Optical Communications
Lecture 5

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Optical Transmitters

- In an optical communication system, transmission begins with the transmitter, which consists of a carrier generator and a modulator.
- The carrier is a light beam that is modulated by turning it on and off with digital pulses.
- The basic transmitter is essentially a light source.
- The receiver is a light or photodetector that converts the received light back into an electrical signal.

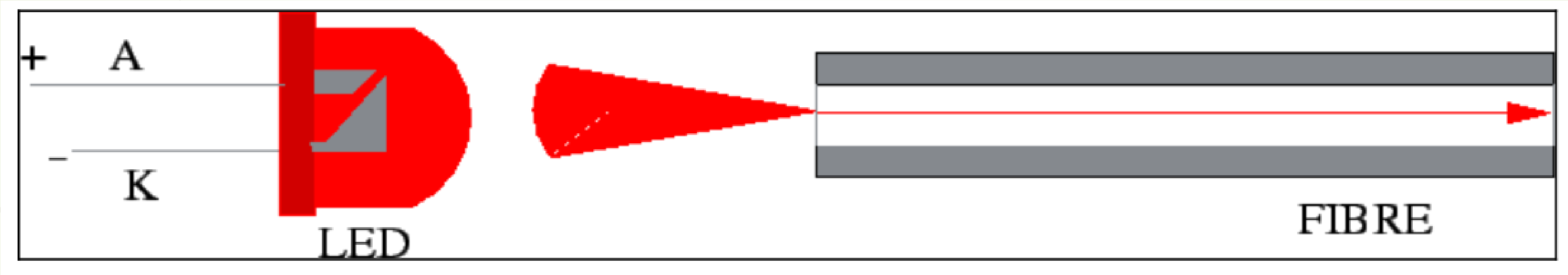
Optical Transmitters

- Conventional light sources such as incandescent lamps cannot be used in fiber-optic systems because they are too slow.
- The two most commonly used light sources are
  - Light-emitting diodes (LEDs) and
  - Semiconductor lasers.

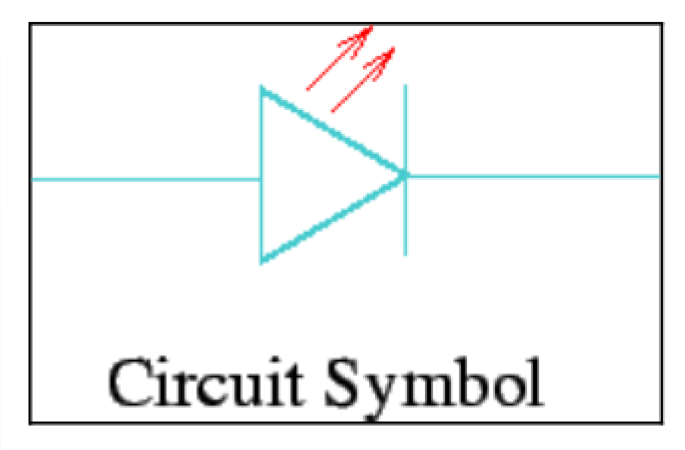
Light Emitting Diode (LED)

- A light emitting diode (LED) is a device which converts electrical energy to light energy.
- LEDs are preferred light sources for short distance (local area) optical fiber network because they are inexpensive, robust and have long life.
- The long life of an LED is primarily due to its being a cold device, i.e. its operating temperature being much lower than that of, say, an incandescent lamp)
- LEDs can be modulated (i.e. switched on and off) at high speeds.
- LEDS are referred to as cold device as they don't have to overcome thermal inertia.

Light Emitting Diode (LED)



There are two leads, a short one, cathode, labelled - or k and a long one, anode, labelled a or +



Circuit symbol of an LED

Light Emitting Diode (LED)

- A light-emitting diode is a PN-junction semiconductor device that emits light when forward-biased.
- A typical LED used for optical communications may have its light output in the range 30 - 60 nm.
- Light emitted from LED is not particularly directional and so it is only possible to couple them to multimode fiber.
- The overall efficiency is low because not all the light can be coupled into the fiber optic cable.

