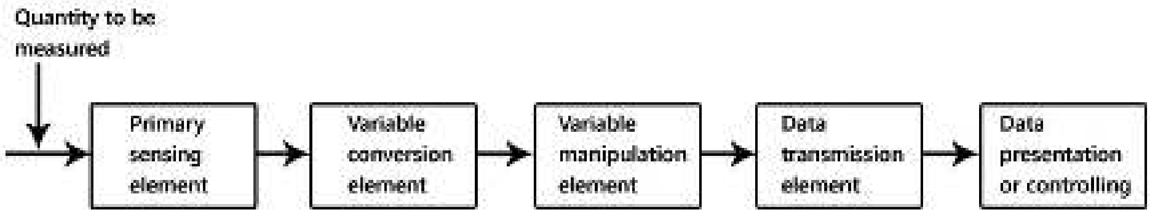
Block diagram of instrumentation:

It is branch of engineering which deals with various types of instrument to record, monitor, indicate and control various physical parameters such as pressure, temperature, etc.



Block diagram of instrumentation system

The block diagram shown above is of basic instrumentation system. It consists of primary sensing element, variable manipulation element, data transmission element and data presentation element.

Primary sensing element

The primary sensing element is also known as sensor. Basically transducers are used as a primary sensing element. Here, the physical quantity (such as temperature, pressure etc.) are sensed and then converted into analogues signal.

Variable conversion element

It converts the output of primary sensing element into suitable form without changing information. Basically these are secondary transducers.

Variable manipulation element

The output of transducer may be electrical signal i.e. voltage, current or other electrical parameter. Here, manipulation means change in numerical value of signal. This element is used to convert the signal into suitable range.

Data transmission element

Sometimes it is not possible to give direct read out of the quality at a particular place (Example – Measurement of temperature in the furnace). In such a case, the data should transfer from one place to another place through channel which is known as data transmission element. Typically transmission path are pneumatic pipe, electrical cable and radio links. When radio link is used, the electronic instrumentation system is called as telemetry system.

Data presentation or controlling element

Finally the output is recorded or given to the controller to perform action. It performs different functions like indicating, recording or controlling.

ERRORS IN SINSTRUMENTATION:

Measurement

Measurement is the foundation for all experimental science. All the great technological development could not have been possible without ever-increasing levels of accuracy of measurements. The measurement of an amount is based on some international standards, which are completely accurate compared with others. Just like your vegetable vendors, measurements are taken by comparing an unknown amount with a known weight. Every measurement carries a level of uncertainty which is known as an error. This error may arise in the process or due to a mistake in the experiment. So 100% accurate measurement is not possible with any method.

An error may be defined as the difference between the measured and actual values. For example, if the two operators use the same device or instrument for measurement. It is not necessary that both operators get similar results. The difference between the measurements is referred to as an ERROR.

To understand the concept of measurement errors, you should know the two terms that define the error. They are true value and measured value. The true value is impossible to find by experimental means. It may be defined as the average value of an infinite number of measured values. The measured value is a single measure of the object to be as accurate as possible.

Types of Errors

There are three types of errors that are classified based on the source they arise from; They are:

- Gross Errors
- Random Errors
- Systematic Errors

GROSS ERRORS:

This category basically takes into account human oversight and other mistakes while reading, recording, and readings. The most common human error in measurement falls under this category of measurement errors. For example, the person taking the reading from the meter of the instrument may read 23 as 28. Gross errors can be avoided by using two suitable measures, and they are written below:

- Proper care should be taken in reading, recording the data. Also, the calculation of error should be done accurately.
- By increasing the number of experimenters, we can reduce the gross errors. If each experimenter takes different readings at different points, then by taking the average of more readings, we can reduce the gross errors

RANDOM ERRORS:

The random errors are those errors, which occur irregularly and hence are random. These can arise due to random and unpredictable fluctuations in experimental conditions (Example: unpredictable fluctuations in temperature, voltage supply, mechanical vibrations of experimental set-ups, etc, errors by the observer taking readings, etc. For example, when the same person repeats the same observation, he may likely get different readings every time.

This article explored the various types of errors in the measurements we make. These errors are everywhere in every measurement we make.

SYSTEMATIC ERRORS:

Systematic errors can be better understood if we divide them into subgroups and they are:

- Environmental Errors
- Observational Errors
- Instrumental Errors

Environmental Errors: This type of error arises in the measurement due to the effect of the external conditions on the measurement. The external condition includes temperature, pressure, and humidity and can also include an externalmagnetic field. If you measure your temperature under the armpits and during the measurement, if the electricity goes out and the room gets hot, it will affect your body temperature, affecting the reading.

Observational Errors: These are the errors that arise due to an individual's bias, lack of proper setting of the apparatus, or an individual's carelessness in taking observations. The measurement errors also include wrong readings due to Parallax errors.

Instrumental Errors: These errors arise due to faulty construction and calibration of the measuring instruments. Such errors arise due to the hysteresis of the equipment or due tofriction. Lots of the time, the equipment being used is faulty due to misuse or neglect, which changes the reading of the equipment. The zero error is a very common type of error. This error is common in devices like Vernier callipers and screw gauges. The zero error can be either positive or negative. Sometimes the scale readings are worn off, which can also lead to a bad reading.

Instrumental error takes place due to:

- An inherent constraint of devices
- Misuse of Apparatus
- Effect of Loading

Errors Calculation

Different measures of errors include:

ABSOLUTE ERROR

The difference between the measured value of a quantity and its actual value gives the absolute error. It is the variation between the actual values and measured values. It is given by

Absolute error = |VA-VE|

PERCENT ERROR

It is another way of expressing the error in measurement. This calculation allows us to gauge how accurate a measured value is with respect to the true value. Per cent error is given by the formula

Percentage error (%) = (VA-VE) / VE) x 100

RELATIVE ERROR

The ratio of the absolute error to the accepted measurement gives the relative error. The relative error is given by the formula:

Relative Error = Absolute error / Actual value

How to Reduce Errors in Measurement

Keeping an eye on the procedure and following the below listed points can help to reduce the error.

- Make sure the formulas used for measurement are correct.
- Cross check the measured value of a quantity for improved accuracy.
- Use the instrument that has the highest precision.
- It is suggested to pilot test measuring instruments for better accuracy.
- Use multiple measures for the same construct.
- Note the measurements under controlled conditions.

Instrument parameters:

In order to avoid confusion and to obtain a consistent result, a set of units and standards have been commonly followed by all countries. Each instrument used is given a separate symbol which makes it easier for its identification and also for process control drawings. All the lists have been developed by The Instrument Society of America (ISA) and are being used worldwide.

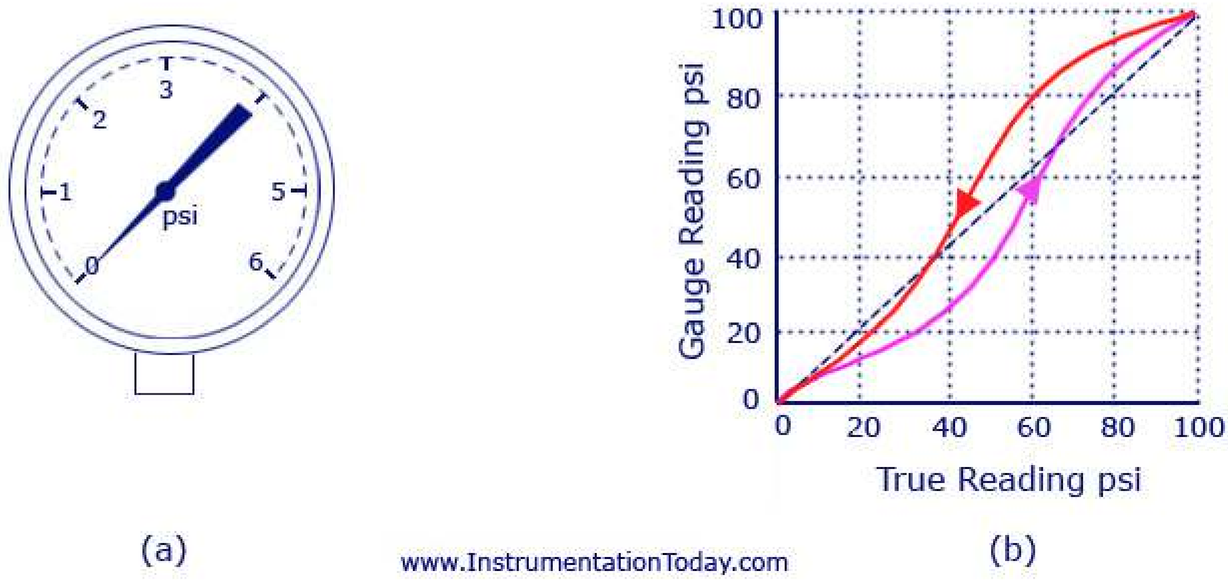
The units that are used for the measurement if different variables fall mainly under two categories. One is the International system, SI (System International D'Unités) and the other is the English system. The problem is that the latter is followed by very few countries including USA, but the former is followed by most of the other countries.

Parameters

There are some parameters that are to be checked during a process. They are all explained below.

- **Accuracy** – It is defined as the difference between the indicated value and the actual value. The actual value may be a known standard and accuracy is obtained by comparing it with the obtained value. If the difference is small accuracy is high and vice versa. Accuracy depends on several other parameters like hysteresis, linearity, sensitivity, offset, drift and so on. It is usually expressed as a percentage of span, percentage of reading or even absolute value. The standard value is set by the government so as to maintain the standard.
- **Reading accuracy:** is the deviation from true at the point the reading is being taken and is expressed as a percentage. Absolute accuracy of an instrument is the deviation from true as a number not as a percentage.
- **Span** – It can be defined as the range of an instrument from the minimum to maximum scale value. In the case of a thermometer, its scale goes from −40°C to 100°C. Thus its span is 140°C. As said before accuracy is defined as a percentage of span. It is actually a deviation from true expressed as a percentage of the span.
- **Precision** – It may be defined as the limits within which a signal can be read. For example if you consider an analog scale, which is set to graduate in divisions of 0.2 psi, the position of the needle of the instrument could be estimated to be within 0.02 psi. Thus the precision of the instrument is 0.02 psi.
- **Range** – It can be defined as the measure of the instrument between the lowest and highest readings it can measure. A thermometer has a scale from −40°C to 100°C. Thus the range varies from −40°C to 100°C.
- **Reproducibility** – It can be defined as the ability of an instrument to produce the same output repeatedly after reading the same input repeatedly, under the same conditions.
- **Sensitivity** – It can also be called as the transfer function of a process. It is the ratio between the changes in the output of an instrument to the corresponding change in the measured variable. For a good instrument or process, the sensitivity should always be high, thus producing higher output amplitudes.
- **Offset** – Offset is the reading of an instrument with zero input.

- **Drift** – Drift is the change in the reading of an instrument of a fixed variable with time.
- **Hysteresis** – It can be defined as the different readings taken down when an instrument approaches a signal from opposite directions. That is the corresponding value taken down as the instrument moves from zero to midscale will be different from that between the midscale and full scale reading. The reason is the appearance of stresses inside the instrument material due to the change of its original shape between the zero reading and the full scale reading.



Gauges (a) pressure gauge showing graduations; (b) hysteresis curve for an instrument

Hysteresis

- **Resolution** – It is the smallest difference in a variable to which the instrument will respond.
- **Repeatability** – It is a measure of the closeness of agreement between a number of readings (10 to 12) taken consecutively of a variable, before the variable has time to change. The average reading is calculated and the spread in the value of the readings taken.
- **Linearity** – It can be defined as a measure of the proportionality between the actual values of a variable being measured to the output of the instrument over its operating range.

Instrument applications

Aerospace and Defense: Instrumentation is used in aircraft, spacecraft, and defense systems for measurement, control, and monitoring purposes. Energy Systems: Instrumentation engineers work on instrumentation and control systems for power plants, renewable energy systems, and oil and gas facilities

In some cases, the sensor is a very minor element of the mechanism. Digital cameras and wristwatches might technically meet the loose definition of instrumentation because they record and/or display sensed information. Under most circumstances neither would be called instrumentation, but when used to measure the elapsed time of a race and to document the winner at the finish line, both would be called instrumentation.

Household

A very simple example of an instrumentation system is a mechanical thermostat, used to control a household furnace and thus to control room temperature. A typical unit senses temperature with a bi-metallic strip. It displays temperature by a needle on the free end of the strip. It activates the furnace by a mercury switch. As the switch is rotated by the strip, the mercury makes physical (and thus electrical) contact between electrodes.

Another example of an instrumentation system is a home security system. Such a system consists of sensors (motion detection, switches to detect door openings), simple algorithms to detect intrusion, local control (arm/disarm) and remote monitoring of the system so that the police can be summoned. Communication is an inherent part of the design.

Kitchen appliances use sensors for control.

- A refrigerator maintains a constant temperature by actuating the cooling system when the temperature becomes too high.
- An automatic ice machine makes ice until a limit switchis thrown.
- Pop-up breadtoasters allow the time to be set.
- Non-electronic gas ovens will regulate the temperature with a thermostatcontrolling the flow of gas to the gas burner. These may feature a sensor bulb sited within the main chamber of the oven. In addition, there may be a safety cut-off flame supervision device: after ignition, the burner's control knob must be held for a short time in order for a sensor to become hot, and permit the flow of gas to the burner. If the safety sensor becomes cold, this may indicate the flame on the burner has become extinguished, and to prevent a continuous leak of gas the flow is stopped.
- Electric ovens use a temperature sensor and will turn on heating elements when the temperature is too low. More advanced ovens will actuate fans in response to temperature sensors, to distribute heat or to cool.
- A common toilet refills the water tank until a float closes the valve. The float is acting as a water level sensor.

Automotive

Modern automobiles have complex instrumentation. In addition to displays of engine rotational speed and vehicle linear speed, there are also displays of battery voltage and current, fluid levels, fluid temperatures, distance travelled, and feedback of various controls (turn signals, parking brake, headlights, transmission position). Cautions may be displayed for special problems (fuel low, check engine, tire pressure low, door ajar, seat belt unfastened). Problems are recorded so they can be reported to diagnostic equipment. Navigation systems can provide voice commands to reach a destination. Automotive instrumentation must be cheap and reliable over long periods in harsh environments. There may be independentairbag systems that contain sensors, logic and actuators. **Anti-skid**braking systems use sensors to control the brakes, while cruise control affects throttle position. A wide variety of services can be provided via communication links on theOnStarsystem.Autonomous cars (with exotic instrumentation) have been shown.

Aircraft

Early aircraft had a few sensors."Steam gauges" converted air pressures into needle deflections that could be interpreted as altitude and airspeed. A magnetic compass provided a sense of direction. The displays to the pilot were as critical as the measurements.

A modern aircraft has a far more sophisticated suite of sensors and displays, which are embedded into avionicssystems. The aircraft may contain inertial navigation systems, global positioning systems, weather radar, autopilots, and aircraft stabilization systems. Redundant sensors are used for reliability. A subset of the information may be transferred to a crash recorderto aid mishap investigations. Modern pilot displays now include computer displays including head-up displays.

