Measurement and Instrumentation

(Course Code: BEL04002)

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Gyan Ranjan Biswal received his B.E. in Electronics Engineering from the Pt. Ravishankar Shukla University, India in 1999 and M. Tech. (Honors) in Instrumentation & Control Engineering from the Chhattisgarh Swami Vivekananda Technical University, India in 2009 followed by Ph.D. in Electrical Engineering, specialized in the area of Power System Instrumentation (Power Generation Automation) from the Indian Institute of Technology Roorkee, India in 2012.

He is expertise in Design and Development of cooling systems for large size electrical generators, and the C&I of process industries. He has been in academia for about twelve years. Presently, he is with VSS University of Technology, Burla, India at the capacity of Head and Associate Professor, EEE from Dec. 2016. He has more than 70 publications in various Journals and Conferences of Internationally repute to his credit. He also holds a patent and filed for two more as well. He also adapted one international edition book published by Pearson India. He received research grants of US$90,000 (INR 53 lakhs). He has been supervised 01 PhD, 09 Masters' theses, and ongoing 04 PhD theses. He has also been recognized with many national and international awards by elite bodies. He has been awarded with CICS award under the head of Indian National Science Academy for travel support to USA, MHRD Fellowship by Govt. of India, and Gopabandhu Das Scholarship in his career. His major areas of interests are Power System Instrumentation, Industrial Automation, the Smart Sensors, IoT enabled Smart Sensors, the Smart Grid, and Fuel Cell backed Sustainable Sources of Energy.

Dr. Biswal is a Fellow IE (India), Senior Member of IEEE, USA, and Life Member of ISTE, India. He is actively involved in review panels of different societies of international repute viz. IEEE, IFAC, and the ISA. Currently, he is also actively involved as a Member of IEEE–SA (Standards Association) working groups; IEEE P1876 WG, IEEE P21451-001 WG, and IEEE P1415. He has also been invited for delivering guest lectures at World Congress on Sustainable Technologies (WCST) Conf. 2012, London, UK, INDICON 2015, New Delhi, India, National Power Training Institute (NPTI), Nangal, India, and G.B. Pant Engineering College, Pauri, Gharwal, India, VSS University of Technology (VSSUT), Burla, and as a guest expert in 2016 IEEE PES General Meeting Boston, MA, USA.

Syllabus

MODULE-I (8 HOURS) [Online mode: 6 HOURS + 1 Test]

Measuring Instruments: Classification, Absolute and secondary instruments, indicating instruments, deflecting, control and damping torques, Ammeters and Voltmeters, PMMC, Moving Iron (MI) type, expression for the deflecting torque and control torque, extension of range using shunts and series resistance. Electrostatic Voltmeters-electrometer type and attracted disc type, extension of range of E.S. Voltmeters.

MODULE-II (8 HOURS) [Online mode: 4 HOURS + 1 Test]

Electrodynamometer type wattmeter – Theory & its errors – Methods of correction – LPF wattmeter – Phantom loading – Induction type KWH meter – Calibration of wattmeter, energy meter. Measurement of active and reactive powers in balanced and unbalanced systems.

Galvanometers: General principle and performance equations of D'Arsonval Galvanometers, Vibration Galvanometer and Ballistic Galvanometer.

MODULE-III (8 HOURS) [Online mode: 6 HOURS + 1 Test]

DC/AC Bridges: General equations for bridge balance, measurement of self-inductance by Maxwell's bridge (with variable inductance & variable capacitance), Hay's bridge, Owen's bridge, measurement of capacitance by Schearing bridge, errors, Wagner's earthing device.

Method of measuring low, medium and high resistance: Kelvin's double bridge for measuring low resistance, Wheat-stone's bridge, measurement of high resistance – loss of charge method.

MODULE-IV (8 HOURS) [Online mode: 4 HOURS + 1 Test]

Instrument Transformers: Potential and current transformers, ratio and phase angle errors, phasor diagram, methods of minimizing errors.

Potentiometers: DC Potentiometer, Crompton potentiometer, construction, standardization, application. AC Potentiometer, Drysdale polar potentiometer; standardization, application.

MODULE-V (7 HOURS) [Online mode: 5 HOURS + 1 Test]

Digital Multi-meter: Block diagram, principle of operation, Accuracy of measurement, Electronic Voltmeter: Transistor Voltmeter, Block diagram, principle of operation, various types of electronic voltmeter, Digital Frequency meter: Block diagram, principle of operation.

Definition of transducers, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of LVDT and capacitor transducers; LVDT Applications, Strain gauge and its principle of operation, gauge factor.

Recommended Text Books:

1. Helfrick & Cooper, “Modern Electronic Instrumentation and Measurement Techniques”, PHI Publishers.

Reference Books:

* Golding & Waddis, “Electrical Measurement and Measuring Instruments”, Reem Publishers.
* David A. Bell, “Electronic Instrumentation and Measurements”, 3rd ed., Oxford University Press.
* P. Purkait, B. Biswas, S. Das and C. Koley, “Electrical and Electronics Measurement and Measuring Instruments”, McGraw Hills.

Other Important References

Reference Sites and Acknowledgement to:	
1.	NPTEL, The National Programme on Technology Enhanced Learning (NPTEL): https://nptel.ac.in/
2.	Study to Accompanying Automotive Electrical & Electronics, Ch. 8: Digital Meters by James D. Halderman, Pearson Int. 2008.

Course Outcomes

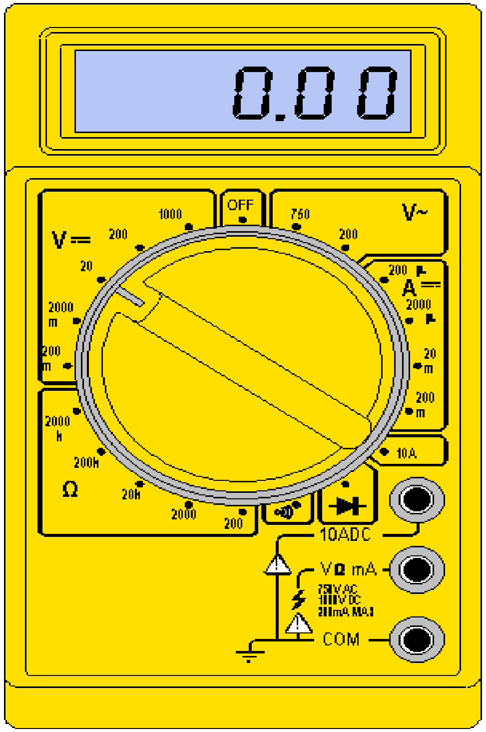
Upon successful completion of this course, you (students) will be able to

CO1	**Understand the principles of basic electrical measuring instruments.**
CO2	Understand the operation of wattmeter, energy meter and galvanometers.
CO3	Understand and analyze the working of different ac and dc bridges.
CO4	Understand the operation of instrument transformers and potentiometers.
CO5	Understand the operation of electronic measuring instruments and transducers.

Digital meters
and
Transducers

MODULE-V (7 HOURS) [Online mode: 5 HOURS + 1 Test]
Digital Multi-meter: Block diagram, principle of operation, Accuracy of measurement, Electronic Voltmeter: Transistor Voltmeter, Block diagram, principle of operation, various types of electronic voltmeter, Digital Frequency meter: Block diagram, principle of operation.
Definition of transducers, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of LVDT and capacitor transducers; LVDT Applications, Strain gauge and its principle of operation, gauge factor.

Digital Meters



What is a multimeter?

- A multimeter is a devise used to measure voltage, resistance and current in electronics & electrical equipment

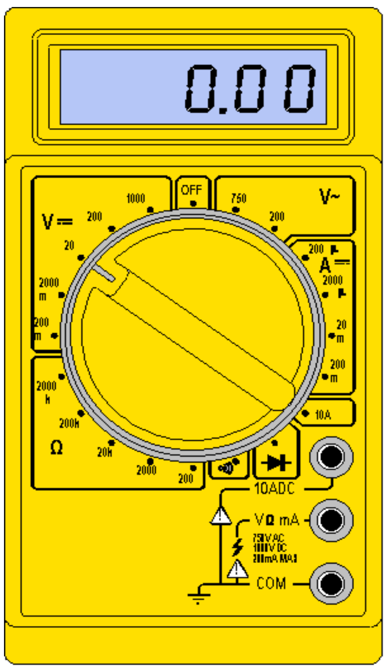
- It is also used to test continuity between to 2 points to verify if there is any breaks in circuit or line

- There are two types of multimeter Analog & Digital
  - Analog has a needle style gauge
  - Digital has a LCD display (Referenced during this PPT)

There are 2 styles of multimeters

Switched

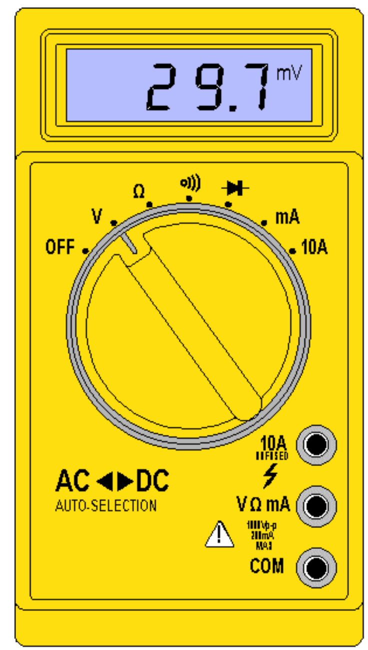
Manually switch between ranges to get most accurate reading.



Both of these styles work the same

Auto Range

Switches between ranges automatically for best reading.



DIGITAL MULTIMETERS

- Digital multimeter (DMM) and digital volt-ohmmilliammeter (DVOM) are terms commonly used for electronic high-impedance test meters.

DIGITAL MULTIMETERS

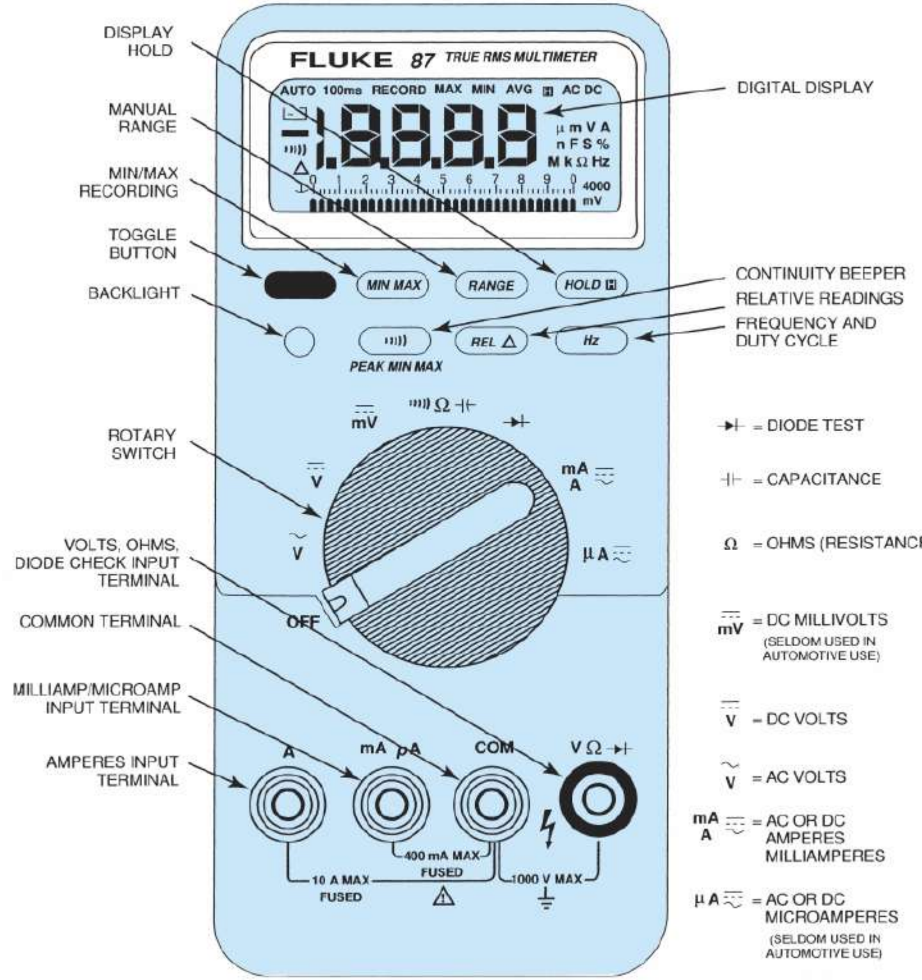


FIGURE: Typical digital multimeter. The black meter lead always is placed in the COM terminal. Except when measuring the current in amperes, the red meter test lead remains in the V terminal.

HOW TO READ DIGITAL METERS

The symbol on the right side of the display tells you what range your meter's in. Ω means the display is the resistance in ohms; kΩ means ohms times 1000, and MΩ is ohms times 1 000 000.

Ω = ohms

If the only symbol on the display is the ohms symbol, the reading on the display is exactly the resistance in ohms.

kΩ = kilohms = ohms times 1000

A "k" in front of the ohms symbol means "kilohms"; the reading on the display is in kilohms. You have to multiply the reading on the display by 1000 to get the resistance in ohms.

MΩ = megohms = ohms times 1000 000

An "M" in front of the ohms symbol means "megohms"; the reading on the display is in megohms. You have to multiply by one million (1000 000) to get the resistance in ohms.

FIGURE: Always look at the meter display when a measurement is being made, especially if using an autoranging meter. *(Courtesy of Fluke Corporation)*

HOW TO READ DIGITAL METERS

- Alternating current voltage waveforms can be true sinusoidal or nonsinusoidal.
  - A true sine wave pattern measurement will be the same for both **root-mean-square (RMS)** and average reading meters.

HOW TO READ DIGITAL METERS

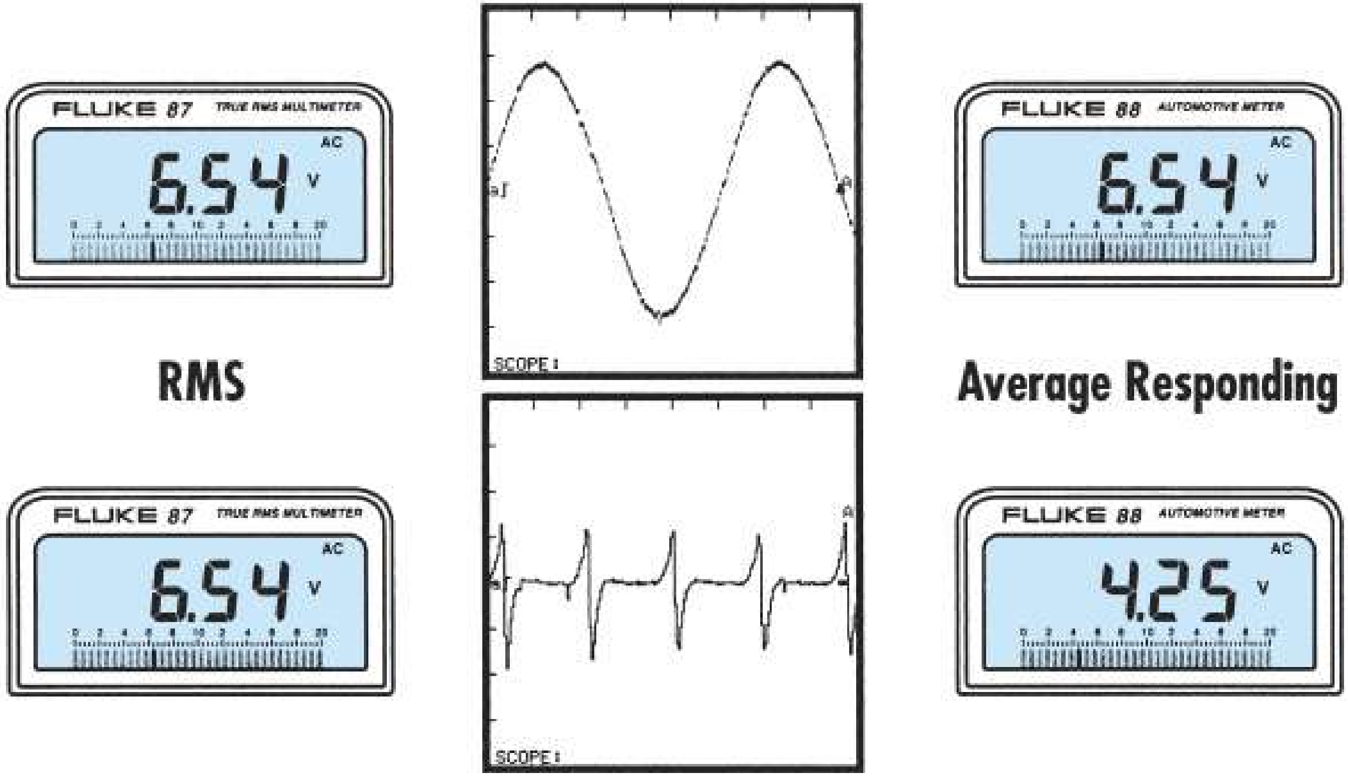


FIGURE: When reading AC voltage signals, a true RMS meter (such as a Fluke 87) provides a different reading than an average responding meter (such as Fluke 88).The only place this difference is important is when a reading is to be compared with a specification. *(Courtesy of Fluke Corporation)*

HOW TO READ DIGITAL METERS

- **Meter resolution** refers to how small or fine a measurement the meter can make.
- The terms *digits* and *counts* are used to describe a meter's resolution.
  - DMMs are grouped by the number of counts or digits they display.

HOW TO READ DIGITAL METERS

FIGURE: This meter display shows 052.2 AC volts. Notice that the zero beside the 5 indicates that the meter can read over 100 volts AC with a resolution of 0.1 volt.

HOW TO READ DIGITAL METERS

- **Meter accuracy** is the largest allowable error that will occur under specific operating conditions.
- Accuracy for a DMM is usually expressed as a percent of reading.
  - An accuracy of 1% of reading means that for a displayed reading of 100.0 V, the actual value of the voltage could be anywhere between 99.0 V to 101.0 V.

HOW TO READ DIGITAL METERS

- ✓ Unacceptable 1.00%
- ✓ Okay 0.50% (1/2%)
- ✓ Good 0.25% (1/4%)
- ✓ Excellent 0.10% (1/10%)

Measuring Voltage

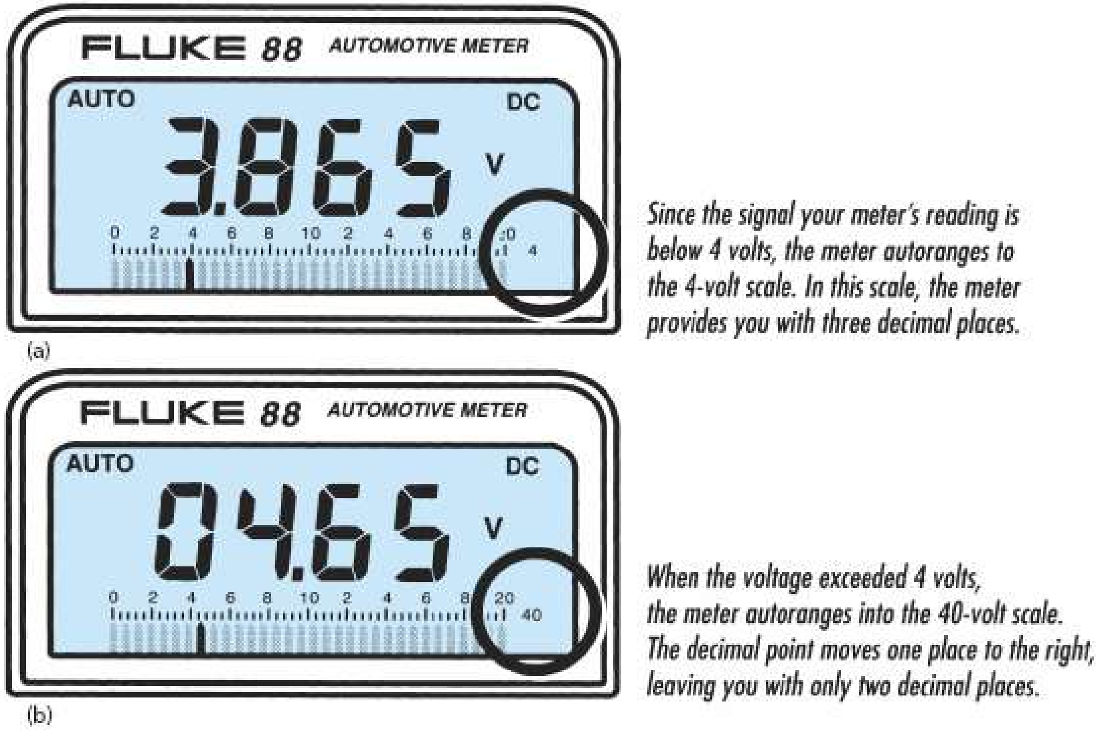


FIGURE: A typical autoranging digital multimeter automatically selects the proper scale to read the voltage being tested. The scale selected is usually displayed on the meter face. (a) Note that the display indicates "4," meaning that this range can read up to 4 volts. (b) The range is now set to the 40 volt scale, meaning that the meter can read up to 40 volts on the scale. Any reading above this level will cause the meter to reset to a higher scale. If not set on autoranging, the meter display would indicate OL if a reading exceeds the limit of the scale selected. *(Courtesy of Fluke Corporation)*

DIGITAL VOLTMETER

- Digital voltmeters display the value of AC or DC voltage being measured directly as discrete numerical instead of a pointer deflection on a continuous scale as in analog instruments.
- Digital voltmeters offers many advantages over analog meters, such as speed in reading, increased accuracy, batter resolution and the capability of automatic operation.

Measuring Voltage

- Voltage (V) is the unit of electrical pressure; one volt is the potential difference needed to cause one amp of current to pass through one ohm of resistance

- Voltage is broke up into 2 sections AC & DC

  Alternating Current (AC) is house voltage (110 V ac)

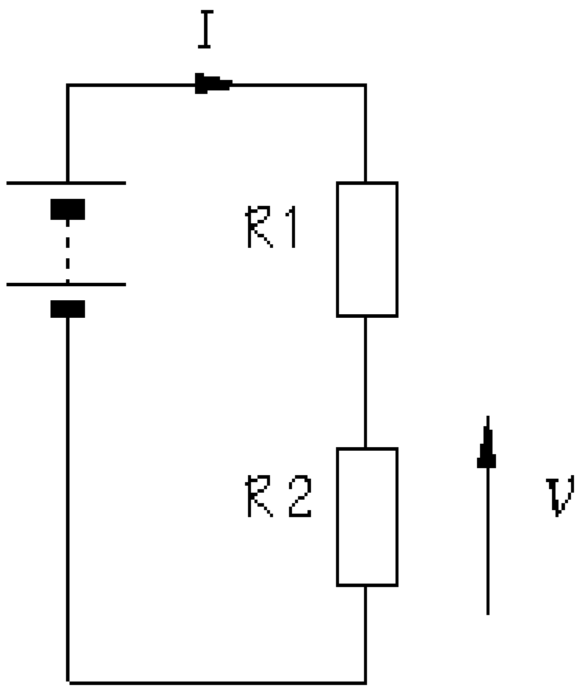
  Direct Current (DC) is battery voltage (12 V dc)

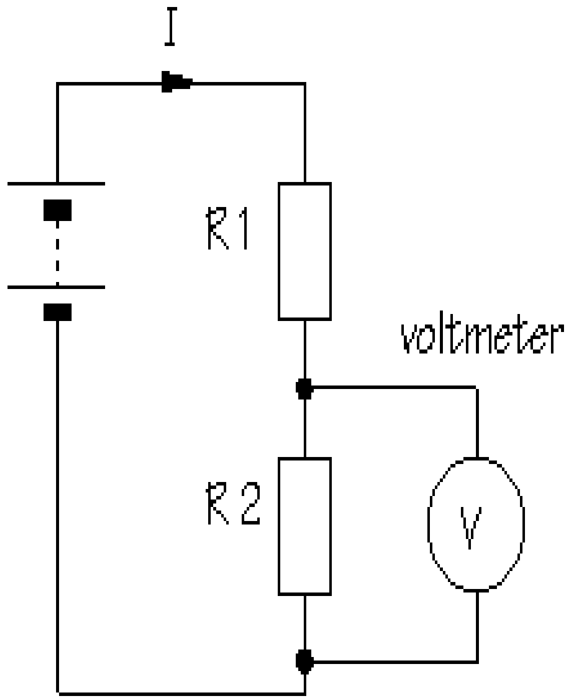
- On switched meters use one value higher than your expected value

- Be very careful to not touch any other electronic components within the equipment and do not touch the tips to each other while connected to anything else