Light Emitting Diode (LED)

- LEDs come in two forms,
- Surface emitting LEDs:
  - Surface emitting LEDs radiate light at wide angles.
  - They are not suitable as sources for coupling to an optical fiber because the radiation is highly incoherent.
  - Such LEDs are usually used as signaling devices and as indicators in panels and instruments.

Light Emitting Diode (LED)

- Edge emitting LEDs:
  - Edge emitting LEDs radiate at a relatively narrower angle.
  - The emitting area is smaller as a result of which the coupling to the end of a fiber is more efficient.

Light Emitting Diode (LED)

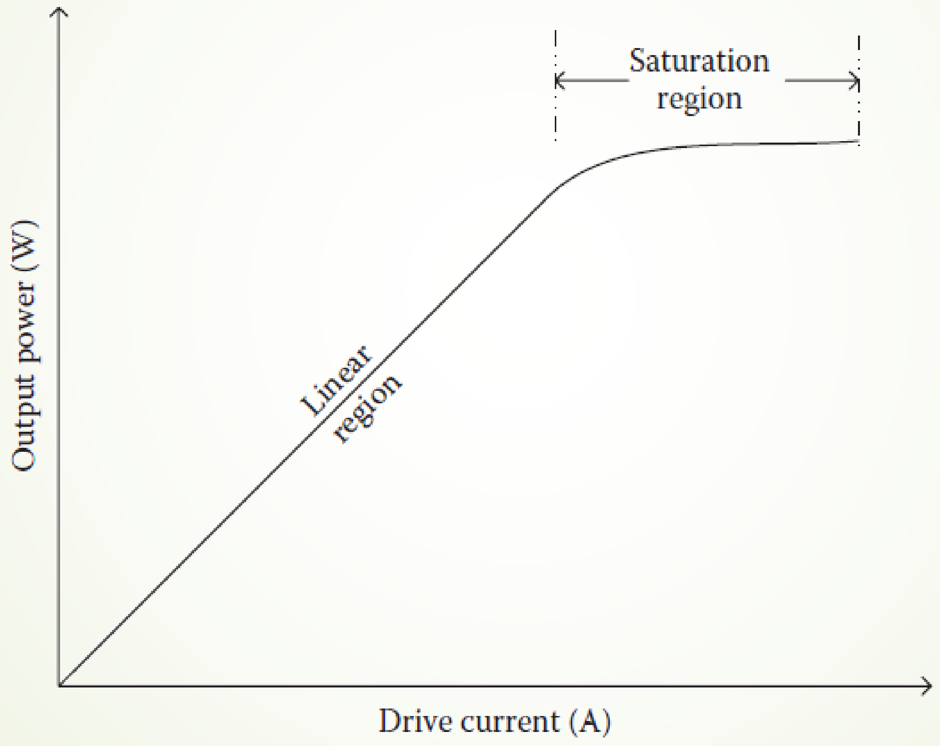
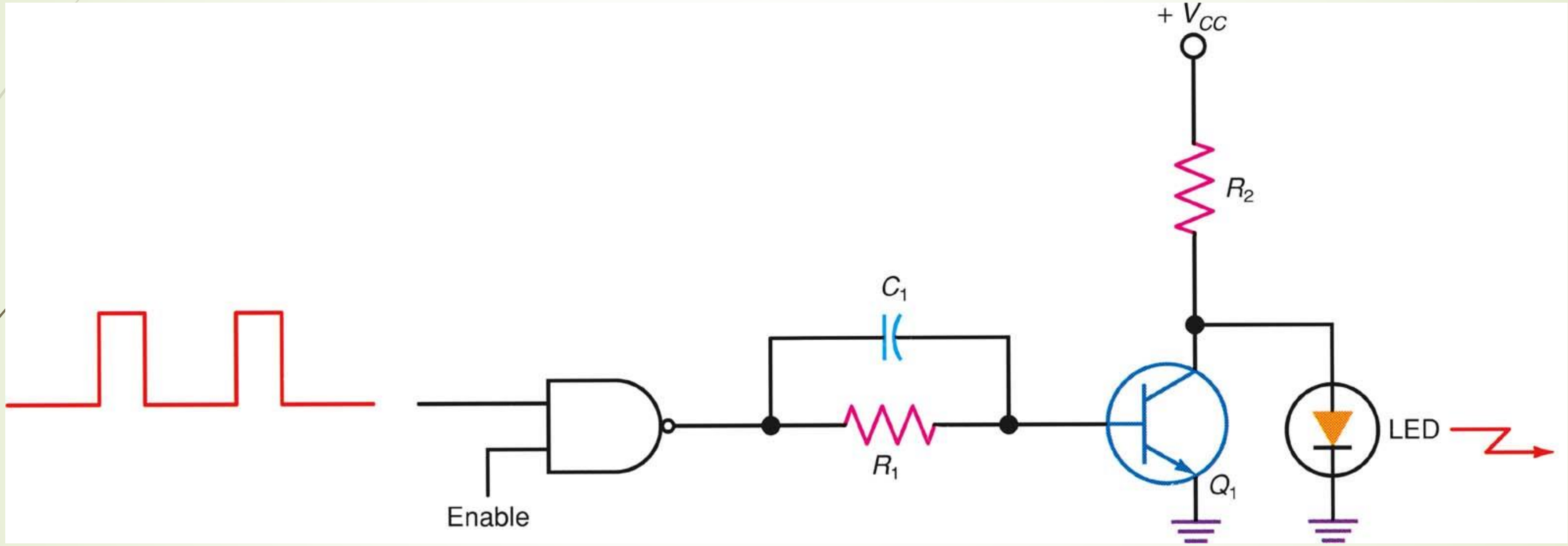