Air traffic control radar is a distributed instrumentation system. The ground part sends an electromagnetic pulse and receives an echo (at least). Aircraft carry transponders that transmit codes on reception of the pulse. The system displays an aircraft map location, an identifier and optionally altitude. The map location is based on sensed antenna direction and sensed time delay. The other information is embedded in the transponder transmission.

Laboratory instrumentation

Among the possible uses of the term is a collection of laboratory test equipment controlled by a computer through an IEEE-488 bus (also known as GPIB for General Purpose Instrument Bus or HPIB for Hewlitt Packard Instrument Bus). Laboratory equipment is available to measure many electrical and chemical quantities. Such a collection of equipment might be used to automate the testing of drinking water for pollutants.

DIGITAL VOLTEMETER:

It is an electrical instrument used for measuring the potential difference present between two points. These voltmeters are of two types

(i) Ana log voltmeter

(ii) Digital Voltmeter.

This measured voltage can be either of AC or DC,Analog voltmeters are made of a dial and a pointer to show the readings. But those instruments had many disadvantages like no accurate results, no precision etc, so those are replaced by digital voltmeters with a digital technology in it.

DVM: A digital voltmeter (**DVM**) displays the value of a.c. or d.c voltage being measured directly as discrete numerals in the decimal number system. Numerical readout of **DVM**s is advantageous since it eliminates observational errors committed by operators. The errors on account of parallax and approximations are entirely eliminated. The use of **digital voltmeters** increases the speed with which readings can be taken. Also, the output of digital voltmeters can be fed to memory devices for storage and future computations.

A digital voltmeter is a versatile and accurate voltmeter which has many laboratory applications. On account of developments in the integrated circuit (IC) technology, it has been possible to reduce the size, power requirements and cost of digital voltmeters. In fact, for the same accuracy, a **digital voltmeter** now is less costly than its analog counterpart. The decrease in the size of **DVM**s on account of the use of ICs, the portability of the instruments has increased.

The various **types of Digital Voltmeters (DVM's)** in general use are :

(i) Ramp type digital voltmeter

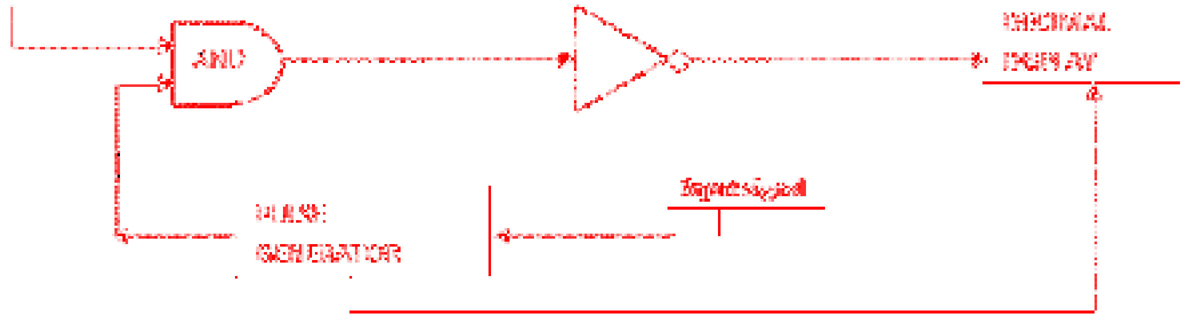
(ii) Integrating type digital voltmeter

(iii) Potentiometric type digital voltmeter

(iv) Successive approximation type digital voltmeter

(v) Continuous balance type digital voltmeter

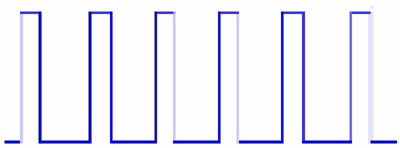
The circuits described here do not represent those of any specific make of a digital voltmeter. These circuits are being described merely to explain the voltage measuring principles on which these instruments operate.



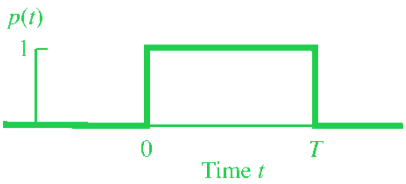
Working Principle of digital voltmeters:

From the above block diagram, the voltage to be measured is given to the input signal present in the circuit diagram. And next to this signal is processed onto the pulse generator which generates a train of rectangular pulses by using both analog and digital techniques.

The digital circuitry present inside the pulse generator will control the width and frequency while analog circuitry will control the amplitude, rise time and fall time of the pulse generator. When AND gate is fed with train pulse and rectangular pulse, it will give train pulses with the same duration of that of the rectangular pulse.

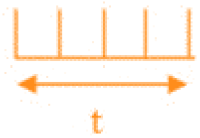


Train Pulse



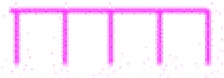
Rectangular pulse

OUTPUT of AND gate:



We can find the AND gate with not, so out will be inverted (NOT + AND)

OUTPUT of NOT gate:



Now the display screen will count duration and number of pulses and displays it on the screen. So here we used basic analog to digital conversion **working principle in the digital voltmeter**. Hence digital voltmeters can be made using the above analog to digital conversion principles.

In every case, the basic function that is performed is an analog to digital (A/D) conversion. For example, a voltage value may be changed to a proportional time interval, which starts and stops a clock oscillator. In turn, the oscillator output is applied to an electronic counter which is provided with readout in terms of voltage values.

Advantages of Digital Voltmeters:

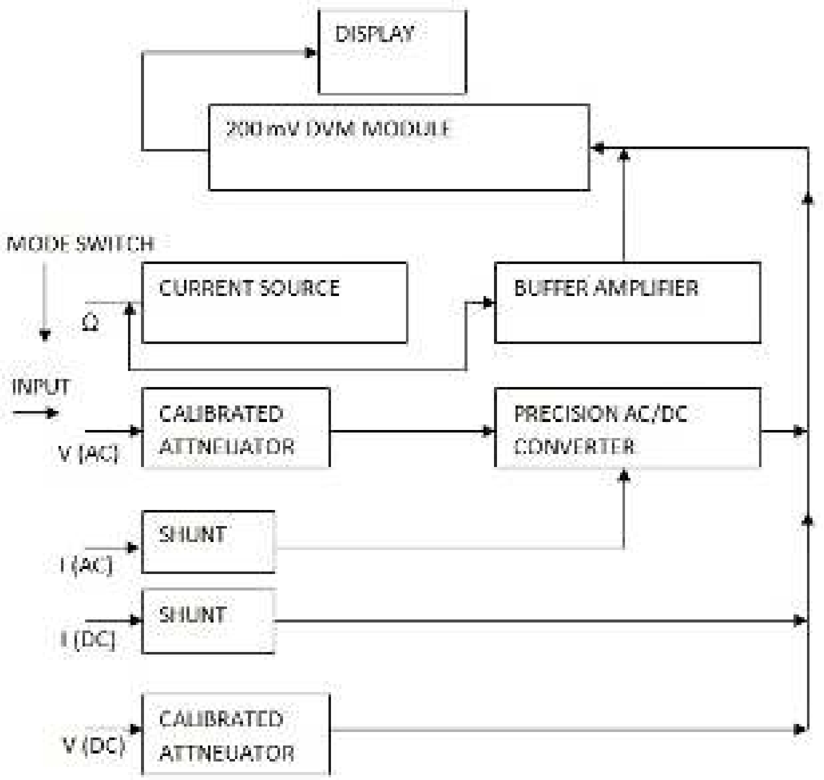
- Outputs on the screen are accurate without any errors
- Readings are taken faster
- Parallax error and approximation is entirely eliminated.
- Output can be stored in memory devices
- Versatile and accurate
- Power consumption is less

- Portable instrument
- Cheap cost and compact

Digital multimeter:

A digital multimeter is one that is capable of measuring voltage, current, of alternating current circuits as well as direct current circuits. In addition it must have a provision for measurement of resistance also. Then only it becomes the digital AVO meter.

As far as voltage measurement is concerned we have seen above the blocks required. For resistance measurement and current measurement we have to know the procedure. Both are indirect methods of measurement. We will be measuring only the voltage. However the reading can be made in amperes or ohms, when switched on to these modes.
The block diagram of digital multimeter is shown below. The 200 mV module is shown as one block. The rest of the blocks are interconnected to the 200 mV module as shown in Figure



The block diagram shows that the input terminal is connected to a mode selector switch. The other input terminal is a common terminal, generally referred as ground or negative terminal. The mode selector switch has five positions. Each position of the switch is marked with its function. In the first position of the switch the input goes to ohms select. ln this mode the input to the multimeter is an unknown resistance. As the unknown resistance has to form a part of the potential divider with the internal constant current source and range multiplier resistor, it is shown to be connected to the buffer amplifier. At the same time the block constant current generator is linked with the input terminal. Therefore the buffer amplifier will amplify only the voltage that is developed across the unknown resistance. The unknown resistance and the internal range resistor form a potential divider using the

current from the constant current source. Hence the resistance to voltage conversion is complete and the D.V.M. reads the resistance.

The second position of the range switch is marked as Volts (A.C.). The input signal as an unknown alternating voltage will go to the calibrated attenuator. The output of the attenuator will go to the precision AC to DC converter. The output of the AC/DC convener will go, to the DVM module. Selecting the proper range we can measure alternating voltage.

The third position of the switch is marked as current (A.C.). Hence the unknown current is to be measured. The internal shunt carries unknown current and the voltage developed across it will be converted in to steady voltage D.C.(voltage), by the AC/DC converter. As the converter's output is given to the D.V.M, module the current is displayed. Different shunts will be selected by a range selector used with the shunt circuit.

In the fourth position the direct current can be measured. The unknown current flows through the selected shunt (range selector is used). The voltage developed across this shunt goes to D.V.M. module. So in the fourth position of the mode selector we will be able to measure direct current. The fifth position is marked as volts D.C. The input is the unknown voltage. This voltage passes through a calibrated attenuator.

The range selection is done. The output of the attenuator goes to the D. V M. Thus the steady voltage or D.C. voltage can be measured. The other blocks that are not shown in the above simple block diagram are auto range circuit, auto polarity circuit, power supply, component testing circuit.

Digital ohmmeter:

The instrument, which is used to measure the value of resistance between any two points in an electric circuit, is called **ohmmeter**. It can also be used to find the value of an unknown resistor. The units of resistance are ohm and the measuring instrument is meter. So, the word "ohmmeter" is obtained by combining the words **"ohm"** and **"meter"**.

Types of Ohmmeters

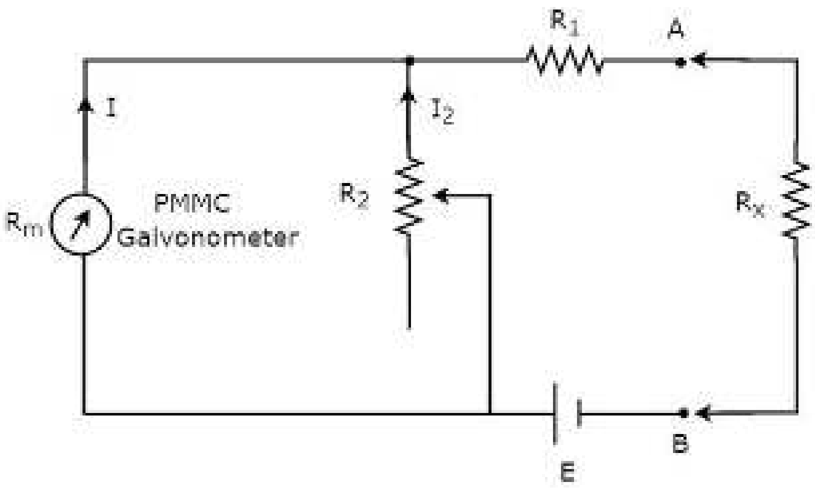
Following are the **two types** of ohmmeters.

- Series Ohmmeter
- Shunt Ohmmeter

Now, let us discuss about these two types of ohmmeters one by one.

Series Ohmmeter

If the resistor's value is unknown and has to be measured by placing it in series with the ohmmeter, then that ohmmeter is called series ohmmeter. The **circuit diagram** of series ohmmeter is shown in below figure.



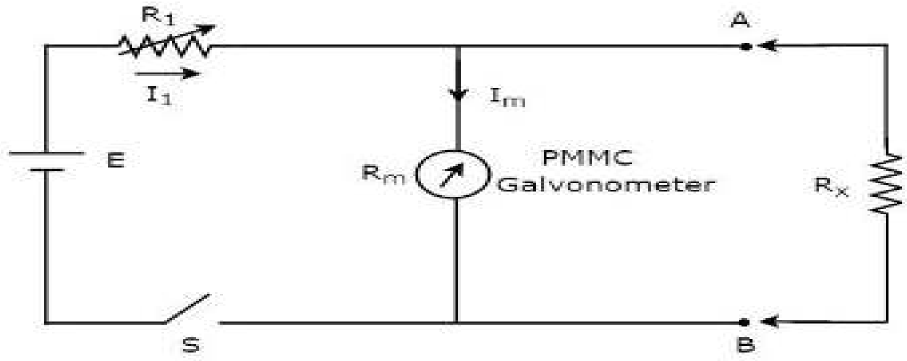
The part of the circuit, which is left side of the terminals A & B is **series ohmmeter**. So, we can measure the value of unknown resistance by placing it to the right side of terminals A & B. Now, let us discuss about the **calibration scale** of series ohmmeter.

- If $R_x = 0\Omega$, then the terminals A & B will be short circuited with each other. So, the meter current gets divided between the resistors, R_1 and R_2. Now, vary the value of resistor, R_2 in such a way that the entire meter current flows through the resistor, R_1 only. In this case, the meter shows full **scale deflection current**. Hence, this full scale deflection current of the meter can be represented as 0Ω.
- If $R_x = \infty\Omega$, then the terminals A & B will be open circuited with each other. So, no current flows through resistor, R_1. In this case, the meter shows null deflection current. Hence, this null deflection of the meter can be represented as $\infty\Omega$.
- In this way, by considering different values of R_x, the meter shows different deflections. So, accordingly we can represent those deflections with the corresponding resistance value.

The series ohmmeter consists of a calibration scale. It has the indications of $0\ \Omega$ and $\infty\Omega$ at the end points of right hand and left hand of the scale respectively. Series ohmmeter is useful for measuring **high values of resistances.**

Shunt Ohmmeter

If the resistor's value is unknown and to be measured by placing it in parallel (shunt) with the ohmmeter, then that ohmmeter is called shunt ohmmeter. The **circuit diagram** of shunt ohmmeter is shown in below figure.



The part of the circuit, which is left side of the terminals A & B is **shunt ohmmeter**. So, we can measure the value of unknown resistance by placing it to the right side of terminals A & B.

Now, let us discuss about the **calibration scale** of shunt ohmmeter. Close the switch, S of above circuit while it is in use.

