r remain unaltered, the two Resistance Rx and S must be equal.
- Thus the value of unknown Resistance Rx is equal to the dial setting of Standard Resistance S.
- This method of measurement is more accurate as compared to the Ammeter Voltmeter Method as in this method measurement is not affected by the accuracy of Ammeter.
- However, the accuracy of this method is greatly affected if there is any change in the Battery EMF during the time when the reading in two settings is taken.
- The accuracy of this method also depend on resistance of circuit excluding R and S, upon the sensitivity of instrument and upon the accuracy with which the Standard Resistance S is known.

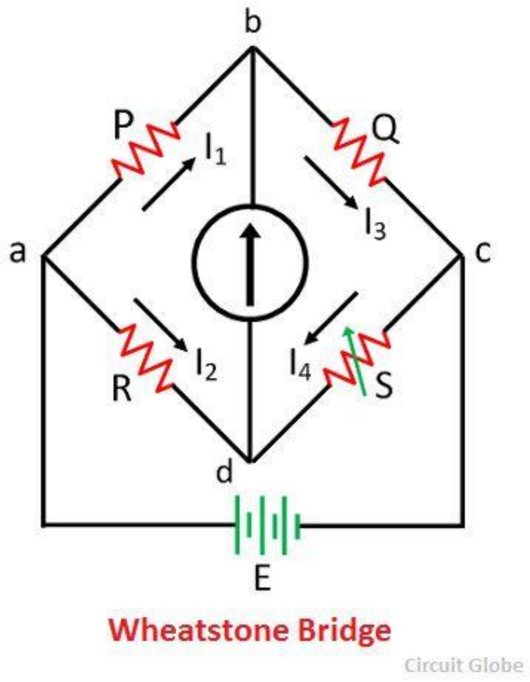
# Wheatstone Bridge for Measuring Resistance

- The device uses for the measurement of medium resistance with the help of comparison method is known as the Wheatstone bridge.
- The value of unknown resistance is determined by comparing it with the known resistance.
- The Wheatstone bridge works on the principle of null deflection, i.e. when no current flows through the galvanometer. The bridge is very reliable and gives an accurate result.



# Construction of Wheatstone Bridge

- The basic circuit of the Wheatstone bridge is shown in the figure below.
- The bridge has four arms which consist of two known resistances- P and Q, two unknown resistances- the variable resistance S and the one unknown resistance R along with the emf source and galvanometer.
- Arms ab and bc are called ratio arms.
- The emf supply is attached between point a and c, and the galvanometer is connected between point b and d. The current through the galvanometer depends on the potential difference across it.



# Working of Whistonbridge

- Now adjust the variable resistance S until the deflection in galvenometer becomes Null. When no current flows through the galvenometer the bridge is said to be in balance condition.
- Which means the potential difference across the galvanometer is zero. i.e. voltage difference between point b and d is zero. So I1=I3 and I2=I4 (KCL)
- So the potential difference across the a to b and a to d are equal, and the potential differences across the b to c and c to d remain same. (KVL)

$$I_1 P = I_2 R \dots \dots \dots equ(1)$$

$$I_3 Q = I_4 S$$

$$I_1 Q = I_2 S \qquad \textit{(since I3=I1 \& I4=I2)}$$

$$\frac{P}{Q} = \frac{R}{S}$$

$$PS = RQ \dots \dots \dots equ(2)$$

$$R = \frac{P}{Q} \times S \dots \dots \dots equ(3)$$

- The equation (2) shows the balance condition of the Wheatstone bridge. **The value of unknown resistance is determined by the help of the equation (3). The R is the unknown resistance, and the S is the standard arm of the bridge and the P and Q are the ratio arm of the bridge.**

# Analog Measurement Parameters

1. Voltage, Current, power & Resistance
2. Impedance, Inductance & capacitance
3. Time Period & Frequency
4. Gain & Loss
5. Frequency response
6. Noise power
7. SNR
8. Noise figure
9. Group Delay
10. Distortion

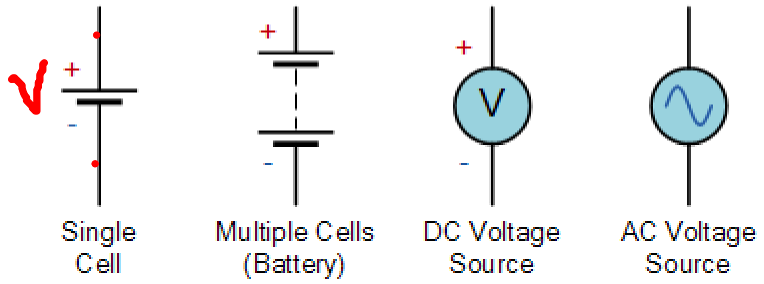
# Basic Electrical quantities: current, voltage, power

1. **Electrical Voltage** ( V ) is the potential energy of an electrical supply stored in the form of an electrical charge and is measured in units of Volts.

- Voltage can be thought of as the force that pushes electrons through a conductor and the greater the voltage the greater is its ability to “push” the electrons through a given circuit.