Illustration of the radiated optical power against driving current of an LED

Light Emitting Diode (LED)



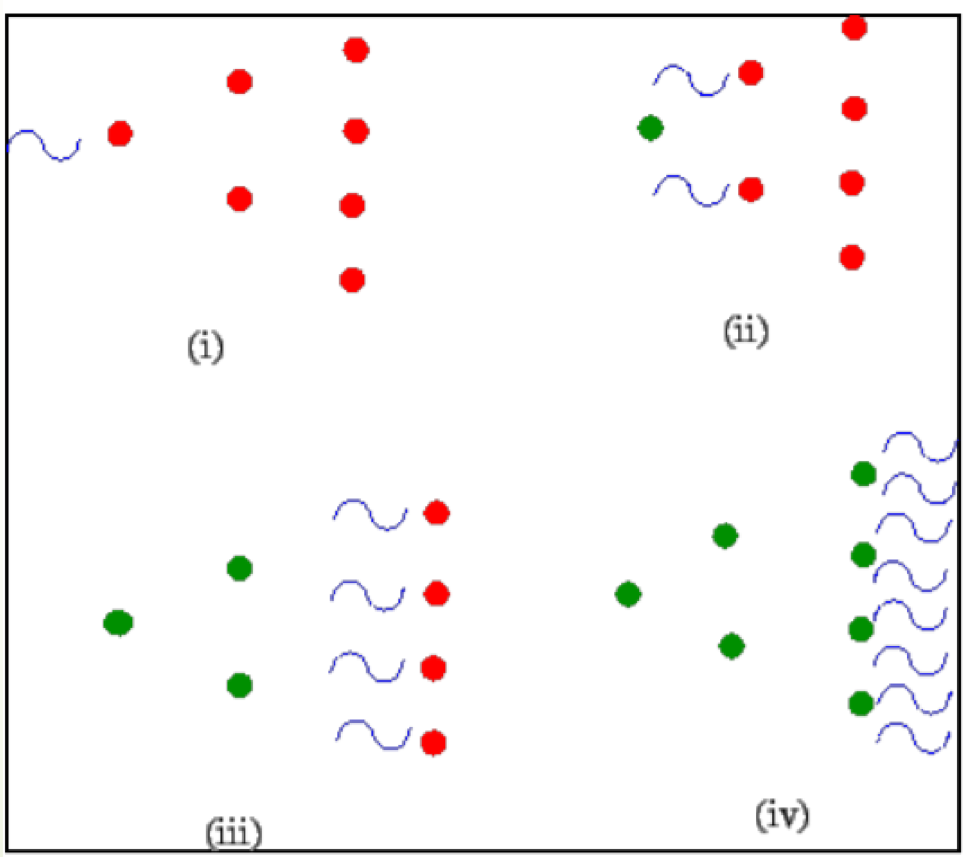
Optical transmitter circuit using an LED

Laser

- In 1958, Charles H. Townes and Arthur L. Schawlow showed that the effect of stimulated emission can be amplified to produce a practical source of light.
- Such a light source is called LASER, an acronym for Light Amplification by Stimulated Emission of Radiation.
- The principle behind such amplification is simple.
- Suppose we start with one photon which strikes an atom in an excited state and releases a photon, we would have two photons and an atom in the ground state.