- If $R_x=0\Omega$, then the terminals A & B will be short circuited with each other. Due to this, the entire current, I_1 flows through the terminals A & B. In this case, no current flows through PMMC galvanometer. Hence, the **null deflection** of the PMMC galvanometer can be represented as 0Ω.
- If $R_x=\infty\Omega$, then the terminals A & B will be open circuited with each other. So, no current flows through the terminals A & B. In this case, the entire current, I_1 flows through PMMC galvanometer. If required vary (adjust) the value of resistor, R_1 until the PMMC galvanometer shows full scale deflection current. Hence, this **full scale deflection** current of the PMMC galvanometer can be represented as $\infty\Omega$.
- In this way, by considering different values of R_x, the meter shows different deflections. So, accordingly we can represent those deflections with the corresponding resistance values.

The shunt ohmmeter consists of a calibration scale. It has the indications of 0Ω and $\infty\Omega$ at the end points of left hand and right hand of the scale respectively.

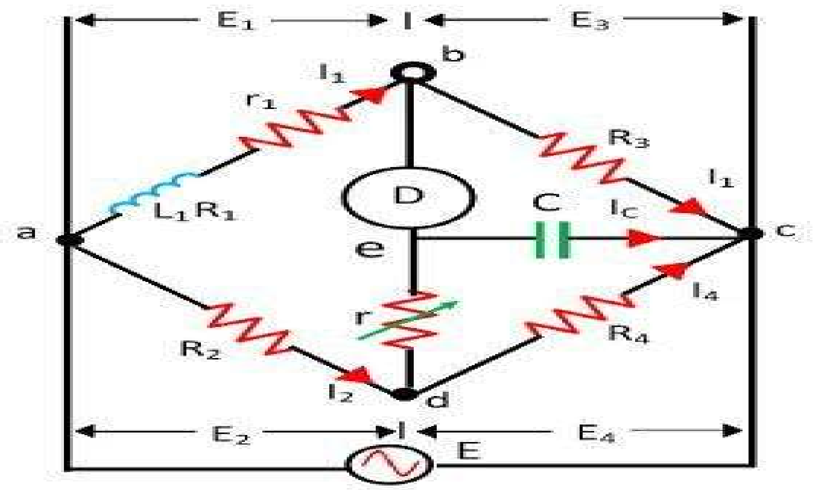
Shunt ohmmeter is useful for measuring **low values of resistances**. So, we can use either series ohmmeter or shunt ohmmeter based on the values of resistances that are to be measured i.e., high or low.

Anderson Bridge:

Definition: The **Anderson's bridge** gives the **accurate measurement** of **self-inductance** of the circuit. The bridge is the **advanced form** of **Maxwell's inductance capacitance bridge.** In Anderson bridge, the **unknown inductance** is compared with the **standard fixed capacitance** which is connected between the two arms of the bridge.

The bridge has fours arms **ab, bc, cd,** and **ad.** The arm **ab** consists unknown inductance along with the resistance.

And the other three arms consist the purely resistive arms connected in series with the circuit.

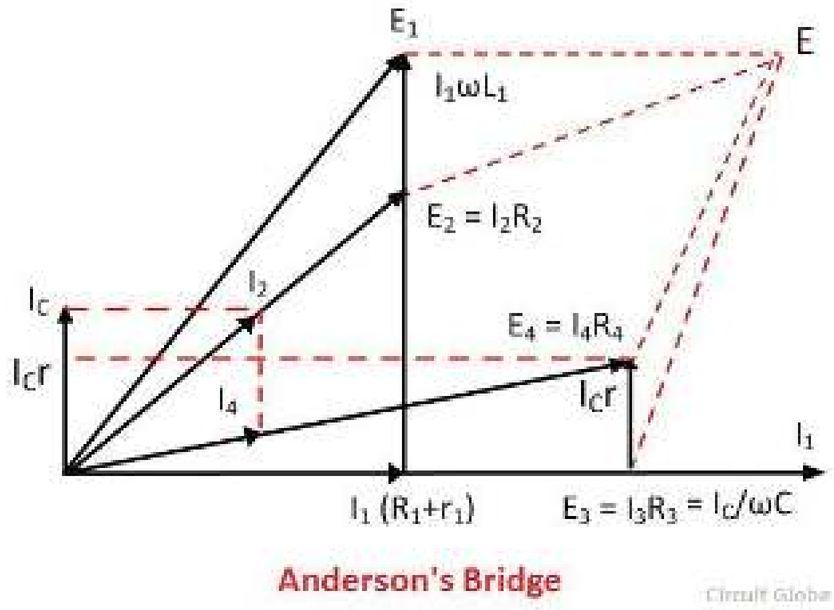


Anderson's Bridge

The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.

Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson bridge is shown in the figure below. The current $\mathbf{I_1}$ and the $\mathbf{E_3}$ are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec** are equal.



he current enters into the bridge is divided into the two parts $\mathbf{I_1}$ and $\mathbf{I_2}$. The $\mathbf{I_1}$ is entered into the arm **ab** and causes the voltage drop $\mathbf{I_1(R_1+R)}$ which is in phase with the $\mathbf{I_1}$. As the bridge is in the balanced condition, the same current is passed through the arms bc and **ec.**

The voltage drop $\mathbf{E_4}$ is equal to the sum of the $\mathbf{I_c/\omega C}$ and the $\mathbf{I_c\, r}$. The current $\mathbf{I_4}$ and the voltage $\mathbf{E_4}$ are in the same phase and representing on the same line of the phasor diagram. The sum of the current $\mathbf{I_c}$ and $\mathbf{I_4}$ will give rise to the current $\mathbf{I_2}$ in the arm **ad.**

When the bridge is at balance condition the emf across the arm **ab** and the point **a, d** and **e** are equal. The phasor sum of the voltage across the arms **ac** and **de** will give rise the voltage drops across the arm **ab**.

The $\mathbf{V_1}$ is also obtained by adding the $\mathbf{I_1(R_1+r_1)}$ with the voltage drop $\mathbf{\omega I_1 L_1}$ in the arm **AB**. The phasor sum of the $\mathbf{E_1}$ and $\mathbf{E_3}$ or $\mathbf{E_2}$ and $\mathbf{E_4}$ will give the supply voltage.

Theory of Anderson Bridge

Let, L_1 – unknown inductance having a resistance R_1.
R_2, R_3, R_4 – known non-inductive resistance
C_4 – standard capacitor

At balance Condition, $I_1 = I_3 \text{ and } I_2 = I_C + I_4$

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

Now, $I_C = I_1 \omega C R_3$

The other balance condition equation is expressed

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_C r$$

as $I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C)R_4$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

and $I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$

on equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1(\frac{R_1 R_2}{R_3} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2)$$

Equating the real and the imaginary part, we get

$$R_1 = \frac{R_1 R_3}{R_4} - r_1$$

$$L_1 = C\frac{R_3}{R_4}[4(R_4 + R_2) + R_2 R_4]$$

Advantages of Anderson Bridge

The following are the advantages of the Anderson's Bridge.

1. The balance point is easily obtained on the Anderson bridge as compared to Maxwell's inductance capacitance bridge.
2. The bridge uses fixed capacitor because of which accurate reading is obtained.
3. The bridge measures the accurate capacitances in terms of inductances.

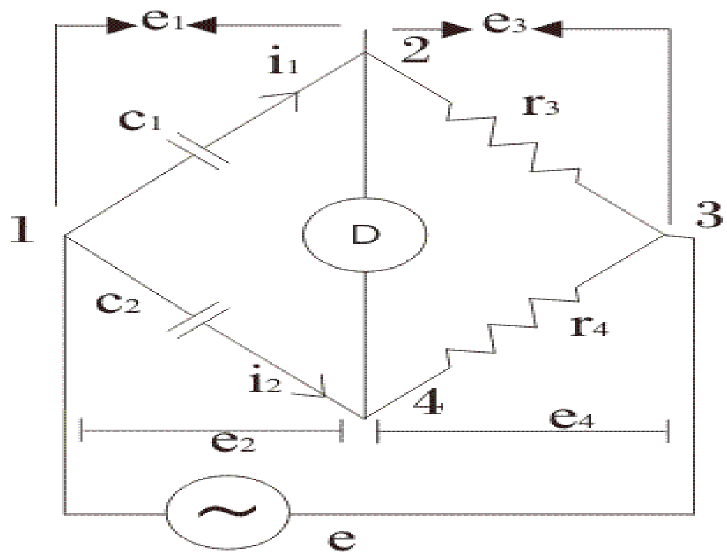
Disadvantages of Anderson Bridge

The main disadvantages of Anderson's bridge are as follow.

1. The circuit has more arms which make it more complex as compared to Maxwell's bridge. The equation of the bridge is also more complex.
2. The bridge has an additional junction which arises the difficulty in shielding the bridge.

DESAUTY BRIDGE:

This bridge provide us the most suitable method for comparing the two values of capacitor if we neglect dielectric losses in the bridge circuit. The circuit of **De Sauty's bridge** is shown below.



Battery is applied between terminals marked as 1 and 4. The arm 1-2 consists of capacitor c_1 (whose value is unknown) which carries current i_1 as shown, arm 2-4 consists of pure resistor (here pure resistor means we assuming it non inductive in nature), arm 3-4 also consists of pure resistor and arm 4-1 consists of standard capacitor whose value is already known to us.

Let us derive the expression for capacitor c_1 in terms of standard capacitor and resistors.

At balance condition we have,

$$\frac{1}{j\omega c_1} \times r_4 = \frac{1}{j\omega c_2} \times r_3$$

It implies that the value of capacitor is given by the expression

$$c_1 = c_2 \times \frac{r_4}{r_3}$$

In order to obtain the balance point we must adjust the values of either r_3 or r_4 without disturbing any other element of the bridge. This is the most efficient method of comparing the two values of capacitor if all the dielectric losses are neglected from the circuit.

Now let us draw and study the phasor diagram of this bridge. Phasor diagram of **De Sauty bridge** is shown below:

Let us mark the current drop across unknown capacitor as e_1, voltage drop across the resistor r_3 be e_3, voltage drop across arm 3-4 be e_4 and voltage drop across arm 4-1 be e_2. At balance condition the current flows through 2-4 path will be zero and also voltage drops e_1 and e_3 be equal to voltage drops e_2 and e_4 respectively.

In order to draw the phasor diagram we have taken e_3 (or e_4) reference axis, e_1 and e_2 are shown at right angle to e_1 (or e_2). Why they are at right angle to each other? Answer to this question is very simple as capacitor is connected there, therefore phase difference angle obtained is 90^o.

Now instead of some advantages like bridge is quite simple and provides easy calculations, there are some disadvantages of this bridge because this bridge give inaccurate results for imperfect capacitor (here imperfect means capacitors which not free from dielectric losses). Hence we can use this bridge only for comparing perfect capacitors.

Here we interested in modify the **De Sauty'sbridge**, we want to have such a kind of bridge that will gives us accurate results for imperfect capacitors also. This modification is done by Grover. The modified circuit diagram is shown below:

Here Grover has introduced electrical resistances r_1 and r_2 as shown in above on arms 1-2 and 4-1 respectively, in order to include the dielectric losses. Also he has connected resistances R_1 and R_2 respectively in the arms 1-2 and 4-1. Let us derive the expression capacitor c_1 whose value is unknown to us. Again we connected standard capacitor on the same arm 1-4 as we have done in **De Sauty's bridge**. At balance point on equating the voltage drops we have:

$$\left(R_1 + r_1 + \frac{1}{jwc_1}\right) r_4 \;=\; \left(R_2 + r_2 + \frac{1}{jwc_2}\right) r_3 \cdots\cdots\cdots (1)$$

On solving above equation we get:

$$\frac{c_1}{c_2} \;=\; \frac{R_2 + r_2}{R_1 + r_1} \;=\; r_4 r_3$$

This the required equation.

By making the phasor diagram we can calculate dissipation factor. Phasor diagram for the above circuit is shown below

Let us mark δ_1 and δ_2 be phase angles of the capacitors c_1 and c_2 capacitors respectively. From the phasor diagram we have tan(δ_1) = dissipation factor = $\omega c_1 r_1$ and similarly we have tan(δ_2) = $\omega c_2 r_2$.

From equation (1) we have

$$c_2 r_2 - c_1 r_1 = c_1 R_1 - c_2 R_2$$

on multiplying ω both sides we have

$$\omega c_2 r_2 - \omega c_1 r_1 \;=\; \omega(c_1 R_1 - c_2 R_2)$$

$$But\ \frac{c_1}{c_2} \;=\; \frac{r_4}{r_3}$$

Therefore the final expression for the dissipation factor is written as

$$tan(\delta_1) - tan(\delta_2) \;=\; \omega c_2 \left(R_1 \frac{r_4}{r_3} - R_2\right)$$

Hence if dissipation factor for one capacitor is known. However this method is gives quite inaccurate results for dissipation factor.

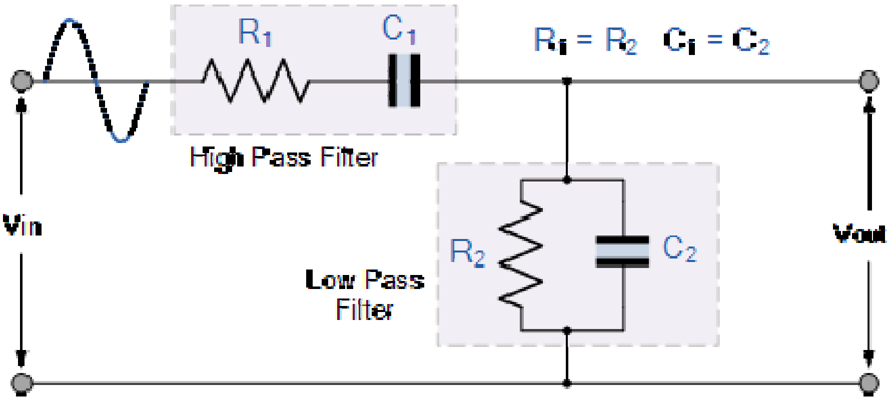
<u>Wien bridge oscillator</u>:

n the *RC Oscillator* tutorial we saw that a number of resistors and capacitors can be connected together with an inverting amplifier to produce an oscillating circuit. One of the simplest sine wave oscillators which uses a RC network in place of the conventional LC tuned tank circuit to produce a sinusoidal output waveform, is called a **Wien Bridge Oscillator**.

The **Wien Bridge Oscillator** is so called because the circuit is based on a frequency-selective form of the Wheatstone bridge circuit. The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune making it a popular circuit as an audio frequency oscillator but the phase shift of the output signal is considerably different from the previous phase shift **RC Oscillator**.

The **Wien Bridge Oscillator** uses a feedback circuit consisting of a series RC circuit connected with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency. At the resonant frequency fr the phase shift is 0^o. Consider the circuit below.