- Voltage is always measured as the difference between any two points in a circuit and the voltage between these two points is generally referred to as the “Voltage drop“ or “potential difference”

**Voltage Symbols:**



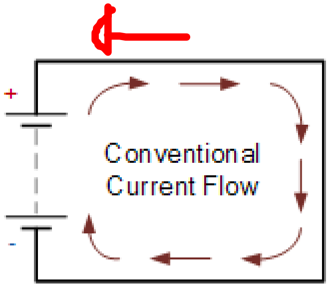
# Basic electrical quantities: current, voltage, power

2. **Electrical Current ( I )** is the movement or flow of electrical charges and is measured in the units of Amperes.

- It is the continuous and uniform flow of electrons (the negative particles of an atom) around a circuit that are being “pushed” by the voltage source.

- In reality, electrons flow from the negative (–ve) terminal to the positive (+ve) terminal of the supply and for ease of circuit understanding conventional current flow assumes that the current flows from the positive to the negative terminal.

**Direction of current flow:**

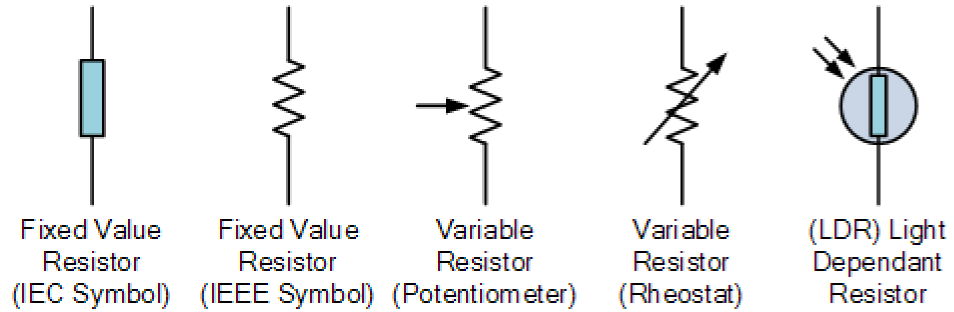


# Basic electrical quantities: current, voltage, power

- **Resistance ( R )** is the property of a material to resist or oppose the flow of current or, more specifically, the flow of electric charge within a circuit. The circuit element which does this perfectly is called the "Resistor".

- Resistance is a circuit element measured in units of Ohms, Greek symbol (Ω) with prefixes used to denote Kilo-ohms ( $1\ k\Omega = 10^3\ \Omega$ ) and Mega-ohms ( $1\ M\Omega = 10^6\ \Omega$ )

- **Resistor Symbols:**



## Ohm’s Law - Relationship between Voltage, Current and Resistance

- Georg Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance.

$$Current, (I) = \frac{Voltage, (V)}{Resistance, (R)} \text{ in } Amperes, (A)$$

- By knowing any two values of the Voltage, Current or Resistance quantities we can use Ohms Law to find the third missing value.

# Basic electrical quantities: current, voltage, power

- **Electrical Power ( P )** in a circuit is the rate at which energy is absorbed or produced within a circuit.
- A source of energy such as a voltage will produce or deliver power while the connected load absorbs it. Light bulbs and heaters for example, absorb electrical power and convert it into either heat, or light, or both. The higher their value or rating in watts the more electrical power they are likely to consume.
- The quantity symbol for power is P and is the product of voltage multiplied by the current with the unit of measurement being the Watt ( W ).

- [ P = V x I ]  P (watts) = V (volts) x I (amps)
- [ P = $V^2$ ÷ R ]  P (watts) = $V^2$ (volts) ÷ R (Ω)
- [ P = $I^2$ x R ]  P (watts) = $I^2$ (amps) x R (Ω)


$P = V.I = I^2R$

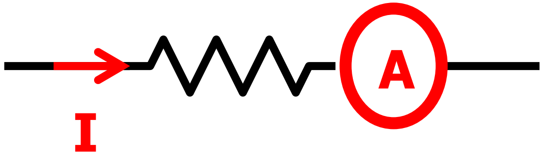
$P = V.\frac{V}{R}$

# Measuring current, voltage, and resistance

**Ammeter:**

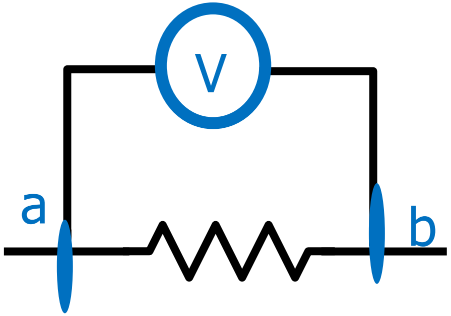
- measures current (A)
- connected **in series**

  (current must go through instrument)