Laser

- These two photons, in turn, may be incident on two more atoms and give rise to four photons, and so on.
- In the below above, the excited state atoms are shown in red while those in the ground states are in green.



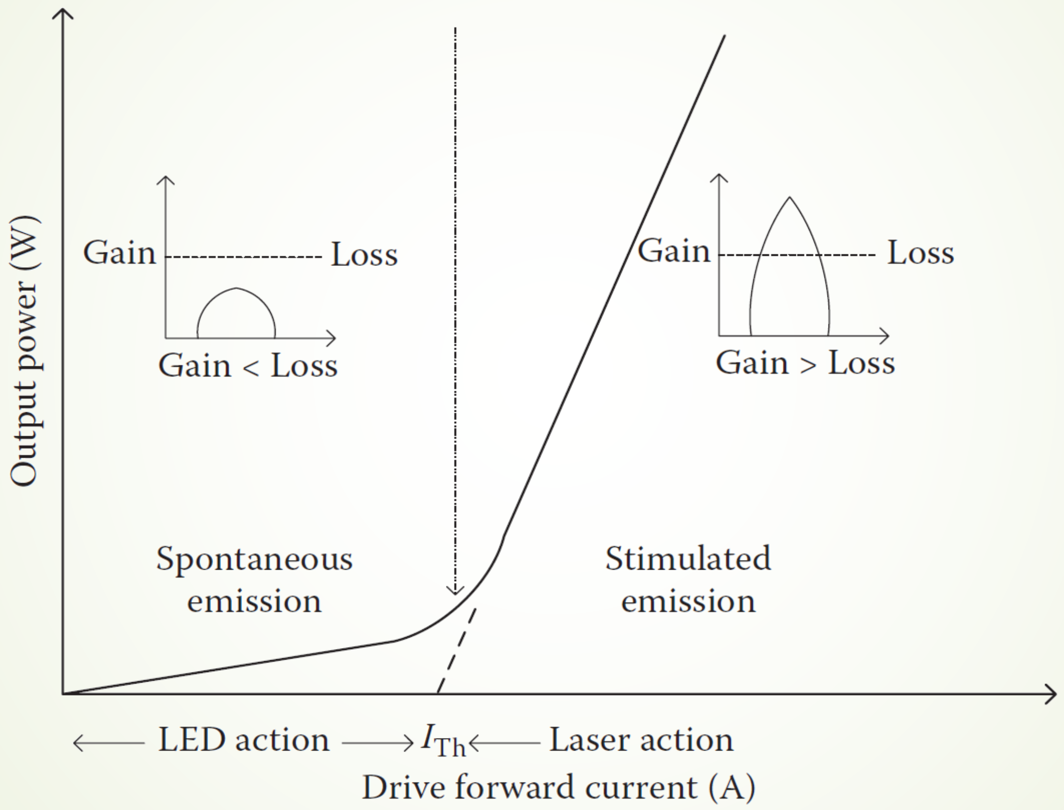
Laser Transmitter

- Light amplification is done by stimulated emitted radiation which generates coherent light.
- The output is more directional than that of a LED, this allows the use of single mode fiber which enables much greater transmission distances to be achieved.
- A further advantage of lasers is that they can be directly modulated with high data rates. Although LEDS can be modulated directly, there is a lower limit to the modulation rate.

Laser Transmitter

- The disadvantage is, Laser diodes are much more expensive than LEDs.
- They are quite sensitive to temperature and to obtain the optimum performance they need to be in a stable environment.
- But long distance telecommunications fiber optic links with Gbps data rates require the use of laser diode fiber optic transmitters.

