Unit-V
PHYSICS OF SENSORS

Prerequisite:
Transducer concept, meaning of calibration, piezoelectric effect, IR waves

Ultrasonic sensors: Concept of inverse piezoelectricity, Applications

Light sensors: (Photodiode, LDR).

Hall sensor: (Principle of Hall effect, Applications)

IR sensor: (Principle & Applications).

ULTRASONIC SENSORS

Ultrasonic sensors used ultrasonic waves.

Ultrasonic wave:

The sound waves having frequency greater than 20 kHz or greater than human auditability limit is called Ultrasonic wave.

Ultrasonic sensors used ultrasonic wave which will be generated by piezoelectric transducers.

Piezoelectric transducer is work on the principle of Inverse piezoelectric effect.

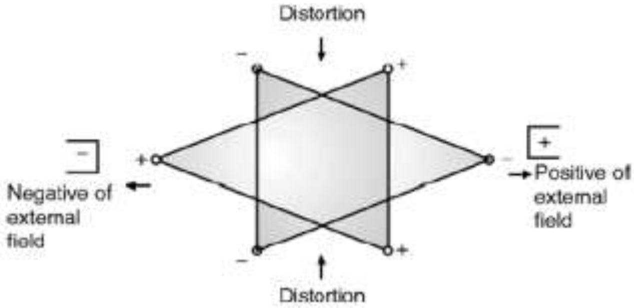
Piezoelectric effect:

"When a pressure is applied to the opposite faces of a quartz crystal plate, then equal and opposite charge developed on the faces which are perpendicular to the subjected to pressure."

If the crystal plate is subjected to tension instead of pressure, the sign of the charges are reverse.

Inverse Piezoelectric effect:

"When a potential difference (voltage) is applied to the two faces of a quartz crystal along electrical axis, then the change in dimensions (expansion or contraction) of a crystal is observed on opposite faces which are perpendicular to the subjected to potential difference is known as Inverse piezoelectric effect".



Applications of Ultrasonic Sensors:

- Ultrasonic sensors are often used in autonomous robots, drones, and automated vehicles for obstacle detection and navigation by measuring the distance to objects around them.
- Ultrasonic sensors are used in conveyor systems to detect the presence or absence of objects, monitor gaps between items, and manage sorting or packaging processes.
- Ultrasonic sensors are used in medical diagnostics, notably in **ultrasound imaging**. They help in non-invasive procedures to monitor the condition of organs, blood vessels, and tissues.
- Ultrasonic sensors can be used in non-destructive testing (NDT) to detect cracks, voids, or material thickness in concrete, metal, or other structural components.
- Ultrasonic sensors can be used in security systems to detect motion or unauthorized entry in sensitive areas, providing real-time alerts.
- Ultrasonic sensors are used to ensure correct measurements of materials and packaging processes in food manufacturing, improving accuracy and reducing waste.
- They can be used to measure the depth of water in soil or check the distance from the soil surface to optimize irrigation systems.
- Ultrasonic sensors are sometimes used in consumer electronics, such as smartphones or smart home devices, to detect gestures or hand movements for controlling functions without physical touch.
- Ultrasonic sensors can detect the levels and the

density of particles suspended in water, which is useful for analyzing water quality.

- In certain applications, ultrasonic sensors can be used to measure the speed of moving objects (e.g., moving vehicles or conveyor belts).
- In some advanced driver-assistance systems (ADAS), ultrasonic sensors help monitor blind spots and provide warnings to drivers.
- Ultrasonic sensors are used to measure the level of liquids or solids in tanks and silos, providing non-contact measurement for industries such as water treatment, oil and gas, and agriculture.
- Ultrasonic waves are used in distance measurement through a method called **ultrasonic ranging** or **ultrasonic distance sensing**.

Formula:

Distance measurement:

$$\mathbf{v} = \frac{\mathbf{2\ d}}{\mathbf{t}}$$

Where, d = distance, v = velocity of ultrasonic wave and t = time required.

$$\mathbf{v = f\ \lambda}$$

Where, v = velocity of ultrasonic wave, f = frequency of ultrasonic wave and λ = wavelength of ultrasonic wave.

Numerical:

How long it will take for an ultrasonic wave of wavelength 20 cm and the frequency of 1.6 KHz to travel a distance of 1.5 Km?

Given:

$\lambda = 20$ cm $= 20 \times 10^{-2}$ m,

f = 1.6 KHz = 1.6×10^{3} Hz,

d = 1.5 Km = 1.5×10^{3} m, t = ?, v = ?