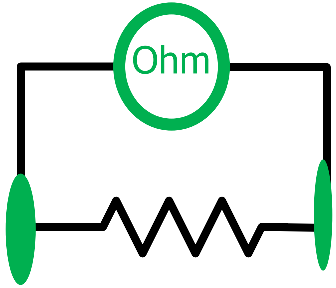

**Voltmeter:**

- measures potential difference (V)
- connected **in parallel**



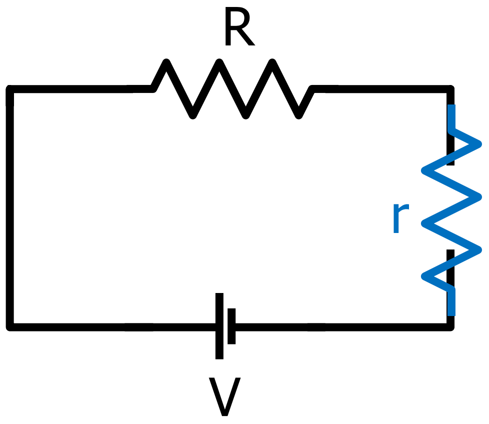

**Ohmmeter:**

- measures resistance of an isolated resistor (not in a working circuit)



# Effect of ammeter on circuit

Measuring current in a simple circuit:




- connect ammeter in series

Are we measuring the correct current?
(the current in the circuit without ammeter)

- any ammeter has **some resistance r.**
- current in presence of ammeter is $I = \frac{V}{R+r}$.
- current without the ammeter would be $I = \frac{V}{R}$.

**To minimize error, ammeter resistance r must be very small.**
(ideal ammeter would have zero resistance)

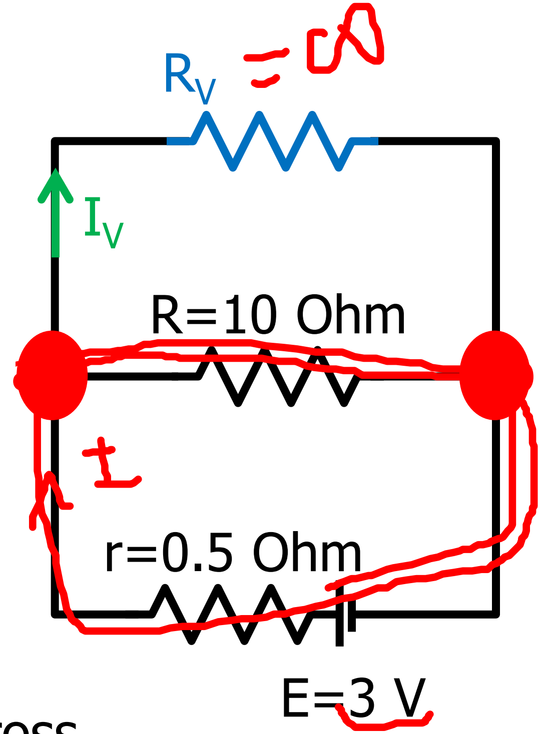
# Effect of voltmeter on circuit

Measuring voltage (potential difference) $V_{ab}$ in a simple circuit:

- connect voltmeter in parallel

Are we measuring the correct voltage?
(the voltage in the circuit without voltmeter)

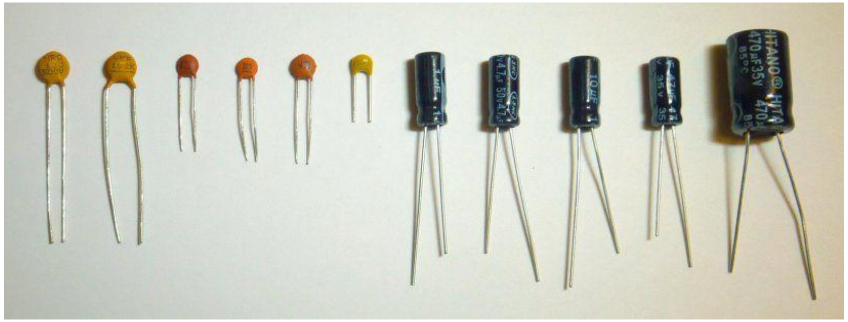
- voltmeter has **some resistance $R_V$**
- **current** $I_V$ flows through voltmeter
- extra current changes voltage drop across R and thus $V_{ab}$




**To minimize error, voltmeter resistance r must be very large.**
(ideal voltmeter would have infinite resistance)

# Capacitance

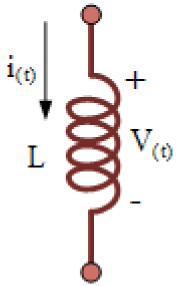
- Capacitance is the ability of a device to store electric charge, and as such, the electronic component that stores electric charge is called a capacitor.
- The simplest capacitor consists of two flat conducting plates separated by a small gap. The potential difference, or voltage, between the plates is proportional to the difference in the amount of the charge on the plates.
- $Q = CV$, where Q is charge, V is voltage and C is capacitance.
- The capacitance of a capacitor is the amount of charge it can store per unit of voltage. The unit for measuring capacitance is the farad (F).
- 1 F is defined as the capacity to store 1 coulomb of charge with an applied potential of 1 volt.



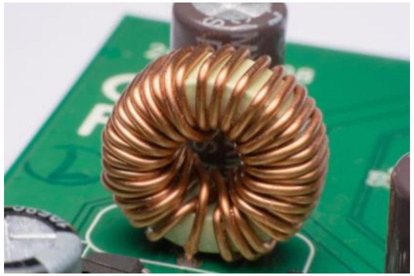
# Inductance

- An inductor is an electronic component consisting of a coil of wire with an electric current running through it, creating a magnetic field. The unit for inductance is the henry (H).

