Optical & Similar Sensors

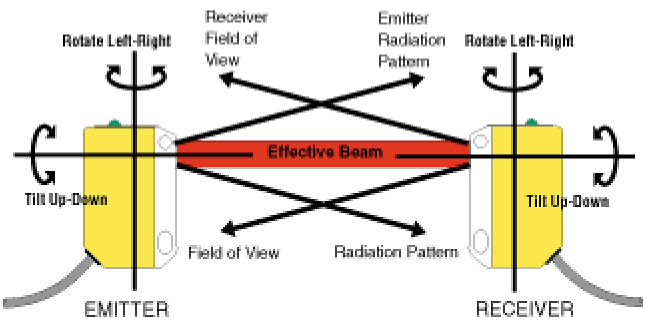
How to select proper Optical Sensing Technology?

A Blue LED will not sense Blue but Red and Green!

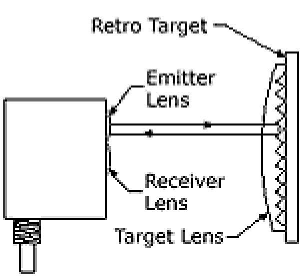
Where to place the emitter and the receiver?

Different Modes of Sensing

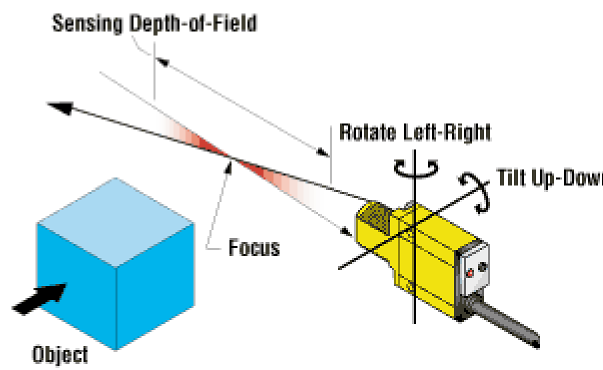
- Opposed Mode (Fig A)
- Retro-reflective Mode (Fig B)
- Proximity Mode (Divergent, Convergent (C) , Background Suppression (D))