RC Phase Shift Network



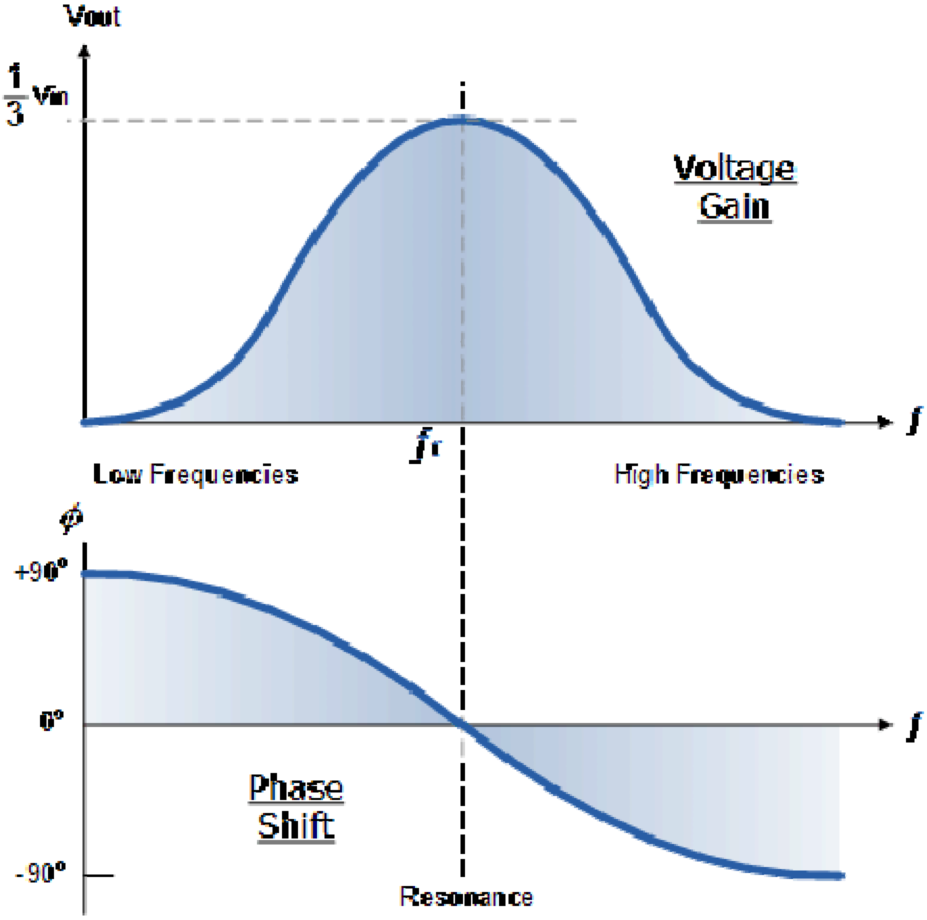
The above RC network consists of a series RC circuit connected to a parallel RC forming basically a High Pass Filter connected to a Low Pass Filter producing a very selective second-order frequency dependant Band Pass Filter with a high Q factor at the selected frequency, *ƒ*r.

At low frequencies the reactance of the series capacitor (C1) is very high so acts a bit like an open circuit, blocking any input signal at Vin resulting in virtually no output signal, Vout. Likewise, at high frequencies, the reactance of the parallel capacitor, (C2) becomes very low, so this parallel connected capacitor acts a bit like a short circuit across the output, so again there is no output signal.

So there must be a frequency point between these two extremes of C1 being open-circuited and C2 being short-circuited where the output voltage, V_{OUT} reaches its maximum value. The frequency value of the input waveform at which this happens is called the oscillators *Resonant Frequency*, (*ƒ*r).

At this resonant frequency, the circuits reactance equals its resistance, that is: Xc = R, and the phase difference between the input and output equals zero degrees. The magnitude of the output voltage is therefore at its maximum and is equal to one third (1/3) of the input voltage as shown.

Oscillator Output Gain and Phase Shift



It can be seen that at very low frequencies the phase angle between the input and output signals is "Positive" (Phase Advanced), while at very high frequencies the phase angle becomes "Negative" (Phase Delay). In the middle of these two points the circuit is at its resonant frequency, (fr) with the two signals being "in-phase" or 0^{o}. We can therefore define this resonant frequency point with the following expression.

Wien Bridge Oscillator Frequency

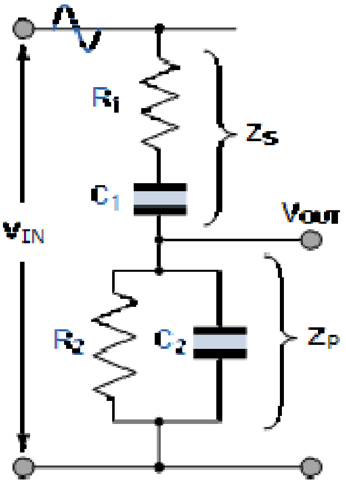
$$f_r = \frac{1}{2\pi RC}$$

- Where:
- fr is the Resonant Frequency in Hertz
- R is the Resistance in Ohms
- C is the Capacitance in Farads

We said previously that the magnitude of the output voltage, Vout from the RC network is at its maximum value and equal to one third (1/3) of the input voltage, Vin to allow for oscillations to occur. But why one third and not some other value. In order to understand why the output from the RC circuit above needs to be one-third, that is 0.333xVin, we have to consider the complex impedance (Z = R ± jX) of the two connected RC circuits.

We know from our AC Theory tutorials that the real part of the complex impedance is the resistance, R while the imaginary part is the reactance, X. As we are dealing with capacitors here, the reactance part will be capacitive reactance, Xc.

The RC Network



If we redraw the above RC network as shown, we can clearly see that it consists of two RC circuits connected together with the output taken from their junction. Resistor R_1 and capacitor C_1 form the top series network, while resistor R_2 and capacitor C_2 form the bottom parallel network.

Therefore the total DC impedance of the series combination (R_1C_1) we can call, Z_S and the total impedance of the parallel combination (R_2C_2) we can call, Z_P. As Z_S and Z_P are effectively connected together in series across the input, V_{IN}, they form a voltage divider network with the output taken from across Z_P as shown.

Lets assume then that the component values of R_1 and R_2 are the same at: 12kΩ, capacitors C_1 and C_2 are the same at: 3.9nF and the supply frequency, f is 3.4kHz.

Series Circuit

The total impedance of the series combination with resistor, R_1 and capacitor, C_1 is simply:

$$R = 12k\Omega, \quad \text{but} \quad X_C = \frac{1}{2\pi f C}$$

$$\therefore X_C = \frac{1}{2\pi \times 3.4kHz \times 3.9nF} = 12k\Omega$$

$$Z_S = \sqrt{R^2 + X_C^2} = \sqrt{12000^2 + 12000^2}$$

$$\therefore Z_S = 16{,}970\Omega \text{ or } 17k\Omega$$

We now know that with a supply frequency of 3.4kHz, the reactance of the capacitor is the same as the resistance of the resistor at 12kΩ. This then gives us an upper series impedance Z_S of 17kΩ.

For the lower parallel impedance Z_P, as the two components are in parallel, we have to treat this differently because the impedance of the parallel circuit is influenced by this parallel combination.

Parallel Circuit

The total impedance of the lower parallel combination with resistor, R_2 and capacitor, C_2 is given as:

$$R = 12k\Omega, \quad \text{and} \quad X_C = 12k\Omega$$

$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{XC} = \frac{1}{12000} + \frac{1}{12000}$$

$$\therefore Z = 6000\Omega \text{ or } 6k\Omega$$

At the supply frequency of 3400Hz, or 3.4kHz, the combined DC impedance of the RC parallel circuit becomes 6kΩ (R||Xc) with the vector sum of this parallel impedance being calculated as:

$$R = 6k\Omega, \quad \text{and} \quad X_C = 6k\Omega \quad (\text{Parallel})$$

$$Z_P = \sqrt{R^2 + X_C^2} = \sqrt{6000^2 + 6000^2}$$

$$\therefore Z_P = 8485\Omega \text{ or } 8.5k\Omega$$

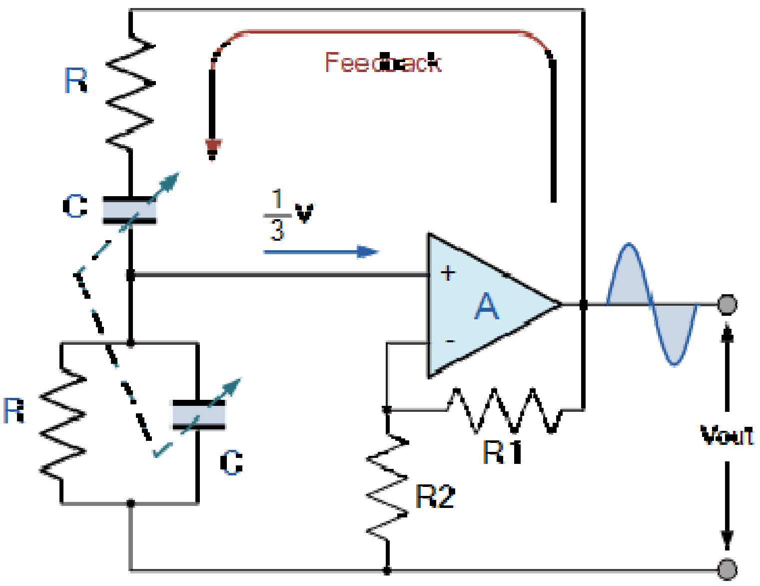
So we now have the value for the vector sum of the series impedance: 17kΩ, (Z_S = 17kΩ) and for the parallel impedance: 8.5kΩ, (Z_P = 8.5kΩ). Therefore the total output impedance, Zout of the voltage divider network at the given frequency is:

$$Z_{OUT} = \frac{Z_P}{Z_P + Z_S} = \frac{8.5k\Omega}{8.5k\Omega + 17k\Omega} = 0.333 \text{ or } \frac{1}{3}$$

Then at the oscillation frequency, the magnitude of the output voltage, Vout will be equal to Zout x Vin which as shown is equal to one third (1/3) of the input voltage, Vin and it is this frequency selective RC network which forms the basis of the **Wien Bridge Oscillator** circuit.

If we now place this RC network across a non-inverting amplifier which has a gain of 1+R1/R2 the following basic Wien bridge oscillator circuit is produced.

Wien Bridge Oscillator



The output of the operational amplifier is fed back to both the inputs of the amplifier. One part of the feedback signal is connected to the inverting input terminal (negative or degenerative feedback) via the resistor divider network of R1 and R2 which allows the amplifiers voltage gain to be adjusted within narrow limits.

The other part, which forms the series and parallel combinations of R and C forms the feedback network and are fed back to the non-inverting input terminal (positive or regenerative feedback) via the RC Wien Bridge network and it is this positive feedback combination that gives rise to the oscillation.

The RC network is connected in the positive feedback path of the amplifier and has zero phase shift a just one frequency. Then at the selected resonant frequency, (fr) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" so the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.

The voltage gain of the amplifier circuit MUST be equal too or greater than three "Gain = 3" for oscillations to start because as we have seen above, the input is 1/3 of the output. This value, ($Av \geq 3$) is set by the feedback resistor network, R1 and R2 and for a non-inverting amplifier this is given as the ratio 1+(R1/R2).

Also, due to the open-loop gain limitations of operational amplifiers, frequencies above 1MHz are unachievable without the use of special high frequency op-amps.

Wien Bridge Oscillator Example No1

Determine the maximum and minimum frequency of oscillations of a **Wien Bridge Oscillator** circuit having a resistor of 10kΩ and a variable capacitor of 1nF to 1000nF.

The frequency of oscillations for a Wien Bridge Oscillator is given as:

$$f_r = \frac{1}{2\pi RC}$$

Wien Bridge Oscillator Lowest Frequency

$$f_{min} = \frac{1}{2\pi(10k\Omega)\times(1000\times 10^{-9})} = 15.9\,Hz$$

Wien Bridge Oscillator Highest Frequency

$$f_{max} = \frac{1}{2\pi(10k\Omega)\times(1\times 10^{-9})} = 15{,}915\,Hz$$

PHASE LOCKED LOOP:

Phase Locked Loop **(PLL)** is one of the vital blocks in linear systems. It is useful in communication systems such as radars, satellites, FMs, etc.

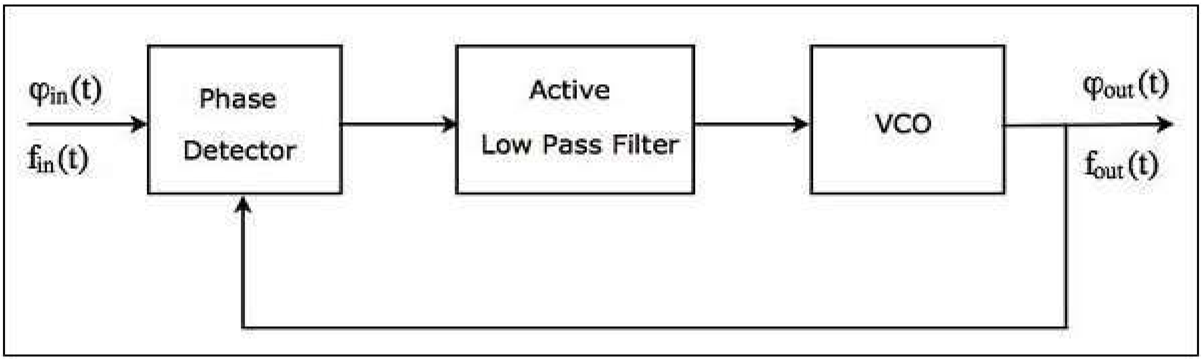
This chapter discusses about the block diagram of PLL and IC 565 in detail.

Block Diagram of PLL

A Phase Locked Loop (PLL) mainly consists of the following **three blocks** −

- Phase Detector
- Active Low Pass Filter
- Voltage Controlled Oscillator (VCO)

The **block diagram** of PLL is shown in the following figure −



The output of a phase detector is applied as an input of active low pass filter. Similarly, the output of active low pass filter is applied as an input of VCO.

The **working** of a PLL is as follows −

- **Phase detector** produces a DC voltage, which is proportional to the phase difference between the input signal having frequency of f_{in} and feedback (output) signal having frequency of f_{out}

• A**Phase detector** is a multiplier and it produces two frequency components at its output − sum of the frequencies f_{in} and f_{out} and difference of frequencies f_{in} & f_{out}.

- An **active low pass filter** produces a DC voltage at its output, after eliminating high frequency component present in the output of the phase detector. It also amplifies the signal.
- A **VCO** produces a signal having a certain frequency, when there is no input applied to it. This frequency can be shifted to either side by applying a DC voltage to it. Therefore, the frequency deviation is directly proportional to the DC voltage present at the output of a low pass filter.

The above operations take place until the VCO frequency equals to the input signal frequency. Based on the type of application, we can use either the output of active low pass filter or output of a VCO. PLLs are used in many **applications** such as FM demodulator, clock generator etc.