- Inductor opposes the rate of change of current flowing through it due to the build up of self-induced energy within its magnetic field.




$$V_L(t) = \frac{d\phi}{dt} = \frac{dLi}{dt} = -L\frac{di}{dt}$$



- Where: L is the self-inductance and di/dt the rate of current change.

- So from this equation we can say that the “Self-induced emf equals Inductance times the rate of current change” and a circuit has an inductance of 1 Henry will have an emf of 1 volt induced in the circuit when the current flowing through the circuit changes at a rate of 1 ampere per second.

# Impedance

**Inductive reactance**

$$X_L = \omega L = 2\pi f L$$

**Capacitive reactance**

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

**Impedance (measured in Ohms) consists of both resistance & reactance:**

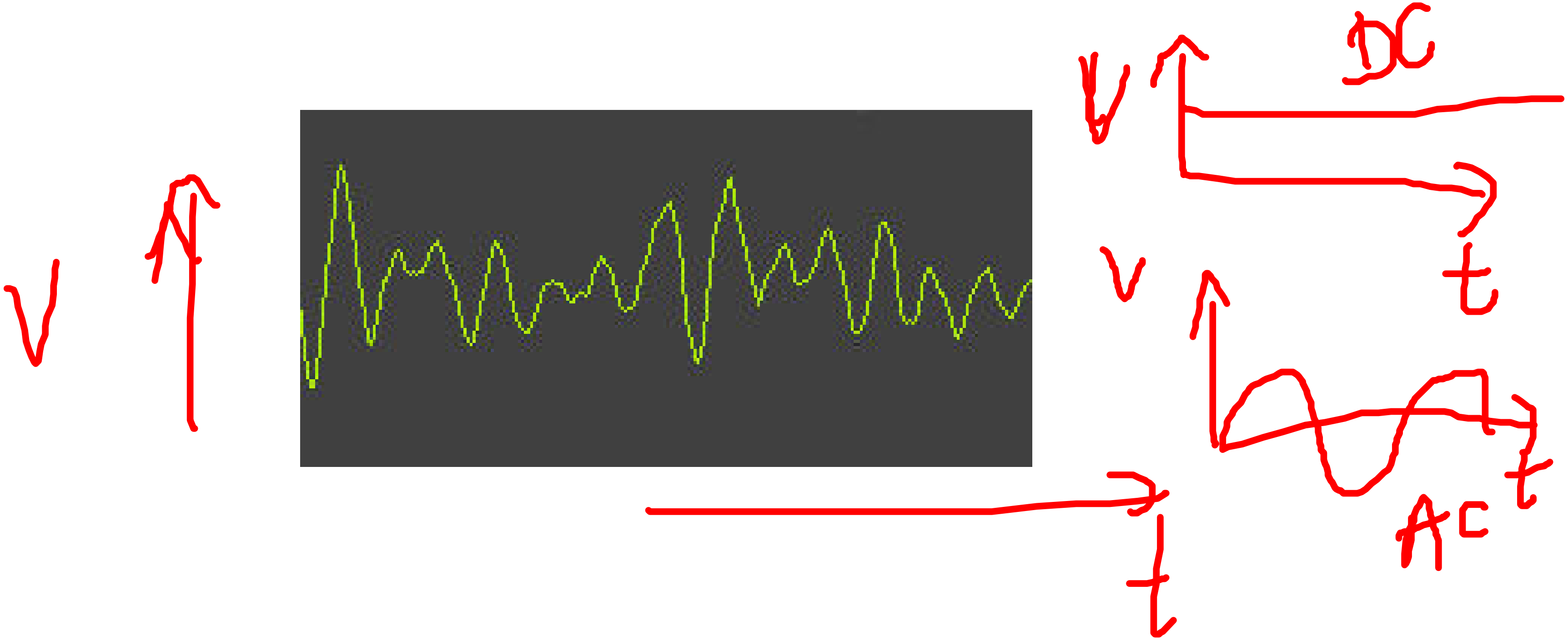
$$\mathbf{Z} = R + \mathbf{j}X$$

- **When both a capacitor and an inductor are placed in series in a circuit, their contributions to the total circuit impedance are opposite.**

$$X = X_L + X_C = \omega L - \frac{1}{\omega C}$$

# Electrical Waveform

- **Electrical Waveforms** are basically visual representations of the variation of a voltage or current over time.
- If we plot these voltage or current variations on a piece of graph paper against a base (x-axis) of time ( t ) the resulting plot would represent the shape of a Waveform as shown.



# Electrical Waveform-Charecteristics

1. **Time Period**: – This is the length of time in seconds that the waveform takes to repeat itself from start to finish. This value can also be called the Periodic Time, ( T ) of the waveform for sine waves, or the Pulse Width for square waves.

2. **Frequency**: – This is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ( $f$ = 1/T ) with the standard unit of frequency being the Hertz, (Hz).

Then Hertz can also be defined as “cycles per second” (cps) and 1Hz is exactly equal to 1 cycle per second.