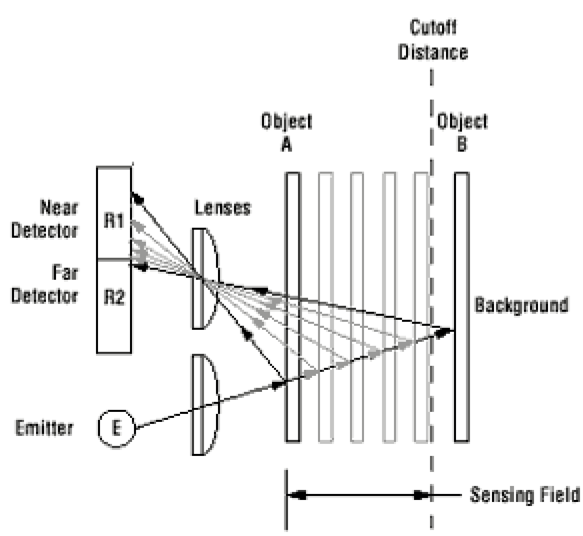
A



B

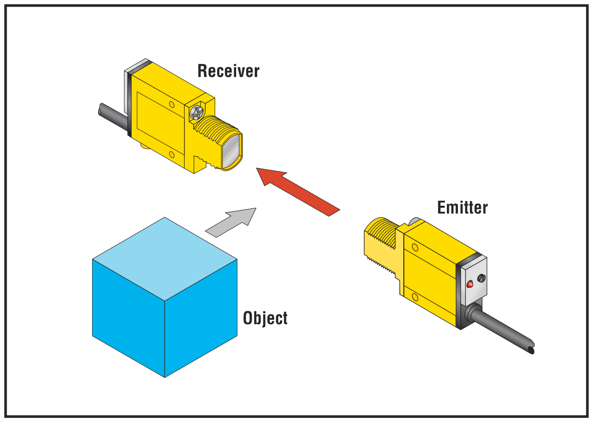


C



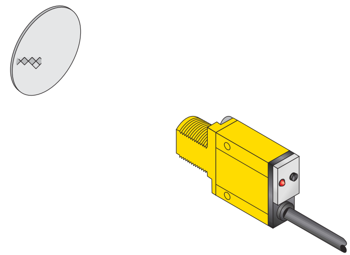
D

Opposed Mode Sensing



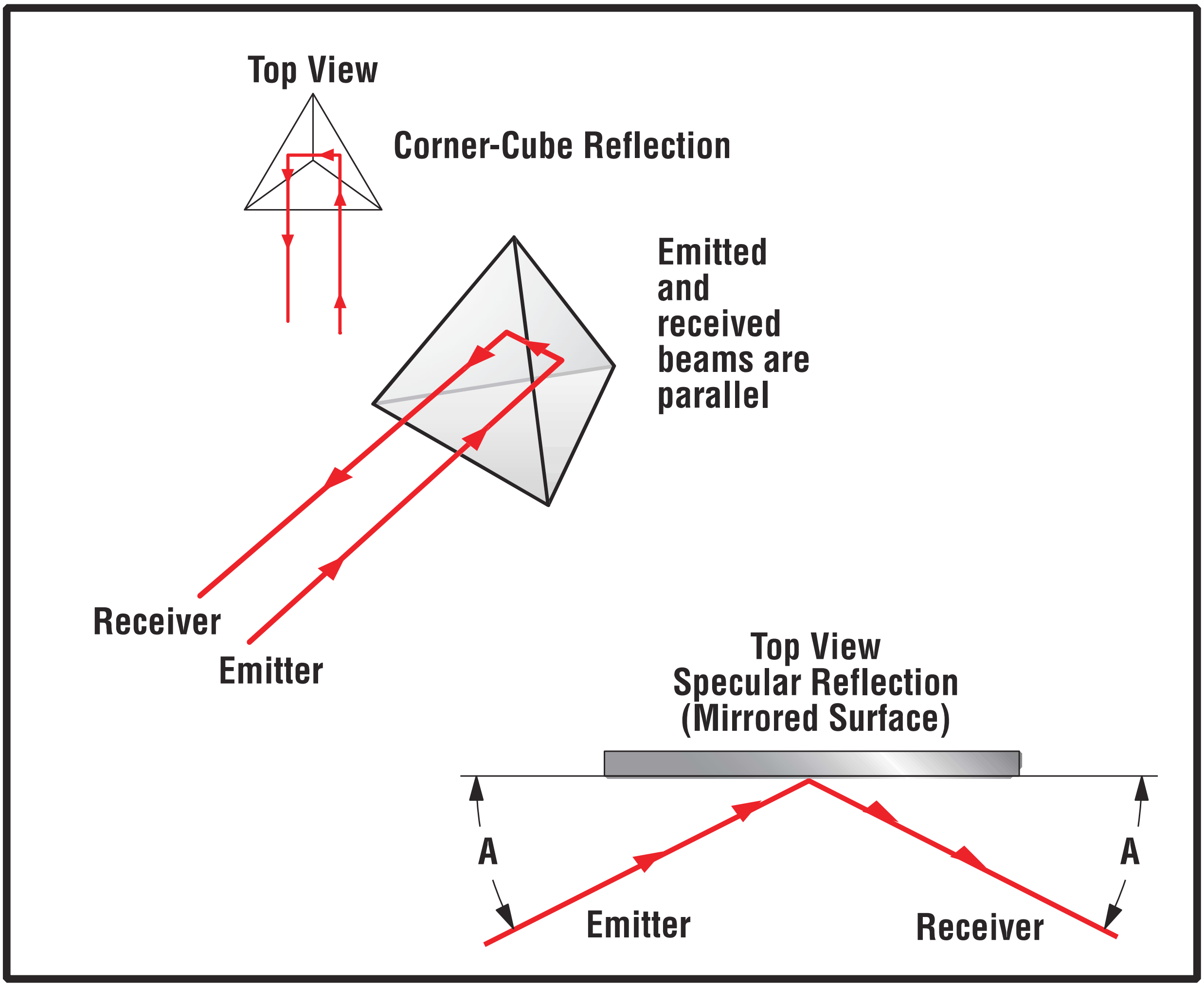
- Opposed-mode sensing also called “direct-scanning,” “beam-break” or “through- beam” mode.
- Opposed-mode emitters and receivers are positioned opposite each other, with the emitter’s light aimed directly at the receiver.
- An object is detected when it interrupts the sensing path between the two components, “breaking” the beam.

Retro-reflective Mode Sensing



- In retroreflective (also called “reflex” or “retro”) mode, one sensor contains both emitter and receiver circuitry.
- Its emitter sends a light beam to a retroreflective target, which reflects the light back to the receiver. As in opposed-mode sensing, an object is sensed when it interrupts the beam.