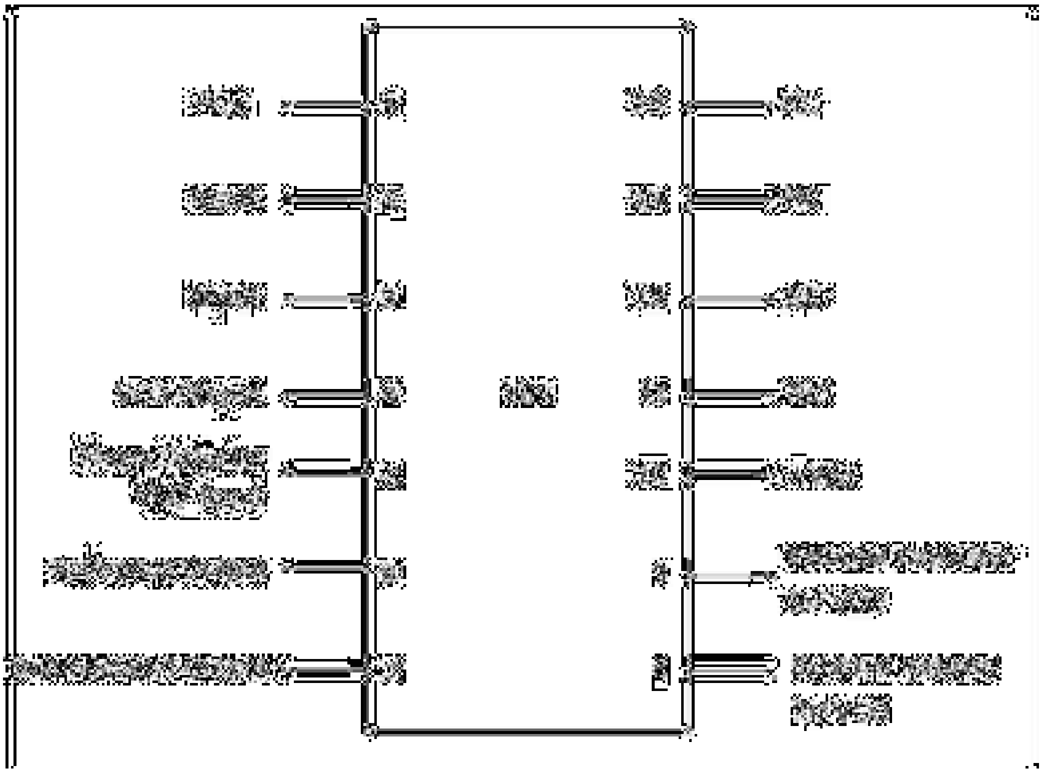
PLL operates in one of the **following three modes** −

- Free running mode
- Capture mode
- Lock mode

Initially, PLL operates in **free running mode** when no input is applied to it. When an input signal having some frequency is applied to PLL, then the output signal frequency of VCO will start change. At this stage, the PLL is said to be operating in the **capture mode**. The output signal frequency of VCO will change continuously until it is equal to the input signal frequency. Now, it is said to be PLL is operating in the **lock mode**.

IC 565

IC 565 is the most commonly used phase locked loop IC. It is a 14 pin Dual-Inline Package (DIP). The **pin diagram** of IC 565 is shown in the following figure −



The purpose of each pin is self-explanatory from the above diagram. Out of 14 pins, only 10 pins (pin number 1 to 10) are utilized for the operation of PLL. So, the remaining 4 pins (pin number 11 to 14) are labelled with NC (No Connection).

The **VCO** produces an output at pin number 4 of IC 565, when the pin numbers 2 and 3 are grounded. Mathematically, we can write the output frequency, f_{out} of the VCO as.

$$f_{out}=0.25R_VC_V$$

where, R_V is the external resistor that is connected to the pin number 8 and C_V is the external capacitor that is connected to the pin number 9By choosing proper values of R_V and C_V, we can fix (determine) the output frequency, f_{out} of VCO.**Pin numbers 4 and 5**are to be shorted with an external wire so that the output of VCO can be applied as one of the inputs of phase detector. IC 565 has an internal resistance of $3.6K\Omega$. A capacitor, C has to be connected between pin numbers 7 and 10 in order to make a **low pass filter** with that internal resistance.

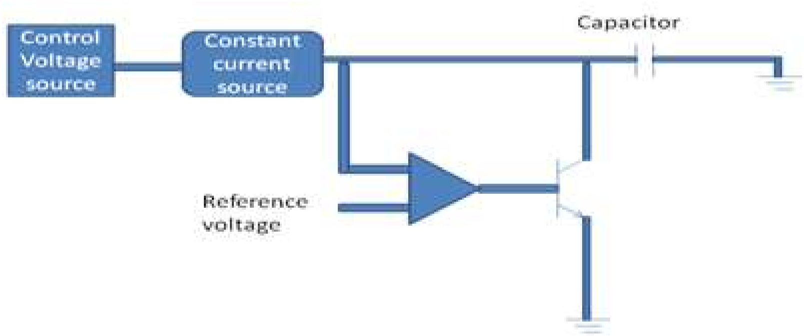
VOLTAGE CONTROLLED OSCILLLATOR:

A voltage-controlled oscillator is an oscillator with an output signal whose output can be varied over a range, which is controlled by the input DC voltage. It is an oscillator whose output frequency is directly related to the voltage at its input. The oscillation frequency varies from few hertz to hundreds of GHz. By varying the input DC voltage, the output frequency of the signalproduced is adjusted.

2 Types of Voltage Controlled Oscillators:

- Harmonic Oscillators: The output is a signal with a sinusoidal waveform. Examples are crystal oscillators and tank oscillators
- Relaxation Oscillators: The output is a signal with a sawtooth or triangular waveform and provides a wide range of operational frequencies. The output frequency depends on the time of charging and discharging of the capacitor.

Basic Working principle of Sawtooth waveform generator VCO



For a Voltage controlled oscillator generating a sawtooth waveform, the main component is the capacitor who’s charging and discharging decides the formation of the output waveform. The input is given in form a voltage that can be controlled. This voltage is converted to a current signal and is applied to the capacitor. As the current passes through the capacitor, it starts charging and a voltage starts building across it. As the capacitor charges and the voltage across it increase gradually, the voltage is compared with a reference voltage using a comparator.When the capacitor voltage exceeds the reference voltage, the comparator generates a high logic output that triggers the transistor, and the capacitor is connected to the ground and starts discharging. Thus the output waveform generated is the representation of the charging and discharging of the capacitor and the frequency is controlled by the input dc voltage.

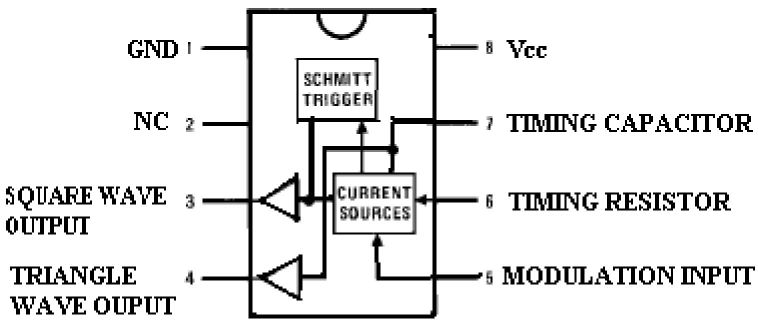
Applications of VCO

- Electronic jamming equipment.
- Function generator.
- Production of electronic music, for the production of different types of noise.
- Phase-locked loop.
- Frequency synthesizers, used in communication circuits.

A Practical VCO – LM566

A practical example of a voltage-controlled oscillator (VCO) is the LM566. The LM566 is a general-purpose VCO that may be used to generate square wave and triangular waveforms as a function input voltage.

The LM566 is specified for operation over 0˚C to 70˚C temperature range. The frequency of which is a linear function of a controlling voltage. The frequency is also controlled by an external resistor and capacitor, whose values control the free-running frequency.



Features:

- The maximum operating voltage is 10V to 24V
- High-temperature stability
- Operating temperature is 0˚C to 70˚C
- The frequency can be controlled using current, voltage, resistor or capacitor
- Power dissipation is 300mV
- Excellentpower supply rejection

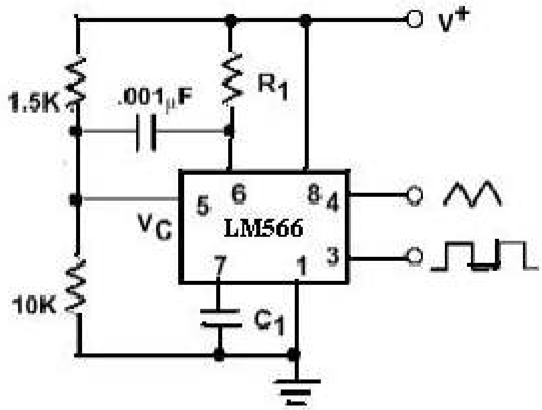
Applications:

- Function generator
- Tone generator
- FM modulation
- Frequency shift keying
- Clock generator.

Working of LM566:

The figure shows that the LM566 IC contains current sources to charge and discharge an external capacitor at a rate set by an external resistor R1 and the modulating dc input voltage V.A 0.001μF capacitor is connected to pin 5 and pin 6. A Schmitt trigger circuit is used to switch the current sources between charging and discharging the capacitor and the triangular voltage produced across the capacitor and square wave from the Schmitt trigger are provided as outputs through buffer amplifiers. Both the output waveforms are buffered so that the output impedance of each is 50 f2. The typical magnitude of the triangular wave and the square wave is 2.4Vpeak to peak and 5.4Vpeak to the peak. The free-running or center-operating frequency, f0 is

$$f_O = \frac{2\ (V^+ - V_C)}{R_1 C_1 V^+}$$



PULSE GENERATOR:

We have to differentiate between a square wave and pulse. The pulse and the square wave differ primarily in their duty cycle. Duty cycle is defined as the ratio of the average value of the pulse over one cycle in the peak value of the pulse.

As the average value and peak value are inversely related to their time duration the duty cycle can be defined in terms of the pulse width and the period or pulse repetition time.

Therefore duty cycle = Pulse width/Period

In a square wave the output voltage will have equal on and off times, such that the duty cycle is 0.5 or 50 %. The duty cycle remains unchanged even if the frequency is changed.

In case of a pulse the duty cycle is not constant, it may vary. Short durations of pulses give a low duty cycle. Short duration of pulse has the advantage that the dissipation of power in the component under test is low.

(a) Pulse Characteristics and Terminology:

The characteristics are explained hereunder:

(i) Raise Time : It is defined as the time required for the pulse to increase from 10% to 90% of its normal amplitude.

(ii) Fall Time : It is defined as the time required for the pulse to decrease from 90% to 10 % of its maximum amplitude

(iii) Over Shoot : An over shoot is defined as excess initial raise of amplitude beyond the correct value. It may be visible as a pip or ringing.

(iv) Droop or Sag : Sag is said to occur when the maximum amplitude of the pulse is not constant but decreases slowly,

b) Types of Pulse Generators :

There are two types of pulse generators. They are :

Active Pulse Generators
Passive Pulse Generators

The active pulse generators are relaxation oscillators. Multivibrators and blocking oscillators are the relaxation type pulse generators.

The passive pulse generators generate a sine wave in original and suitable wave shaping will be done to get the required wave shape.

(c) Pulse Generator :

Pulse generators usually have their range from I Hz to 10 MHz. A linearly calibrated dial will be provided. There will be provision for variation in the duty cycle. There will be two independent output terminals. The pulse generator can be free running or can also be synchronised with external signals.Pulse differs from a square wave in that it needs neither base line, nor left-right symmetry. Pulse generator consists of three parts called square wave generator (i.e. stable multivibrator). MonostableMultivibrator (i.e. one shot) and a attenuator.

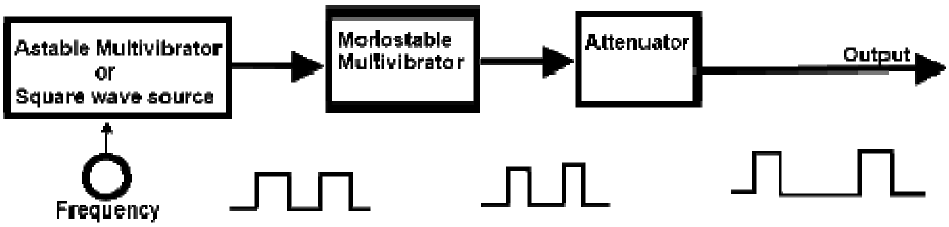


Figure 1: Pulse Generator Block Diagram

Figure 1 shows the block diagram to contract a pulse generator. A Monostablemultivibrator i.e. one shot follows a square wave oscillator. The pulse repetition rate is set by the square wave frequency. The one shot triggers on the leading edge of the square wave and produced me output pulse for each input cycle. The duration of each output pulse is set by the one time of the one shot, and may be either very short or may approach the period of the square wave.

Requirements of a Pulse:

1. The pulse should have minimum distortion, so that any distortion, in the display is solely due to the circuit under test.
2. The basic characteristics of the pulse are rise time, overshoot, ringing, sag, and undershoot.
3. The pulse should have sufficient maximum amplitude, if appreciable output power is required by the test circuit, e.g. for magnetic core At the same time, the attenuation range should be adequate to produce small amplitude pulses to prevent over driving of some test circuit.
4. The range of frequency control of the pulse repetition rate (PRR) should meet the needs of the experiment. For example, a repetition frequency of 100 MHz is required for testing fast circuits. Other generators have a pulse-burst feature which allows a train of pulses rather than a continuous
5. Some pulse generators can be triggered by an externally applied trigger signal; conversely, pulse generators can be used to produce trigger signals, when this output is passed through a differentiator circuit.
6. The output impedance of the pulse generator is another important In a fast pulse system, the generator should be matched to the cable and the cable to the test circuit. A mismatch would cause energy to be reflected back to the generator by the test circuit, and this may be re-reflected by the generator, causing distortion of the pulses.
7. DC coupling of the output circuit is needed, when dc bias level is to be

The basic circuit for pulse generation is the asymmetrical multi-vibrator. A laboratory type square wave and pulse generator is shown in Fig. 8.6.