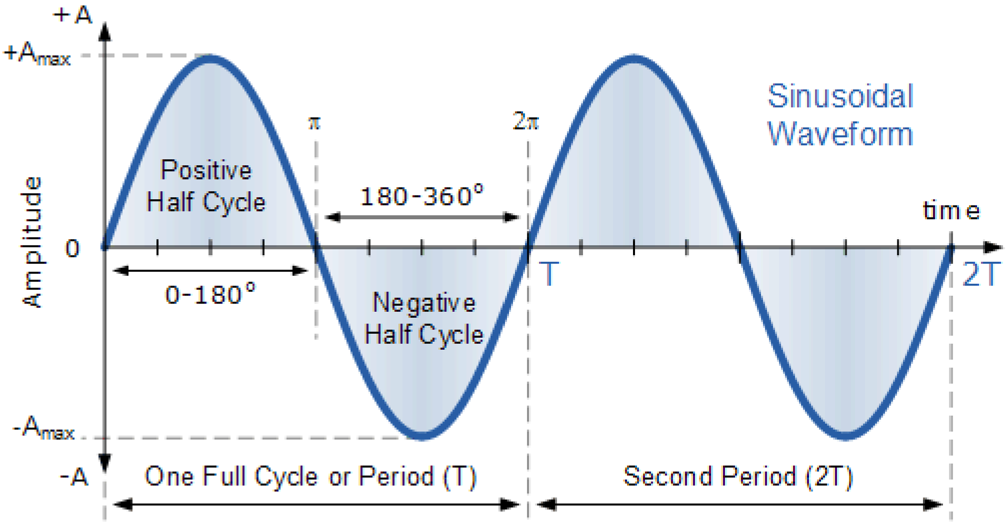
$$\text{Frequency} = \frac{1}{\text{Periodic time}} \quad \text{or} \quad f = \frac{1}{T}\ \text{Hz}$$

$$\text{Periodic time} = \frac{1}{\text{Frequency}} \quad \text{or} \quad T = \frac{1}{f}\ \text{sec}$$

3. **Amplitude**: – This is the magnitude or intensity of the signal waveform measured in volts or amps.

# Periodic Waveforms

- Periodic waveforms are the most common of all the electrical waveforms as it includes Sine Waves.
- The AC (Alternating Current) mains waveform in your home is a sine wave and one which constantly alternates between a maximum value and a minimum value over time.



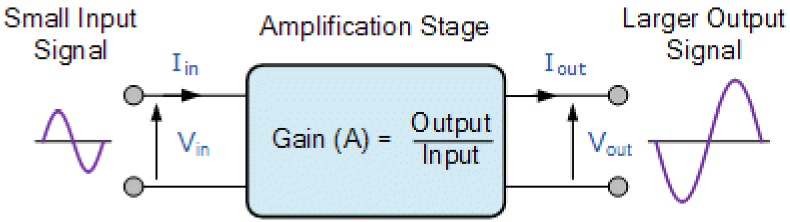
# Gain & Loss

- **Attenuator** circuit causes loss of energy by reducing the signal level.
- **Amplifiers** circuit enhances the enregy by amplifying the signal.
- To show the loss or gain of energy the unit “decibel” is used.

$$dB = 10 \log_{10} (P_2/P_1)$$

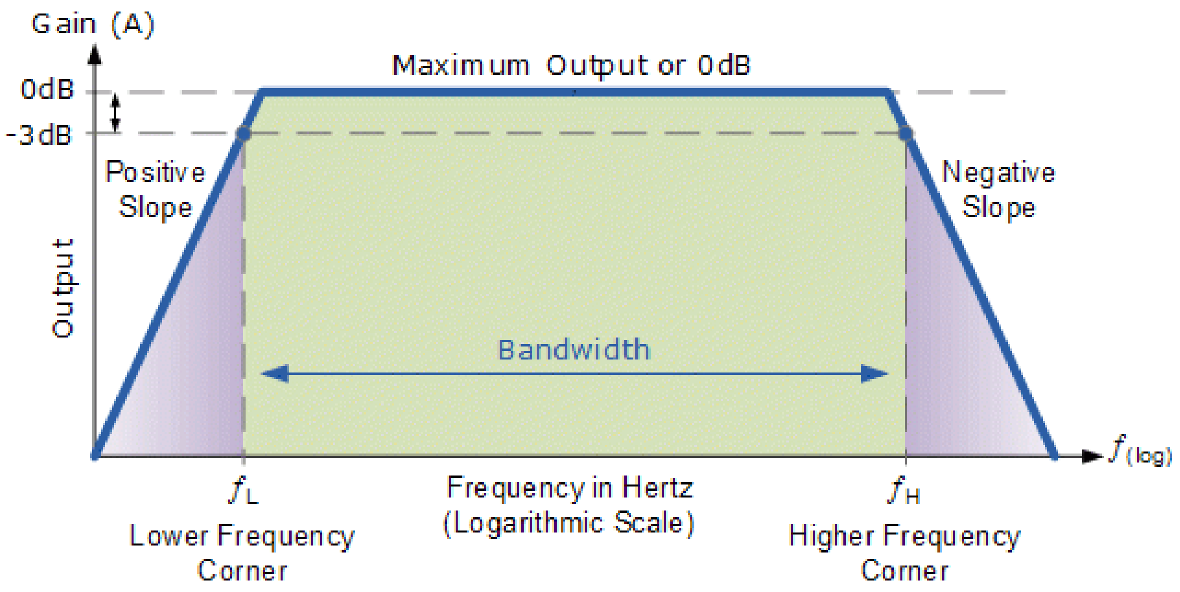
$P_1$ - input signal

$P_2$ - output signal



# Frequency Response

- Frequency Response of an amplifier or filter shows how the output gain responds to input signals at different frequencies.