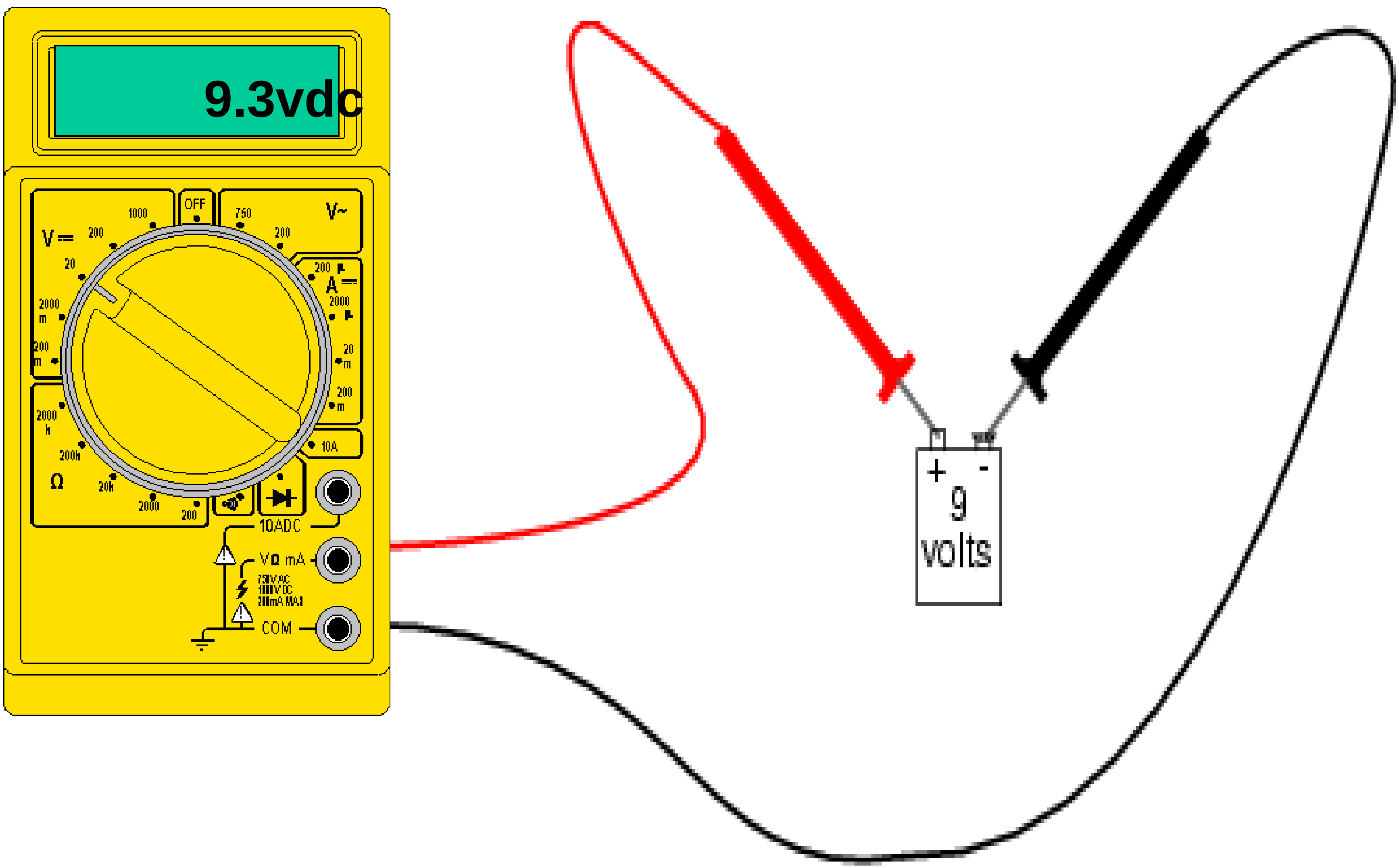
- To measure voltage connect the leads in parallel between the two points where the measurement is to be made. The multimeter provides a parallel pathway so it needs to be of a high resistance to allow as little current flow through it as possible

Measuring Voltage

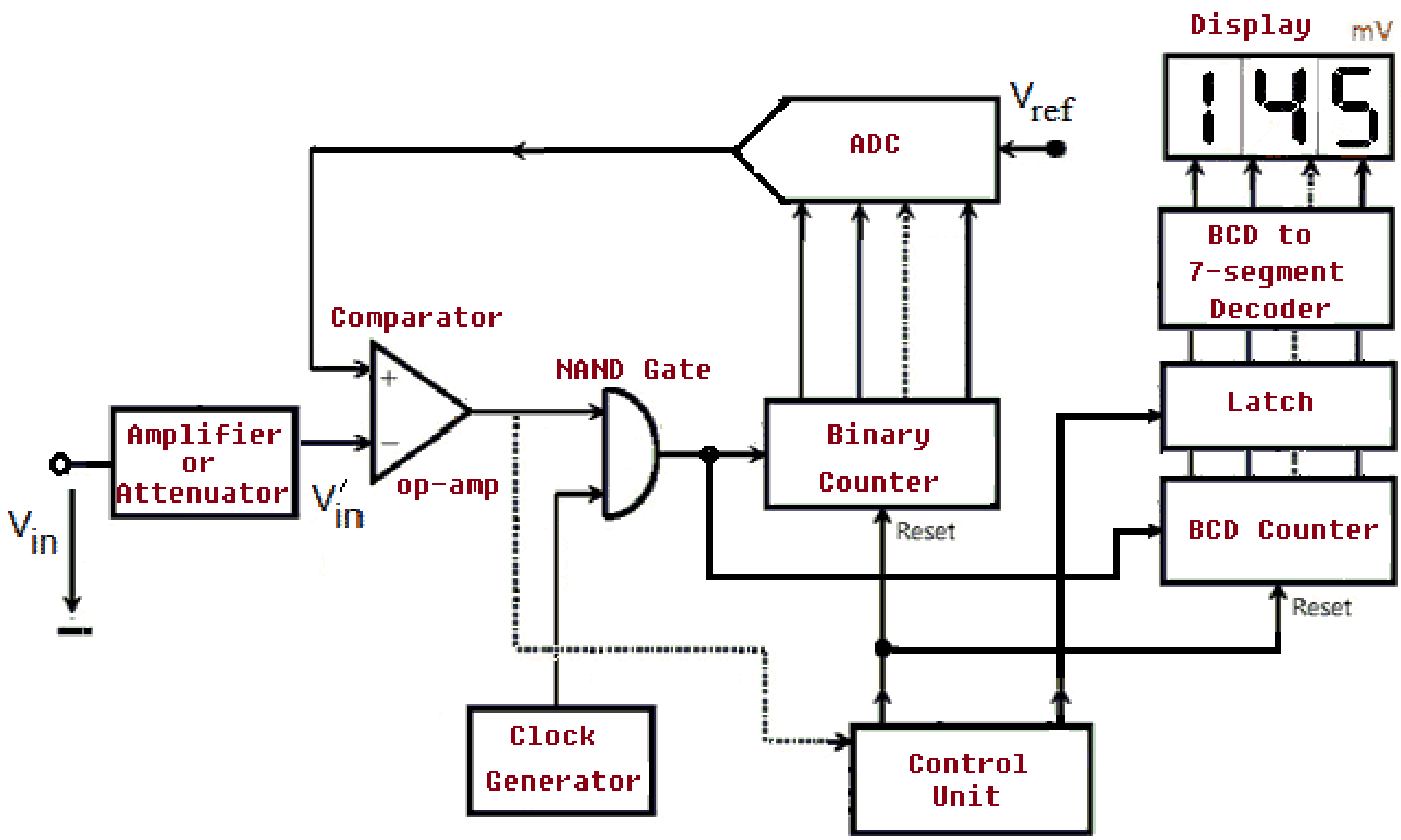




Measuring Voltage



Block diagram of Digital Voltmeter



Principle of Operation

- The working principle of a Digital Voltmeter can be categorized into five functional sections. They are:
  - Pulse Generator
  - Voltage Control and Gating
  - Counting Clock Pulses
  - Analog to Digital Conversion
  - Latching and Display Section
- **Pulse Generator:** In electronics, it is called a ‘Clock’ which generates pulses.
- **Voltage Control and Gating:** This section of control and gating is based on an integrated circuit called the Comparator.

The IC compares the two voltages and signals for which of the two voltages is larger. One of the voltage is the input voltage (V_{in}) and the other will be the voltage across the capacitor.

- Voltage is monitored across the capacitor and signals are generated when the voltage becomes equal to the voltage to be measured (V_{in}) and the charging starts at zero volts. The comparator does not draw any appreciable current, otherwise it will interfere with the constant-current charging. To achieve near-zero input current, an Op-Amp is used as a comparator.
- The Op-Amp is a IC with two inputs called the non-inverting and inverting input V+ and V- respectively. It has only one output. If the voltage at the + input of Op-amp is greater (more positive) than the voltage at the – input (V+ > V-), then the output is high.

- **Counting Clock Pulses:**
  - The number of clock pulses that occur between the start and stop charging signals is counted.
  - The voltmeter will work by counting the pulses from the time the capacitor starts charging.
  - To achieve this a simple NAND gate is used in the circuit
- **ADC (Analog to Digital Converter):**
  - An A/D converter or ADC (Analog to Digital Converter) converts an analog voltage sample and returns a binary number that describes the sample.
- **Latching and Display Section:**
  - The number of pulses counted is displayed in a numerical format using a seven segment LED display. The latch is used to statically display the final result of one capacitor charging cycle operation.

Measuring Resistance and Continuity

- Resistance (W) is the opposition to current
- Resistance is measured in Ohm's
- Disconnect power source before testing
- Remove component or part from system before testing
- Measure using lowest value, if OL move to next level
- Testing for continuity is used to test to verify if a circuit, wire or fuse is complete with no open
- Audible continuity allows an alarm if circuit is complete
- If there is no audible alarm resistance of 1ohm to .1ohm should be present

DIGITAL MULTIMETERS

Measuring Resistance

- An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit.

DIGITAL MULTIMETERS

Measuring Resistance

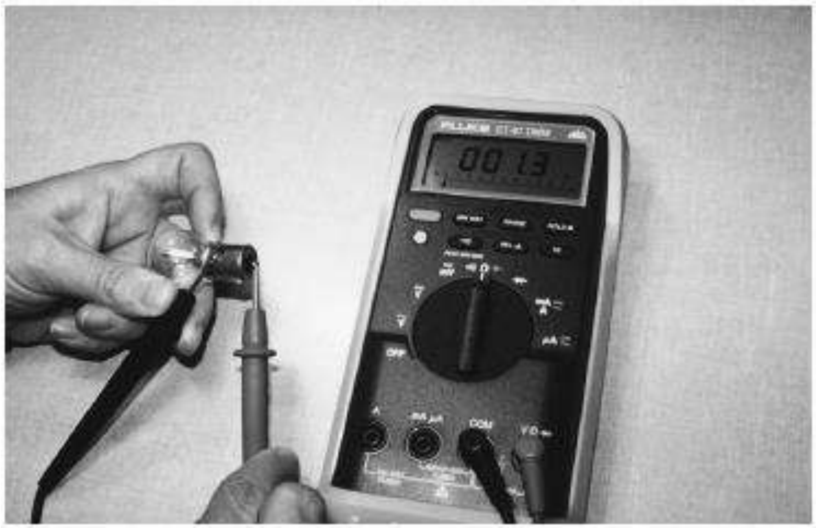


FIGURE: Using a digital multimeter set to read ohms () to test this light bulb. The meter reads the resistance of the filament.

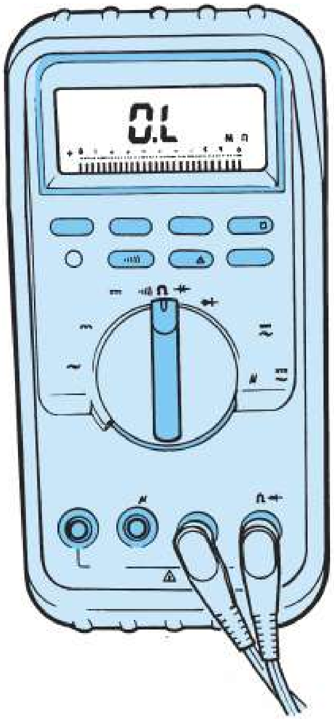


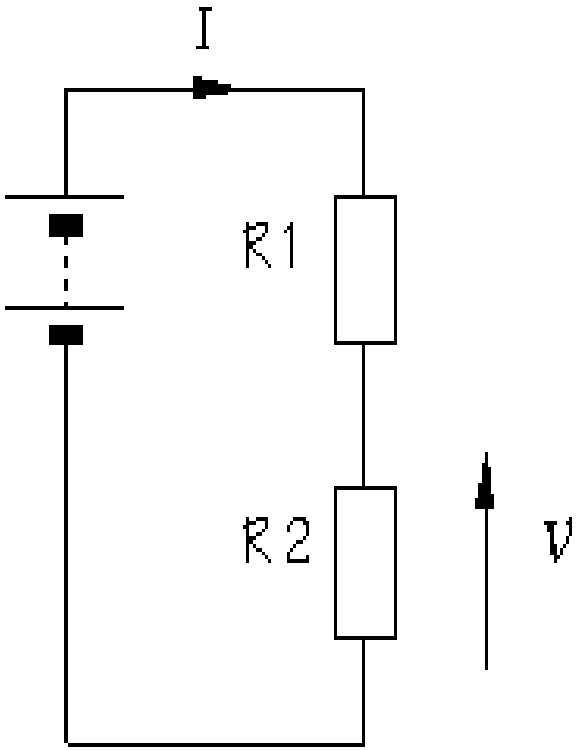
FIGURE: Typical digital multimeter showing OL (over limit) on the readout with the ohms () unit selected. This usually means that the unit being measured is open (infinity resistance) and has no continuity.

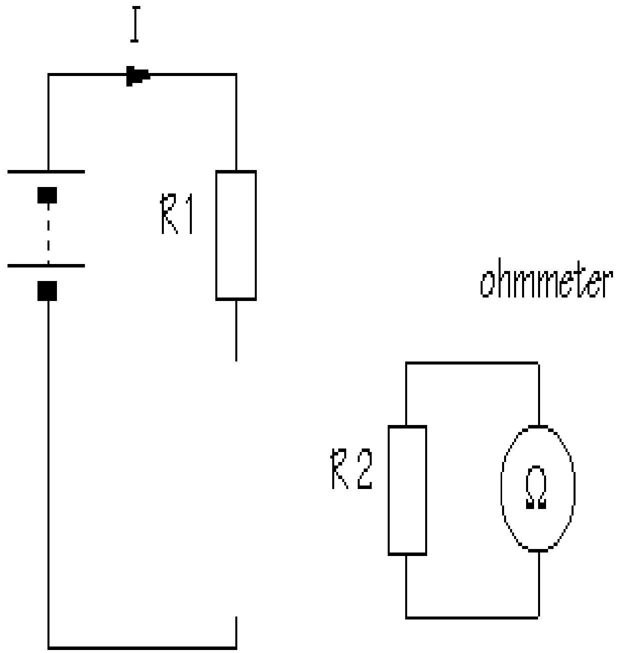
DIGITAL MULTIMETERS

Measuring Resistance

	To					
From	Mega	Kilo	Base	Milli	Micro	Nano
Mega	0 places	3 places to the right	6 places to the right	9 places to the right	12 places to the right	15 places to the right
Kilo	3 places to the left	0 places	3 places to the right	6 places to the right	9 places to the right	12 places to the right
Base	6 places to the left	3 places to the left	0 places	3 places to the right	6 places to the right	9 places to the right
Milli	9 places to the left	6 places to the left	3 places to the left	0 places	3 places to the right	6 places to the right
Micro	12 places to the left	9 places to the left	6 places to the left	3 places to the left	0 places	3 places to the right
Nano	15 places to the left	12 places to the left	9 places to the left	6 places to the left	3 places to the left	0 places

Measuring Resistance





DIGITAL MULTIMETERS

Measuring Resistance

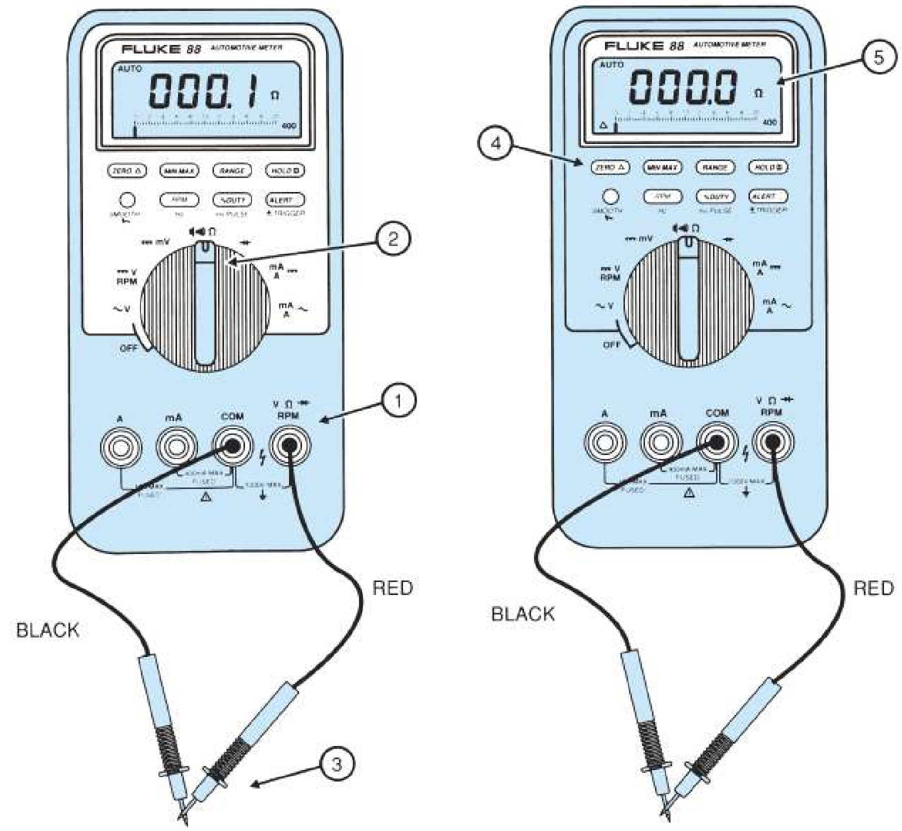
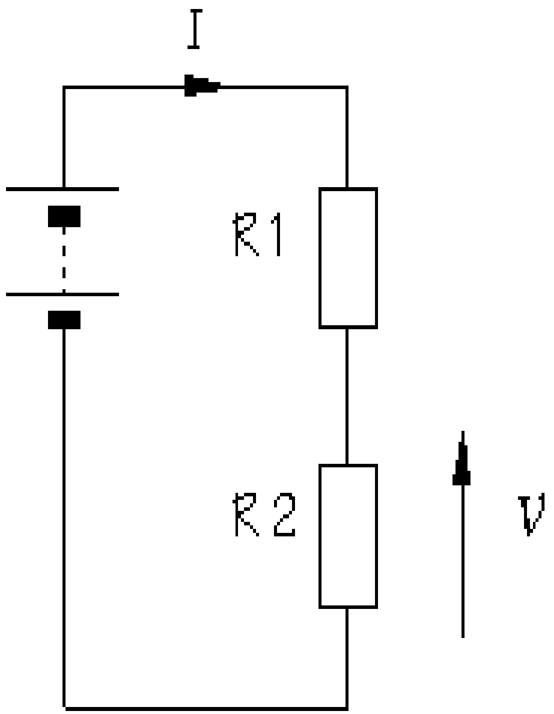
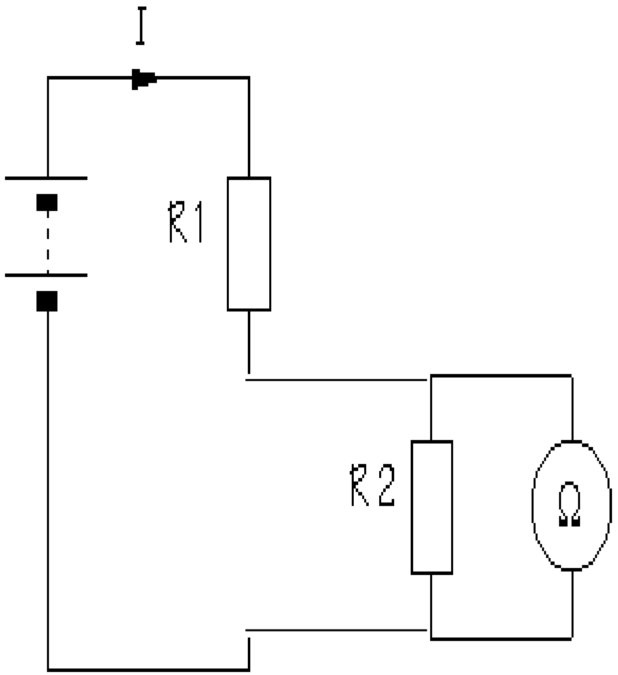


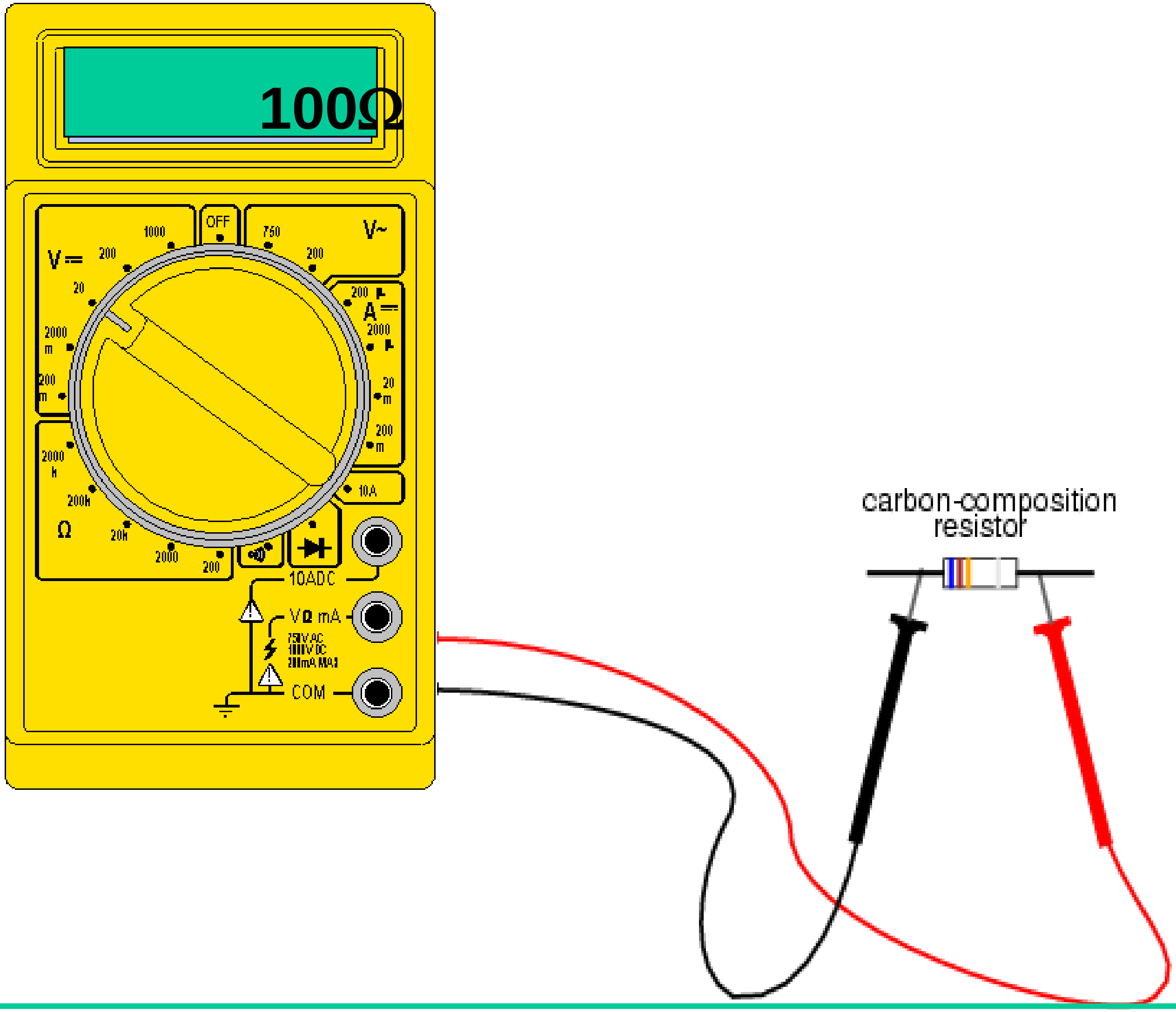
FIGURE: Many digital multimeters can have the display indicate zero to compensate for test lead resistance.(1) Connect leads in the Vand COM meter terminals.(2) Select the scale.(3) Touch the two meter leads together.(4) Push the “zero” or “relative” button on the meter.(5) The meter display will now indicate zero ohms of resistance. *(Courtesy of Fluke Corporation)*

Measuring or Testing Continuity

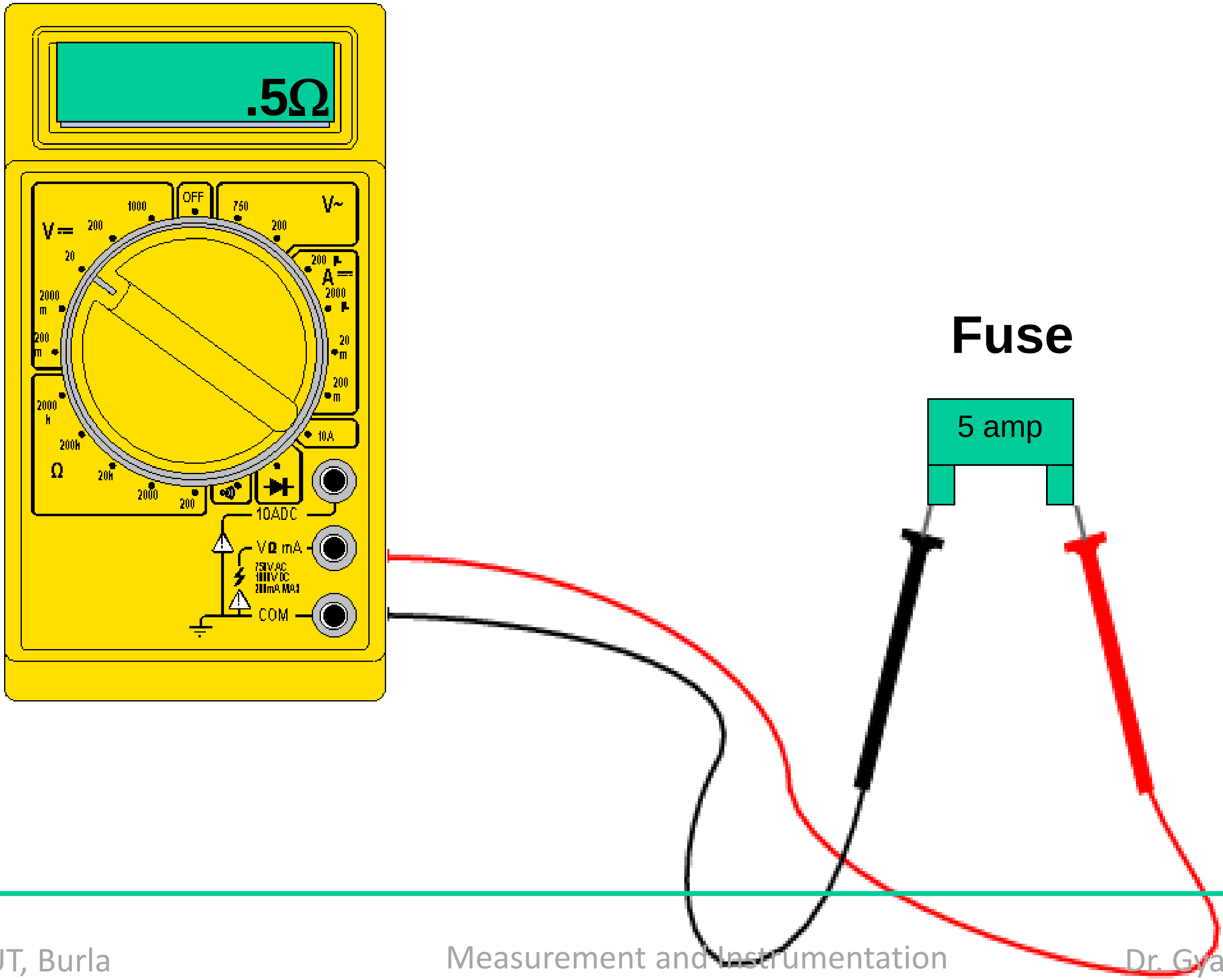




Measuring Resistance



Measuring Continuity



Measuring Current

- Current (amps) is the flow of electrical charge though a component or conductor
- Current is measured in amps or amperes
- Disconnect power source before testing
- Disconnect completed circuit at end of circuit
- Place multimeter in series with circuit
- Reconnect power source and turn ON
- Select highest current setting and work your way down.