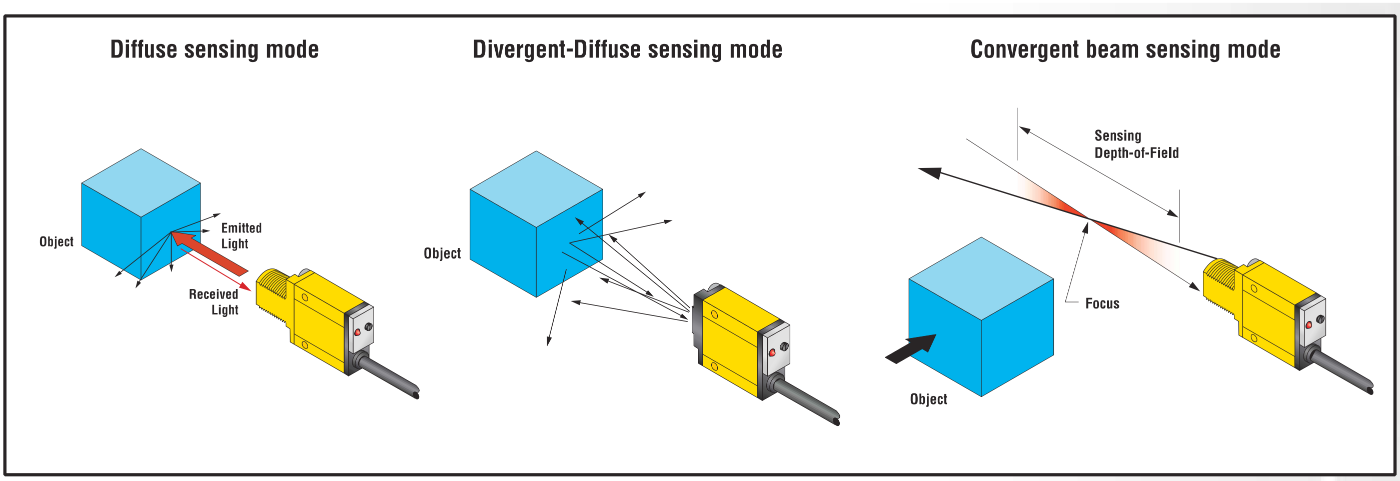
Configuration of a Retro



Retroreflective targets ("retroreflectors" or "retro targets") are usually a matrix of tiny corner-cube prisms, each with three mutually perpendicular surfaces and a hypotenuse face.

A light beam entering a corner-cube prism through its hypotenuse face is reflected from the three surfaces and emerges back through the hypotenuse face, parallel to the entering beam. In this way, the retroreflective target returns the light beam to its source.

Proximity and Divergent Mode

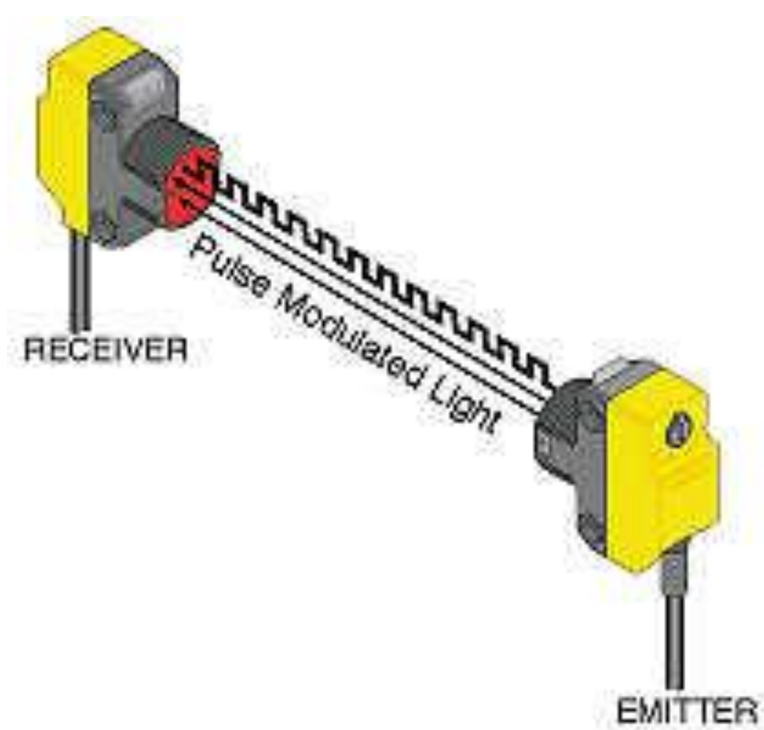


- Photoelectric/Ultrasonic proximity-mode sensing detects an object directly in front of the sensor by detecting the sensor's own transmitted energy reflected back from the object's surface.
- An object establishes the beam when it is present, rather than interrupting it, as in opposed-mode sensing.
- In diffuse mode, the emitted light strikes the surface of an object at some arbitrary angle. The light diffuses at many angles, some small portion of which reaches the receiver.
- It is relatively inefficient, the receiver gets a small amount of returned light. A bright white surface will be sensed at a longer range than a dull black surface.