# Frequency Response

- Frequency Response of an electric or electronics circuit allows us to see exactly how the output gain (known as the magnitude response) changes at a particular single frequency, or over a whole range of different frequencies from 0Hz, (d.c.) to many thousands of mega-hertz, (MHz) depending upon the design characteristics of the circuit.

- Generally, the frequency response analysis of a circuit or system is shown by plotting its gain (i.e. Output/Input) against a frequency scale over which the circuit or system is expected to operate.

- Then by knowing the circuits gain, (or loss) at each frequency point helps us to understand how well (or badly) the circuit can distinguish between signals of different frequencies.

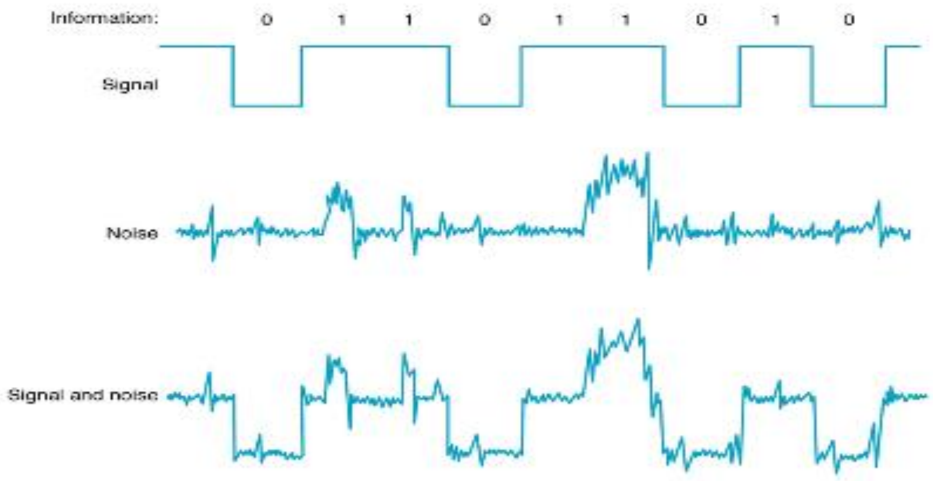
- Most modern audio amplifiers have a flat frequency response as shown above over the whole audio range of frequencies from 20 Hz to 20 kHz. This range of frequencies, for an audio amplifier is called its Bandwidth, (BW) and is primarily determined by the frequency response of the circuit.

$$\text{Bandwidth, (BW)} = f_H - f_L$$

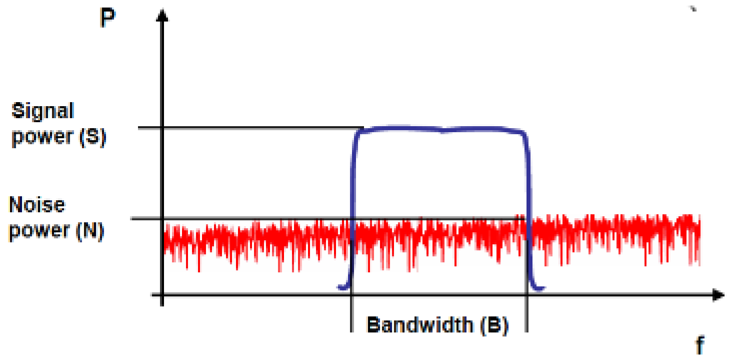
- Frequency points $f_L$ and $f_H$ relate to the lower cornero cut-off frequency and the upper corner cut-off frequency points respectively where the circuits gain falls off to 50% of its maximum value.

# Noise

- "Any unwanted input" - UNDESIRABLE portion of an electrical signal
- Limits systems ability to process weak signals



# Noise Power

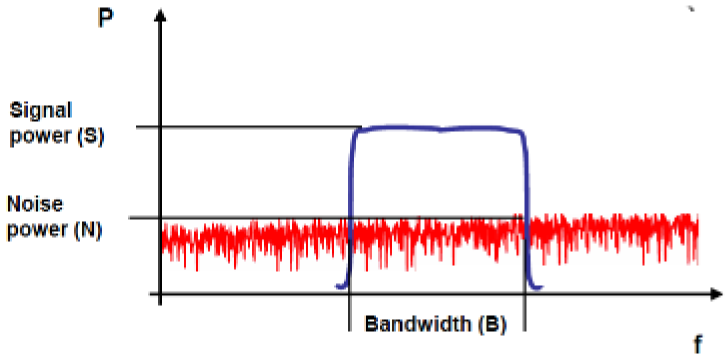



- Most of input noise = Thermal Noise
- Noise power $N_p = k_B T B$

$k_B$ = Boltzmann's constant 1.38x10 $^{-23}$ J/K
T = Absolute temperature of device
B = Circuit bandwidth

- Thermal noise is produced due to random motion of thermally agitated electrons.