Measuring Amperes

- An ammeter measures the flow of *current* through a complete circuit in units of amperes.

DIGITAL MULTIMETERS

Measuring Amperes

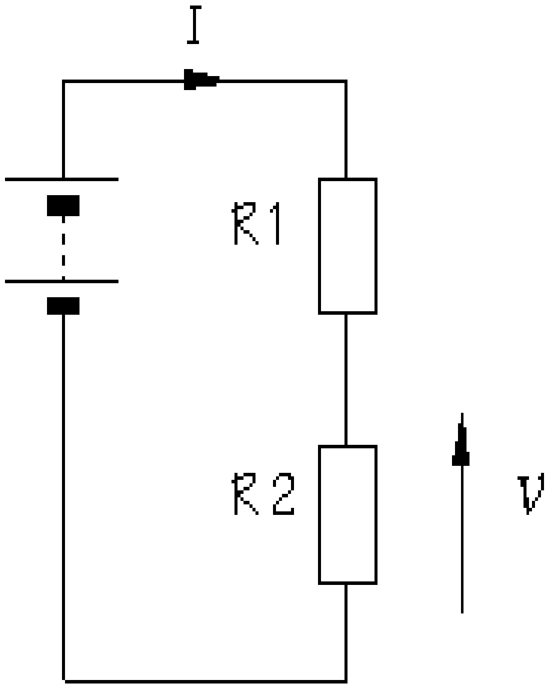
FIGURE: In this digital multimeter set to read DC amperes, note that the red lead is placed in the far left-hand socket of the meter. The meter is displaying the current flow (4.18A) through the electric fuel pump on this General Motors 3800 V6 engine.

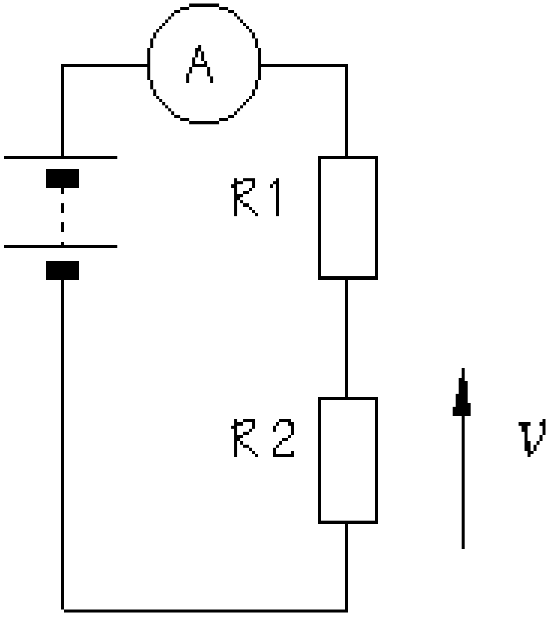
DIGITAL MULTIMETERS

Measuring Amperes

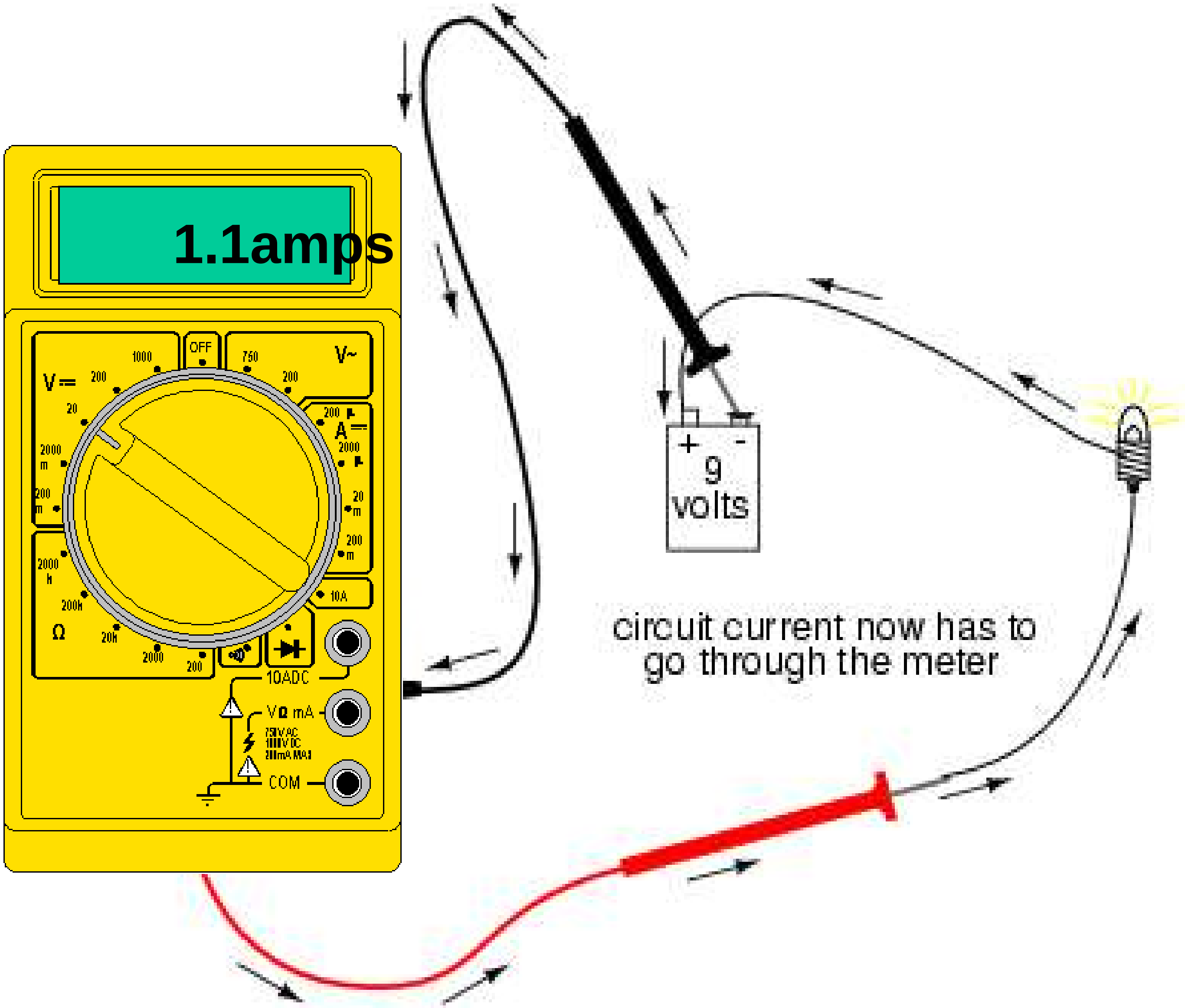
FIGURE: An inductive ammeter clamp is used with all starting and charging testers to measure the current flow through the battery cables.

Measuring Current





Measuring Current



Review

- A meter capable of checking for voltage, current, and resistance is called a *multimeter*,
- When measuring Voltage the multimeter must be connected to two points in a circuit in order to obtain a good reading. Be careful not to touch the bare probe tips together while measuring voltage, as this will create a short-circuit!
- Never read Resistance or test for Continuity with a multimeter on a circuit that is energized.
- When measuring Current the multimeter must be connected in a circuit so the electrons have to flow *through* the meter
- Multimeters have practically no resistance between their leads. This is intended to allow electrons to flow through the meter with the least possible difficulty. If this were not the case, the meter would add extra resistance in the circuit, thereby affecting the current

AC/DC CLAMP-ON DIGITAL MULTIMETER

- An **AC/DC clamp-on digital multimeter (DMM)** is a useful meter for automotive diagnostic work and uses a Hall-effect sensor to measure current.

AC/DC CLAMP-ON DIGITAL MULTIMETER

FIGURE: A typical mini clamp-on-type digital multimeter. This meter is capable of measuring alternating current (AC) and direct current (DC) without requiring that the circuit be disconnected to install the meter in series. The jaws are simply placed over the wire and current flow through the circuit is displayed.

FIGURE: An AC and DC current clamp such as the one shown can be used with a regular digital multimeter. The amp probe contains a separate battery and electronic circuit that converts the amperage reading into a millivolt (mV) signal.

AC/DC CLAMP-ON DIGITAL MULTIMETER

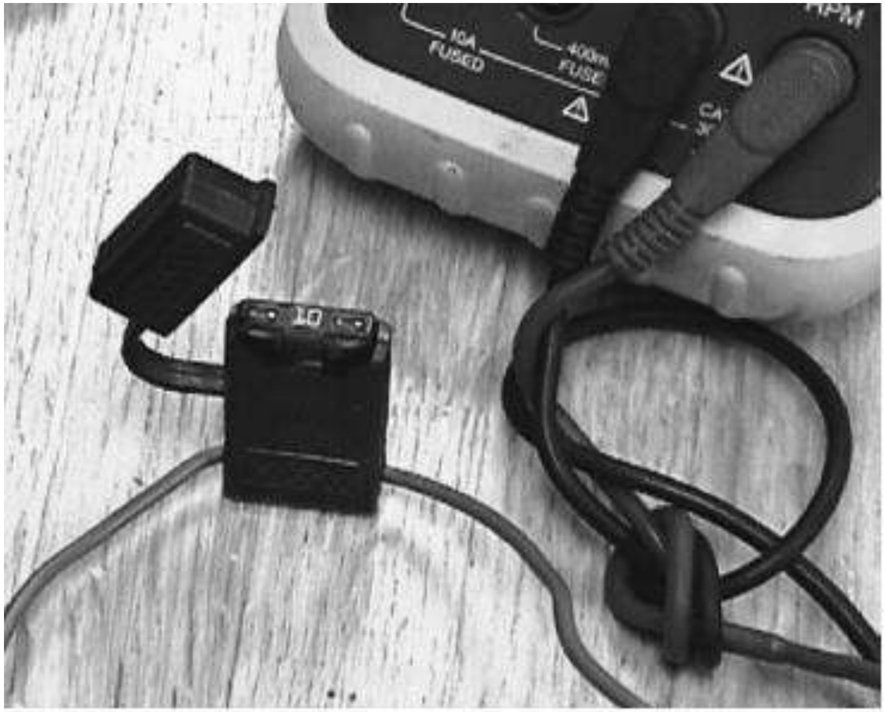


FIGURE: Note the blade-type fuse holder soldered in series with one of the meter leads. A 10 amp fuse helps protect the internal meter fuse (if equipped) and the meter itself from damage that might result from excessive current flow if accidentally used incorrectly.

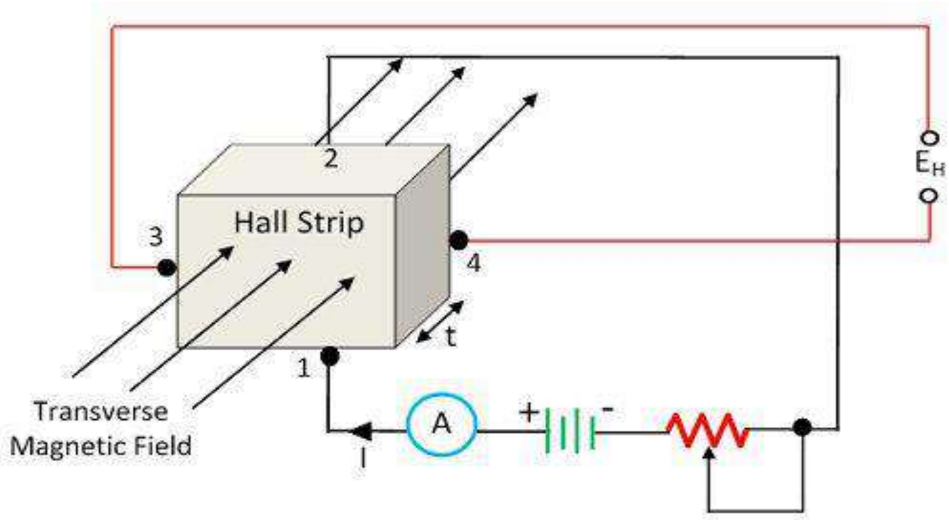
HALL EFFECT TRANSDUCERS

- The hall effect element is a type of transducer used for measuring the magnetic field by converting it into an emf.
- The direct measurement of the magnetic field is not possible. Thus the Hall Effect Transducer is used.
- The transducer converts the magnetic field into an electric quantity which is easily measured by the analog and digital meters.

PRINCIPLE

- The principle of hall effect transducer is that:
  - If the current carrying strip of the conductor is placed in a transverse magnetic field, then the EMF develops on the edge of the conductor.
  - The magnitude of the develop voltage depends on the density of flux, and this property of a conductor is called the Hall effect.
  - The Hall effect element is mainly used for magnetic measurement and for sensing the current.
  - The metal and the semiconductor has the property of hall effect which depends on the densities and the mobility of the electrons.

- Consider the hall effect element shown in the figure below. The current supply through the lead 1 and 2 and the output is obtained from the strip 3 and 4. The lead 3 and 4 are at same potential when no field is applied across the strip.



Hall Effect Element

- When the magnetic field is applied to the strip, the output voltage develops across the output leads 3 and 4. The develops voltage is directly proportional to the strength of the material.

- The output voltage is,

- Where $$E_H = K_H IB/t$$

$$K_H - Hall\ effect\ coefficient\ ;\ \frac{V - m}{A - Wbm^{-2}}$$

$$t - thickness\ of\ Strip\ ; m$$

I is the current in ampere and the B is the flux densities in Wb/m^2

- The current and magnetic field strength both can be measured with the help of the output voltages. The hall effect EMF is very small in conductors because of which it is difficult to measure. But semiconductors like germanium produces large EMF which is easily measured by the moving coil instrument.

APPLICATIONS

- **Magnetic to Electric Transducer –** The Hall effect element is used for converting the magnetic flux into an electric transducer.

- **Measurement of Displacement** – The Hall effect element measures the displacement of the structural element.

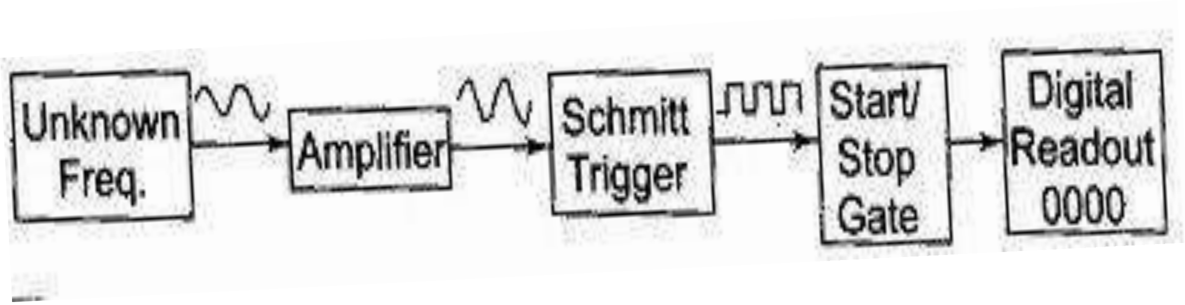
- **Measurement of Current** – The hall effect transducer is also used for measuring the current without any physical connection between the conductor circuit and meter.

- **Measurement of Power** – The hall effect transducer is used for measuring the power of the conductor.

DIGITAL FREQUENCY METER

- **Digital frequency meter** is a general purpose instrument that displays the frequency of a periodic electrical signal to an accuracy of three decimal places. It counts the number events occurring within the oscillations during a given interval of time.
- For measuring low frequencies, we usually use deflection type meters
- The deflection type instruments are of two types:
  - electrically resonant circuits,
  - ratio meter.

BLOCK DIAGRAM



- The signal whose frequency we have to be measured is first to be amplified through amplifier.
- The output of amplifier is applied to the Schmitt trigger. The Schmitt trigger is convert input signal into a square wave which has a fast rise and fall time.
- The square wave is then differentiated and clipped. Each pulse is proportional to each cycle of unknown signal.

- Now the output from Schmitt trigger is applied to a start and stop gate.
- The input pulses are allowed to pass through it, when the gate is open.
- The counter starts to count these pulses.
- The gate is closed the output pulses are not allowed to pass through the gate. The counter stops the counting.
- When the gate is open the number of pulse are counted by the counter. The interval between start and stop condition is the frequency of unknown signal which has to be mean.

$$F = N/t$$

Where, **F** = Unknown frequency.

N = Number of counts.

t = Time interval between start and stop condition of the gate.

- The Principle of Operation of Digital Frequency Meter is given by
- The signal waveform is converted to trigger pulses and applied continuously to an AND gate, as shown in Fig. 6.4. A pulse of 1 s is applied to the other terminal, and the number of pulses counted during this period indicates the frequency.

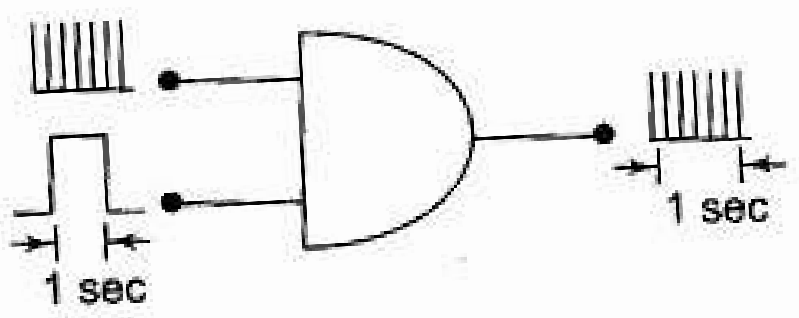


Fig. 6.4 Principle of Digital Frequency Measurement

- The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal.
- The number of pulses occurring in a definite interval of time is then counted by an electronic counter.
- Since each pulse represents the cycle of the unknown signal, the number of counts is a direct indication of the frequency of the signal (unknown).
- Since electronic counters have a high speed of operation, high frequency signals can be measured.

Applications

- For testing radio equipment.
- Measuring the temperature, pressure, and other physical values.
- Measuring vibration, strain.
- Measuring transducers.

Transducers

- **Sensor / Transducer (Instrument Society of America)**: A device which provides a usable output in response to a specified measurand.
- Output: defined as an Electrical Quantity (finally).
- Measurand: as a Physical quantity / property / condition which is measured.

- **Physical quantity** – pressure, heat, flow rate, liquid level, flow, position, humidity etc.
- **Output** - measured in terms of parametric change or electrical signal.

- **Transducer**: device which converts one form of energy into another form for the purpose of measurement / control.

- **Sensor** : Transducer (physical into electrical) + electrodes and I/O mechanisms.

- Sensor ⟺ I/P Transducer

- Actuator ⟺ O/P Transducer

Classification of Transducers

1. Based on principle of transduction

2. Primary and secondary

3. Active & passive

4. Analog & digital

5. Transducer and Inverse transducer

6. Smart / Intelligent (latest one)

Based on principle used

- Thermo electric
- Magneto resistive
- Electro kinetic
- Optical

Based on Applications

- ❖ Industry Automation / Process Control
- ❖ Embedded Control: Automobiles; Medical; Aircraft; Consumer Electronics

Passive Transducer

- Device which derive power reqd. for transduction from auxiliary power source
- externally powered
- Examples : resistive, inductive, capacitive
- Without power they will not work

Active Transducer

- No extra power reqd. to produce I/P

- Self generating

- Draw power from input applied

- Examples: Smart accelerometer or vibration sensor ; Piezo-resistive Si-type Diaphragm Pressure sensor (with the strain gauge and a thin film resistor network) ; Piezo-electric type accelerometer

Analog Transducer

- Convert I/P quantity into an analog O/P
- Analog O/P - a continuous function of ‘amplitude and time’
- Examples: Strain gauge, LVDT, thermocouple, manometer

Digital Transducer

- Converts I/P into an electrical O/P in the form of pulses (quasi-digital O/P) or a discrete function of 'amplitude and time'

- Examples: Smart and Intelligent transducers

Inverse Transducer

- Converts electrical signal to physical quantity, typically, known as Actuator'.

- Accepts a data sample (samples) and converts them into physical action.

Smart Sensor

- **Smart Sensor**: A module containing sensor element(s) suitably integrated with necessary electronics such that the O/P is truly or easily compatible with the intended end device, and the module is usually takes the form of a single IC chip.

- **Intelligent Sensor**: Smart sensor + Digital Processor (DPU)

Motion and Vibration Measurement

- ❖ Translational and Rotational Displacement using: ~~Potentiometer~~; Strain gauges; Differential transformer (LVDT); ~~Synchros and induction potentiometer~~; Capacitance (capacitive type transducer); ~~Techometers~~
- ~~❖ Accelerometers~~

Displacement Measurement

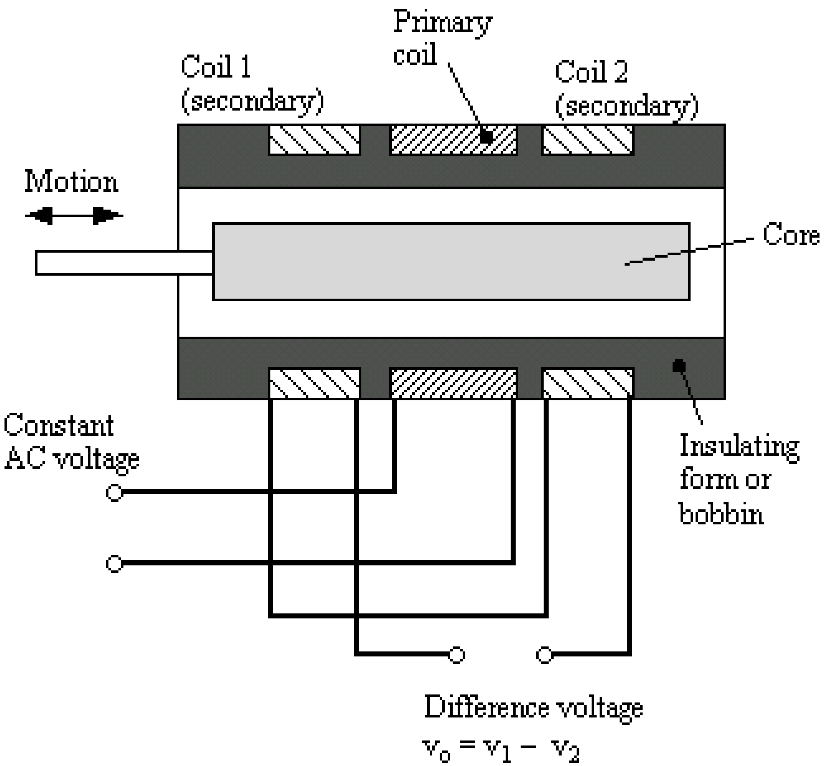
Linear Variable Displacement Transducer (LVDT):

- A very basic transducer which is always useful in the field of instrumentation. Also recognized as Linear Variable Differential Transducer, is a kind of variable inductance transducer.

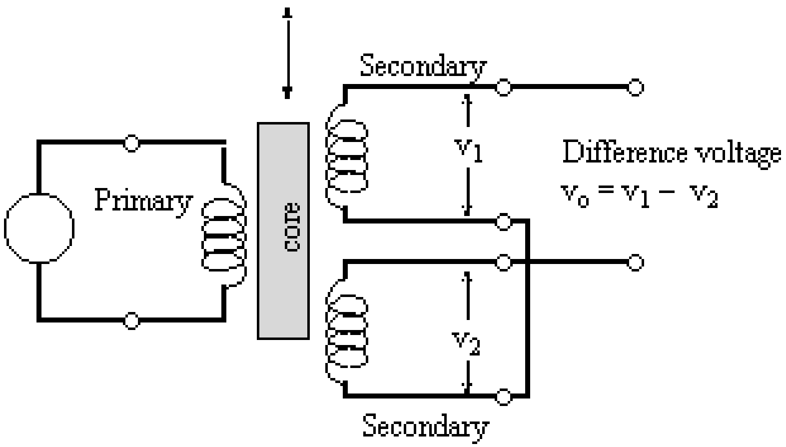
Principle of LVDT:

LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.