$\mathbf{v = f\ \lambda} = 1.6 \times 10^{3} \times 20 \times 10^{-2}$

$\mathbf{v = 320\ m/s}$

$\mathbf{v} = \frac{\mathbf{2\ d}}{\mathbf{t}} \Rightarrow \mathbf{t} = \frac{\mathbf{2\ d}}{\mathbf{v}}$

$\mathbf{t} = \frac{2\ \times 1.5 \times 10^{3}}{320} = \mathbf{9.375}\ \boldsymbol{sec}.$

Find the echo time of ultrasonic pulse travelling with velocity 5.9 × 10³ m / sec in a mild steel whose correct thickness displayed by gauge is 18 mm.

Given:

v = 5.9×10^{3} m / sec,

d = 18 mm = 18×10^{-3} m, t = ?,

$\mathbf{v} = \frac{\mathbf{2\ d}}{\mathbf{t}} \Rightarrow \mathbf{t} = \frac{\mathbf{2\ d}}{\mathbf{v}}$

$\mathrm{t} = \frac{2\ \times 18 \times 10^{-3}}{5.9 \times 10^{3}}$

$\mathbf{t = 6.1\ \times 10^{-6}}\ \boldsymbol{sec}$

A ship on the surface of water sends a signal and receive it back from the submarine inside water after 4 sec. calculate the distance of the submarine from the ship (Given: the speed of sound in water is 1450 m/s.)

Given:

v = 1450 m / sec,

t = 4 sec, d = ?

$\mathbf{v} = \frac{\mathbf{2\ d}}{\mathbf{t}} \Rightarrow \mathbf{d} = \frac{\mathbf{v\ t}}{\mathbf{2}}$

$\mathrm{d} = \frac{1450 \times 4}{2}$

$\mathbf{d = 2900\,\frac{m}{sec} = 2.9\ Km}$

OPTICAL SENSORS

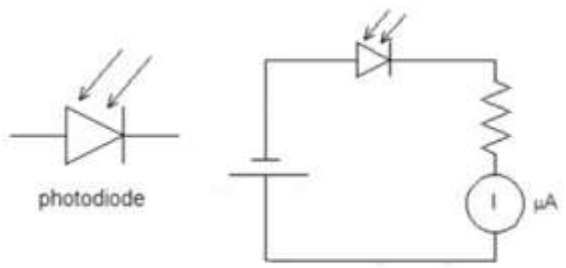
Optical sensors convert light signal into electrical signal.

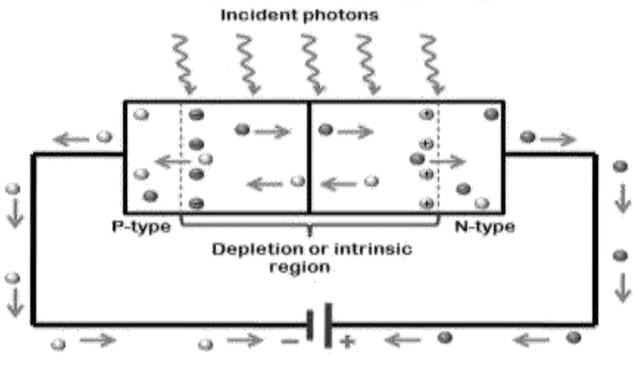
Optical sensors are of different types:

- Photodiode
- Photoresistors (LDR- light dependent resistors)
- Phototransistor
- Solar Cell

PHOTODIODE

- It works on the principle of the **photoelectric effect.**
- A photodiode is a PN-junction diode that consumes light energy to produce electric current. Sometimes it is also called as photo-detector, a light detector, and photo-sensor.
- These diodes are particularly designed to work in reverse bias condition, it means that the P-side of the photodiode is associated with the negative terminal of the battery and n-side is connected to the positive terminal of the battery.





Working:

- When a photon of sufficient energy strikes the diode, it excites an electron (typically semiconductor materials like silicon) of the diode, promoting them from the valence band to the conduction band. This creates electron-hole pairs (free electrons and holes). This mechanism is also known as the inner photoelectric effect.
- Once the electron-hole pairs are generated, they are separated by the internal electric field of the photodiode, which is usually created by a built-in potential at the junction of the p-type and n-type semiconductor materials.
- The electric field pushes the electrons toward the n-type region and the holes toward the p-type region.
- The movement of these charge carriers (electrons and holes) in opposite directions produces a current, known as the **photocurrent**.
- **This device can be used in three modes: photovoltaic as a solar cell, reversed–biased as a photo detector and forward– biased as an LED.**

Dark Current: The small reverse bias current that flows through the diode even when it is not exposed to light is known as dark current.

This current is primarily due to the thermal generation of charge carriers (electrons and holes) in the semiconductor material of the photodiode, causing them to move across the junction.