With the exception of infared types, LEDs produce less light than incandescent and fluorescent light sources; often less light than the ambient light level around them.

Modulation of the sensor's light beam provides the sensing power needed to sense reliably at these low light levels. Most modern photoelectric sensors use modulated LED emitters and phototransistor receivers.

LEDs can be turned "on" and "off" (or modulated) at a high rate of speed, typically at a frequency of several kilohertz. This modulating of the LED means that the amplifier of the phototransistor receiver can be "tuned" to the frequency of modulation, and amplify only light signals pulsing at that frequency.



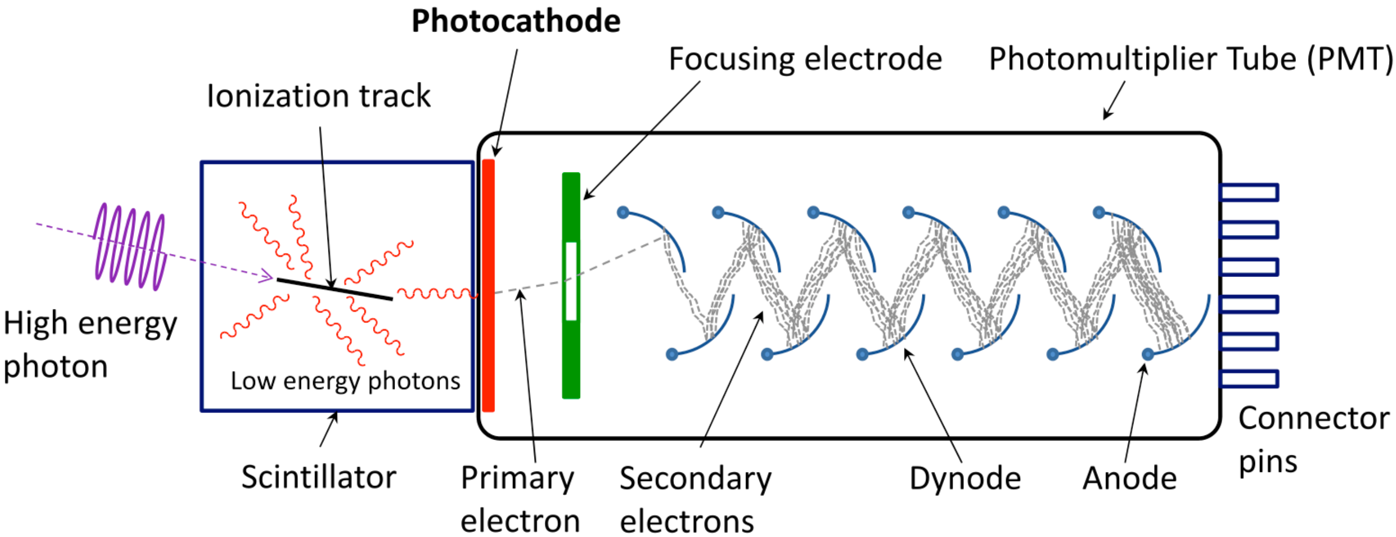
Photomultipliers

Photomultiplier tubes (PMT) are members of the class of vacuum tubes that are extremely sensitive detectors of light in the UV, Visible, and near infra ranges. These detectors multiply the current produced by incident light by as much as 100 million times (i.e., 160 dB), in multiple dynode stages, enabling even individual photons to be detected when the incident flux of light is low.