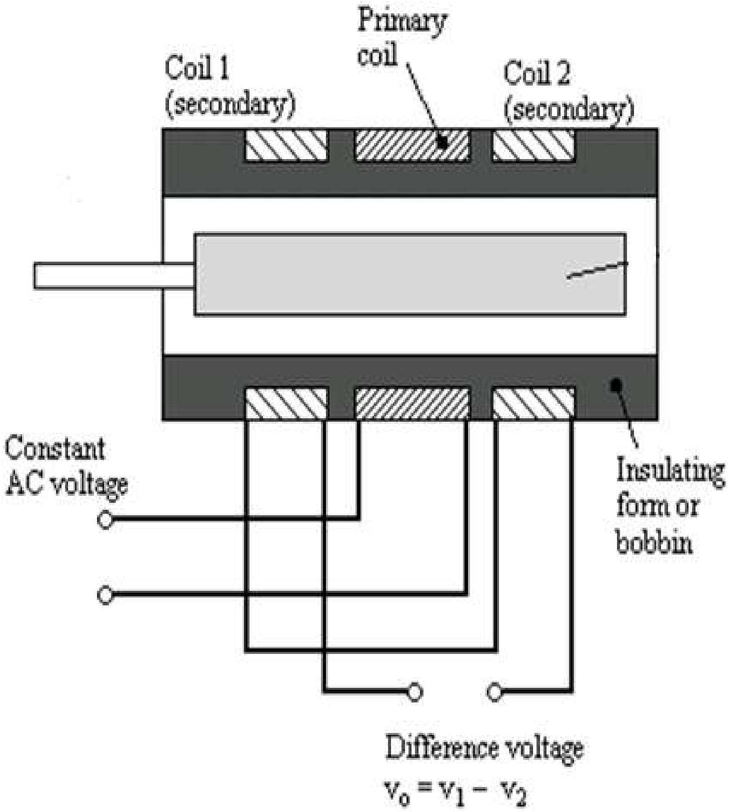
Construction of LVDT:



(a)



(b)



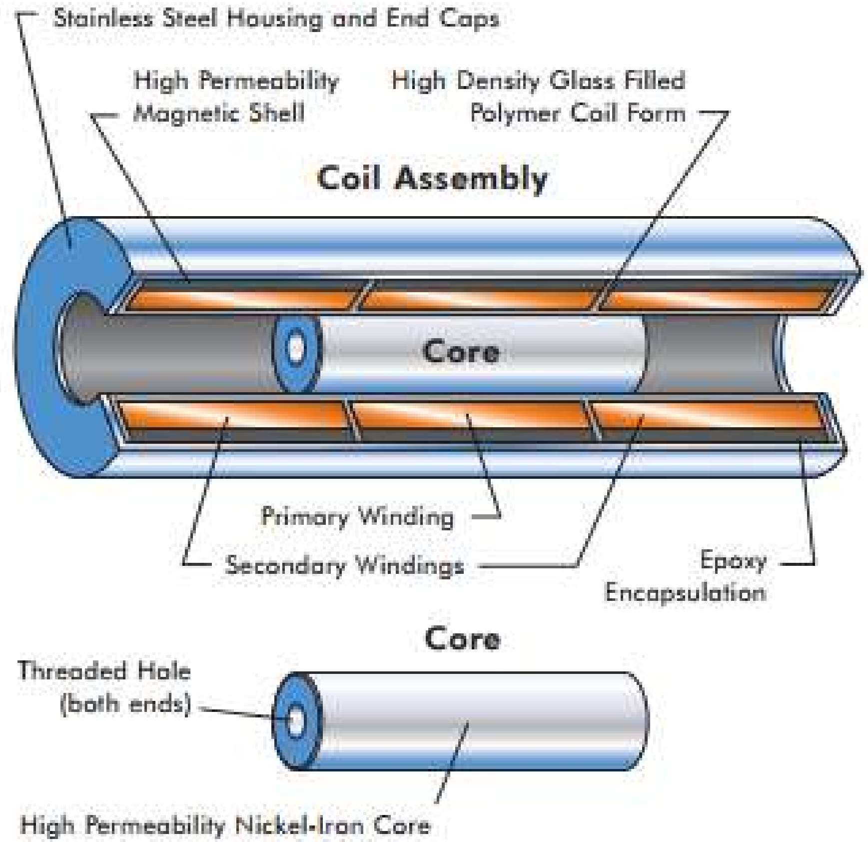
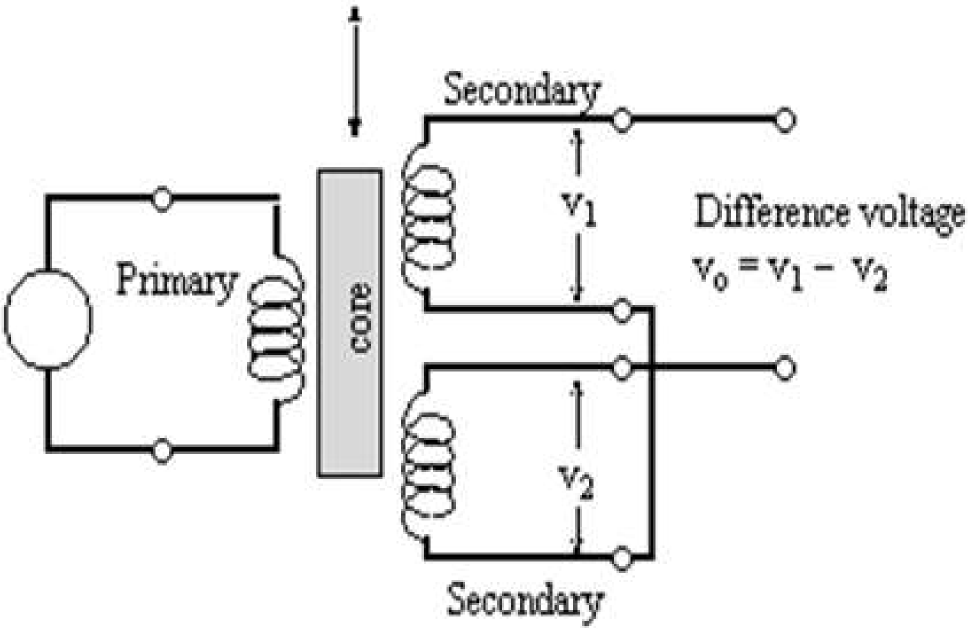


Figure 1

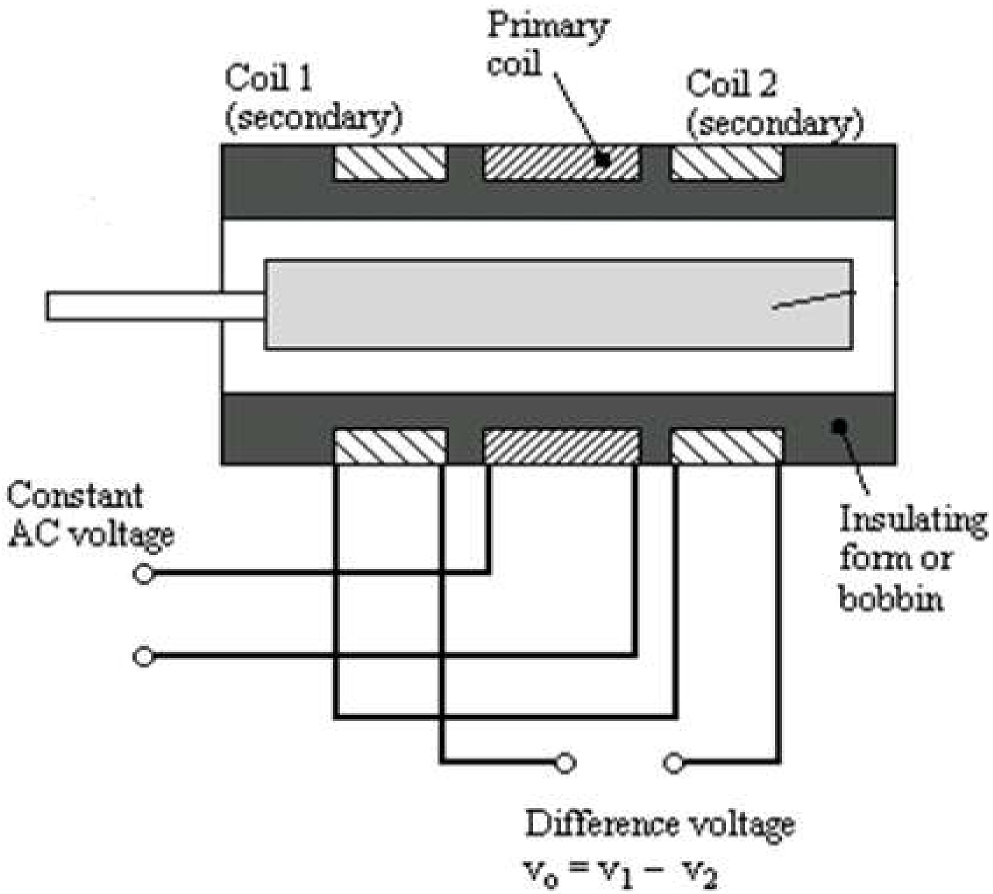
The features that make an LVDT environmentally robust are evident in this cutaway view.

- LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides.



- The number of turns in both the secondary windings are equal, but they are opposite to each other.

That is, if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, and hence, the net output voltages will be the difference in voltages between the two secondary coil.



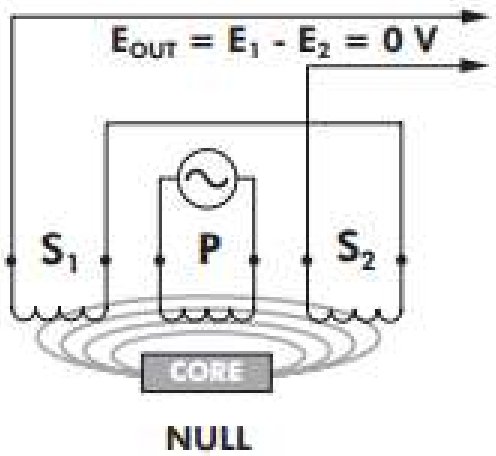
- The two secondary coil is represented as S1 and S2. Esteem iron core is placed in the centre of the cylindrical former which, can move in to and fro motion as shown in the figure.

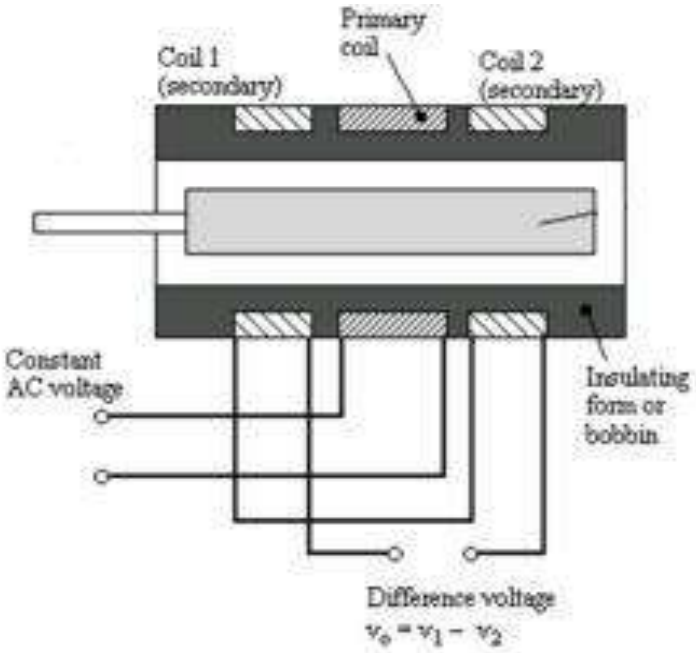
Working of LVDT:

Case 1:

On applying an external force, which is the displacement, if the core reminds in the null position itself without providing any movement then the voltage induced in both the secondary windings are equal which results in net output is equal to zero.

Esec1-Esec2=0

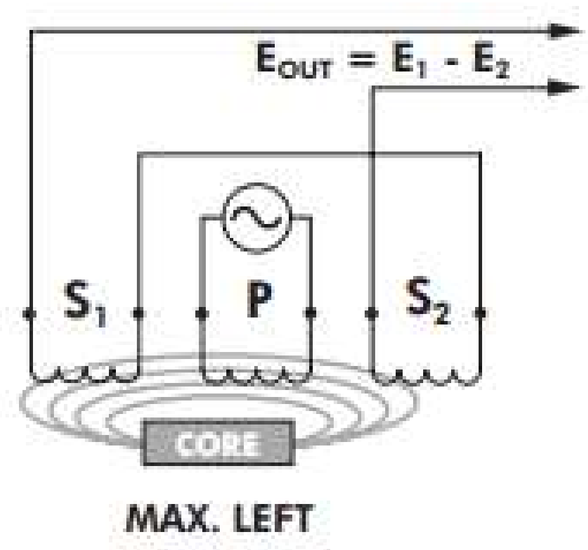


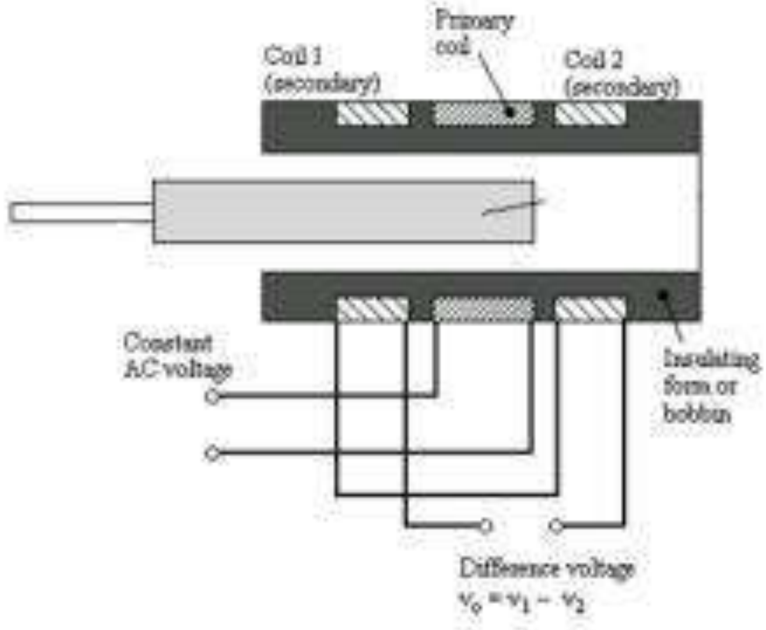


Case 2:

When an external force is applied and if the steel iron core tends to move in the left hand side direction then the EMF voltage induced in the secondary coil is greater when compared to the EMF induced in the secondary coil 2.

Thus, the net output will be Esec1-Esec2

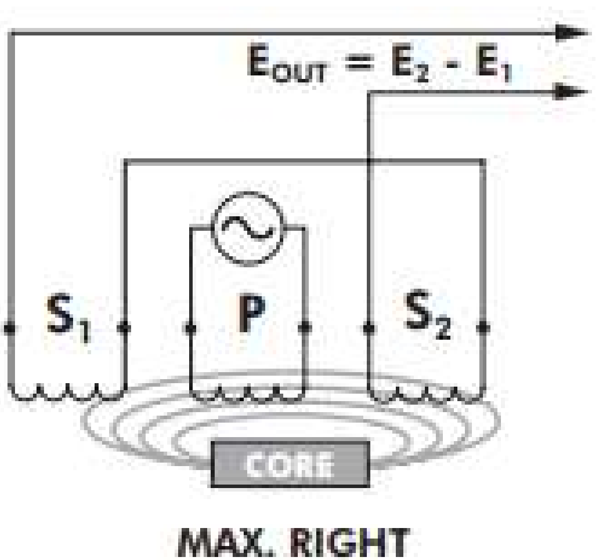


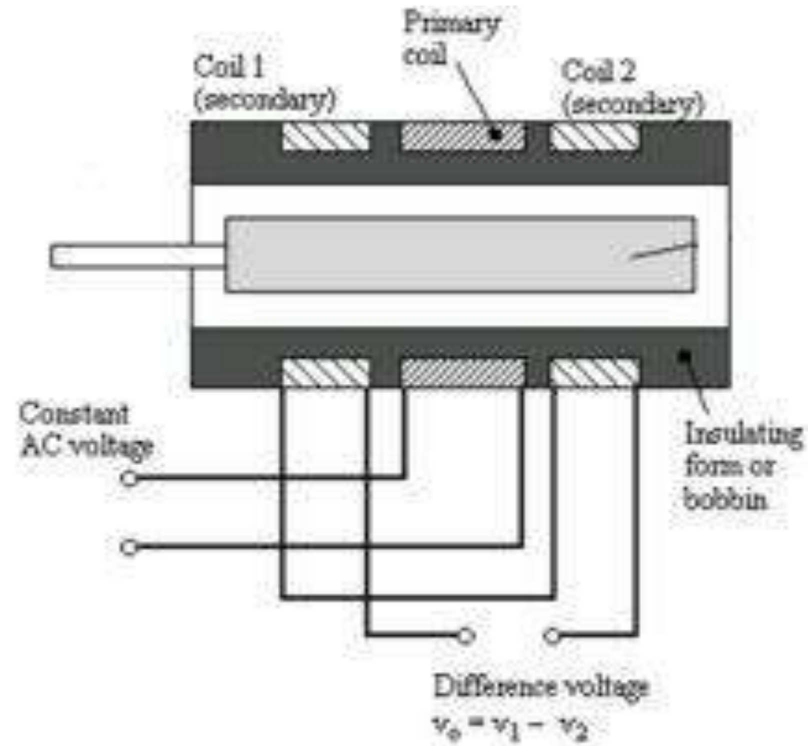


Case 3:

When an external force is applied and if the steel iron core moves in the right hand side direction then the EMF induced in the secondary coil 2 is greater when compared to the EMF voltage induced in the secondary coil 1.

The net output voltage will be Esec2-Esec1





Benefits of LVDT:

1) Infinite resolution is present in LVDT
2) High output
3) LVDT gives High sensitivity
4) Very good linearity
5) Ruggedness
6) LVDT Provides Less friction
7) Low hysteresis
8) LVDT gives Low power consumption.

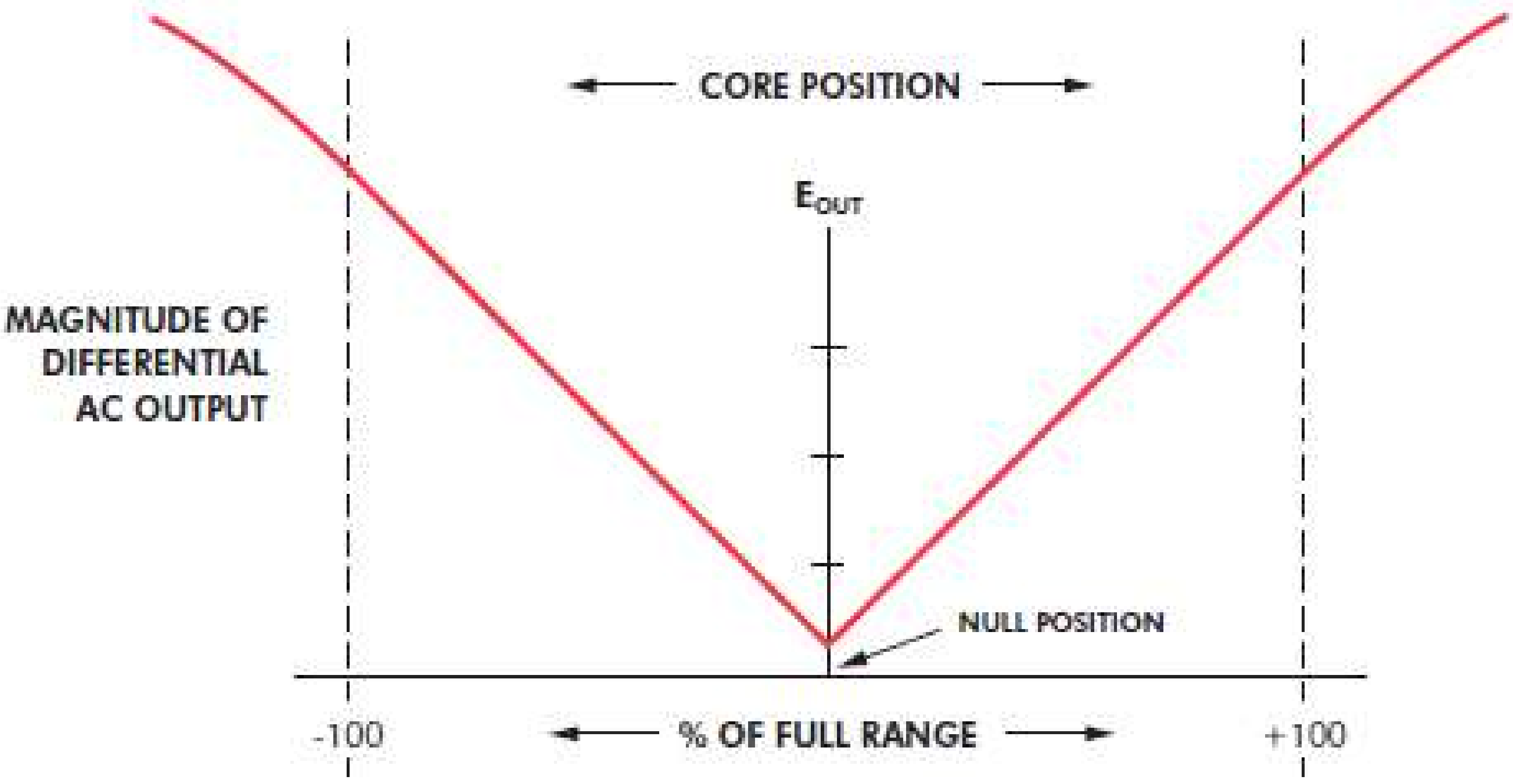
Applications of LVDT:

1) LVDT is used to measure displacement ranging from fraction millimeter to centimeter.
2) Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc..

Limitations

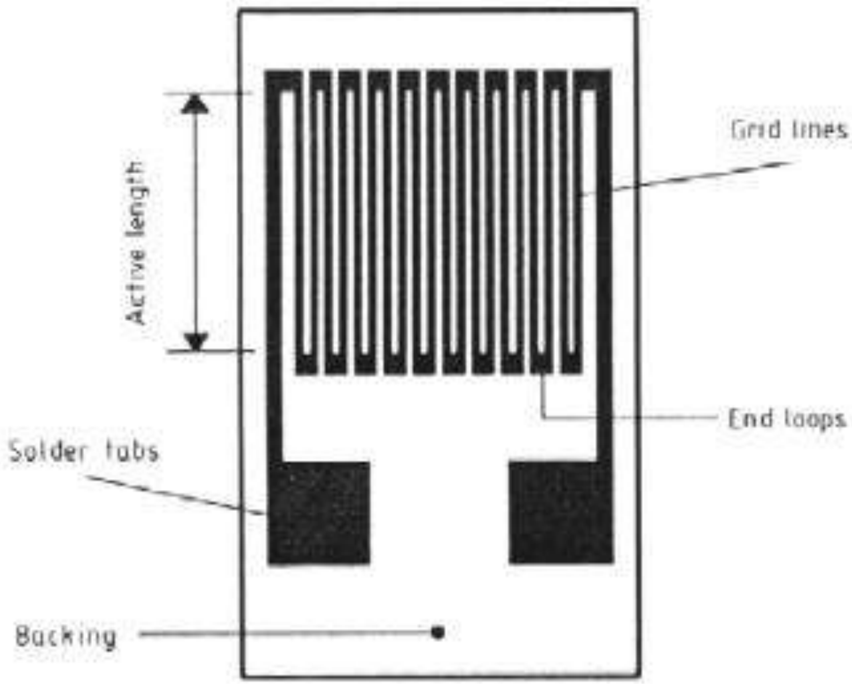
- Not sensitive.
- Excited with A.C. only; 50 Hz to 20KHz

Characteristics of LVDT:



CONTENTS

- Introduction
- Electrical Resistance Strain Gages
- Types of Strain Gages
- Strain Gage Signal Conditioning
- Calibration

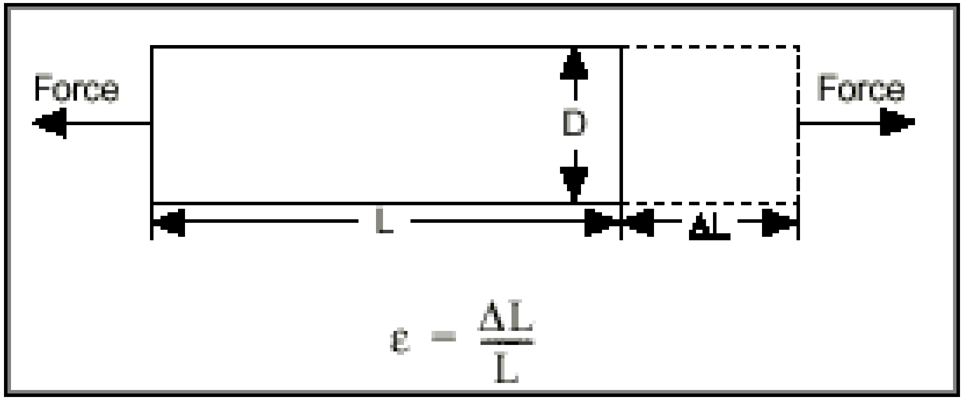


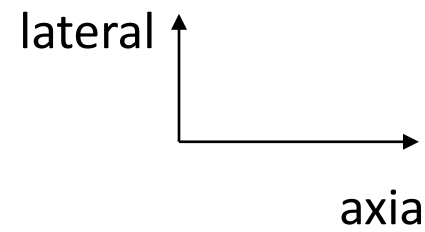
From [BW96]

The electrical resistance strain is a metal wire or metal foil strip, which is wafer-like and can be stuck onto surfaces like a postage stamp.

Strain Gauges

WHAT IS STRAIN?





- Strain is the amount of deformation of a body to an applied force
- For axial direction from the figure above $\varepsilon_a = \dfrac{\Delta L}{L}$;usually multiple of (ex10^{-6})
- Because of Poisson strain phenomena, D will be contracted in lateral direction, with magnitude depends on Poisson ratio (n) $\nu = \dfrac{-\varepsilon_L}{\varepsilon_a}$
- ‘n’ is the property of material, for example, steel has $0.25 \le n \le 0.3$

When strain gauges measure the changing dimensions of an object, they are measuring strain. Strain is the ratio of the change in dimension of an object to the original dimension

Mechanical strain $\varepsilon = \Delta L / L$

When subject to strain, its resistance R changes, the fractional change in resistance $\Delta R/R$ being proportional to the mechanical strain i.e.

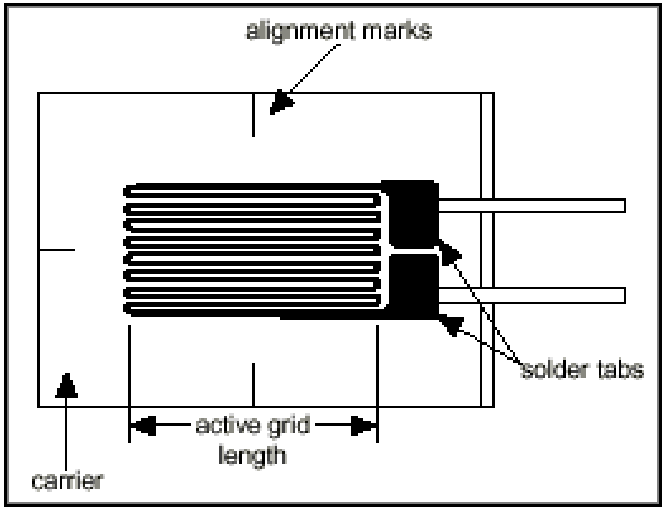
Electrical strain $\Delta R/R = G \cdot \Delta L/L$

where G is the gauge factor (1.8 – 2.2)

R varies between 50 Ω and 2KΩ

Electrical Resistance Strain Gages

- The most common method for measuring strain is using strain gauge.