Laser Transmitter



Laser output power against drive current plot

Optical Transmitters

A Comparison of an LED and a Semiconductor Laser Diode

Characteristics	LED	LD
Optical output power	Low power	High power
Optical spectral width	25–100 nm	0.01–5 nm
Modulation bandwidth	Tens of kHz to hundreds of MHz	Tens of kHz to tens of GHz
E/O conversion efficiency	10–20%	30–70%
Eye safety	Considered eye safe	Must be rendered eye safe
Directionality	Beam is broader and spreading	Beam is directional and is highly collimated
Reliability	High	Moderate
Coherence	Noncoherent	Coherent
Temperature dependence	Little temperature dependence	Very temperature dependent
Drive and control circuitry	Simple to use and control	Threshold and temperature compensation circuitry
Cost	Low	Moderate to high
Harmonic distortions	High	Less
Receiving filter	Wide—increase noise floor	Narrow—lower noise floor

Optical Receivers

- Optical receiver is a device which absorbs light and converts the optical energy to measurable electric current.
- Optical receiver consists typically of :
  - Optical detector
  - Low-noise amplifier
  - Other circuitry
- The purpose of optical receiver is:
  - To convert the optical signal to electrical domain
  - Recover data

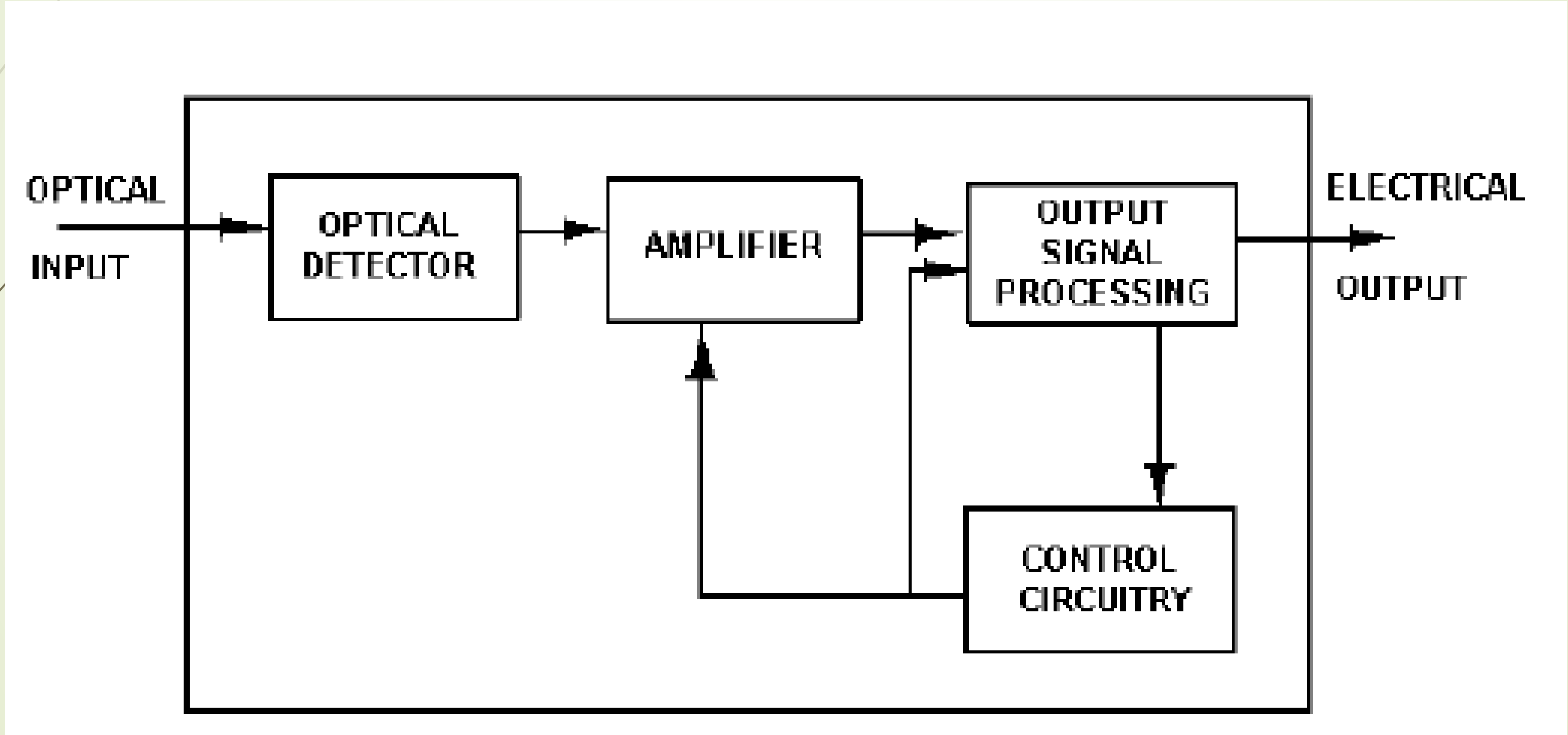
Optical Receivers

- Optical Detectors:
  - These are transducers that convert optical signals into electrical signals.
  - Transducers are devices that convert input energy of one form into output energy of another.
  - An optical detector does so by generating an electrical current proportional to the intensity of the incident optical light.

Optical Receivers

- Optical Detector Requirements:
- Compatible in size to low-pass optical fibers for efficient coupling and packaging.
- High sensitivity at the operating wavelength of the source.
- Low noise contribution.
- Maintain stable operation in changing environmental conditions.

Optical Receivers



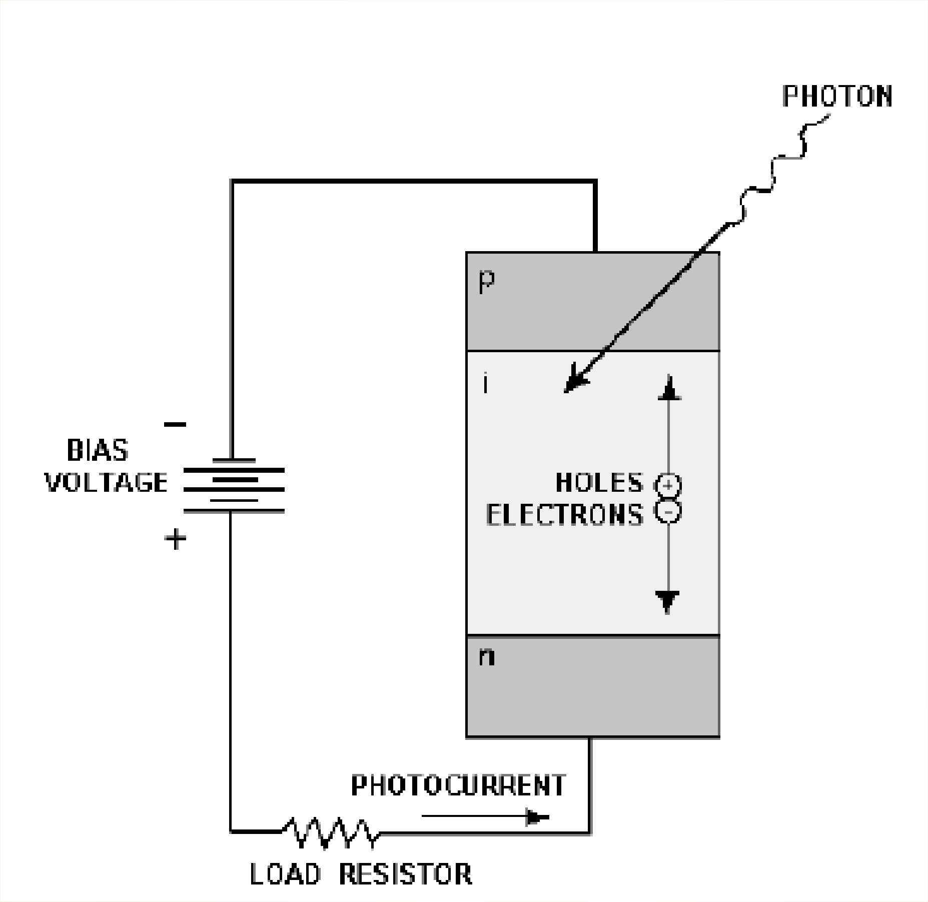
Optical Receivers

- Photo detectors are classified as:
- Thermal detectors
  - When light falls on the device, it raises its temperature, which, in turn, changes the electrical properties of the device material, like its electrical conductivity.
  - Examples of thermal detectors are thermopile (which is a series of thermocouples), pyroelectric detector.