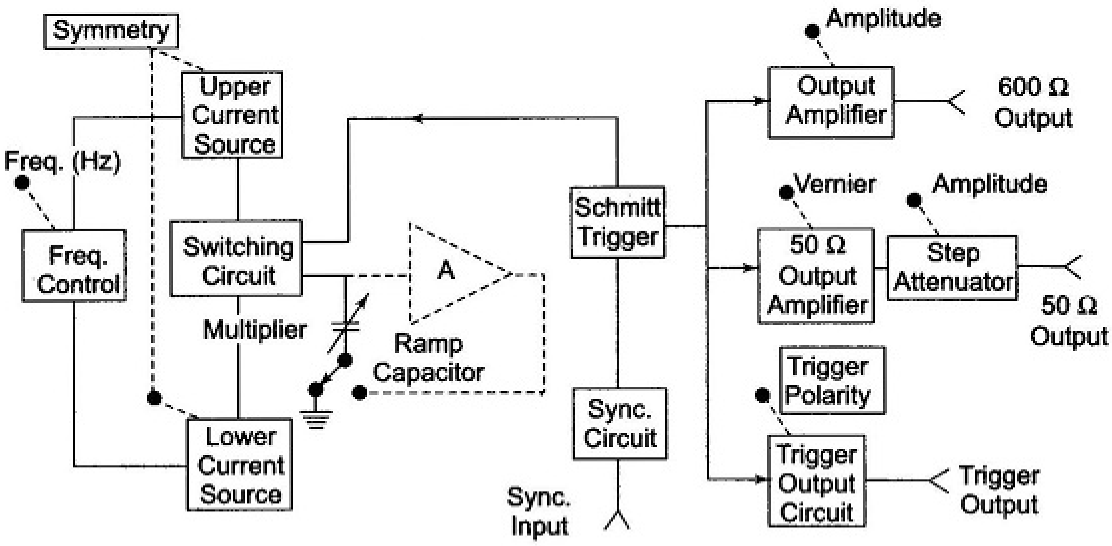


Fig. 8.6 Block Diagram of a Pulse Generator

The frequency range of the instrument is covered in seven decade steps from 1 Hz to 10 MHz, with a linearly calibrated dial for continuous adjustment on all ranges.

The duty cycle can be varied from 25 – 75%. Two independent outputs are available, a 50 Q source that supplies pulses with a rise and fall time of 5 ns at 5 V peak amplitude and a 600 Q source which supplies pulses with a rise and fall time of 70 ns at 30 V peak amplitude. The instrument can be operated as a free-running generator, or it can be synchronized with external signals.

The basic generating loop consists of the current sources, the ramp capacitor, the Schmitt trigger and the current switching circuit, as shown in Fig. 8.7.

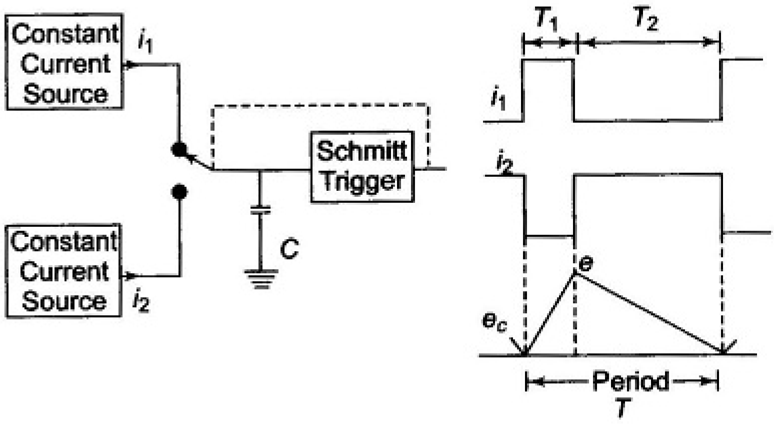


Fig. 8.7 Basic Generating Loop

The upper current source supplies a constant current to the capacitor and the capacitor voltage increases linearly. When the positive slope of the ramp voltage reaches the upper limit set by the internal circuit components, the Schmitt trigger changes state. The trigger circuit output becomes negative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by the lower current source. When the negative ramp reaches a predetermined lower level, the Schmitt trigger switches back to its original state. The entire process is then repeated. The ratio i_1/i_2 determines the duty cycle, and is controlled by symmetry control. The sum of i_1 and i_2 determines the frequency. The size of the capacitor is selected by the multiplier switch.

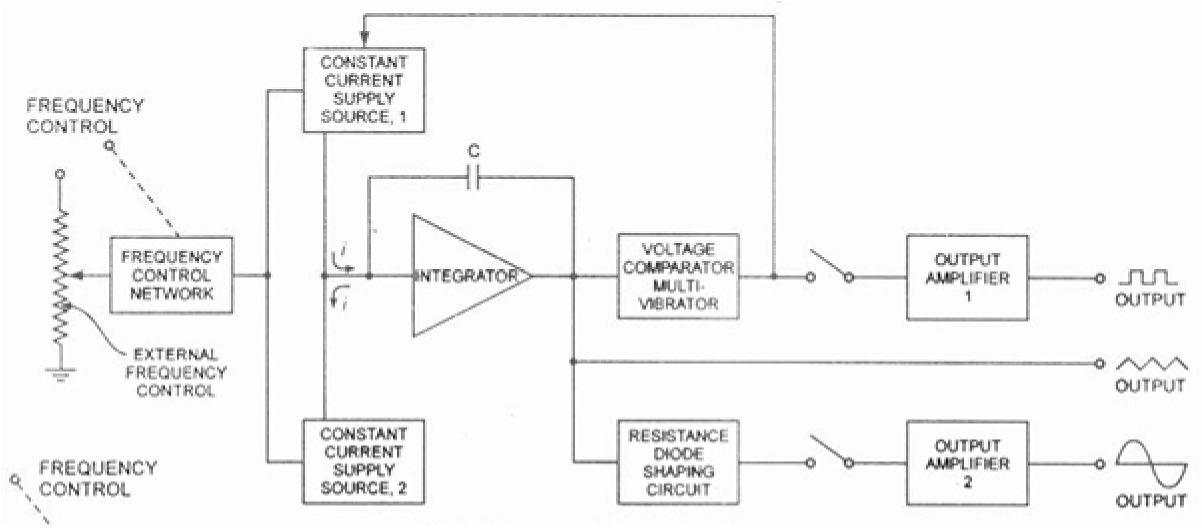
FUNCTION GENERATOR:

Definition: The function generator is defined as a type of device which produces various types of waveforms as its output signals. The common waveforms generated by this generator are sine wave, square wave, triangular wave, and Sawtooth waves. The waveforms of these frequencies may be adjusted from hertz to a hundred kHz. This generator is considered as the most versatile instrument in the electrical and electronics laboratory because the waveforms generated by this generator have applications in different areas.

The analog function generator and digital function generators are types of function generators. The advantages of an analog generator are cost-effective, simple to use, flexibility, amplitude and frequencies are adjustable. The advantages of digital generators are of high accuracy and stability. The main disadvantages of this digital generator are complicated and costly.

Function Generator Block Diagram

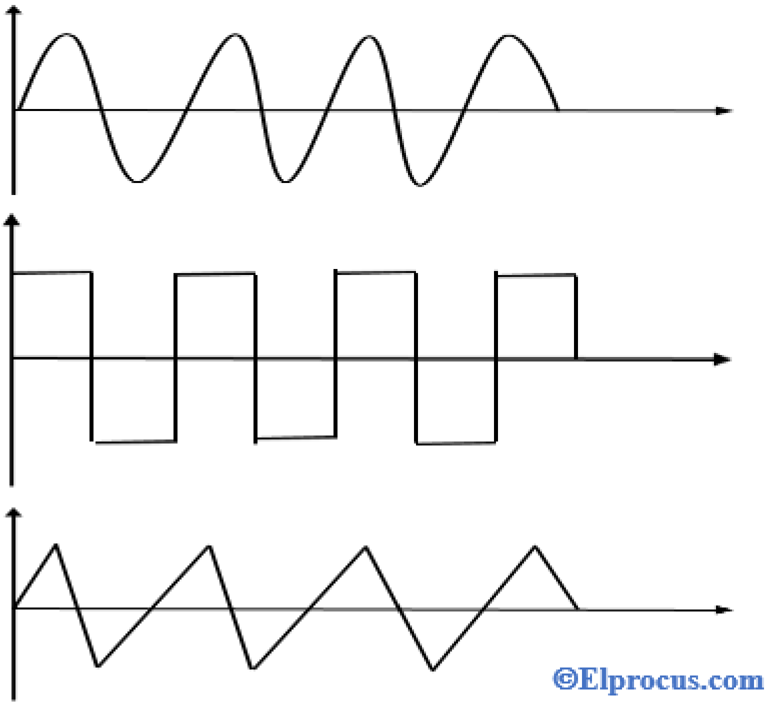
The block diagram of function generator contains various components they are frequency control network, constant current supply source 1, constant current supply source 2, integrator, voltage comparator multivibrator, capacitor, a resistance diode shaping circuit, and two output amplifiers. The block diagram of this generator is shown in the below figure.



Function Generator Block Diagram

The frequencies can be controlled by varying the current magnitude. The two constant-current supplies will change the frequency of the output signal. The output waveforms generated by this generator are sinusoidal, triangular, and square. The frequency range of these waveforms ranges from 0.01 Hz to 100 kHz. The frequency control network controls the frequency on the front panel of this generator, and there is a knob called frequency control. The frequency of the o/p waveforms can be changed by using this knob & varying the frequency.The frequency control network provides the voltage, and this voltage goes to regulate the two constant current supply sources like upper and lower. The first output voltage of constant current supply can be increased linearly with the time, whereas the lower current source provides a voltage to change the output voltage of the integrator which will decrease linearly with time. The output voltage of the integrator due to the upper current source is expressed.

When the slope of the o/p voltage increases or decreases then the constant current supply source 1 will be increases or decreases. The lower constant current source two supplies reverse control to the integrator, and due to this reverse current, the output voltage of the integrator decreases linearly with the time. The output of the comparator provides a square wave which has the same frequency as the output voltage. The resistance diode network changes the triangle waveform slope as its amplitude produces and changes a sine waveform with a <1% distortion. The output waveforms of this generator are shown below.

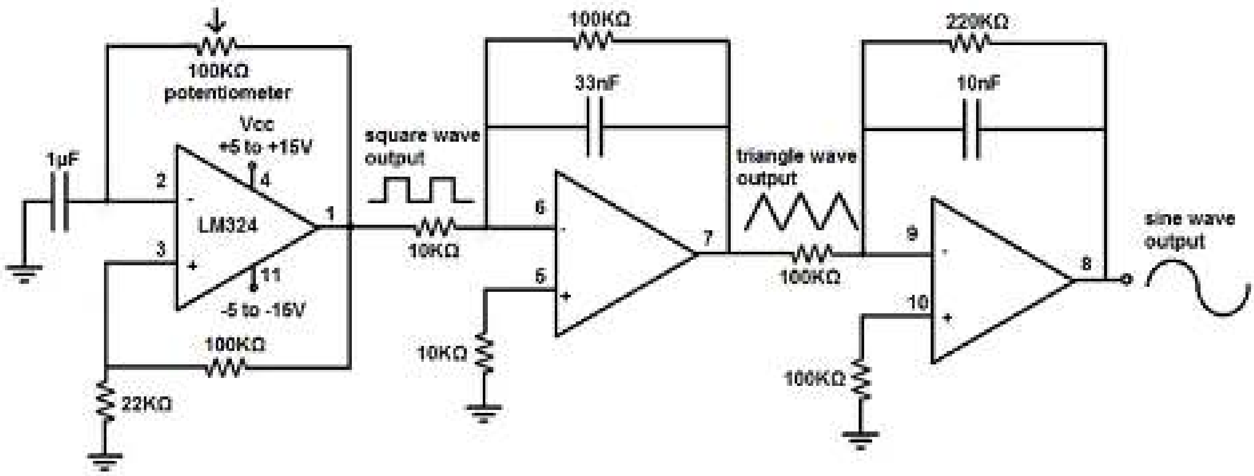


Output Waveforms of Function Generator

In this way, the three types of waveforms are produced by this generator which are having different frequencies. The clock source, timing margin test, dc power supply test, testing audio DAC are some of the applications of a function generator.

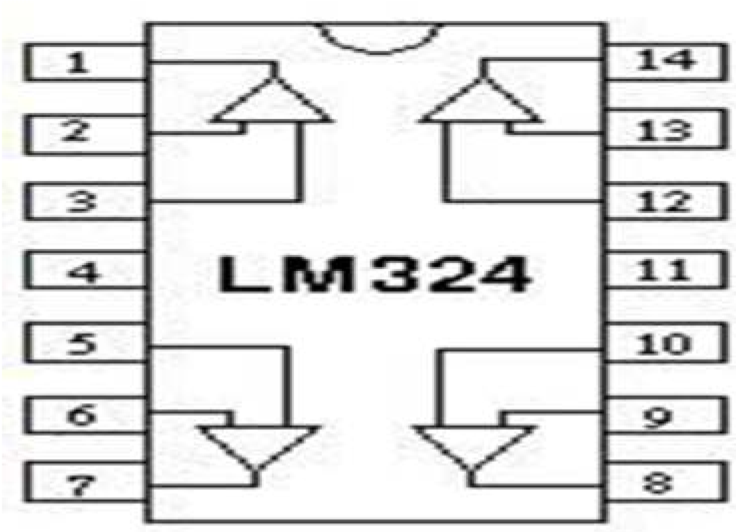
Function Generator Circuit Diagram with LM324 Op-Amp

The LM324 is a 14-pin integrated circuit, the circuit diagram of the function generator with LM324 is shown below. The components required for this circuit are LM324 op-amp chip, two 10kΩ resistors, four 100kΩ resistors, 22kΩ resistor, 220kΩ resistor, 1µF ceramic capacitor, 33 nF ceramic capacitor, 10nF capacitor, and 100k Ω potentiometer. The circuit contains three operational amplifiers, the first operational amplifier generates the square wave, the second operational amplifier generates the triangle wave output, and the third operational amplifier generates the sine wave output.



Function Generator Circuit Diagram with LM324 Op-Amp

The pin diagram of the LM324 IC is shown below.



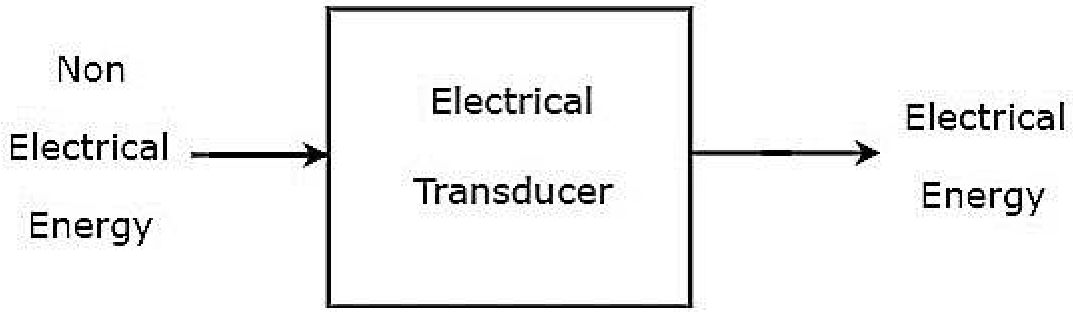
LM324 IC Pin Diagram

The LM324 is an integrated chip that consists of 14 pins. The pin 1, 7,8,14 are the output pins, pin 2,6,9,4 are the inverting input pins, and pin 3,5,10, 12 are the non-inverting input pins, pin 4 is the Vcc (power supply), and pin 11 is the ground.

:

TRANSDUCER

Basically, Transducer converts one form of energy into another form of energy. The transducer, which converts non-electrical form of energy into electrical form of energy is known as **electrical transducer**. The **block diagram** of electrical transducer is shown in below figure.