- Strain gage is a device whose electrical resistance varies in the proportion of the amount of strain A in the device.
- The most widely used strain gages is the bonded metallic strain gage

- The resistance of the conductor of the strain gage

$$R = \rho \frac{L}{A}$$

where ρ = resistivity of conductor material
L =conductor length
A = cross-sectional area of conductor

If, differentiated this equation become:

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dL}{L} - \frac{dA}{A}$$

$$A \approx D^2$$

$$\frac{dA}{A} \approx 2\frac{dD}{D}$$

↑ Lateral strain

Then the equation :

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \varepsilon_a(1 + 2\nu)$$

Gauge Factor

$$R = \rho \frac{\ell}{A}$$

$$\log R = \log \rho + \log(\ell/A)$$

Taking the differential

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{d(\ell/A)}{\ell/A}$$

Change in resistance is from change in shape as well as change in resistivity

Gauge factor: (2-6 for metals and 40 – 200 for semiconductor)

Gauge Factor

Strain gage factor, S (GF) is defined

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \varepsilon_a (1 + 2\nu)$$

$$S = \frac{dR/R}{\varepsilon_a}$$

$$S = (1 + 2\nu) + \frac{d\rho/\rho}{\varepsilon_a}$$

If, the surface of a structure is in the biaxial stress condition there will be a transverse strain that will affect the strain gage output can be described with transverse gage factor, S_t

$$S_t = \frac{dR/R}{\varepsilon_t}$$

and

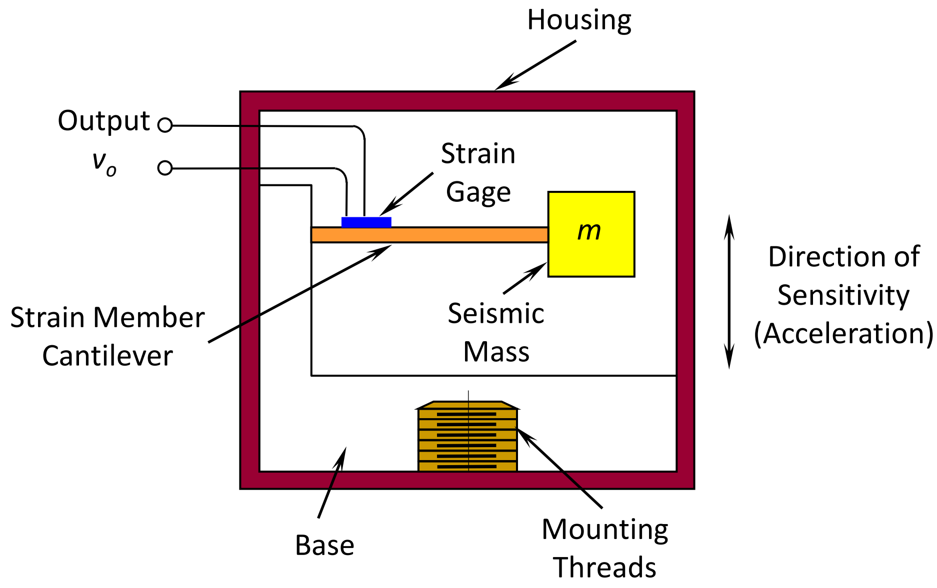
Transverse sensitivity ⟶ $K_t = \frac{S_t}{S_a}$

Usually small (less than 0.01)

Q1: Derive the express of strain gauge factor? Also, comment over gauge factor, In case of semiconductor type and mechanical type of strain gauges?

Applications

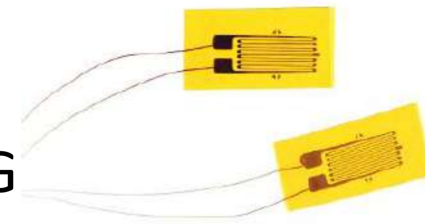
- The change in resistance is measured using an electrical circuit.
- Many variables can be measured – displacement, acceleration, pressure, temperature, liquid level, stress, force and torque.
- Some variables (stress, force, torque) can be determined by measuring the strain directly.
- Other variables can be measured by converting the measurand (M) into stress using a front-end device.

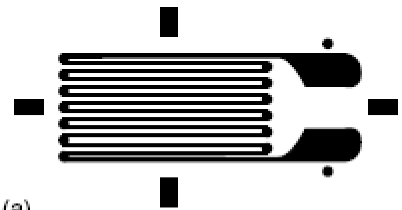


Strain gauge accelerometer

Types of Strain Gauges

TYPICAL METALLIC FOIL STRAIN GAG

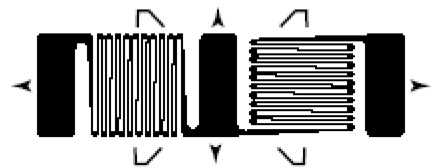




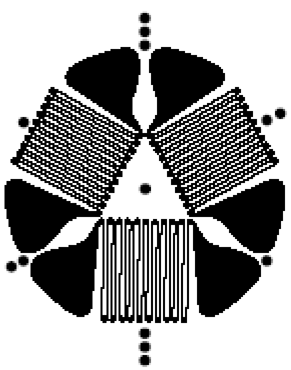
(a)

single element strain gage

two element rossete

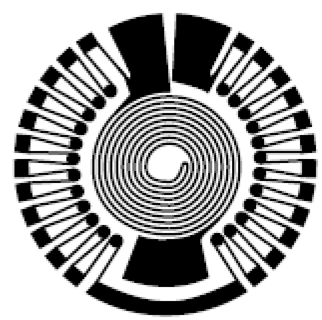


(b)



(c)

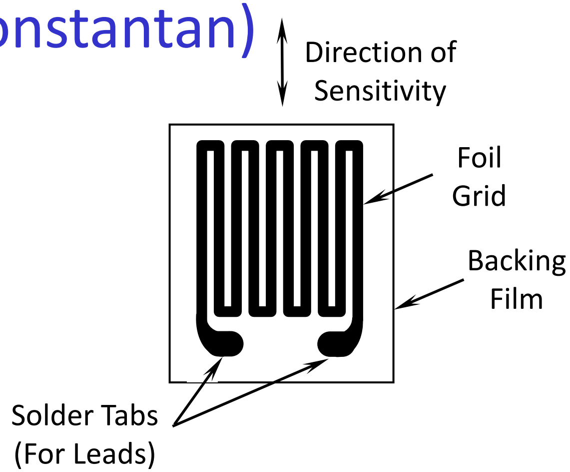
three-element rossete

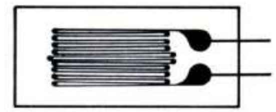


(d)

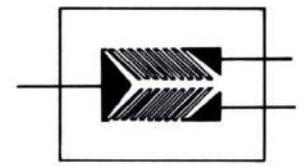
used in pressured diaphragms

Strain gages are manufactured **as metallic foil (**copper-nickel alloy – constantan)

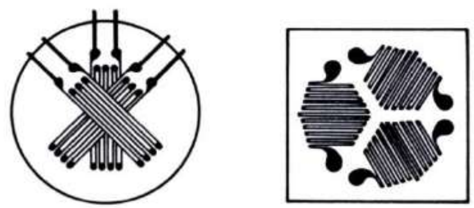




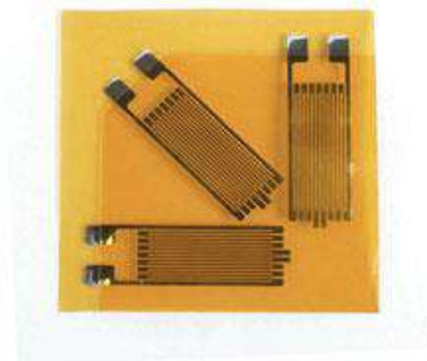
Single Element



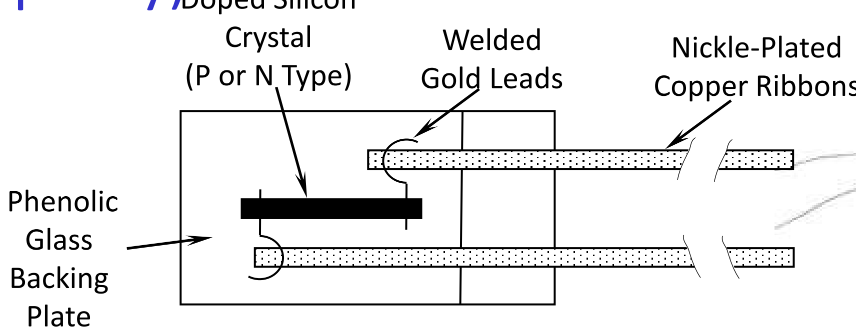
Two-Element Rosette

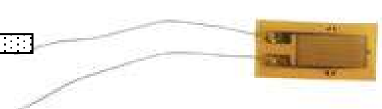


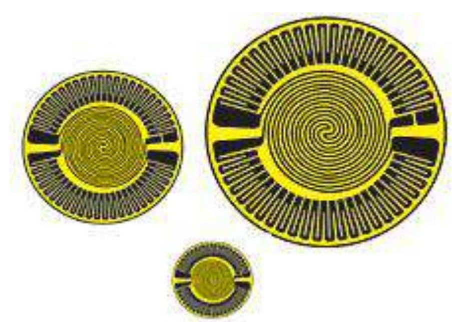
Three-Element Rosettes



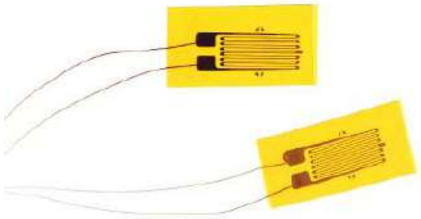
Semiconductor (silicon with impurity)







Types of Strain Gauges

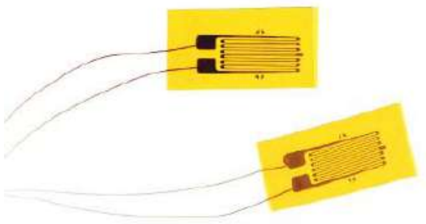


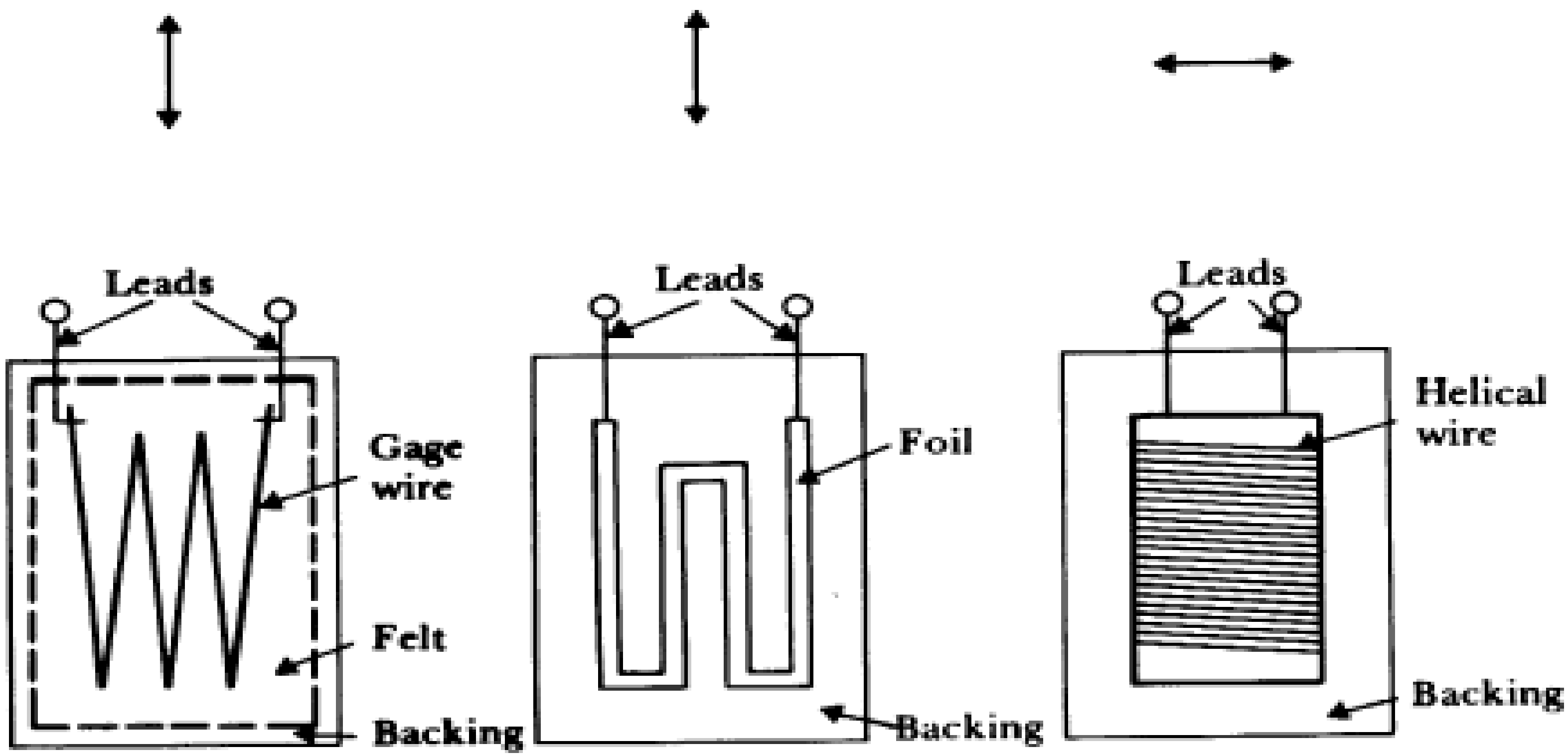
❖ Bonded type: (metallic type) grid wire spread over the area to provide uniform stress distribution.

❖ Unboned type: (semiconductor type and some metallic type) non-uniform distributed stress.

Semiconductor type $\boldsymbol{\sigma \,\alpha\, 1/\rho\ ;\ \Delta\rho \,\alpha\, \Delta T \,\alpha\, \Delta R \,\alpha\, 1/\sigma \,\alpha\, 1/\mu}$

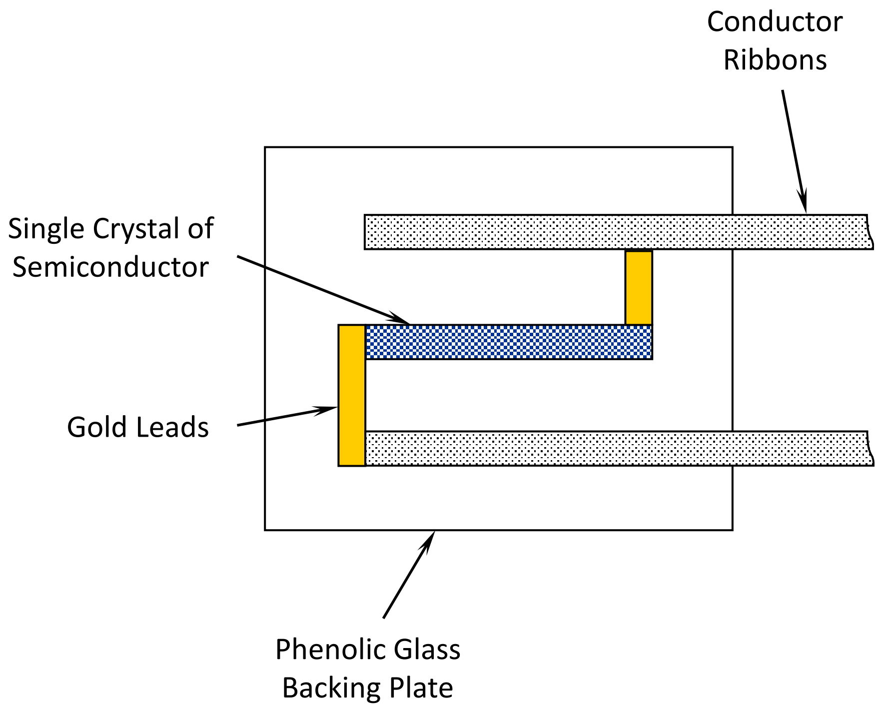
Bonded Strain Gauges





(a) (b) (c)

Semiconductor Strain Gauges

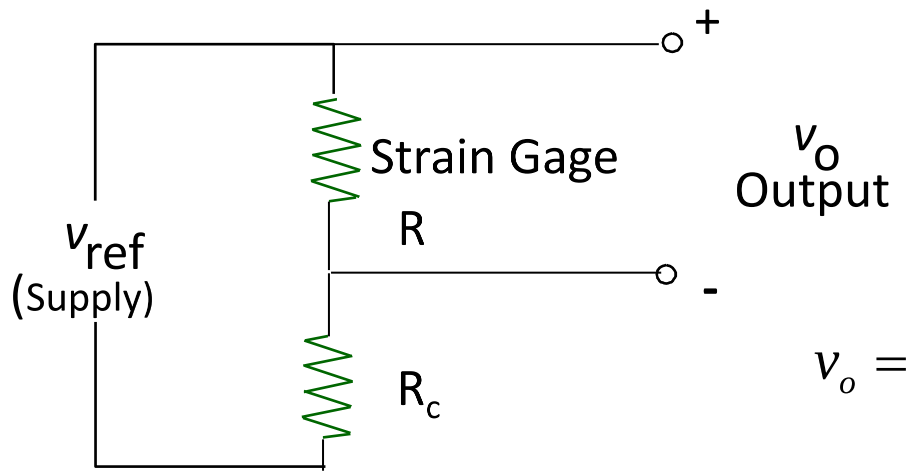


- Gage factor – 40 – 200
- Resitivity is higher – reduced power consumption
- Resistance – 5kΩ
- Smaller and lighter

CALIBRATION METHOD

- Introducing, a small change in resistance at the gauge, and calculating equivalent ‘Strain’ in the gauge using shunt resistor in parallel with gauge .

- Mounting a strain gauge on a cantilever beam into one arm of the Wheatstone bridge, and observing deflection as known strain is applied to the gauge, then, using deflection formula for cantilever beam deflected a distance ‘d’ .



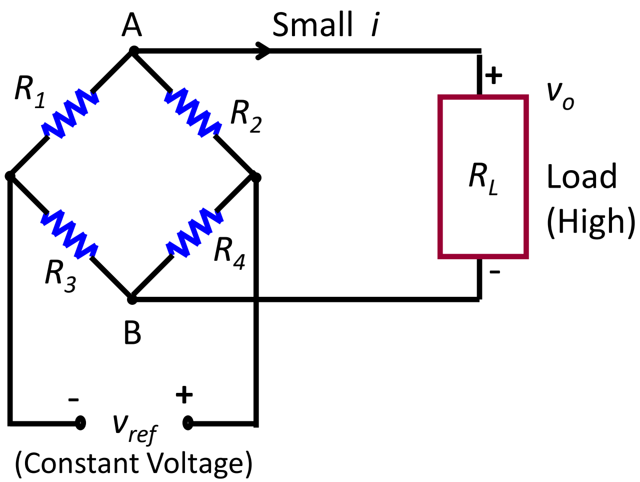
$$v_o = \frac{R}{(R + R_c)} v_{ref}$$

Issues

- Ambient temperature changes introduce error.
- Variations in supply voltage may affect the output.
- Electrical loading effect can be significant
- Change in voltage due to strain is a very small percentage of the output

Q3.: Show that errors due to ambient temperature changes will cancel if the temperature coefficients of R and R_c are the same .

Wheatstone Bridge



$$v_o = \frac{R_1 v_{ref}}{(R_1 + R_2)} - \frac{R_3 v_{ref}}{(R_3 + R_4)} = \frac{(R_1 R_4 - R_2 R_3)}{(R_1 + R_2)(R_3 + R_4)} v_{ref}$$

When the bridge is balanced

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

True for any R_L

Null Balance Method

- When the stain gage in the bridge deforms, the balance is upset.
- Balance is restored by changing a variable resistor
- The amount of change corresponds to the change in stain

Direct Measurement of Output Voltage

- Measure the output voltage resulting from the imbalance
- Determine the calibration constant
- Bridge sensitivity

$$\frac{\delta v_o}{v_{\text{ref}}} = \frac{\left(R_2 \delta R_1 - R_1 \delta R_2\right)}{\left(R_1 + R_2\right)^2} - \frac{\left(R_4 \delta R_3 - R_3 \delta R_4\right)}{\left(R_3 + R_4\right)^2}$$

To compensate for temperature changes, temperature coefficients of adjacent pairs should be the same

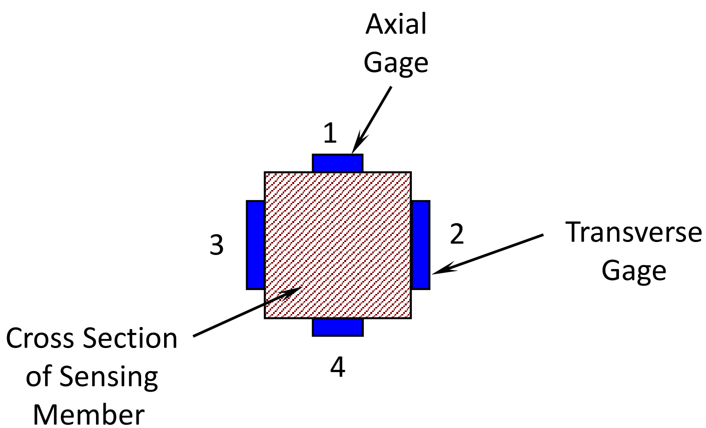
The Bridge Constant

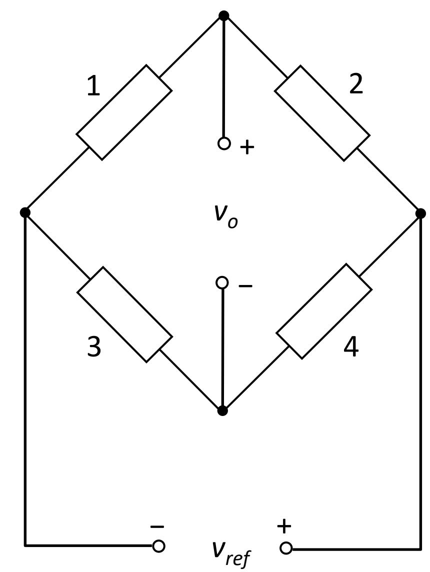
- More than one resistor in the bridge can be active
- If all four resistors are active, best sensitivity can be obtained
- R1 and R4 in tension and R2 and R3 in compression gives the maximum sensitivity
- The bridge sensitivity can be expressed as

$$\frac{\delta v_o}{v_{ref}} = k \frac{\delta R}{4R}$$

Bridge Constant $k = \dfrac{\text{bridge output in the general case}}{\text{bridge output if only one strain gage is active}}$

Q3: A strain gage load cell (force sensor) consists of four identical strain gages, forming a Wheatstone bridge, that are mounted on a rod that has square cross-section. One opposite pair of strain gages is mounted axially and the other pair is mounted in the transverse direction, as shown below. To maximize the bridge sensitivity, the strain gages are connected to the bridge as shown in below. Determine the bridge constant *k* in terms of *Poisson's ratio 'v'* of the rod material.





Transverse strain = (-*v*) x longitudinal strain

Calibration Constant

$$\frac{\delta v_o}{v_{\text{ref}}} = C\varepsilon$$

$$\frac{\delta R}{R} = S_s \varepsilon$$

$$C = \frac{k}{4} S_s$$

$$\frac{\delta v_o}{v_{ref}} = k \frac{\delta R}{4R}$$

k – Bridge Constant

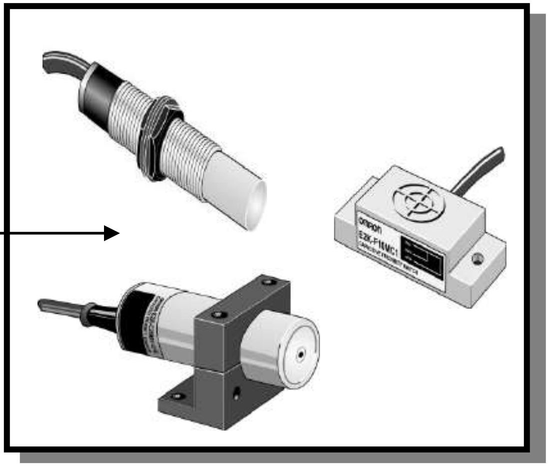
S_s – Sensitivity or gage factor

Topics covered

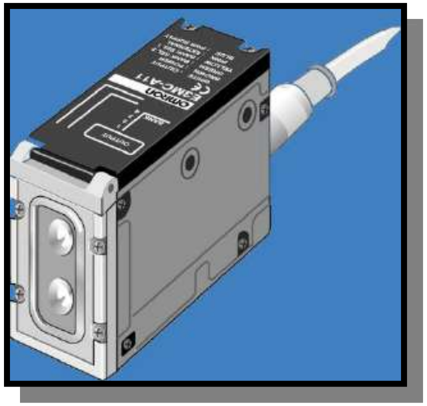
TYPES OF SENSORS

Inductive Proximity

Capacitive Proximity



Photoelectric



❖ Proximity sensors (to measure displacement) and accelerometers, are the two most common types of measuring devices used in machine protection systems for condition monitoring, fault detection, control of large machinery.

What is a Proximity Sensor?

- A device that uses various methods to measure a relative distance.
- Outputs the distance as an electrical signal.

http://www.omron-ap.com/product_info/E2EM/e2em_proximity_sensor

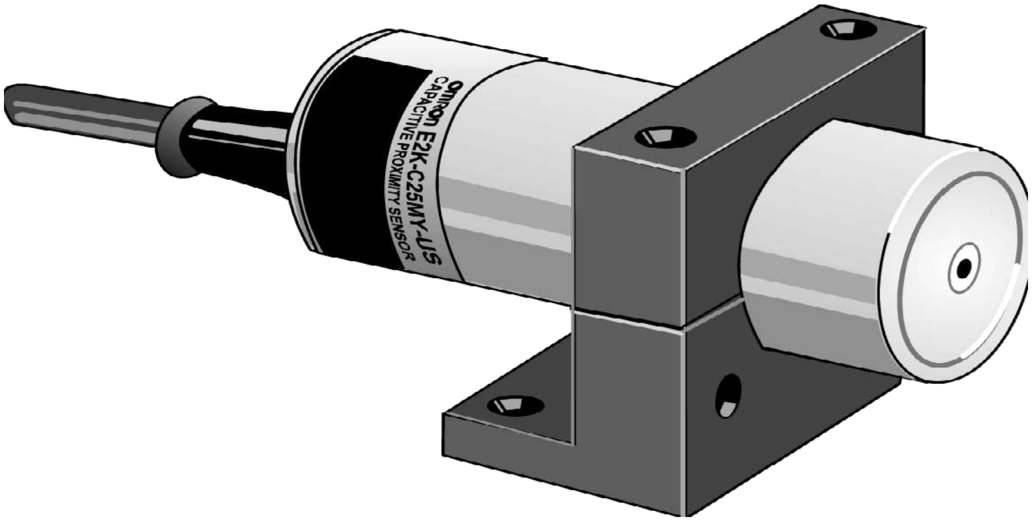
Why Use Proximity Sensors?