Photocurrent: The reverse bias current that flows through the diode when it is exposed to light is known as dark current.

The photocurrent is directly proportional to the intensity of the incoming light.

Applications of Photodiode:

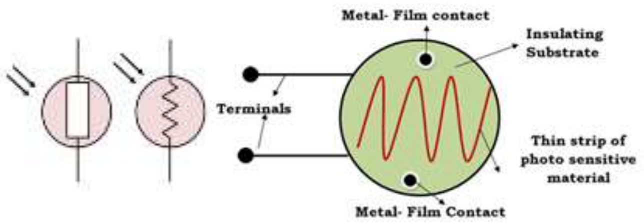
- Photodiodes are used in optical communication systems, such as fiber-optic communication, to convert the optical signals back into electrical signals for processing.
- Photodiodes are used in various light sensing applications, such as light meters, automatic lighting systems, and in consumer electronics like cameras for light intensity measurements.
- In medical diagnostics, photodiodes are used in devices like pulse oximeters to measure blood oxygen levels by detecting the absorption of light by blood.
- Photodiodes are used in barcode scanners to detect the reflected light from a laser or LED that is directed at the barcode.
- Photodiodes are used in laser rangefinders and Light Detection and Ranging (LIDAR) systems for distance measurement and mapping by detecting the reflected laser light.

- Photodiodes are a key component in digital cameras and other imaging devices, where they convert light into electrical signals that are processed to create images.
- Photodiodes are used in spectrometers to measure the intensity of light at various wavelengths, useful in chemical analysis and research.
- Photodiodes are used in motion detection systems, such as automatic doors, to detect changes in the amount of light reflected from objects in the environment.
- Photodiodes are used in systems that monitor air quality, pollution levels, and other environmental parameters, often using light absorption methods.

LDR (Light Dependent Resistors)

A **Light Dependent Resistor (LDR)**, also known as a **photoresistor**, is a type of resistor whose resistance decreases with increasing incident light intensity. In other words, an LDR is a variable resistor that changes its resistance based on the amount of light exposed to it.

Constuction:



- The LDR is constructed by placing a thin zigzag shaped strip of photosensitive device upon the insulating material.
- The light sensitive materials used in LDR are Cadmium Sulphide (Cds), Cadmium Selenide (CdSe) or lead Sulphide (Pbs).
- The insulating material used in LDR is ceramic. The metal films are connected with the terminal leads.
- The whole structure is placed inside a plastic or resin case to have direct exposure to the sunlight.
- When there is no light the resistance is very high in Mega Ohms. When the light is incident the resistance value decreases and the conductivity increases.

Working:

- The photoconductive material does not consists of any free electrons or it consists of few free electrons when it is not exposed to light.
- When the light is incident on the LDR the covalent bond breaks and many free electrons and holes are formed.
- The free electrons and holes gains energy and they jump from valence band to the conduction band. Thus current is generated.
- The resistivity of LDR decreases with increase in the incident light. More the light, more the charge carriers.

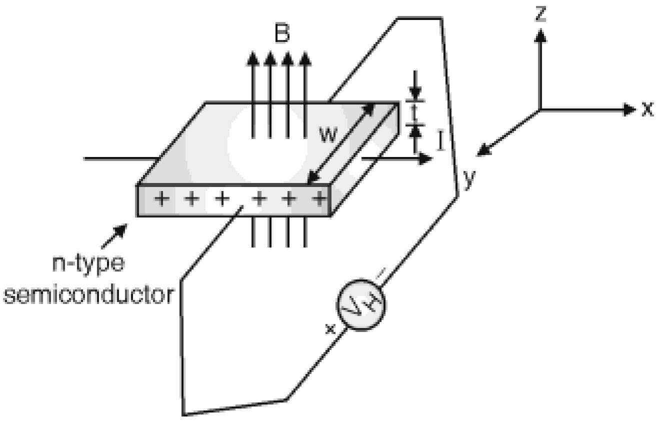
Applications of Photodiode:

- LDRs are used in street lights to automatically turn on at dusk and turn off at dawn. The LDR detects the ambient light level and activates or deactivates the light based on the surrounding light conditions.
- LDRs are used in cameras to adjust the exposure automatically. They detect the brightness of the scene and modify the camera's settings get the best image quality.
- LDRs are used in security systems, such as automatic light triggers, where the presence of a person is detected by the change in light patterns.
- LDRs can be used to detect smoke or fire. If a fire or smoke affects the light level in an area, the LDR will detect the change in light and trigger an alarm.
- LDRs can be used in automatic watering systems where they sense the amount of sunlight and adjust irrigation levels according to the time of day or brightness.
- DRs are used in some toys and gadgets that react to light by triggering sounds, movements, or other effects based on the amount of light present.
- LDRs are used in light meters for measuring the intensity of light.
- In clocks or digital displays, LDRs can adjust the brightness of the display depending on the surrounding light conditions.
- In solar-powered garden lights, LDRs detect the level of ambient light and turn the light on during the night when it gets dark.