As shown in the figure, electrical transducer will produce an output, which has electrical energy. The output of electrical transducer is equivalent to the input, which has non-electrical energy.

Types of Electrical Transducers

Mainly, the electrical transducers can be classified into the following **two types**.

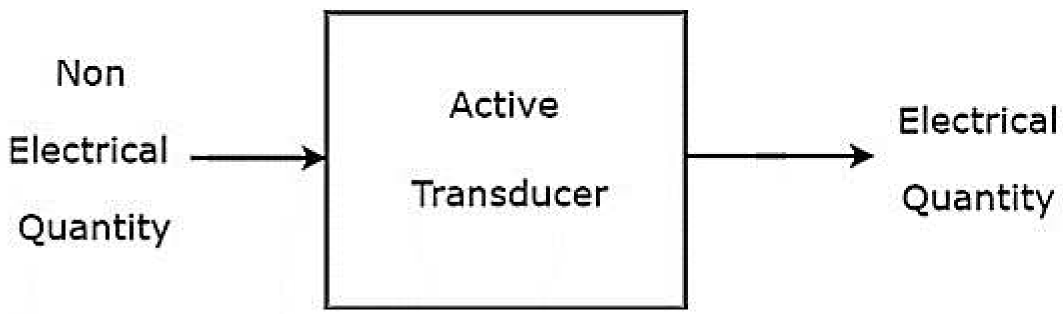
- Active Transducers
- Passive Transducers

Now, let us discuss about these two types of transducers briefly.

Active Transducers

The transducer, which can produce one of the electrical quantities such as voltage and current is known as **active transducer**. It is also called self-generating transducer, since it doesn't require any external power supply.

The **block diagram** of active transducer is shown in below figure.



As shown in the figure, active transducer will produce an electrical quantity (or signal), which is equivalent to the n.on-electrical input quantity (or signal).

Examples

Following are the examples of active transducers.

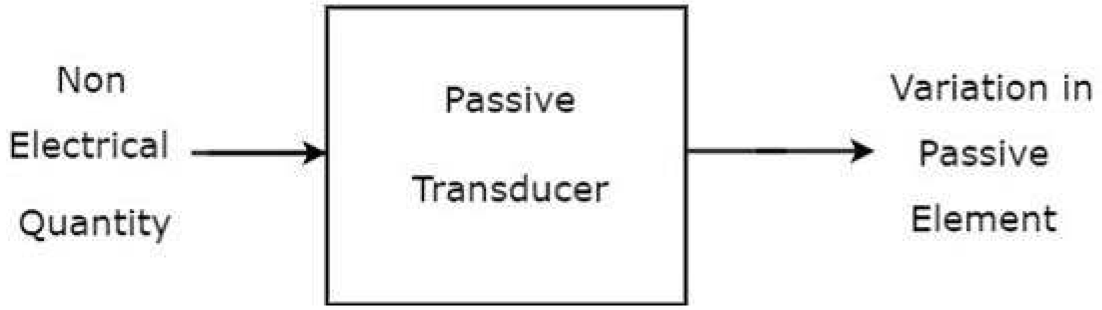
- Piezo Electric Transducer
- Photo Electric Transducer
- Thermo Electric Transducer

We will discuss about these active transducers in next chapter.

Passive Transducers

The transducer, which can't produce the electrical quantities such as voltage and current is known as **passive transducer**. But, it produces the variation in one of passive elements like resistor (R), inductor (L) and capacitor (C). Passive transducer requires external power supply.

The **block diagram** of passive transducer is shown in below figure.



As shown in the figure, passive transducer will produce variation in the passive element in accordance with the variation in the non-electrical input quantity (or signal).

Examples

Following are the examples of passive transducers.

- Resistive Transducer
- Inductive Transducer
- Capacitive Transducer

Active transducer is a transducer, which converts the non-electrical quantity into an electrical quantity. Let us consider the non-electrical quantities such as pressure, illumination of light and temperature. Hence, we will get the following three active transducers depending on the non-electrical quantity that we choose.

- Piezo Electric Transducer
- Photo Electric Transducer
- Thermo Electric Transducer

Now, let us discuss about these three active transducers one by one.

Piezo Electric Transducer

An active transducer is said to be **piezo electric transducer**, when it produces an electrical quantity which is equivalent to the pressure input. The following three substances exhibit piezo electric effect.

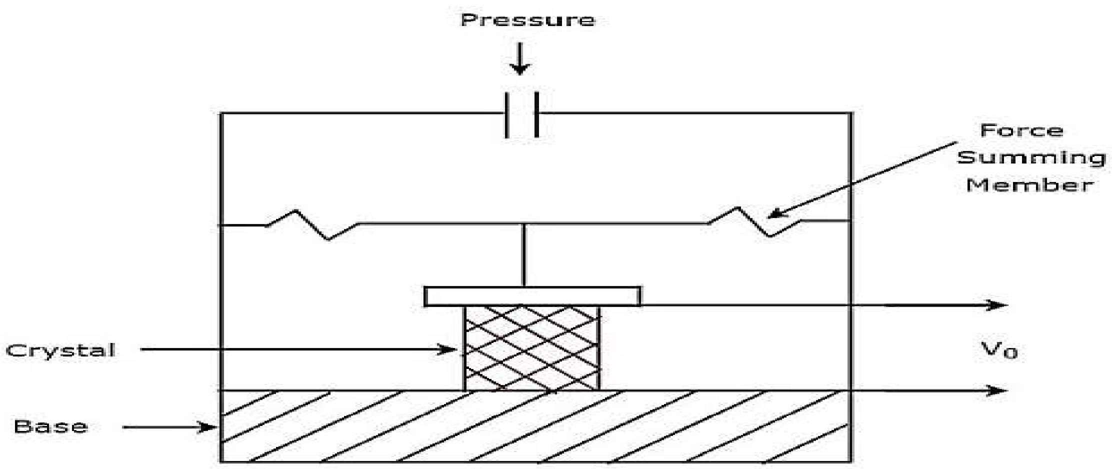
- Quartz
- Rochelle salts
- Tourmaline

The piezo-electric effect exhibited by these three substances is Tourmaline, Quartz, and Rochelle salts, in this ascending order. The ascending order of mechanical strength having by these three substances is Rochelle salts, Quartz, Tourmaline.

Quartz is used as piezo electric transducer, as it exhibits the moderate piezo electric effect and having moderate mechanical strength among those three piezo electric substances.

Quartz Transducer

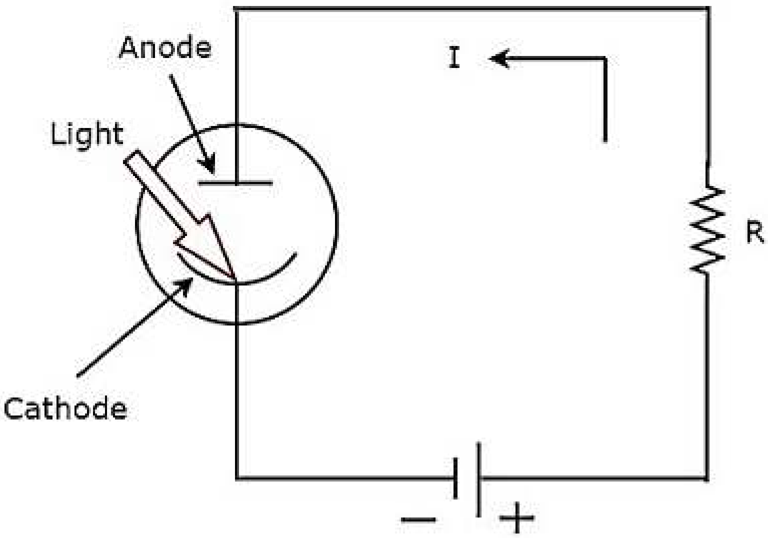
The **circuit diagram** of Quartz transducer is shown in below figure. As shown in the figure, quartz crystal is placed between base and force summing member. The output voltage can be measured across the metal electrodes, which are placed on two sides of quartz crystal.



The output voltages is v0=q/c

Photo Electric Transducer

An active transducer is said to be photo electric transducer, when it produces an electrical quantity which is equivalent to the illumination of light input. The **circuit diagram** of photo electric transducer is shown in below figure.



The **working** of photo electric transducer is mentioned below.

- **Step1** − The photo electric transducer releases electrons, when the light falls on cathode of it.
- **Step2** − The photo electric transducer produces a current, I in the circuit due to the attraction of electrons towards anode.

We can find the **sensitivity** of photo electric transducer by using the following formula.

S=I/i�=��

Where,

S� is the sensitivity of photo electric transducer
I� is the output current of photo electric transducer
i� is the illumination of the light input of photo electric transducer

Thermo Electric Transducer

An active transducer is said to be **thermo electric transducer**, when it produces an electrical quantity which is equivalent to temperature input. The following two transducers are the examples of thermo electric transducers.

- Thermistor Transducer
- Thermocouple Transducer

Now, let us discuss about these two transducers one by one.

Thermistor Transducer

The resistor, which depends on temperature is called thermal resistor. In short, it is called **Thermistor**. The temperature coefficient of thermistor is negative. That means, as temperature increases, the resistance of thermistor decreases.

Mathematically, the relation between resistance of thermistor and temperature can be represented as

$$R_1 = R_2 e^{\left(\beta\left[\frac{1}{T_1} - \frac{1}{T_2}\right]\right)}$$

Where,

R_1 is the resistance of thermistor at temperature $T_1 {}^{0}K$

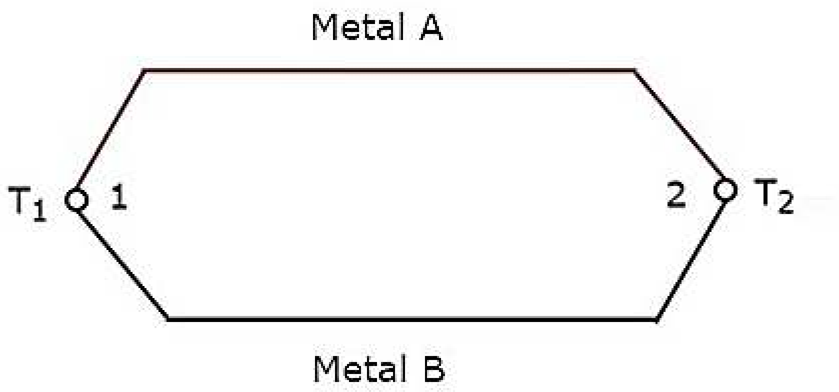
R_2 is the resistance of thermistor at temperature $T_2 {}^{0}K$

β is the temperature constant

The **advantage** of Thermistor transducer is that it will produce a fast and stable response.

Thermocouple Transducer

Thermocouple transducer produces an output voltage for a corresponding change of temperature at the input. If two wires of different metals are joined together in order to create two junctions, then that entire configuration is called **Thermocouple**. The circuit diagram of basic thermocouple is shown below −



The above thermocouple has two metals, A & B and two junctions, 1 & 2. Consider a constant reference temperature, T_2 at junction 2. Let the temperature at junction, 1 is T_1. Thermocouple generates an **emf** (electro motive force), whenever the values of T_1 and T_2 are different.

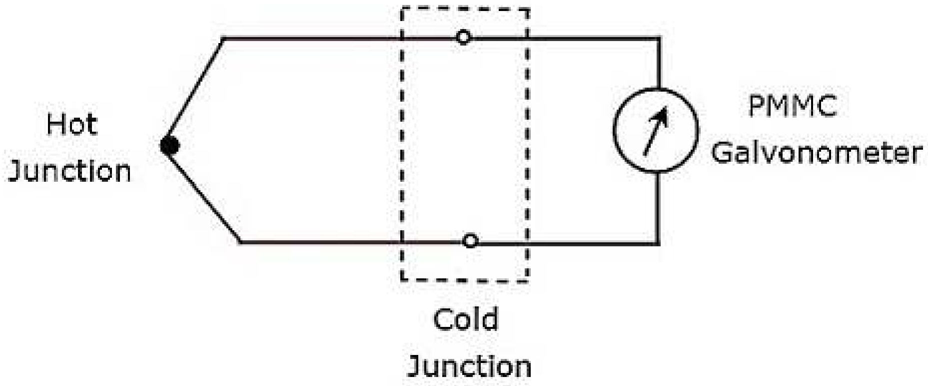
That means, thermocouple generates an emf, whenever there is a temperature difference between the two junctions, 1 & 2 and it is directly proportional to the temperature difference between those two junctions. **Mathematically**, it can be represented as

$$e \alpha (T_1 - T_2)$$

Where,

e is the emf generated by thermocouple

The above thermocouple circuit can be represented as shown in below figure for practical applications.



The part of the circuit, which lies between hot & cold junctions including those two junctions is an equivalent model of basic thermocouple. A PMMC galvanometer is connected across the cold junction and it deflects according to the emf generated across cold junction. **Thermocouple transducer** is the most commonly used thermoelectric transducer.

RTD: RESISTANCE TEMPERATURE DETECTOR

When a metal wire is heated the resistance increases. So, a temperature can be measured using the resistance of a wire. RTD incorporates pure metals or certain alloys that increases resistance as temperature increases and it conversely decreases resistance as temperature decreases. RTDs act similar to an electrical transducer.

It converts changes the temperature to voltage signals by the measurement of resistance.

The metals that are best suited for use as RTD sensors are pure of uniform quality and stable within to given range of temperature and able to give reproducible resistance- temperature readings. Only a few metals have the properties necessary for use in RTD elements. ,

RTD elements are normally constructed of platinum, copper, nickel or nickel-iron alloys.

Working principle of RTD

Resistance thermometers or resistance temperature detector works on the principle of positive temperature coefficient of resistance i.e. as temperature increases, resistance offered by thermometer also increases.
The resistance element of platinum and iron metal wire is wrapped around an electrically insulating support of glass, ceramic or mic and from the outside, the protective sheath of metallic tube can be provided. The lead wires are taken out from the resistance elements which are joined to the circuitry.

RTD formula

The resistance thermometers which are alternatively known as RTD works on the principle that " The resistance of a metal varies with a change in temperature" according to the relation as,

$$RT = R0 [1+\alpha(T-T0)]$$

RT: Resistance at temperature (T)
R0 : Resistance at temperature (0˚C)
α : Temperature coefficient.
T: temp(˚C)
T0 : Initial temp.

To measure the change in the resistance bridge network is used.
The resistance thermometer is connected to one of the arms of the Wheatstone bridge circuit when resistance thermometer is subjected to temperature variation, the Wheatstone bridge gets unbalanced. The galvanometer deflection can be directly calibrated to give temperature.

RTD Diagram:

Construction of a resistance temperature detector

Figure shows the construction of an RTD. It has a resistor element connected to a Wheatstone bridge. The element and the connection leads are insulated and protected by a sheath. A small amount of current is continuously passing through the coil. As the temperature changes the resistance of the coil changes which is detected at the Wheatstone bridge.