- Can detect objects with or without making direct contact
- Extremely accurate measurements
- Very fast measurements (responses)
- Interface with Programmable Logic Controller
- Robust
  - Long lifetime due to absence of mechanical parts
  - Large temperature range
  - Operate in contaminated environments

Common Proximity Sensors

- Inductive
- Capacitive
- Resistive
- Infrared
- Sonar

Capacitive Proximity Sensors



Capacitive Proximity Sensors

- Three basic components
  - Probe that uses capacitance to sense changes in distance to the target
  - Driver electronics to convert capacitance changes into voltage changes
  - Device to indicate and/or record the resulting voltage change

http://www.automationdirect.com/adc/Overview/Catalog/Sensors_-z-_Encoders/Capacitive_Proximity_Sensors

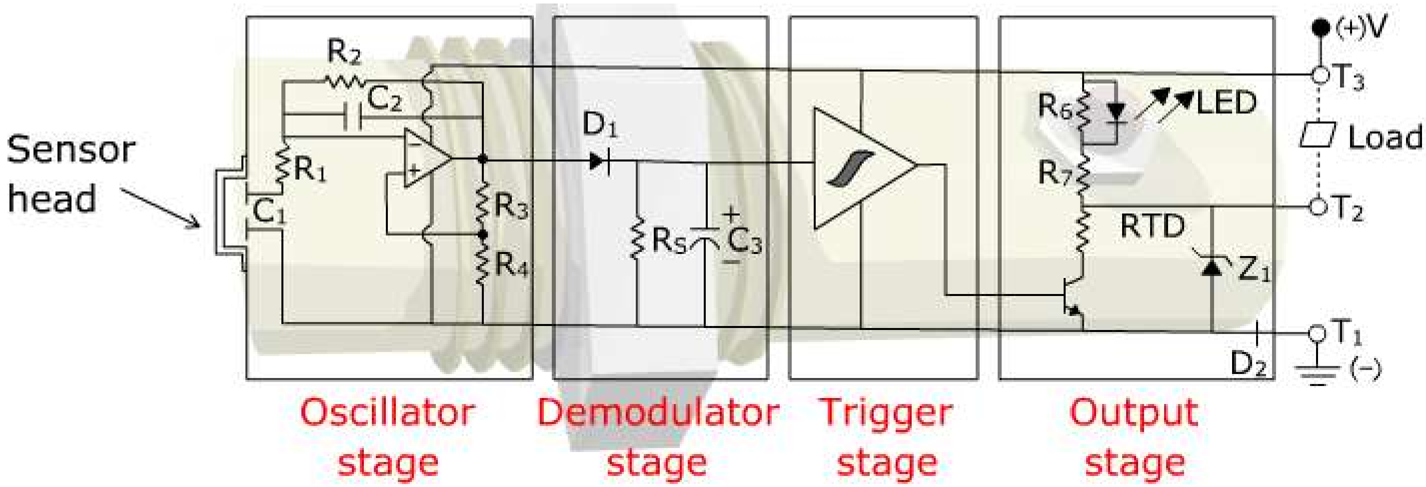
- How capacitance relates to distance
  - Size of plates
  - Gap Size
  - Dielectric material (material between plates)
  - For ordinary sensing, only gap size is variable

$$C = \frac{\text{Area} \times \text{Dielectric}}{\text{Gap}}$$

$$C \propto \frac{1}{\text{Gap}}$$

Internal Circuit

- ***Oscillator*** that causes a pulsating electric field from the sensor head. Voltage change observed when target present.
- ***Demodulator*** that acts as a positive peak detector to obtain a steady DC voltage from a sine wave input.
- ***Schmidt Trigger*** that forces rapid transitions between low and high voltage inputs
- ***Output*** that provides 0-V to load when low, or a specific voltage correlating to gap distance when high



http://www.wisc-online.com/objects/ViewObject.aspx?ID=IAU5207

Contd…

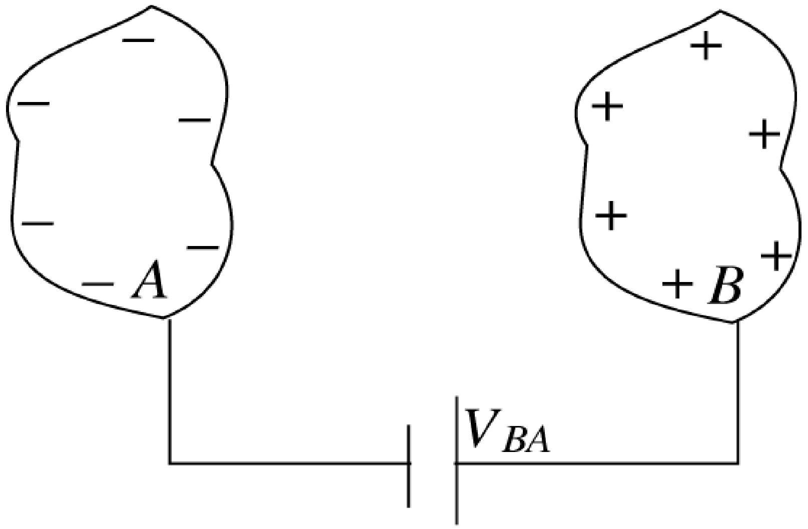
- Advantages
  - Unaffected by dust or opaque containers
  - Higher resolutions (often sub-nanometer)
  - Inexpensive
  - Not sensitive to material changes
    - Responds to all conductors equally
  - Can measure non-conductors as well
- Disadvantages
  - Slower than other sensors (100 µsec)
  - Not good in dirty or wet environments
  - Challenging output conditioning
- Applications
  - Displacement measurement and related applications
  - Bulk-handling machines, level detectors, package detection

Capacitance

- Capacitance: the ratio between charge and potential of a body
- Measured in coulombs/volt. This unit is called the farad [F].
- Capacitance is only defined for two conducting bodies, across which the potential difference is connected.

$$C = \frac{Q}{V} \quad \left[\frac{\mathrm{C}}{\mathrm{V}}\right]$$

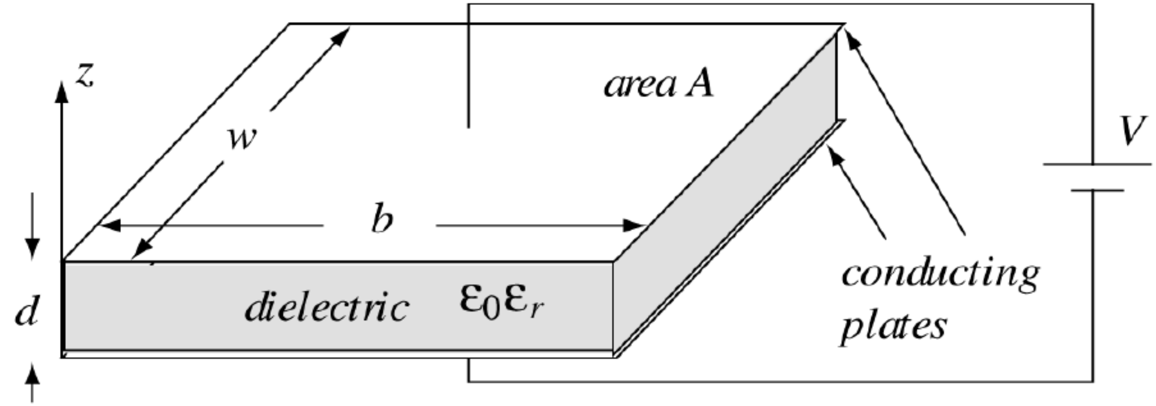
- Body B is charged by the battery to a positive charge Q and body A to an equal but negative charge –Q.
- Any two conducting bodies, regardless of size and distance between them have a capacitance.



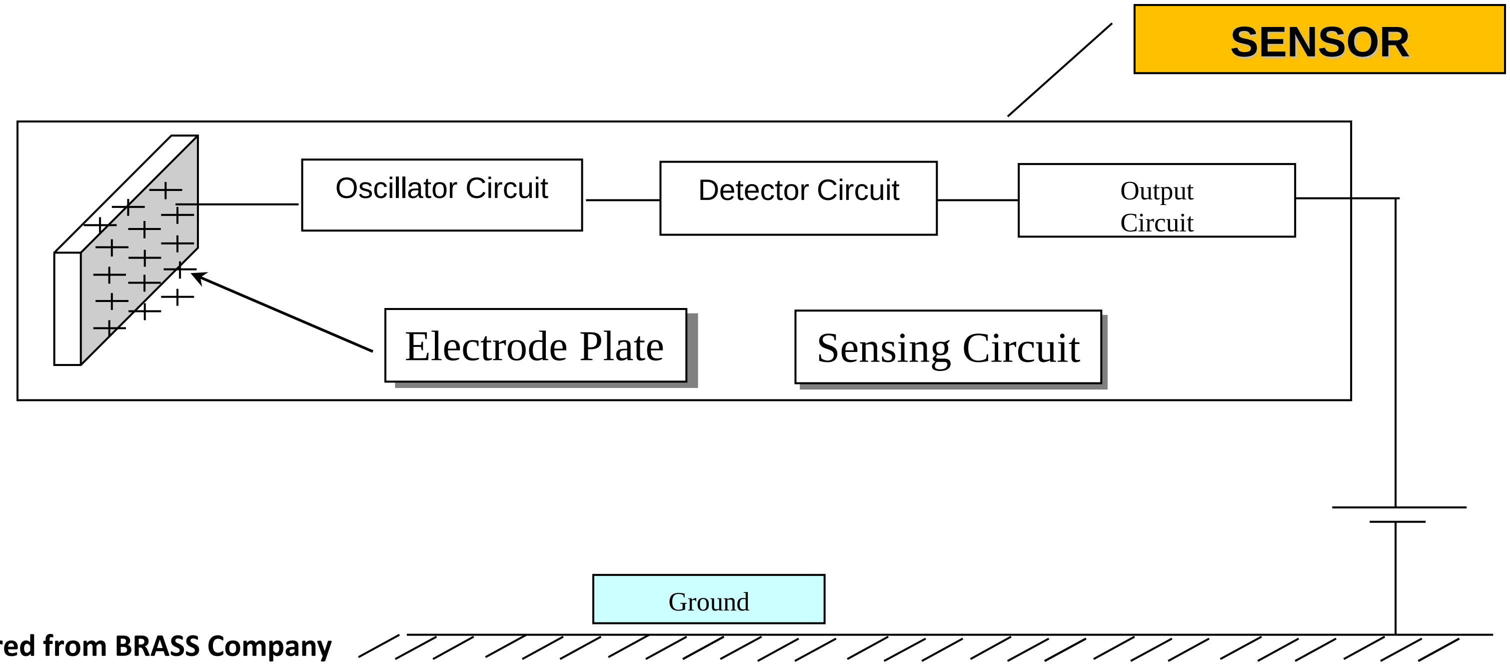
Parallel plate capacitor

- Parallel plate capacitor:
  - Assumes d is small,
  - ε_0 is the permittivity of vacuum,
  - ε_r the relative permittivity (dielectric constant) of the medium between plates,
  - S the area of the plates and
  - *d* the distance between the plates.
  - ε_0 is a constant equal to 8.854x10^{-12} F/m
  - ε_r is the ratio between the permittivity of the medium to that of free space.
  - available as part of the electrical properties of materials.

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} \quad [F]$$

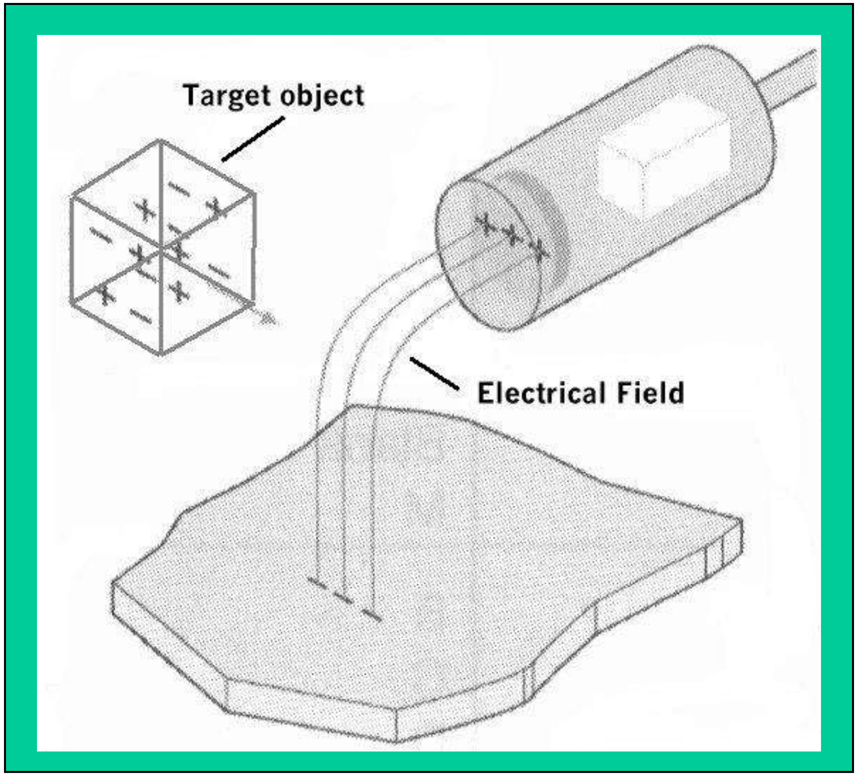


❖ A Capacitive Proximity sensor is similar to an inductive sensor in that it has a Oscillator, Detector and Output circuit. It differs in that it uses a plate shaped Electrode instead of a wire-wound core. In operation, it forms an electrostatic capacitive field formed between it and the sensors ground. (In practice the supply line is in effect the ground.)

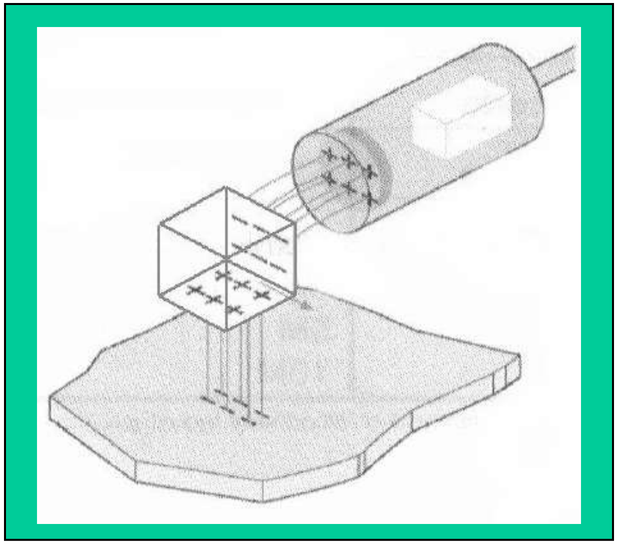


Referred from BRASS Company

❖ When there is no target object in the area of the sensor, the field, that is formed, will be stable.

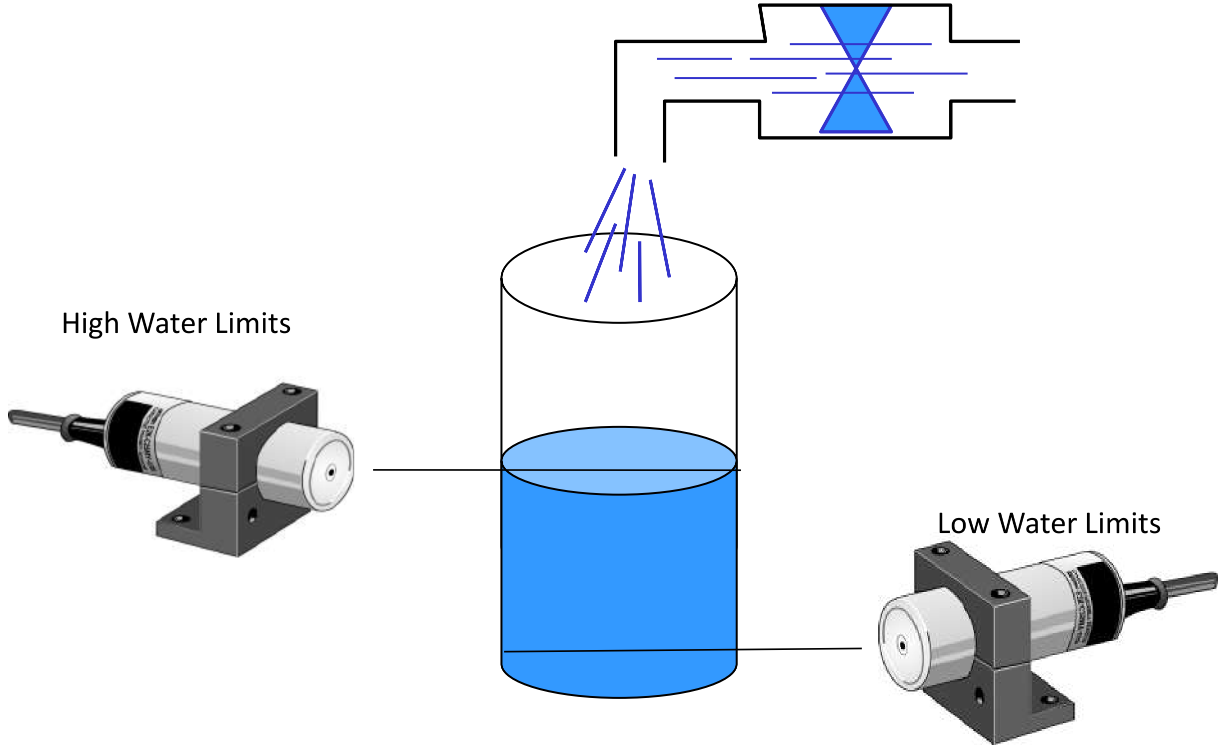


❖ When a target object nears the sensor its positive and negative charges (normally neutralized) separate. The negative charges in the target are attracted towards the electrode, and its positive charges towards ground. This "influence" increases the electrostatic capacitance of the electrode which increases its coupling with ground. This provides increased amplitude in the oscillator circuit, which is in turn used to switch the output in the detection circuit.

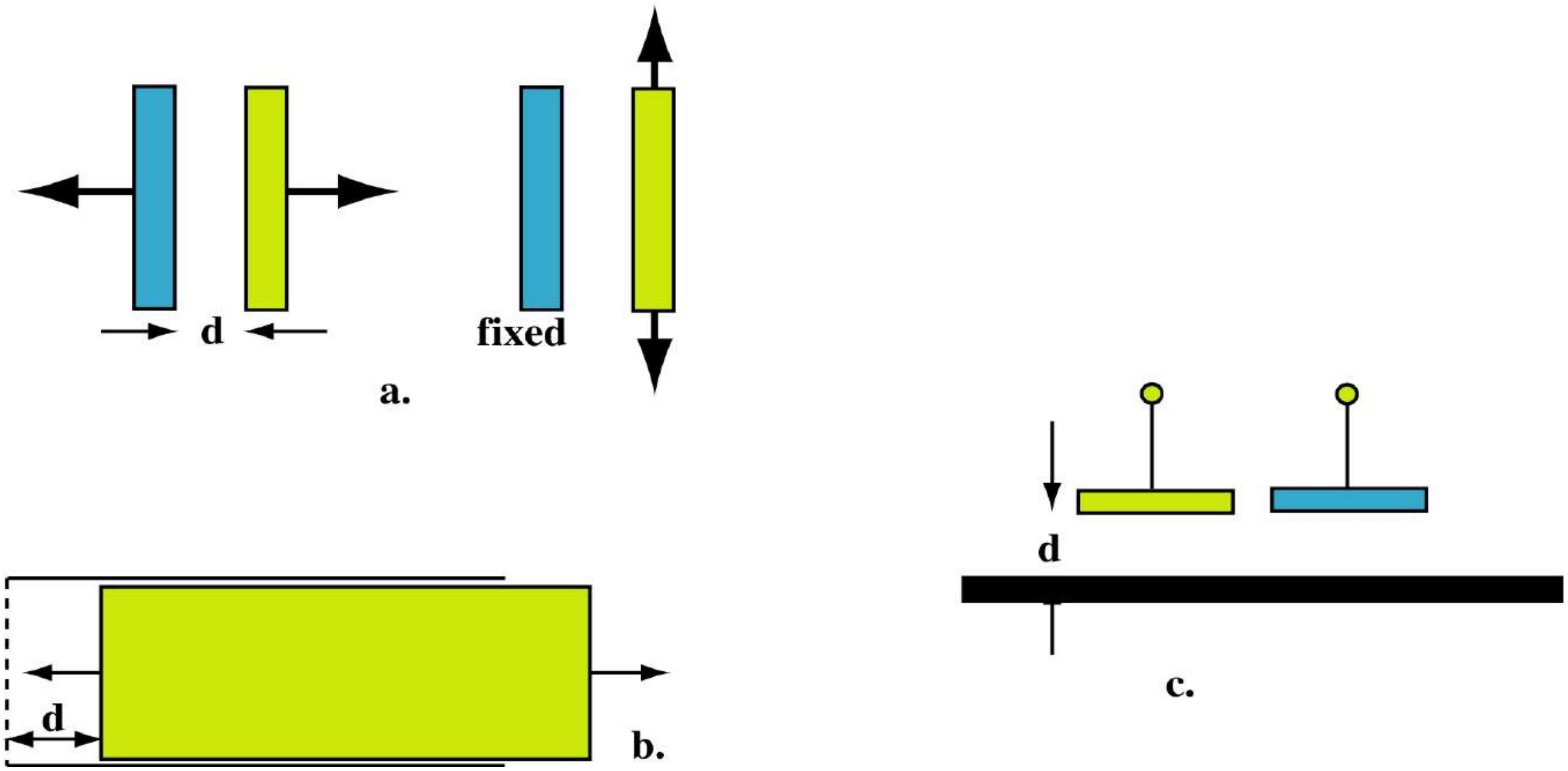


Capacitive Method of Detection	
Configuration	Requires clearance around sensing end to prevent false signals from surrounding mounting materials. Available in cylindrical and flat rectangular sensor shapes.
Advantages	Detects plastic, glass, liquids, leather and wood as well as metals. Can be used to detect materials inside non-metallic containers.
Disadvantages	Sensor is not protected from accidental impact damage. Usable to 0.9inch maximum.