HALL SENSOR

Principle (Hall Effect):

when a conductor or semiconductor carrying current (I) are placed in an transverse (perpendicular) magnetic field (B), then voltage is develop across the conductor or semiconductor in the direction perpendicular to both current(I) and magnetic field(B). This phenomenon is known as **Hall Effect** and the voltage is known as **Hall voltage (V_H).**



Applications of Photodiode:

- Hall sensors are used in motors and other rotating machinery to determine the position of a rotating shaft.
- Hall sensors are used in vehicles, industrial equipment, and electric motors to measure the rotational speed of wheels, gears, or shafts.
- Hall sensors detect the proximity of magnets or ferrous objects and are used in systems where non-contact detection is needed, such as in security systems, automotive door open sensors, or automatic doors.
- Hall sensors are employed in scientific instruments and magnetic field mapping applications for measuring the strength and direction of magnetic fields.
- Hall sensors are often used to measure the speed of rotating parts, such as the wheel speed sensors for anti-lock braking systems (ABS).DC transformers: The Hall Effect sensor is used to measure the DC magnetic flux, and as a result, the DC current can be calculated.
- Fuel level indicator: The Hall Effect sensor senses the position of a floating element using position sensing and employed as automotive fuel level indicator.
- Hall Effect sensors are used to control and stabilize the position of objects in magnetic levitation systems, which have applications in high-speed trains.
- The Hall Effect sensors is used to measure the properties of semiconductors and materials, such as carrier concentration and mobility.

IR (Infrared) SENSOR

Principle:

An **infrared (IR) sensor** is a device that detects infrared radiation, which is emitted by objects in the form of heat.

Active IR Sensor:

- This active infrared sensor includes both the transmitter as well as the receiver.
- They consist of an emitter (usually an LED) and a detector (such as a photodiode or phototransistor).
- Active IR sensors are commonly used in object detection and distance measurement.

Passive IR Sensor:

- The passive infrared sensor includes detectors only but they don’t include a transmitter.
- The passive infrared sensor detect the infrared radiation emitted by objects, typically the heat emitted by living beings, such as humans and animals.
- PIR sensors are often used in motion detectors, alarm systems, and energy-saving lighting systems.
- These sensors are classified into two types like thermal IR sensor and quantum IR sensor.

Applications of Photodiode:

- **Motion detection**: PIR sensors are used in security systems to detect the presence of people or animals.
- **Temperature sensing**: IR sensors can measure the temperature of an object or surface without direct contact.
- **Proximity sensing**: Used in devices such as touchless faucets or automatic doors.
- **Night vision**: In combination with cameras, IR

sensors enable vision in low-light or no-light conditions.

- **Distance measurement**: Active IR sensors are often used in devices like rangefinders.
- **Weather Stations**: IR sensors are used in weather stations to measure the temperature of surfaces like the ground or oceans to understand weather patterns.
- **Pollution Detection**: IR sensors can detect certain gases and pollutants, contributing to air quality monitoring.
- **Military and Defense**: IR sensors are used for surveillance, search and rescue, and target tracking, providing an advantage in low-visibility situations.
- **Infrared Therapy**: Some IR devices are used in therapeutic treatments, like infrared saunas or physical therapy devices that use infrared radiation to reduce pain and inflammation.
- **Remote Controls**: Many consumer electronics, like TVs and audio equipment, use IR sensors to communicate via infrared signals.
- **Collision Avoidance**: IR sensors are integrated into advanced driver-assistance systems (ADAS) to detect obstacles and help with parking and navigation.
- **Object Detection**: IR sensors help robots detect objects or obstacles in their path, aiding in navigation and object manipulation in industrial settings.
- **Spectroscopy**: IR sensors are used in various scientific instruments to study materials and their properties through infrared absorption and emission.
- **Astronomy**: IR sensors on telescopes can observe celestial bodies and phenomena that are not visible in the standard optical spectrum.
- **Irrigation Management**: They also help optimize irrigation by detecting soil moisture levels and the heat emitted by the soil, ensuring that water is used efficiently.
- **Crop Monitoring**: IR sensors are used in precision agriculture to assess crop health by measuring infrared radiation reflected by plants, which can indicate levels of water stress, disease, and overall plant condition.