Applications:

low light level spectroscopy, confocal microscopy, Raman spectroscopy, fluorescence spectroscopy, nuclear and particle physics, astronomy, medical diagnostics

Working Principle of PMT



Photoelectric Effect + Secondary Emission

The electron multiplier -> a number of electrodes called *dynodes*. Each dynode is held at a more positive potential, by ≈100 Volts, than the preceding one.
A primary electron leaves with the energy of the incoming photon ~ 3 eV (blue photons) - φ of the photocathode.
Primary electrons arrive with ≈100 eV kinetic energy imparted by the potential difference. Upon striking the first dynode, more low energy electrons are emitted, and these electrons are accelerated toward the second dynode.
If at each stage an average of 5 new electrons are produced for each incoming electron, and if there are 12 dynode stages, then at the last stage one expects for each primary electron about $5^{12} \approx 10^8$ electrons. This large number of electrons reaching the anode results in a sharp current pulse that is easily detectable

Digital Transducers

- A measuring device that produces a digital output.
- Any measuring device that presents information as discrete samples and does not introduce a *quantization error* may be classified as a digital transducer.
- A transducer whose output is a pulse signal may be considered in this category since the pulses can be counted and presented in the digital form using a counter.
- An analog sensor such as thermocouple along with an ADC is not a digital transducer!

Digital Transducers

- When the output of a digital transducer is a pulse signal, a common way of reading the signal is by using a counter, either to count the pulses (for high-frequency pulses) or to count clock cycles over one pulse duration (for low-frequency pulses).
- The count is placed as a digital word in a buffer, which can be accessed by the host (control) computer, typically at a constant frequency (sampling rate).

Motion Sensing Transducers

- Our discussion will be limited primarily to motion transducers.
- However, by using a suitable auxiliary front-end sensor, other *measurands*, such as force, torque, temperature, and pressure, may be converted into a motion and subsequently measured using a motion transducer.
- Altitude (or pressure) in aerospace applications are obtd. using a pressure-sensing front end - a bellow or diaphragm, in conjunction with an optical encoder to measure the resulting displacement.