Application:

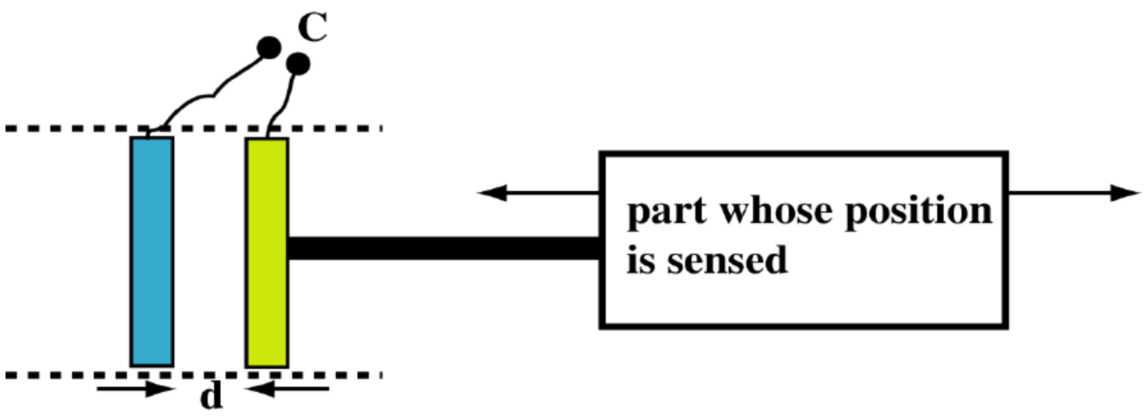


Position and displacement sensing

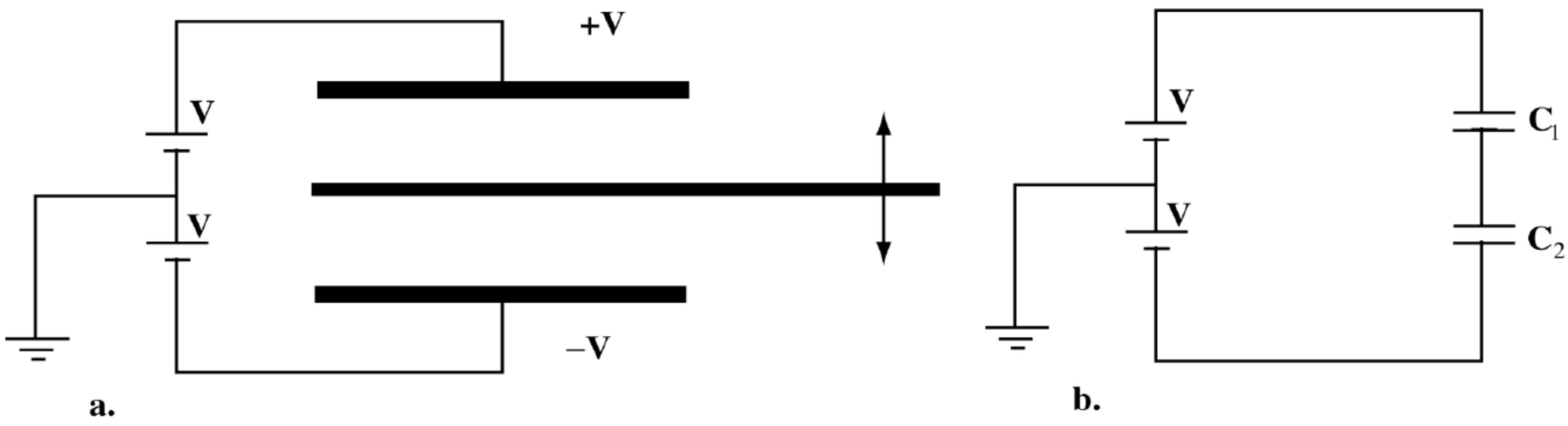


Position sensing relative to a fixed conductor

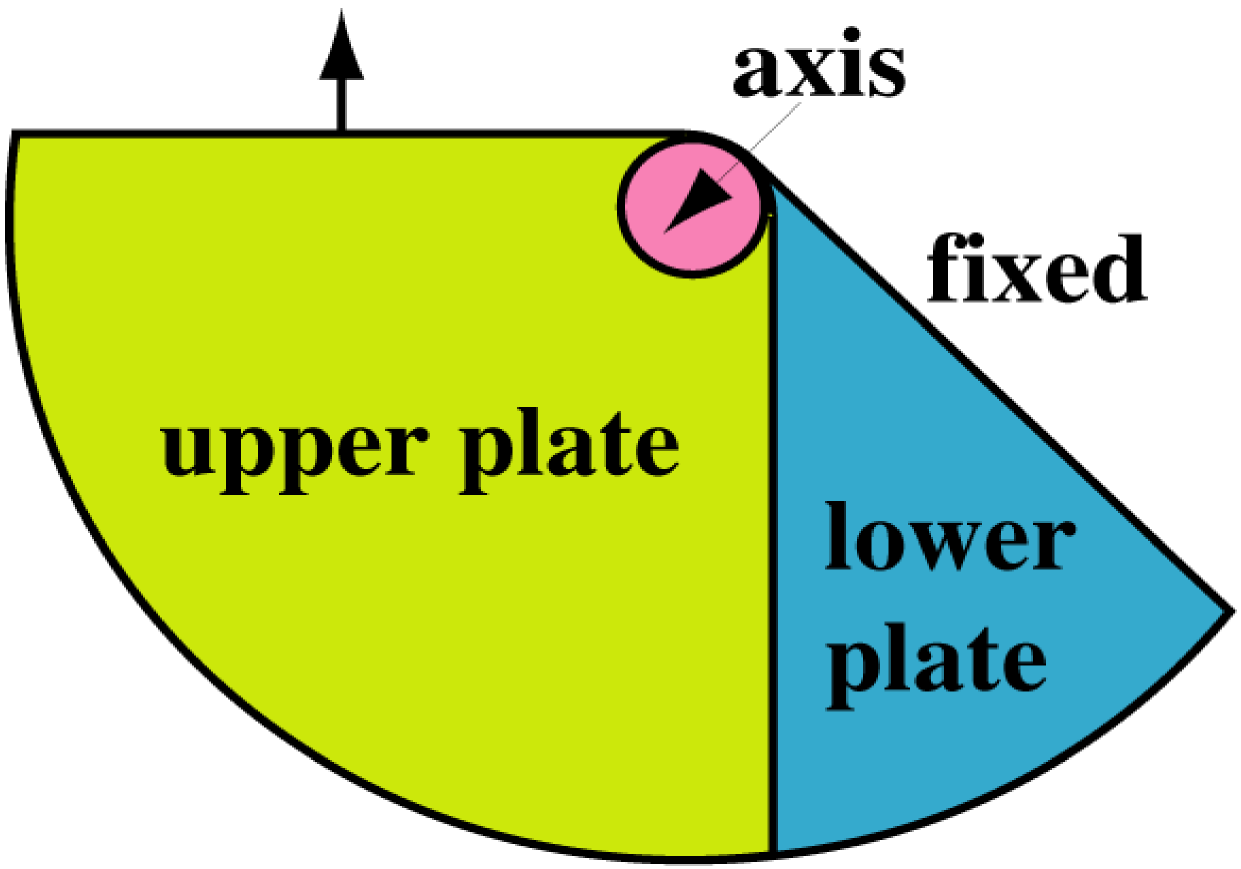
- A schematic position sensor is shown in below
- One plate is fixed while the other is pushed by the moving device.
- The position of the moving device causes a change in position of the dielectric and this changes the capacitance. C
- Capacitance is inversely proportional to the motion and
- As long as the distances sensed are small, the output is linear.



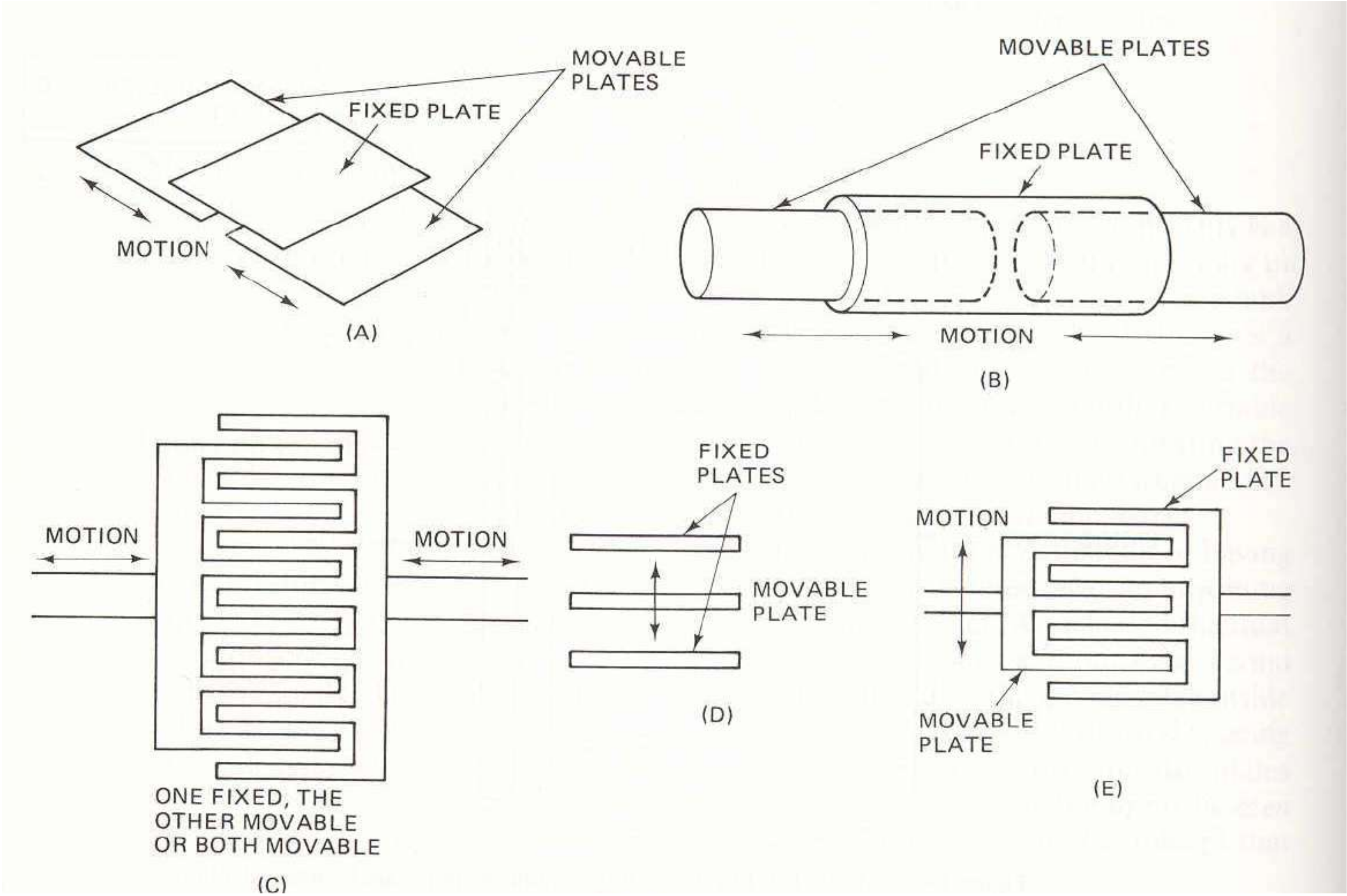
Q7: ΔC = ?



Rotary position sensor



Other configurations for linear displacement sensors



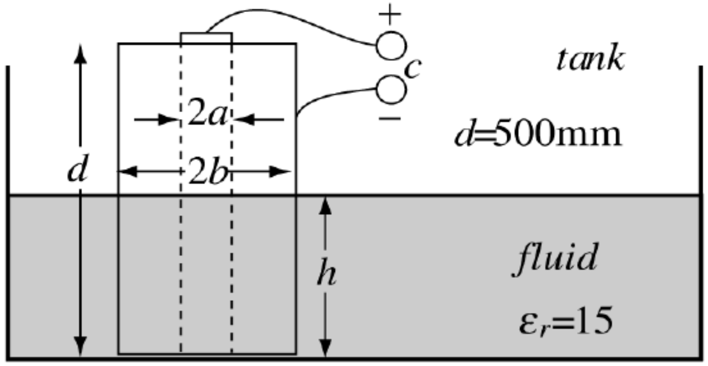
Capacitive fluid level sensors

- Fluid level:
  - may be sensed by any of the position or proximity sensors discussed in the previous paragraph
  - by sensing the position of the fluid surface directly
  - or through a float which then can change the capacitance of a linear capacitor or a rotary capacitor.

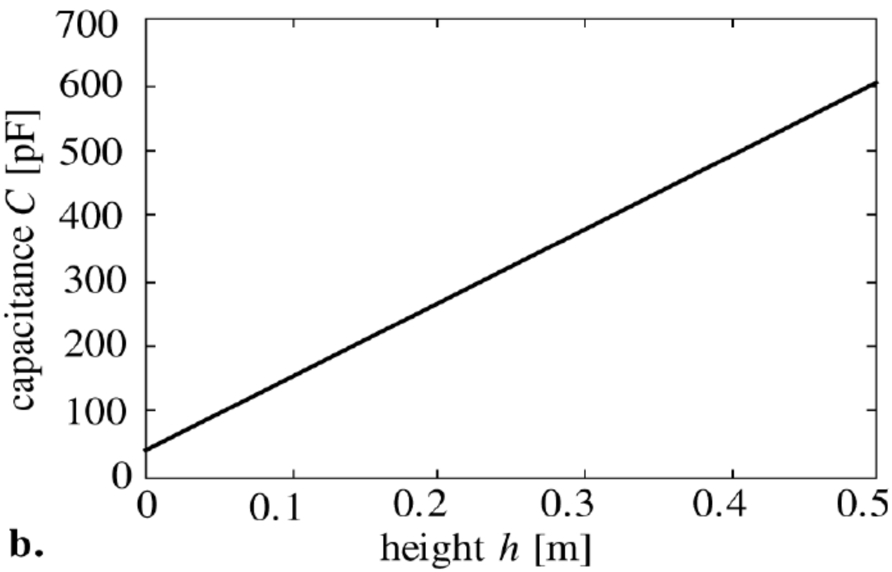
- There is however another method which is linear but can have a very large range. The method is shown next:

Co-axial fluid level sensor

$$C_0 = \frac{2\pi\varepsilon_0 L}{ln(b/a)} \quad [F]$$



a.



b.

$$C_0 = \frac{2\pi\varepsilon_0}{ln(b/a)}(h\varepsilon_r + L - h) \quad [F]$$

- A coaxial capacitor is made of two concentric cylinders establishing a capacitance C_0.
- Capacitance of a coaxial capacitor of length L, inner radius a and outer radius b is:

$$C_0 = \frac{2\pi\varepsilon_0 L}{ln(b/a)} \quad [F]$$

- If the fluid fills the capacitor to a height h, capacitance is:

$$C_0 = \frac{2\pi\varepsilon_0}{ln(b/a)}(h\varepsilon_r + L - h) \quad [F]$$

- Capacitance is linear with respect to h from h=0 to h=L
- Capacitive fuel gauges are of this type but the idea can be used for any fluid that is nonconductive such as oils.

Capacitive sensors - Features

- Simple and rugged sensors
- Useful in many other applications (pressure, acoustic sensors, etc.)
- Capacitances are small and changes in capacitance even smaller.
  - Require special methods of transduction.
  - Often part of LC oscillator (measure freq.)
  - Others use an ac source (measure impedances)

Capacitive actuators

Capacitive actuation is simple:

- Potential is connected across the two plates of a capacitor
- Plates acquire opposite charges.
- These charges attract each other based on Coulomb's law
- Force tends to pull the plates together.

Contd...

- Mechanical motion of the plates is possible - constitutes actuation
- In a parallel plate capacitor the force is:
- For other configurations: no exact relation but:
- Same general behavior

$$F=\frac{CV^2}{d}=\frac{\varepsilon_0\varepsilon_r SV^2}{d^2}$$

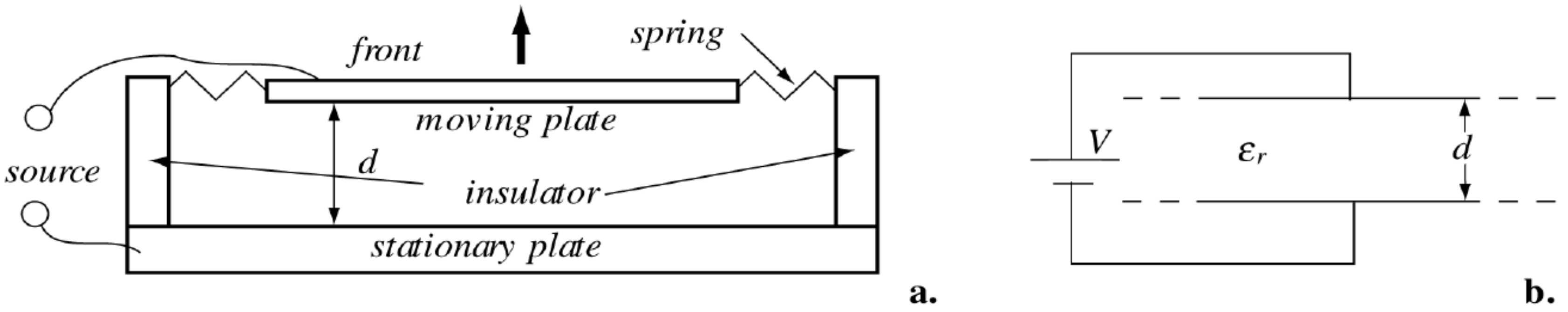
- Force developed is proportional to:

$$F=\frac{CV^2}{d}=\frac{\varepsilon_0\varepsilon_r SV^2}{d^2}$$

- Capacitance:
- Distance between plates:
- Potential across plates
- Forces are typically small (e is very small)

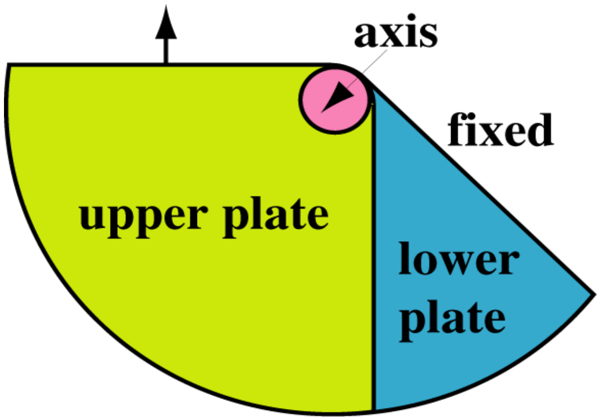
Basic capacitive actuator

- An electrostatic actuator (electrostatic speaker):
- Upper plate is attracted or repelled by lower, fixed plate.
- Motion may be used for positioning or for voice reproduction.



Angular capacitive actuator

- Upper plate moves relative to lower plate
- Force proportional to position (capacitance changes)
- Useful for small, low force motion.



Tachometers – An Overview

- Referred from Utah State University

- Tachometer is used for <u>measuring rotational speed</u>

✓ to measure speed of a rotating shaft

✓ to measure flow of liquid by attaching a wheel with inclined vanes

❖An electrical instrument used to measure the speed of a rotating object, in general with out any physical contact.

❖ Limit: distance of 1meter.

Types of Tachometer

1. Can be classified on the **basis of data acquisition** – contact or non contact types

2. Can also be classified on the **basis of the measurement technique** used that is – time based or frequency based technique of measurement

3. Can also be classified on the basis of type of signal – **analog or digital type**

Analog Tachometer

- Indicator: Has a needle and dial type of interface.
- Storage: No provision for storage of readings
- Processing: Cannot compute average, deviation, etc

Digital Tachometer

- Indicator: Has a LCD or LED readout.
- Storage: Memory is provided for storage
- Processing: Can perform statistical functions like averaging, etc

Classification Based on Data Acquisition Technique

- Contact type – The wheel of the tachometer needs to be brought into contact with the rotating object.

- Non Contact type – The measurement can be made without having to attach the tachometer to the rotating object.

Classification based on Measurement Technique

- Time Measurement – The tachometer calculates speed by measuring the time interval between the incoming pulses. (Pulse Time Modulation / PTM)

- Frequency Measurement – The tachometer calculates speed by measuring the frequency of the incoming pulses. (Pulse Frequency Modulation / PFM)

Comparison Between Contact and Non Contact Tachometers

Contact Type

- The tachometer has to be in physical contact with the rotating shaft.
- Preferred where the tachometer is generally fixed to the machine.
- Generally, optical encoder / magnetic sensor is attached to shaft of tachometer.

Non Contact Type

- The tachometer does not need to be in physical contact with the rotating shaft.
- Preferred where the tachometer needs to be mobile.
- Generally, laser is used or an optical disk ID attached to rotating shaft and read by an 'IR' beam or laser.

Comparison Between Time and Frequency based Measurement

Time based

- The tachometer calculates speed by measuring the time interval between pulses.
- More accurate for low speed measurement.
- 'Time to take a reading' is dependant on the speed and increases with decrease in speed.
- The resolution of the tachometer is independent of the speed of the measurement.

Frequency based

- The tachometer calculates speed by measuring the frequency of pulses.
- More accurate for high speed measurement.
- 'Time to take a reading' is independent of speed of rotation.
- The resolution of the tachometer depends on the speed of the rotating shaft.

Typical Specifications of a Non Contact Type Tachometer

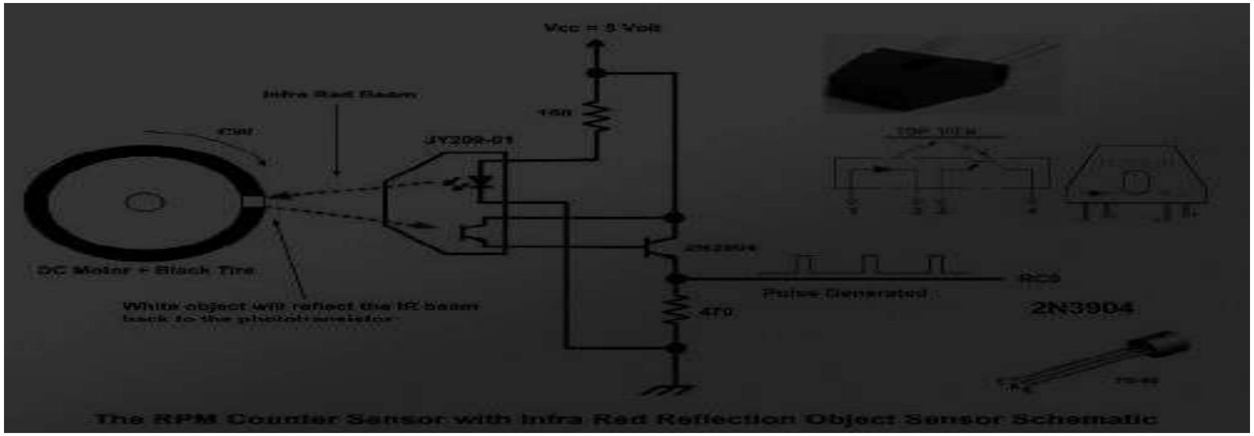
- Display 5 digits large LCD
- Range: 2.5 - 99,999 RPM
- Distance: 50 to 1,000 mm; 12 to 40 inches.
- Resolution: 0.1 RPM<1000 RPM (2.5 to 9,999 RPM)
  1.0RPM >1000 RPM
- Measurement angle: at less than 120 degrees.
- Range selection: Auto
- Laser Output Power: <1mW class II
- Sampling Time: 1.0 seconds (over 60 RPM)
- Memory: Last value, Max Value, Min. Value
- Time base: Quartz crystal
- Circuit: Exclusive one-chip LSI circuit
- Battery: 4 X 1.5V AA
- Weight: 300g/0.65lb
- Size: 190 X 72 X 37 mm

Typical Specifications of a Contact Type Tachometer

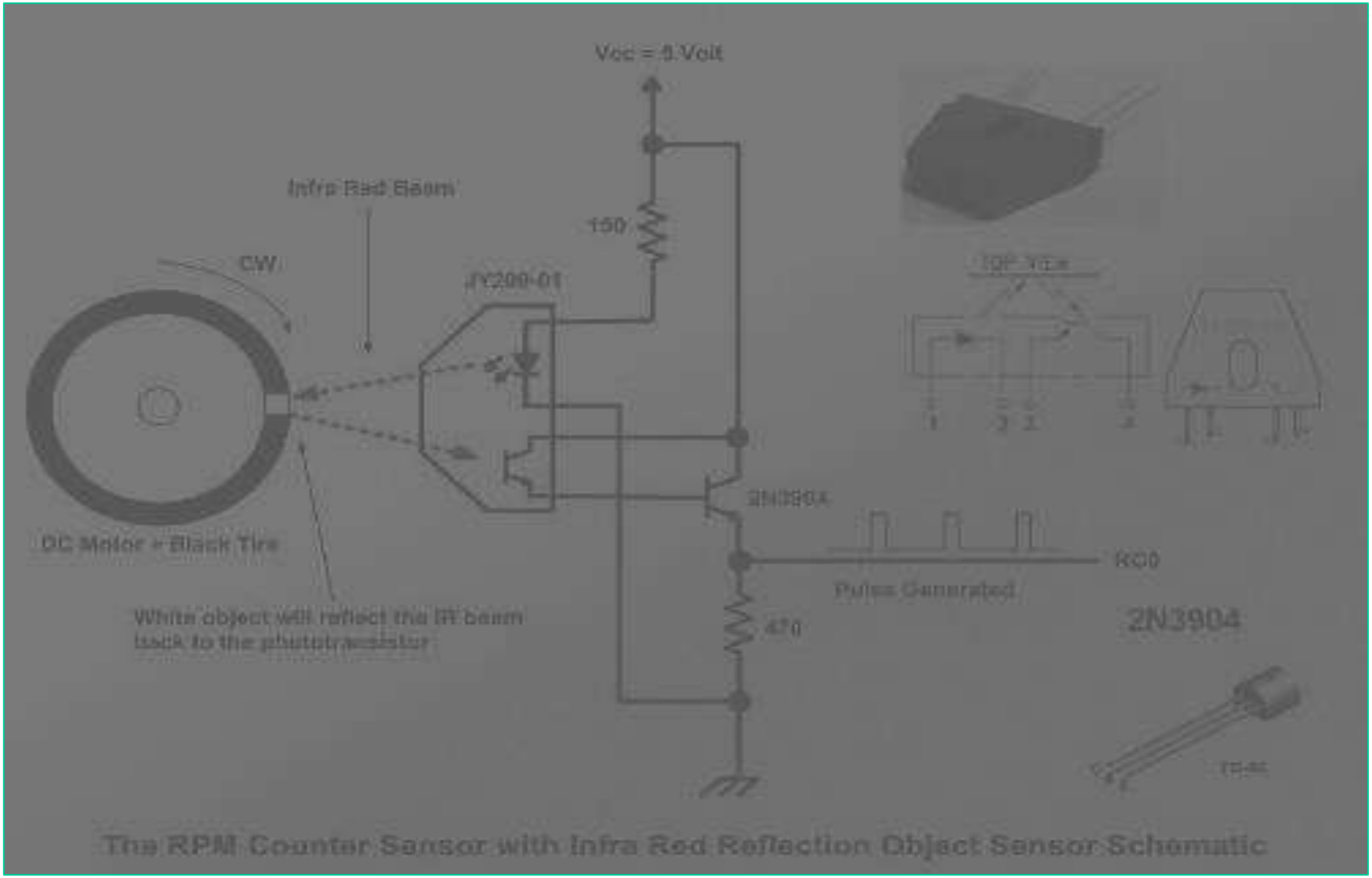
- Display 5-digit LCD Display
- Range selection Automatic range selection
- Time Base 4MHz Quartz Crystal
- Sampling Time 1 second (>60 rpm); >1 second (10 to 60 rpm)
- Accuracy ± (0.1% of reading + 2 digits)
- Photo Tachometer Distance 2 to 12” (5 to 30cm)
- Operating Temperature 32 to 122^{0}F (0 to 50^{0}C)
- Operating Humidity 80% RH Max.
- Power supply 9V Battery
- Battery Life 40 hours (approx.)
- Applicable standards EN 50081-1/1992 (EN 55022) EN 50082-1/1997 (EN 55024)
- Dimensions 461700: 4.9 x 2.0 x 1.3” (124 x 51 x 33mm)
- Weight 461700: 4.0 oz. (114g)

PROXIMITY TYPE SENSOR

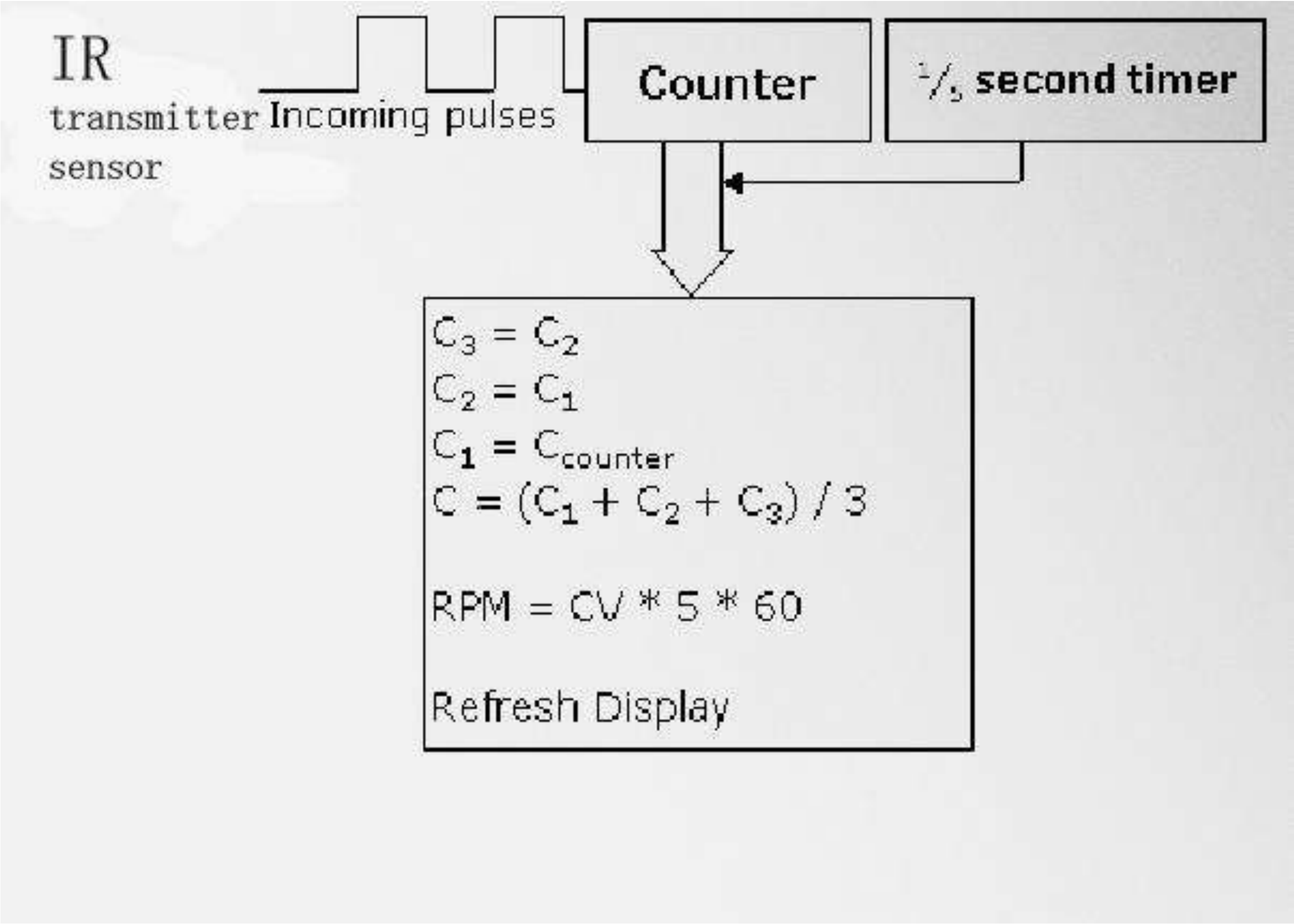
- A sensor which detects some things near by with out any physical contact is called proximity sensor.
- IR sensor is nothing but an diode in which the diode produces a small current when the light falls on it.
- These currents are very small to detect so we use operation amplifier to detect the small voltage changes.
- Transistor amplifies the current.