Optical Receivers

- Photon detectors:
  - Photon detectors work on the principle of conversion of photons to electrons.
  - Unlike the thermal detectors, such detectors are based on the rate of absorption of photons rather than on the rate of energy absorption.
  - Photon detectors, in terms of the technology, could be based on
    - Vacuum tubes - e.g. photomultipliers
    - Semiconductors - e.g. photodiode
- For optical fiber applications, semiconductor devices are preferred because of their small size, good responsivity and high speed.

Optical Receivers



Schematic of a Photodiode

Optical Receivers

- The most widely used light sensor is a photodiode. It is a silicon PN-junction diode that is sensitive to light.
- The phototransistor amplifies the small leakage current into a larger, more useful output.
- PIN diodes are more sensitive than the PN-junction photodiode.

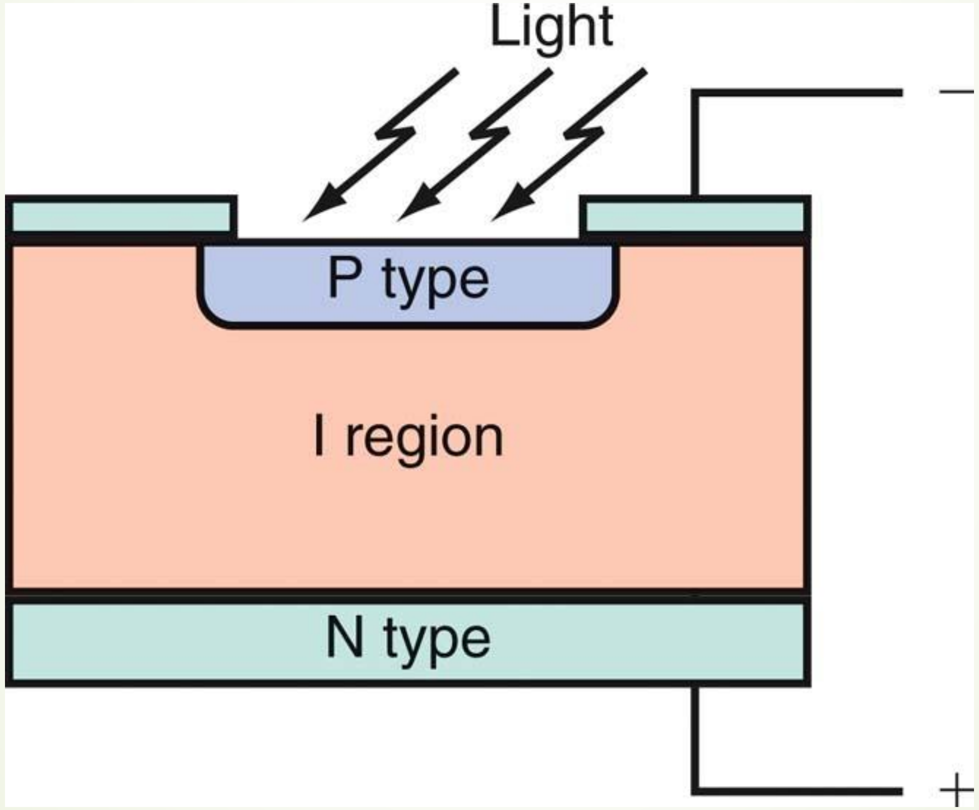
PN-Junction Photodiode

- Reverse bias applied to the p-n junction creates a depletion region with high electric field.
- Photons absorbed in the depletion regions create electron-hole pairs, which are separated by the electric field and contribute to the photocurrent.

PIN Photodiode

- The output electrical current is linearly proportional to the input optical power making it a highly linear device.
- Low bias voltage(<4v).
- Low noise
- Low dark current
- High-speed response

PIN Photodiode



Structure of a PIN photodiode

AVALANCHE Photodiodes

- An APD internally amplifies the photocurrent by an avalanche process when a large reverse-bias voltage is applied across the active region.
- The gain of the APD can be changed by changing the reverse-bias voltage.
- The avalanche photodiode (APD) is widely used and is the fastest and most sensitive photodiode, but it is expensive and its circuitry is complex.

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