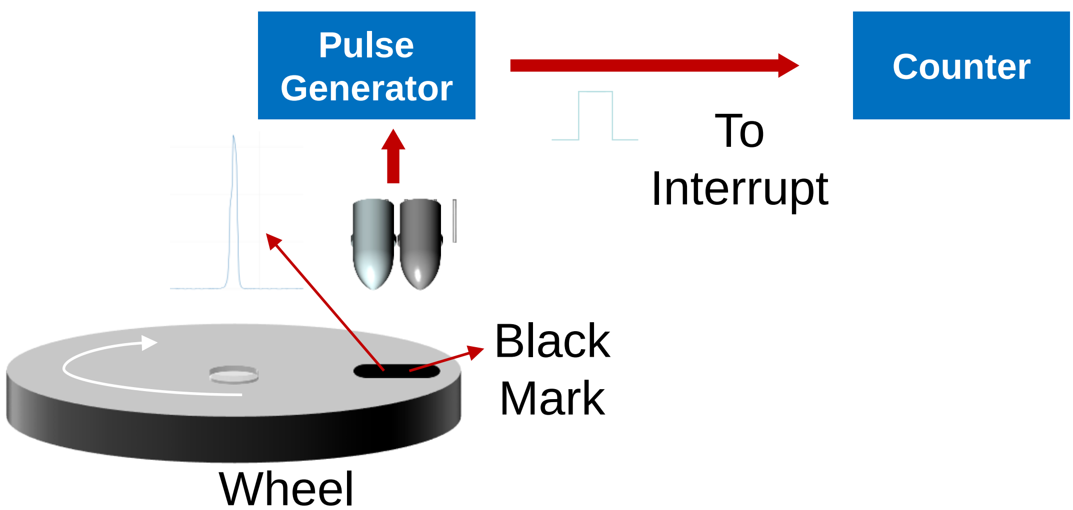
Advantages

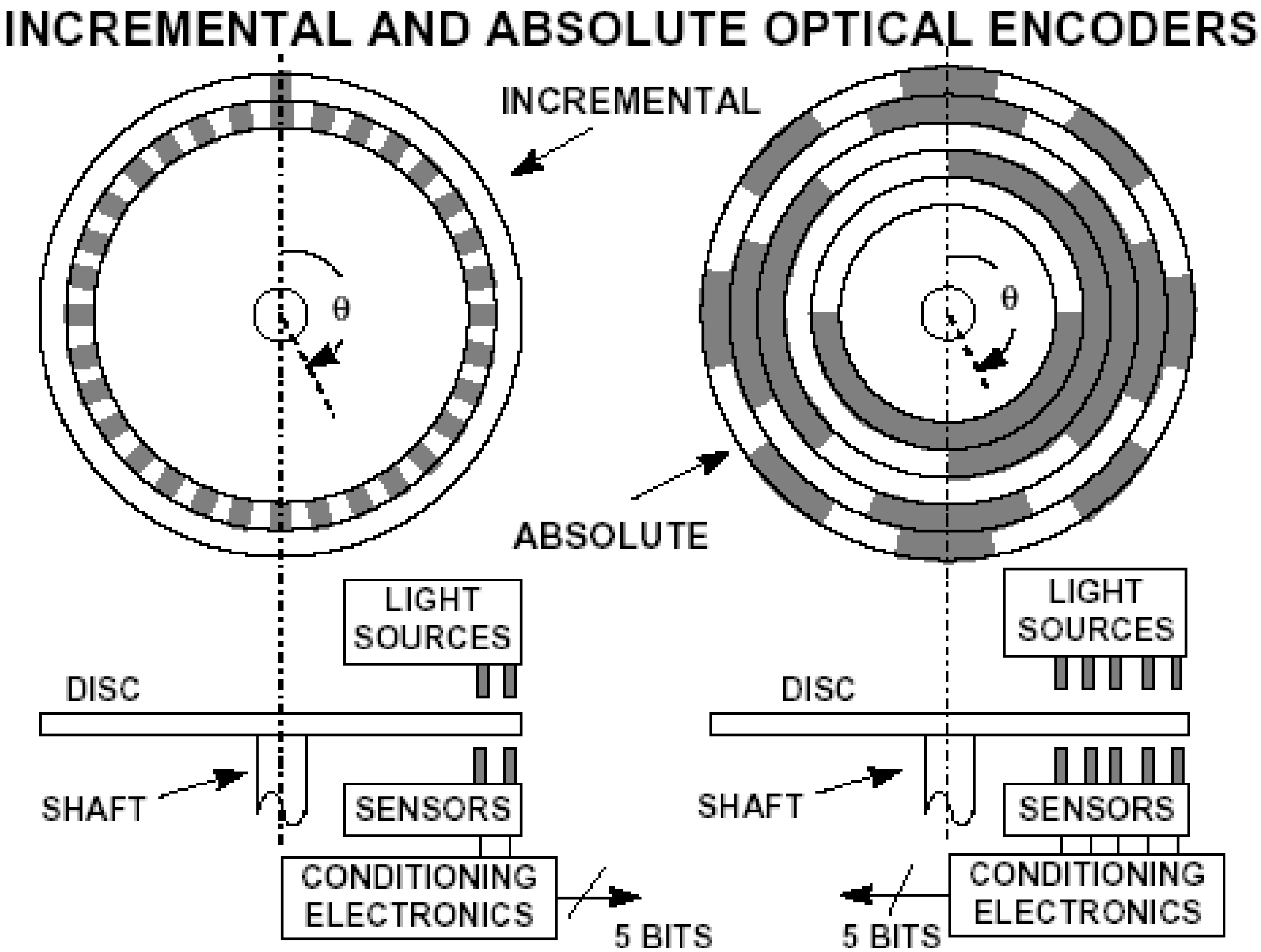
- Digital signals are less susceptible to noise, disturbances: robust
- Complex signal processing with very high accuracy and speed
- High reliability in a system by minimizing analog hardware components.
- Large amounts of data storage using compact, high-density, data storage methods.
- Fast data transmission over long distances.
- Use low voltages (e.g., 0–12 V dc) and low power.
- Typically have low overall cost.

Shaft Encoder

- Shaft encoders are digital transducers that are used for measuring angular displacements and angular velocities.
- Applications include performance monitoring and the control of robotic manipulators, machine tools, industrial processes (e.g., food processing and packaging), digital data storage devices, positioning tables, satellite mirror positioning systems, and rotating machinery such as motors, pumps, compressors, turbines, and generators.