Working Circuit / Model

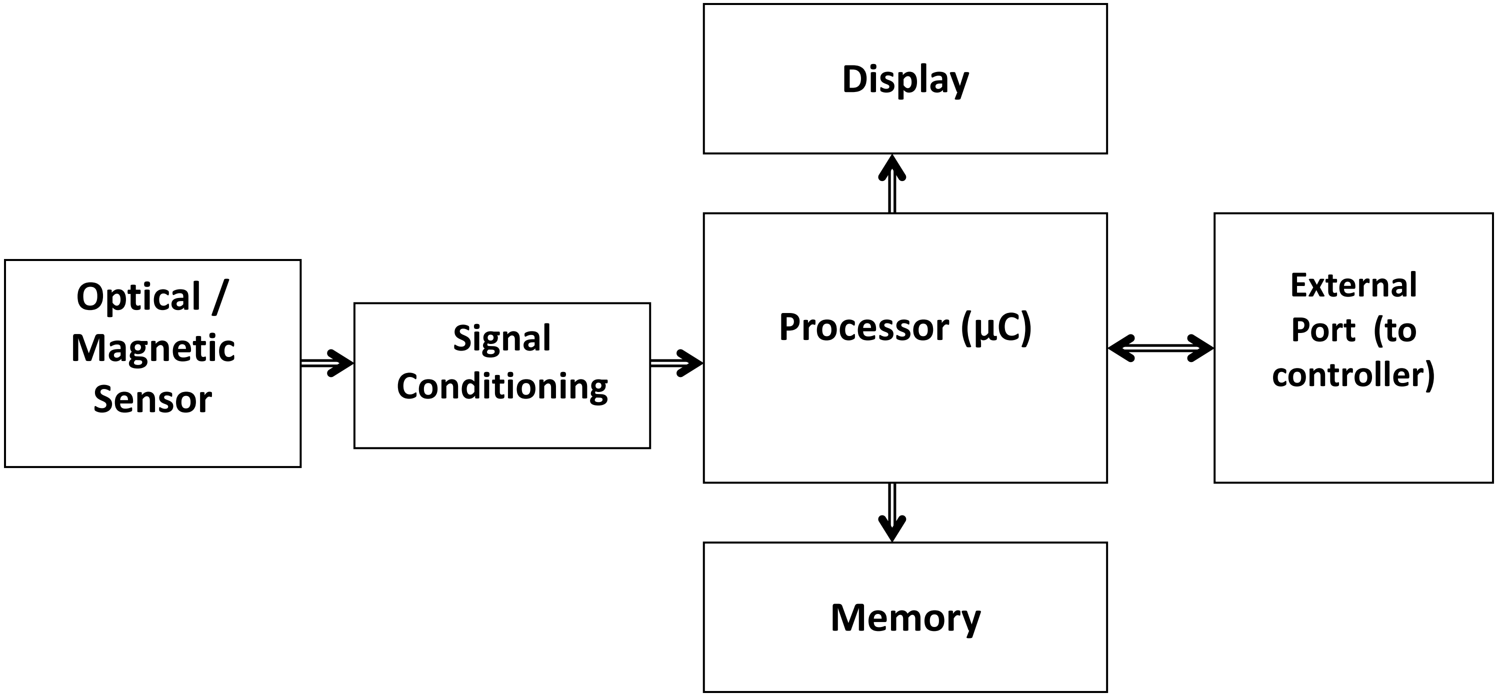


Principle of counter



- Referred from IITH

Block Diagram of a Digital Tachometer



Optical Sensing

- It is used to generate pulses proportional to the speed of the rotating shaft.

- Can be achieved by the following ways:
  - Attaching a disk, which has an alternate black and white pattern, to the shaft and reading the pulses by an 'IR' module pointed towards it.
  - Using a slotted disk and a U shaped IR emitter detector pair to generate waveforms.

Magnetic Sensing

- **Hall effect sensors** – These make use of the Hall effect to generate pulses proportional to the speed of the shaft.

- **Passive magnetic sensors** – These make use of variable reluctance to generate pulses.

Signal Conditioning

1. The output of the sensors may be noisy.
2. The output may have to be amplified.
3. It has to be digitized. It is done using a Schmitt trigger so as to bring voltage to TTL levels.

Signal Processing Unit

- Not essential, but is generally the norm to have a microcontroller.
- Compute the speed.
- Store / memorize the readings.
- Transmit / propagate the values to a display unit.
- Generate warning signal when speed reduces / increases beyond set margins (SP).
- Transfer data to the master processing unit (MPU) / the external controller.

Display Unit

- Used to output the values to the operator.
- Can be used to observe the stored values.

Analog Tachometers

- These are generally the ones that display the speed of your car.
- The interface is needle and dial arrangement.
- Generally, the speed is converted to voltage through the use of an external frequency to voltage converter.
- The tachometer can also act as a generator, and produce a voltage that is, <u>proportional to the speed of the shaft</u>.
- This <u>voltage</u> is then <u>displayed</u> by an analog voltmeter.

How to Choose a Tachometer?

- Accuracy
- Precision
- Range
- Acquisition Time
- Contact type / Non Contact type
- Portable / Fixed
- Digital / Analog
- Cost

Calibration

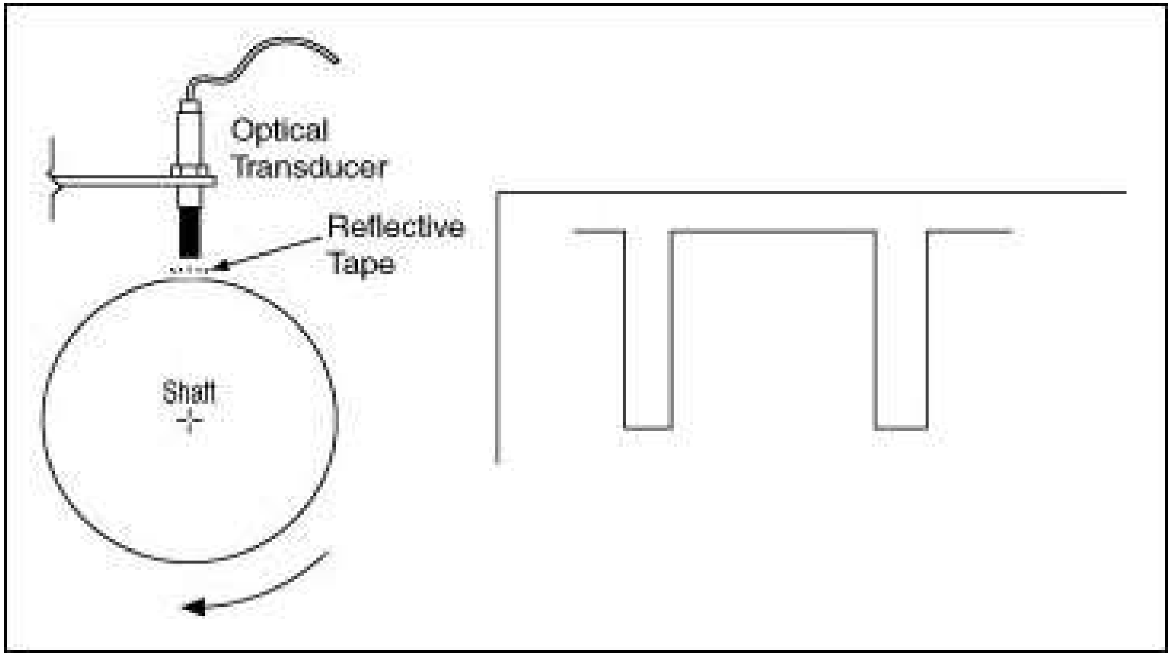
- Why calibrate?
  - Incorrect calibration = Incorrect readings.
  - Calibration compensates for ageing, wear and tear, and other degrading effects.

- How to calibrate?
  - Calibration is done by comparing the reading from tachometer to a standard speed (reference value(s)).
  - Necessary changes are made so that the actual reading matches the desired reading.

Thanking You

OPTICAL TRANSDUCER

- An optical transducer converts light rays into an electronic signal. The purpose of an optical transducer is to measure a physical quantity of light and, depending on the type of transducer, then translates it into a form that is readable by an integrated measuring device.
- They are also called as photoelectric transducers.

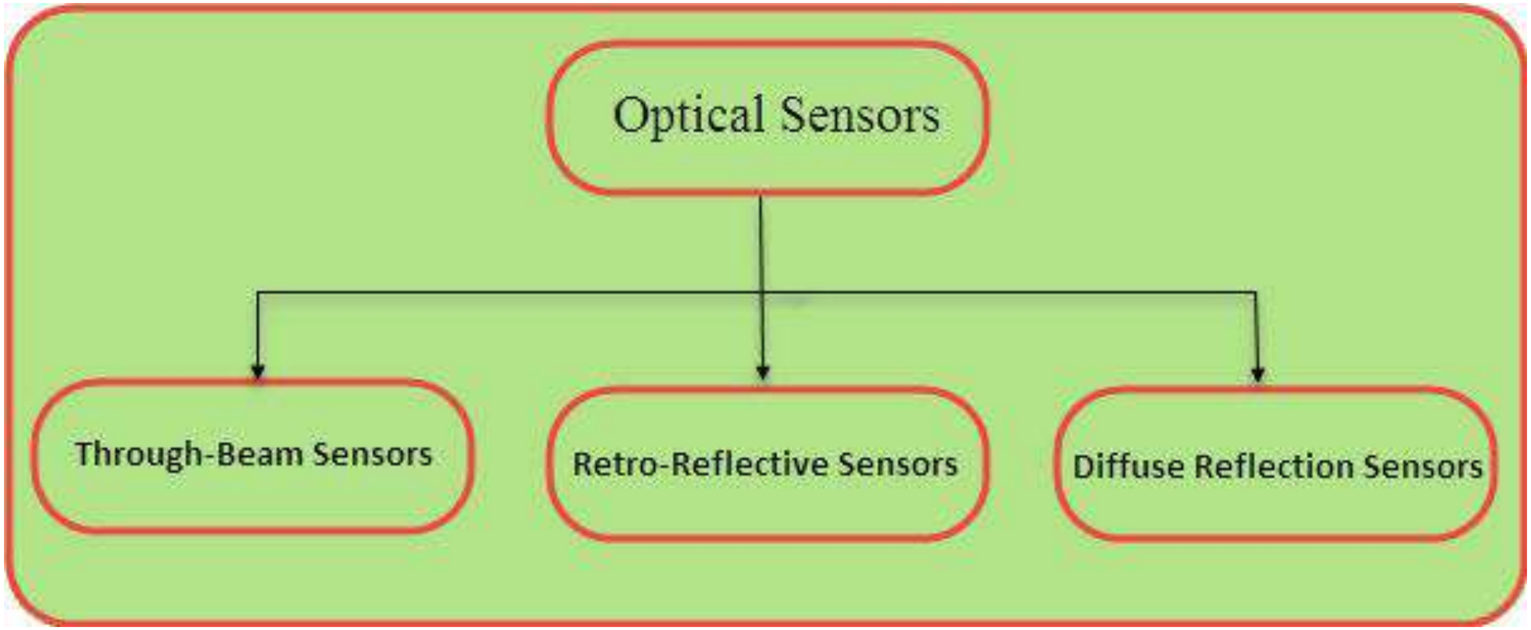


- The optical transducer can be classified as
  - photo emissive
    - The photo emissive devices operate on the principle that radiation falling on a cathode causes electrons to be emitted from the cathode surface.
  - photoconductive
    - The photoconductive devices operate on the principle that whenever a material is illuminated, its resistance changes.
  - photovoltaic transducers.
    - The photovoltaic cells generate an output voltage that is proportional to the radiation intensity. The radiation that is incident may be x-rays, gamma rays, ultraviolet, infrared or visible light

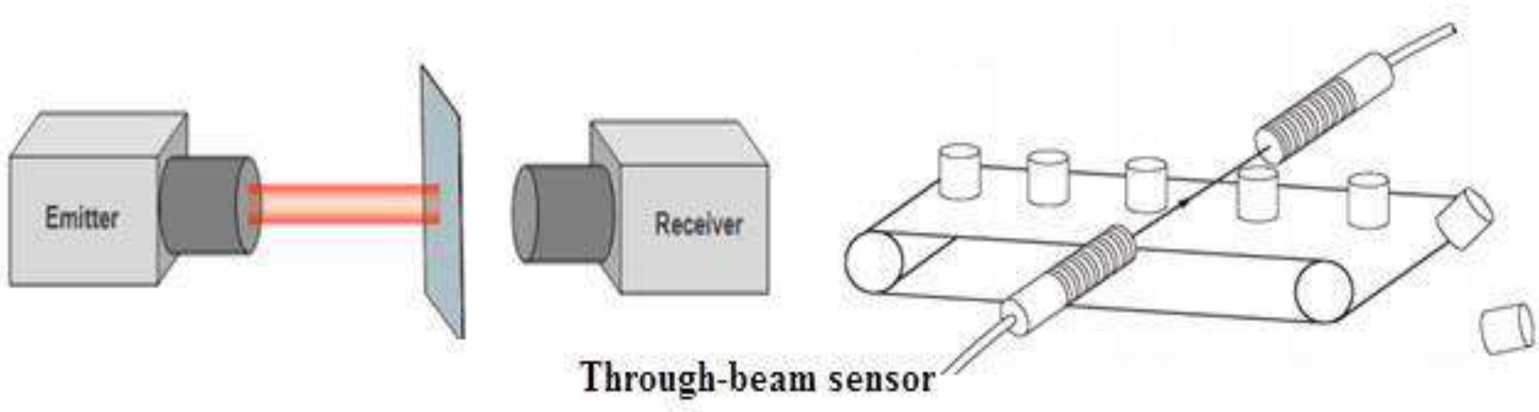
PRINICIPLE

- The operating principle is the transmitting and receiving of light in an optical sensor, the object to be detected reflects or interrupts a **light beam sent out by an emitting diode**.
- Depending on the type of device, the interruption or reflection of the light beam is evaluated.
- This makes it possible to detect objects independently of the material they are constructed from (wood, metal, plastic or other).
- Special devices even allow for a detection of transparent objects or those with different colors or variations in contrast.

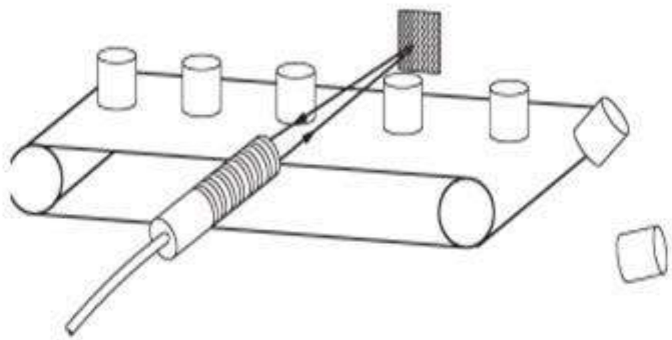
- Interruption and reflection of light depends on type of devices used.
- According to this optical transducers or sensors are of three types as given below :-



- Through-Beam Sensors:
  - The system consists of two separate components the transmitter and the receiver are placed opposite to each other.
  - The transmitter projects a light beam onto the receiver.
  - An interruption of the light beam is interpreted as a switch signal by the receiver. It is irrelevant where the interruption occurs.



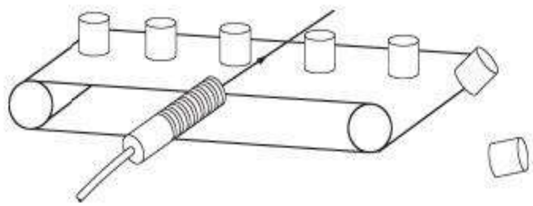
- Retro-Reflective Sensors:
  - Transmitter and receiver are both in the same house, through a reflector the emitted light beam is directed back to the receiver.
  - An interruption of the light beam initiates a switching operation. Where the interruption occurs is of no importance.



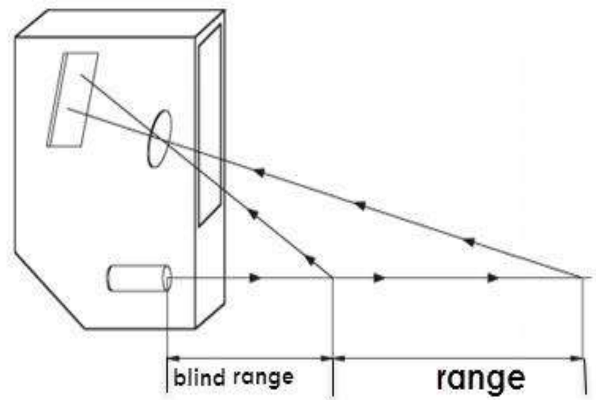
Retro-Reflective Sensors

- Retro-reflective sensors enable large operating distances with switching points, which are exactly reproducible requiring little mounting effort.

- Diffuse Reflection Sensors
  - Both transmitter and receiver are in one housing.
  - The transmitted light is reflected by the object to be detected



Diffuse Reflection Sensor



APPLICATIONS

- Electro-optical sensors are used whenever light needs to be converted to energy.
  - Smart phones, where sensors are used to adjust screen brightness
  - Smart watches, in which sensors are used to measure the wearer's heartbeat.
  - Optical sensor is to measure the concentration of different compounds by both visible and infrared spectroscopy.
  - Optical sensors can be found in the energy field to monitor structures that generate, produce, distribute, and convert electrical power

TORQUE METERS

- A **torque transducer** or **torque meter** is a device for measuring and recording the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission, rotor, a bicycle crank.
- A torque transducer or meter converts torque into an electrical signal.
- Static torque: easy to measure.
- Dynamic torque: not easy to measure.
  – since it generally requires transfer of some effect (electric, hydraulic or magnetic) from the shaft being measured to a static system.

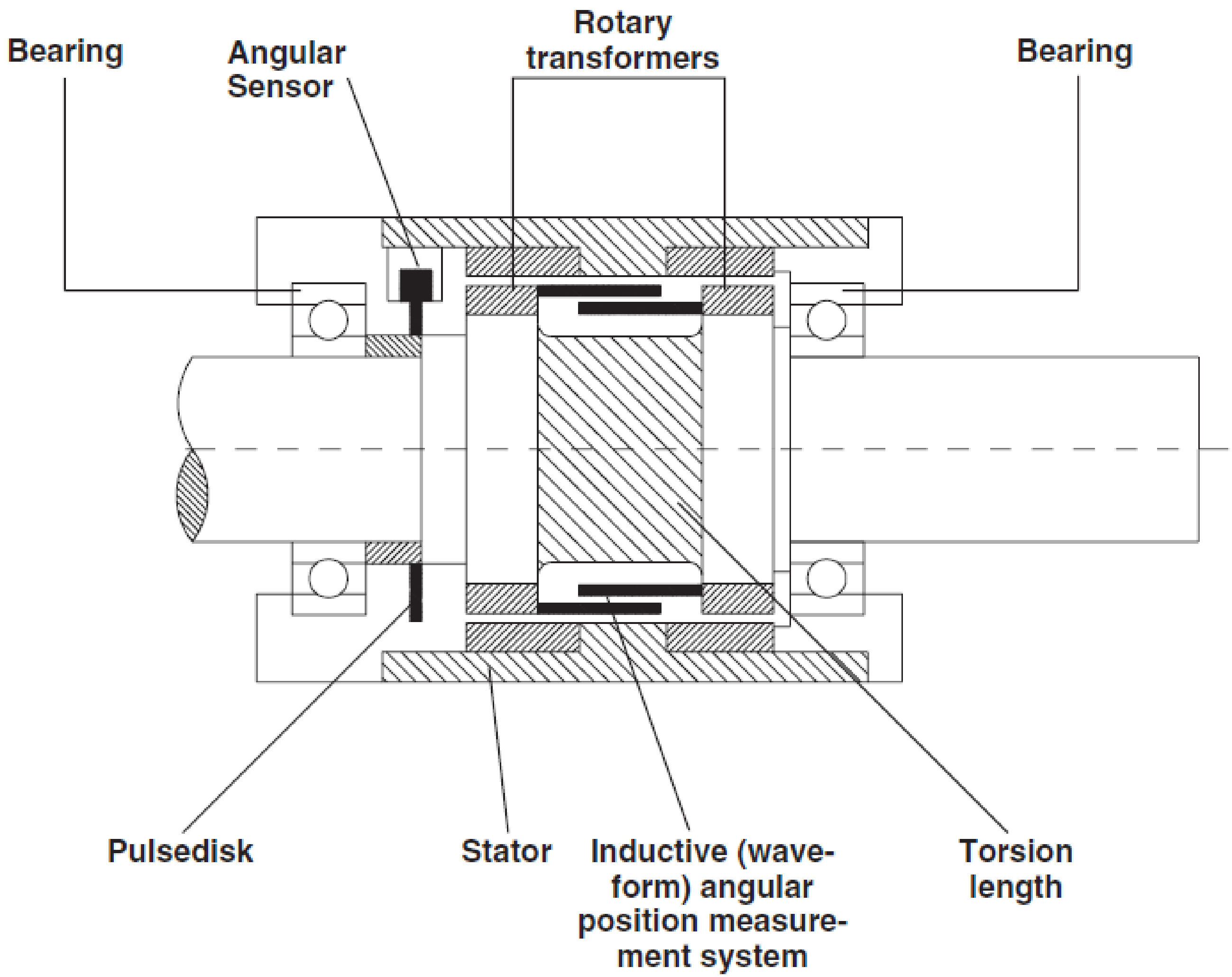
- The need for torque measurements has led to several methods of acquiring reliable data from objects moving.
  - Two common ways to obtain torque measurements are by strain-gauging the shaft and by using in-line torque cells.
- The most common transducer is a strain gauge that converts torque into a change in electrical resistance.
- The strain gauge is bonded to a beam or structural member that deforms when a torque or force is applied. Deflection induces a stress that changes its resistance.
- A Wheatstone bridge converts the resistance change into a calibrated output signal.

- The methods to Getting power to the gauges over the stationary/rotating gap are:
  - Contact method: Slip rings are used in contact-type torque sensors to apply power to and retrieve the signal from strain gauges mounted on the rotating shaft.
  - Non-contact method: Radio telemetry of the signal coupled with wireless induced power for the strain gauge excitation offers an easy solution for bridging the stationary-rotating gap. A stationary antenna induces power in a loop antenna on the rotating shaft. The power from the rotating shaft antenna is conditioned and excites the strain gauges. A shaft-mounted radio transmitter sends the measurement signal back to the stationary antenna. The telemetry antennas need to be somewhat flexible for ease of mechanical installation, and receivers should have adjustments for peak coupling of the antenna for maximum induced power and received signal strength.

INDUCTIVE TORQUE TRANSDUCER

- **Inductive transducers** work on the principle of inductance change due to any appreciable change in the quantity to be measured i.e. measurand.
- Usually the measurand could be a rotary or linear displace, force, pressure, torque ,velocity, acceleration and vibration.
- Inductive transducers work on one of the following principles:
  - Change of self inductance
  - Change of mutual inductance
  - Production of eddy current

- TORQUE TRANSDUCER WITH INDUCTIVE ANGULAR POSITION MEASUREMENT SYSTEM:-



- The transducer consists of a stator through which a bearing-mounted shaft passes.
- A certain length of the shaft is utilized to convert the torque into a proportional torsional angle.
- This torsional angle or angle of twist is measured between the two ends of this shaft length by an inductive (wave-form) angular position measurement system.
- The inductive angular position measurement system converts the angle of twist into a proportional electrical signal.
- The electrical power for operation of the inductive angular position measurement system, which rotates along with the shaft, is provided by means of a rotary transformer.

- The electrical output signal, which is proportional to the torque, is transferred to the stator by a second rotary transformer.
- The connection box on the stator contains the electronics, the power supply unit, and the instrument amplifier.

Thanking You