# Noise Power




- Signal to Noise Ratio (SNR)

$$SNR = \frac{S(f)}{N(f)} = \frac{average - signal - power}{average - noise - power}$$

## Signal to Noise Ratio (SNR)

Signal to Noise ratio(SNR) is defined as the ratio of signal power to the noise power corrupting the signal.

SNR = average signal power/average noise power

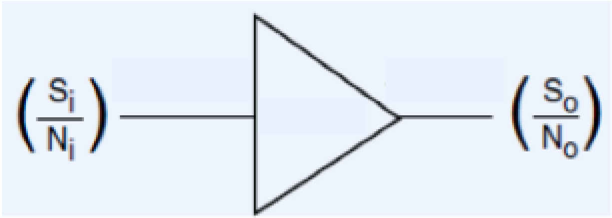
Because many signals have a very wide dynamic range, SNRs are often expressed using the logarithmic decibel scale

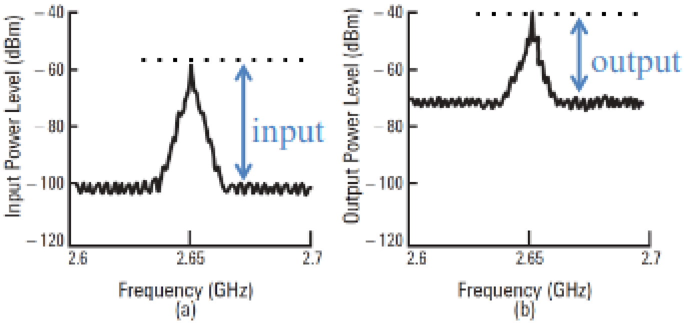
$$SNR_{dB} = 10 \log_{10}\left(\frac{P_{signal}}{P_{noise}}\right)$$

High SNR means the signal is less corrupted by noise

# Noise Figure

- Noise Figure




- Noise figure represents the degradation in signal/noise ratio as the signal passes through a device.

$$F = \frac{S_i/N_i}{S_o/N_o}$$

- F is always greater than 1.

# Noise Figure

- Noise Figure

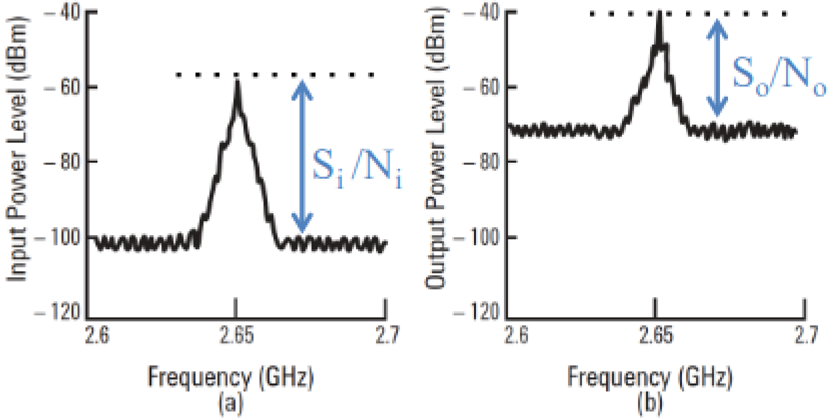
Noise Factor

$$F = \frac{S_i/N_i}{S_o/N_o}$$

Modern usage of "noise figure" usually is reserved for the quantity NF, expressed in dB units:

$$NF = 10 \log_{10} F \quad [\text{dB}]$$

$$\mathbf{NF = (Si/Ni)_{dB} - (So/No)_{dB}}$$




$(Si/Ni)_{dB} = 40$ dB

$(So/No)_{dB\,=} = 30$ dB

Noise Figure = 10 dB

# Numerical

1. If the signal power is 10mW and noise power is 1micro W.

Calculate SNR and SNRdb.