Optical Rotary Encoder

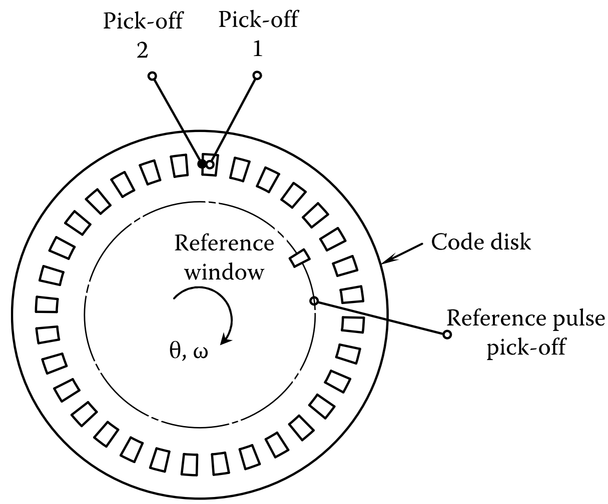


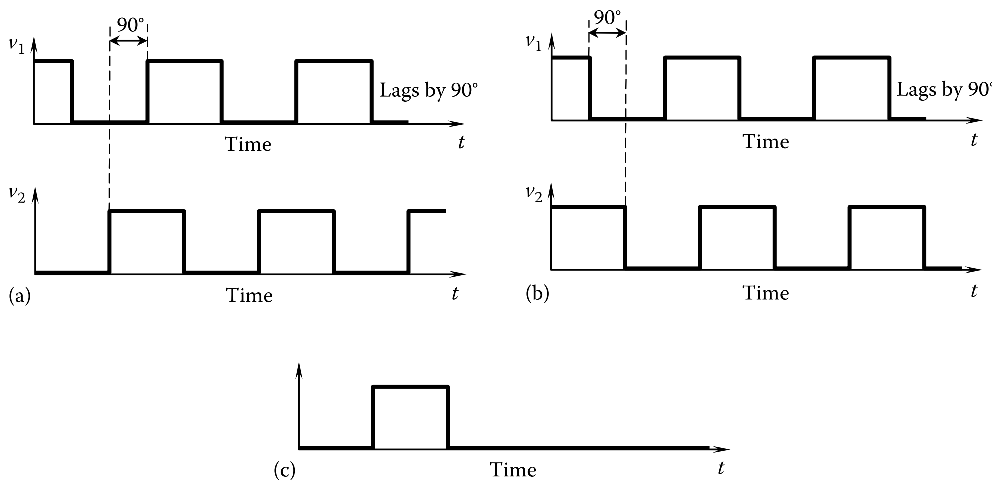


Four techniques of transducer signal:

1. The optical (photo-sensor) method
2. The sliding contact (electrical conducting) method
3. The magnetic saturation (reluctance) method
4. The proximity sensor method

Incremental Encoder





$$\theta = \frac{n}{M}\theta_{\max}$$

M – max no of pulses
n – no of pulses measured
θ_{max} - range of angle

if there is a falling edge in v_1 when v_2 is logic high $\Rightarrow$ cw rotation
if there is a rising edge in v_1 when v_2 is logic high $\Rightarrow$ ccw rotation

$$\text{Speed } \omega = \frac{2\pi/N}{T/n} = \frac{2\pi n}{NT}$$

T – time period
N – no of windows

Absolute Encoder

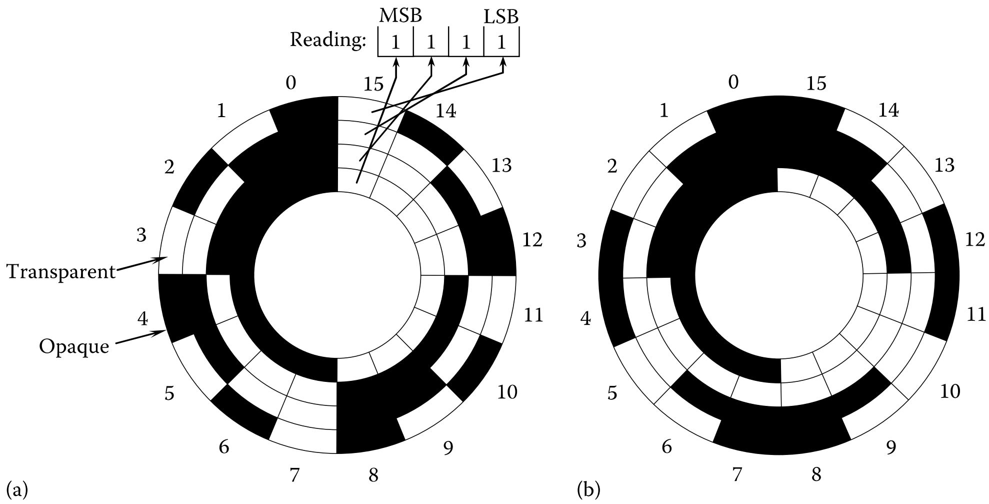


TABLE 6.8

Sector Coding for a 4 Bit Absolute Encoder

Sector Number	Straight Binary Code (MSB → LSB)	A Gray Code (MSB → LSB)
0	0 0 0 0	0 0 0 0
1	0 0 0 1	0 0 0 1
2	0 0 1 0	0 0 1 1
3	0 0 1 1	0 0 1 0
4	0 1 0 0	0 1 1 0
5	0 1 0 1	0 1 1 1
6	0 1 1 0	0 1 0 1
7	0 1 1 1	0 1 0 0
8	1 0 0 0	1 1 0 0
9	1 0 0 1	1 1 0 1
10	1 0 1 0	1 1 1 1
11	1 0 1 1	1 1 1 0
12	1 1 0 0	1 0 1 0
13	1 1 0 1	1 0 1 1
14	1 1 1 0	1 0 0 1
15	1 1 1 1	1 0 0 0