RTDs are used in the form of thin films, wire wound, or coil. They are generally made of metals such as platinum, nickel, or nickel-copper alloys. Platinum wire held by a high-temperature glass adhesive in a ceramic tube is used to measure the temperature in a metal furnace.

Applications of RTD:

Applications of Resistance temperature detector are as follows,

- Air conditioning and refrigeration servicing
- Food Processing
- Stoves and grills
- Textile production
- Plastics processing
- Petrochemical processing
- Microelectronics
- Air, gas and liquid temperature measurement in pipes and tanks
- Exhaust gas temperature measurement

Advantages:

1. It is suitable for measuring high temperatures
2. It has a high degree of accuracy
3. It ensures good stability and repeatability
4. It does not need a reference temperature junction

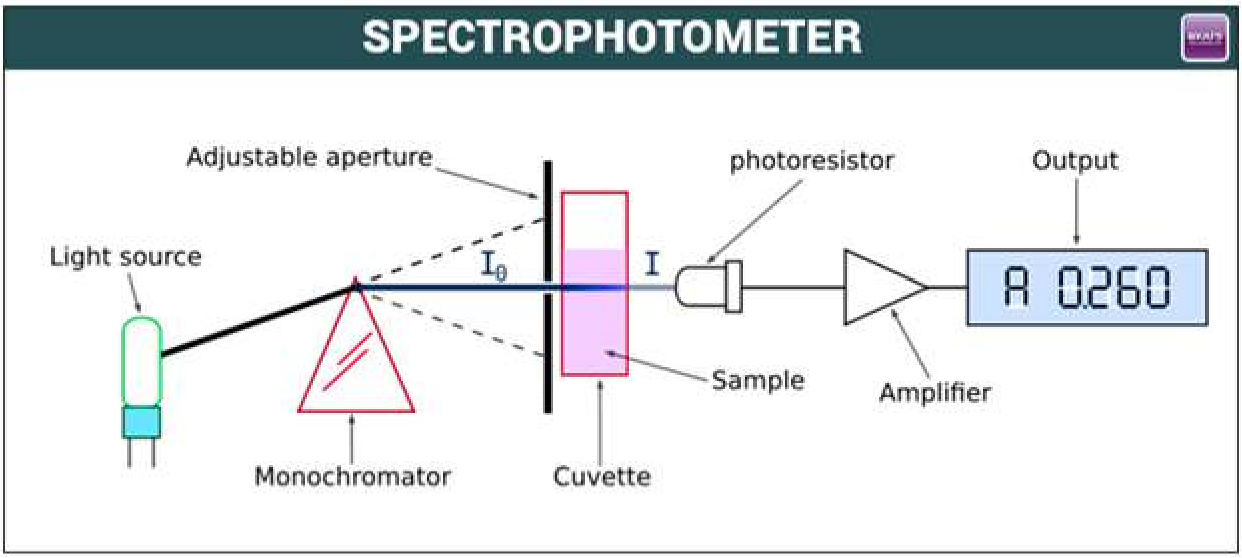
Disadvantages:

1. Size is more than the thermocouple
2. Power supply is required
3. It needs an auxiliary apparatus to get the required form of output

SPECTRO PHOTO METER:

The spectrophotometer is an instrument which measures the amount of light that a sample absorbs. The spectrophotometer works by passing a light beam through a sample to measure the light intensity of a sample. These instruments are used in the process of measuring colour and used for monitoring colour accuracy throughout production. They are primarily used by researchers and manufacturers everywhere. The major Spectrophotometer Applications are limitless as they are used in practically every industrial and commercial field. However, it finds its major applications in liquids, plastics, paper, metals and fabrics. This helps in ensuring that the colour chosen remains consistent from its original conception to the final, finished product.

Spectrophotometer Instrumentation



A spectrophotometer is made up of two instruments: a spectrometer and a photometer. The spectrometer is to produce light of any wavelength, while the photometer is to measure the intensity of light. The spectrophotometer is designed in a way that the liquid or a sample is placed between spectrometer and photometer. The photometer measures the amount of light that passes through the sample and delivers a voltage signal to the display. If the absorbing of light changes, the voltage signal also changes. Spectrophotometers come in a variety of shapes and sizes and have multipurpose uses to them. The different types of spectrophotometers available are all different from one another, based on their application and desired functionality. The most popular spectrophotometers are 45 degrees, sphere and multi-angle spectrophotometers. Another closely related concept is **Spectroscopy,**that simply measures the absorption of light from its source and the intensity of light as well.

The basic spectrophotometer instrument consists of a light source, a digital display, a monochromator, a wavelength sector to transmit a selected **wavelength**, a collimator for straight light beam transmission, photoelectric detector and a cuvette to place a sample.

The intensity of light is symbolized as l_0 measure the number of photons per second. When the light is passed through the blank solution, it does not absorb light and is symbolized as (l). Other important factors are Absorbance (A) and Transmittance (T).

Here, we need to measure the intensity of light that passes a blank solution, and later measure the intensity of light passing a sample. Calculate the transmittance and the absorbance. For the measurement of absorbance, we can use an isosbestic point where the absorbance and wavelength of two or more species are the same.

The number of protons transmit and absorb totally depending on the length of the cuvette and the concentration of the sample.

The transmittance and absorption relation is:

The transmittance of an unknown sample can be calculated using the formula given below.

Here,

Further, there are several varieties of spectrophotometer devices such as UV Spectrometry, atomic emission spectrophotometry and atomic absorption spectrophotometry and much more. It can also be classified into two types based on the range of light source wavelengths like IR spectrophotometer and UV-visible spectrophotometer. Some major real-life applications of spectrophotometry in various fields are laundry soap, carpeting and production of small parts such as toys or intricate machinery. The major types of spectrophotometers are categorized into 2, these are mainly portable spectrophotometers and bench spectrophotometers, they both are unique and have their own uses.

THERMISTOR

A **thermistor** (or **thermal resistor**) is defined as a type of resistor whose electrical resistancevaries with changes in temperature. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.

Thermistors act as a passive component in a circuit. They are an accurate, cheap, and robust way to measure temperature.

While thermistors do not work well in extremely hot or cold temperatures, they are the sensor of choice for many different applications.

Thermistors are ideal when a precise temperature reading is required. The circuit symbol for a thermistor is shown below:

Uses of Thermistors

Thermistors have a variety of applications. They are widely used as a way to measure temperature as a thermistor thermometer in many different liquid and ambient air environments. Some of the most common uses of thermistors include:

- Digital thermometers (thermostats)
- Automotive applications (to measure oil and coolant temperatures in cars & trucks)
- Household appliances (like microwaves, fridges, and ovens)
- Circuit protection (i.e. surge protection)
- Rechargeablebatteries (ensure the correct battery temperature is maintained)
- To measure the thermal conductivity of electrical materials
- Useful in many basic electronic circuits (e.g. as part of a beginner Arduino starter kit)
- Temperature compensation (i.e. maintain resistance to compensate for effects caused by changes in temperature in another part of the circuit)
- Used inwheatstone bridge circuits

How Does a Thermistor Work

The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter.

If we know the exact relationship between how changes in the temperature will affect the resistance of the thermistor – then by measuring the thermistor's resistance we can derive its temperature.

How much the resistance changes depends on the type of material used in the thermistor. The relationship between a thermistor's temperature and resistance is non-linear.

Thermistor Types: They are of two types

- Negative Temperature Coefficient (NTC) Thermistor
- Positive Temperature Coefficient (PTC) Thermistor

NTC Thermistor

In an NTC thermistor, when the temperature increases, resistance decreases. And when temperature decreases, resistance increases. Hence in an NTC thermistor temperature and resistance are inversely proportional. These are the most common type of themistor.

The relationship between resistance and temperature in an NTC thermistor is governed by the following expression:

$$R_T=R_0 exp\ (B(1/T-1/T0))$$

Where:

- R_T is the resistance at temperature T (K)
- R_0 is the resistance at temperature T_0 (K)
- T_0 is the reference temperature (normally 25°C)
- β is a constant, its value is dependent on the characteristics of the material. The nominal value is taken as 4000.

THERMOCOUPLE

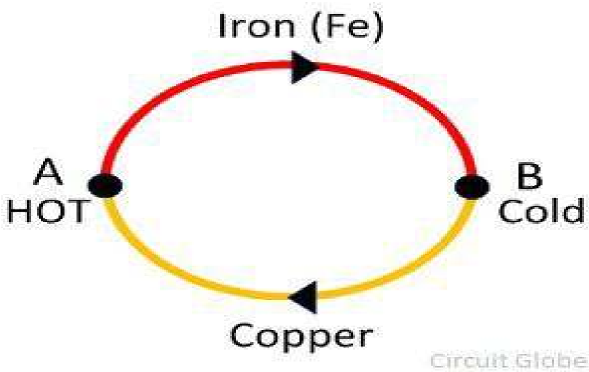
Definition: The thermocouple is a temperature measuring device. It uses for measuring the temperature at one particular point. In other words, it is a type of sensor used for measuring the temperature in the form of an electric current or the EMF.

The thermocouple consists two wires of different metals which are welded together at the ends. The welded portion was creating the junction where the temperature is used to be measured. The variation in temperature of the wire induces the voltages.

Working Principle of Thermocouple

The working principle of the thermocouple depends on the three effects.

See back Effect – The See back effect occurs between two different metals. When the heat provides to any one of the metal, the electrons start flowing from hot metal to cold metal. Thus, direct current induces in the circuit.



In short, **it is a phenomenon in which the temperature difference between the two different metals induces the potential differences between them**. The See beck effect produces small voltages for per Kelvin of temperature.

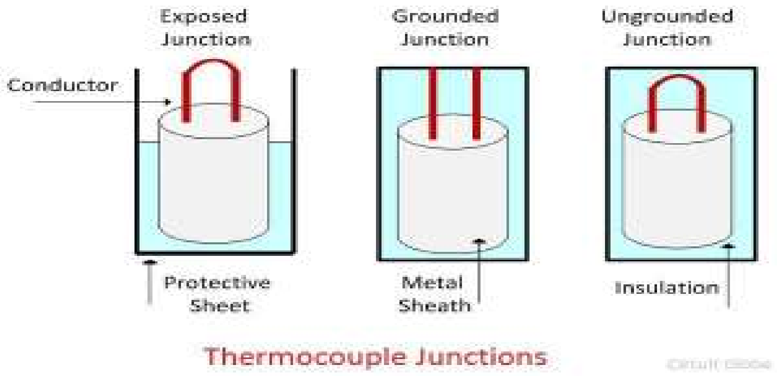
Peltier Effect – The Peltier effect is the inverse of the Seebeck effect. The Peltier effect state that **the temperature difference can be created between any two different conductors by applying the potential difference between them.**

Thompson Effect – The Thompson effect state that **when two dissimilar metals join together and if they create two junctions then the voltage induces the entire length of the conductor because of the temperature gradient**. The temperature gradient is a physical term which shows the direction and rate of change of temperature at a particular location.

Construction of Thermocouple

The thermocouple consists two dissimilar metals. These metals are welded together at the junction point. This junction considers as the measuring point. The junction point categorises into three types.

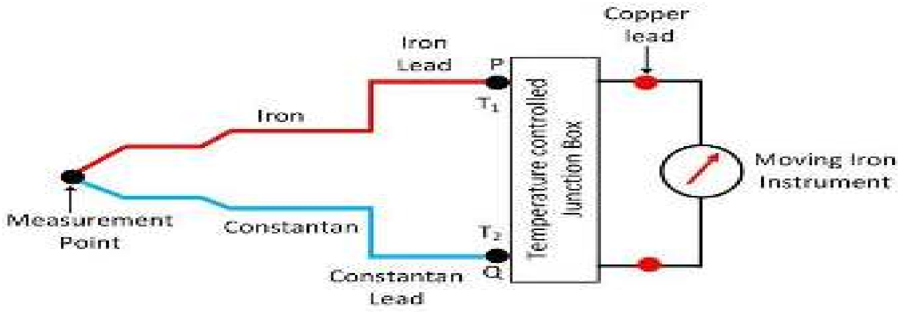
1. **Ungrounded Junction** – In ungrounded junction, **the conductors are entirely isolated from the protective sheath**. It is used for high-pressure application works. The major advantage of using such type of junction is that it reduces the effect of the stray magnetic field.
2. **Grounded Junction** – In such type of junction **the metals and protective sheath are welded together.** The grounded junction use for measuring the temperature in the corrosive environment. This junction provides resistance to the noise.
3. **Exposed Junction** – Such type of junction uses in the places where fast response requires. The exposed junction is used for measuring the temperature of the gas.



The material uses for making the thermocouple depends on the measuring range of temperature.

Working of Thermocouple

The circuit of the thermocouple is shown in the figure below. The circuit consists two dissimilar metals. These metals are joined together in such a manner that they are creating two junctions. The metals are bounded to the junction through welding.



Iron Constonant Thermocouple

Let the P and Q are the two junctions of the thermocouples. The T_1 and T_2 are the temperatures at the junctions. As the temperature of the junctions is different from each other, the EMF generates in the circuit.

If the temperature at the junction becomes equal, the equal and opposite EMF generates in the circuit, and the zero current flows through it. If the temperatures of the junction become unequal, the potential difference induces in the circuit. The magnitude of the EMF induces in the circuit depends on the types of material used for making the thermocouple. The total current flowing through the circuit is measured through the measuring devices.

The EMF induces in the thermocouple circuit is given by the equation

$$E = a(\Delta\theta) + b(\Delta\theta)^2$$

Where $\Delta\theta$ – temperature difference between the hot thermocouple junction and the reference thermocouple junction.
a, b – constants

Measurement of Thermocouple Output

The output EMF obtained from the thermocouples can be measured through the following methods.

1. **Multimeter** – It is a simpler method of measuring the output EMF of the thermocouple. **The multimeter is connected to the cold junctions of the thermocouple**. The deflection of the multimeter pointer is equal to the current flowing through the meter.
2. **Potentiometer** – The output of the thermocouple can also be measured with the help of the DC potentiometer.
3. **Amplifier with Output Devices** – The output obtains from the thermocouples is amplified through an amplifier and then feed to the recording or indicating instrument.

Advantages :

1. The thermocouple is cheaper than the other temperature measuring devices.
2. The thermocouple has the fast response time.
3. It has a wide temperature range.

Disadvantages

1. The thermocouple has low accuracy.
2. The recalibration of the thermocouple is difficult.

Nickel-alloy, platinum/rhodium alloy, Tungsten/rhenium-alloy, chromel-gold, iron-alloy are the name of the alloys used for making the thermocouple.

PH-METER

- PH is a unit of measure which describes the degree of acidity or basicity of a solution.
- It is measured on a scale of 0 to 14.
- The formal definition of pH is the negative logarithm of the hydrogen ion activity.
- $pH = -\log[H^+]$ in the above equation P-power and H-Hydrogen
- The pH value of a substance is directly related to the ratio of the hydrogen ion and hydroxyl ion concentrations.
- If the H^+ concentration is higher than OH^- the material is acidic.
- If the OH^- concentration is higher than H^+ the material is basic.
- 7 is neutral, < is acidic, >7 is basic