1. IF SNRdb is 35 db find SNR.

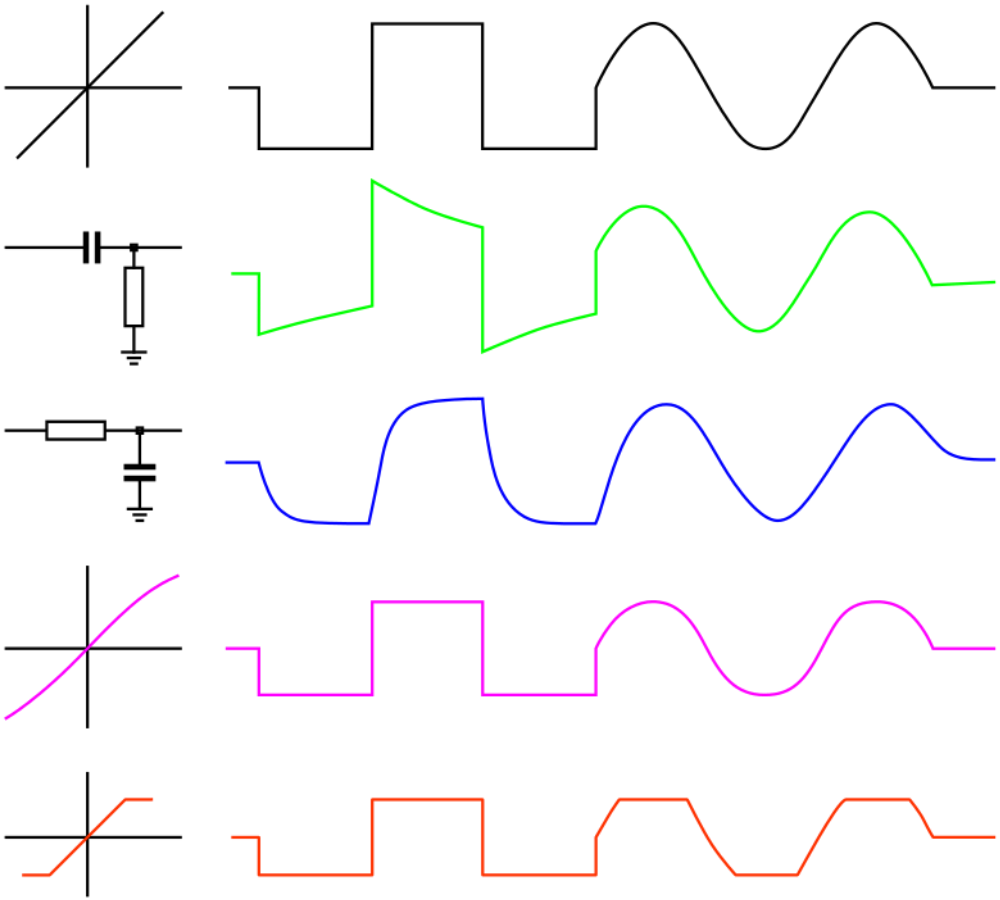
# Group Delay

- All frequency components of a signal are delayed when they pass though a filter.
- Group delay in a filter is the time delay of the signal through the device under test as a function of frequency.
- If we take the example of a modulated sine wave, for example an AM radio signal. Group delay is a measurement of the time taken by the modulated signal to get through the system.
- Group Delay is measured in seconds.
- For an ideal filter,  the group delay would be constant.
- However, in the real world group delay distortions occur, as signals at different frequencies take different amounts of time to pass through a filter.

# Distortion

- Distortion, in electronics, undesired change in an electric signal waveform as it passes from the input to the output of some system or device.
- In an audio system, distortion results in poor reproduction of recorded or transmitted sound. In passing through an electronic device, the amplitude of an input signal may be changed.
- For example, any voltage that is applied to an amplifier may be increased by a factor of 10. Amplitude distortion occurs when this factor is not the same for all input voltages.
- Frequency distortion occurs when the amplitudes of the different frequency components of an input signal are changed by a factor that is not the same for all frequencies.

# Distortion



# Digital measurement parameters

1. Delay
2. Jitter
3. BER
4. Eye Diagram

# Jitter

- Packets transmitted continuously on the network will have differing delays, even if they choose the same path.
- This is inherent in a packet-switched network for two key reasons. First, packets are routed individually. Second, network devices receive packets in a queue, so constant delay pacing cannot be guaranteed.
- This delay inconsistency between each packet is known as jitter.
- It can be a considerable issue for real-time communications, including IP telephony, video conferencing, and virtual desktop infrastructure.
- It causes packet loss and network congestion.
- In order to make up for jitter, a jitter buffer is used at the receiving endpoint of the connection. The jitter buffer collects and stores incoming packets, so that it may determine when to send them in consistent intervals.
- Static Jitter Buffer - Static jitter buffers are implemented within the hardware of the system and are typically configured by the manufacturer.
- Dynamic Jitter Buffer - Dynamic jitter buffers are implemented within the software of the system and are configured by the network administrator. They can adjust to fit network changes.

# Bit Error Rate

- In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors.
- The bit error rate (BER) is the number of bit errors per unit time. The bit error ratio (also BER) is also defined as the number of bit errors divided by the total number of transferred bits during a studied time interval.
- As an example, assume this transmitted bit sequence:

0 1 1 0 0 0 1 0 1 1

and the following received bit sequence:

0 0 1 0 1 0 1 0 0 1,

The number of bit errors (the underlined bits) is, in this case, 3. The BER is 3 incorrect bits divided by 10 transferred bits, resulting in a BER of 0.3 or 30%.

# Eye Diagram

- Eye diagram is a means of evaluating the quality of a received “digital waveform”
    - By quality is meant the ability to correctly recover symbols and timing.
    - The received signal could be examined at the input to a digital receiver or at some stage within the receiver before the decision stage.
- Eye diagrams reveal the impact of Inter Symbol Interference and noise.
- Two major issues are 1) sample value variation, and 2) jitter and sensitivity of sampling instant
- Eye diagram reveals issues of both.
- Eye diagram can also give an estimate of achievable BER.

# Vertical and Horizontal Eye Openings

- The vertical eye opening or noise margin is related to the SNR, and thus the BER
  - A large eye opening corresponds to a low BER
- The horizontal eye opening relates the jitter and the sensitivity of the sampling instant to jitter.
  - The red brace indicates the range of sample instants with good eye opening.
  - At other sample instants, the eye opening is greatly reduced, as governed by the indicated slope.