Ranges of Encoders

Table 7.4 Maximum specifications of optical encoders

Encoder type	Range (FS)	Resolution	T_{max} (°C)
Incremental linear[a]	1 cm to 3 m[b]	80 lines/mm	100
Incremental angular[a]	2π	18,000 lines/2π	80
Absolute linear	1 cm to 3 m	1 μm	
Absolute angular	2π	14 bit	80

[a]Without interpolation.
[b]Larger range encoders are constructed upon request.

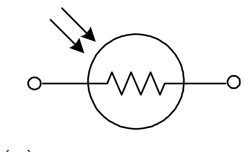
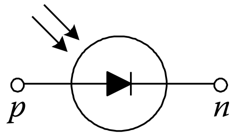


Photo-resistors: like CdS



Photodiodes: Like Si, Ge

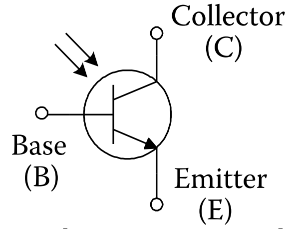
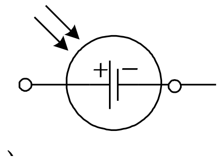


Photo-transistors (n-p-n)



Photocell

Photoelectric receivers typically use one of three light-sensitive electronic elements.

Photodiodes are generally reserved for applications requiring either extremely fast response time or linear response over several magnitudes of light level change. It is based on p-n junction. Sensitivity and the output current are quite low.

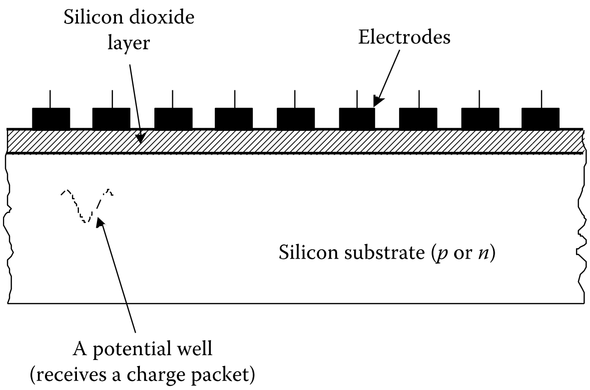
A **photocell** is used whenever greater sensitivity to visible wavelengths is required, as in some color mark and ambient light detection applications. Photocells do not respond to infrared light.

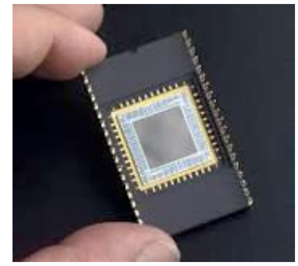
The **Phototransistor** is the most widely used receiver opto-element in industrial photoelectric sensor design, because they offer the best tradeoff between light sensitivity and response speed compared to photo-resistive and other photo-junction devices. Phototransistors respond well to both visible and infrared light.

For a given level of source voltage (usually applied between the emitter lead of the transistor and load), the collector current *ic* is nearly proportional to the intensity of the light falling on the collector–base junction of the transistor. Hence, *ic* can be used as a measure of the light intensity.

Germanium or silicon is the semiconductor material that is commonly used in phototransistors.

Charge Coupled Device (CCD)





- Charge-coupled device (CCD) is an integrated circuit (a *monolithic device*) element of semiconductor material.
- A silicon wafer (*p*-type or *n*-type) is oxidized to generate a layer of SiO2 on its surface. A matrix of metal electrodes is deposited on the oxide layer and is linked to the CCD output leads.
- When light falls onto the CCD element (from an object), *charge packets* are generated within the substrate *silicon wafer*.
- Now if an external potential is applied to a particular electrode of the CCD, a *potential well* is formed under the electrode and a charge packet is deposited here.
- This charge packet can be moved across the CCD to an output circuit by sequentially energizing the electrodes using pulses of external voltage. Such a charge packet corresponds to a *pixel* (a picture element) of the image of the object.