Optical Communication

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Unit – 5
POWER LAUNCHING AND COUPLING

In launching optical power from a source into a fiber the following fiber parameters are to be considered.

- NA
- Core size
- Refractive index
- Core-Cladding index difference
- Radiance
- Power distribution

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A measure of the amount of optical power emitted from a source that can be coupled into a fiber is usually given by the coupling efficiency η defined as

$$\eta = P_f / P_s$$

Where P_f is the power coupled into fiber;
P_s is the power emitted from the light source.

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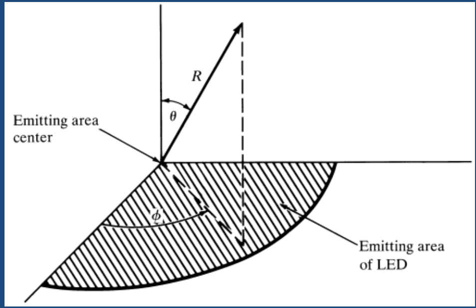
Source to fiber power launching

Radiance is the most important parameter when considering the source to fiber coupling efficiencies.

Radiance is defined as the optical power radiated into a unit solid angle per unit emitting surface area and it can be measured in terms of watt per square centimeter per steridian.



Emission-pattern coordinate system

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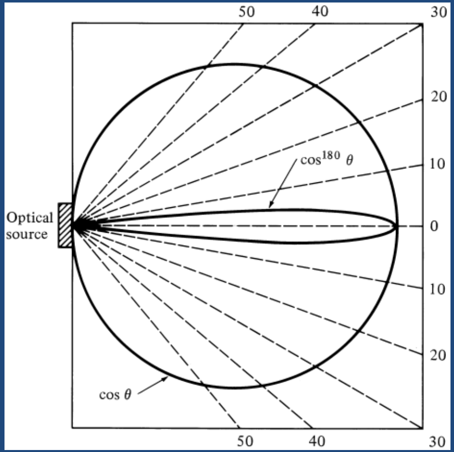
Surface emitting LEDs are characterized by their Lambertian output pattern.

In Lambertian output pattern , light source emits equal brightness when viewed from any direction.



Lambertian radiance pattern

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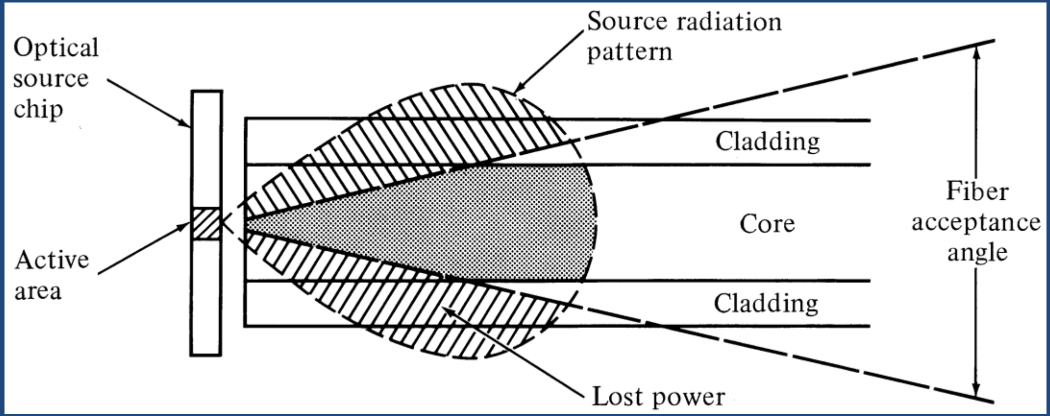
To calculate the maximum optical power coupled into the fiber consider the case shown in the figure.
It is a symmetric source of brightness B(As,Ωs).
Where As is the area and Ωs is the solid emission angle.



Source-to-fiber coupling

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Coupled power (surface emitting LED)

$$P_{\mathrm{LED,step}} = \left(\frac{a}{r_s}\right)^2 P_s (\mathrm{NA})^2$$

rs = source radius

a = fiber core radius

Where Ps is the total optical power.

$$P_s = \pi^2 r_s^2 B_0$$

B0 = radiance along the normal to the radiating surface

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Power coupled from the LED to the graded indexed fiber is given as

$$P_{LED,gin} = 2\pi^2 B_o \int_0^{r_s} \left[n^2(r) - n_2^2 \right] r\,dr$$

$$= 2 P_s n_1^2 \Delta \left[1 - \frac{2}{\alpha + 2} \left(\frac{r_s}{a} \right)^{\alpha} \right]$$

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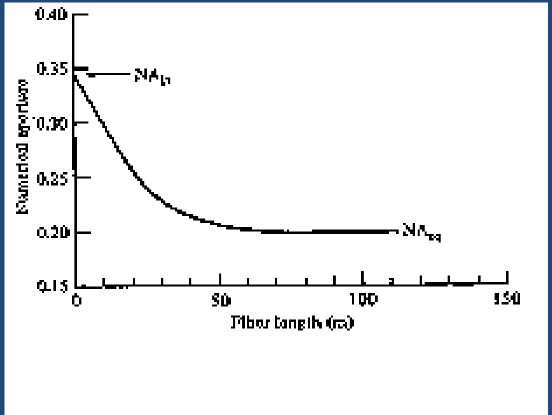
Equilibrium Numerical aperture

For fibers with flylead attachments the connecting fiber should have the same NA. A certain amount of loss occurs at this junction which is almost 0.1 – 1dB. Exact loss depends on the connecting mechanism.

- Excess power loss occurs for few tens of meters of a multimode fiber as the launched modes come to the equilibrium.
- The excess power loss is due to the non propagating modes
- The loss is more important for SLED.
- Fiber coupled lasers are less prone to this effect as they have very few non propagating modes.
- The optical power in the fiber scales as

$$P_{eq} = P_{50}\left(\frac{NA_{eq}}{NA_{in}}\right)^2$$



Lensing Scheme for Coupling Improvement

Several Possible lensing schemes are:

1. Rounded end fiber
2. Nonimaging Microsphere (small glass sphere in contact with
both the fiber and source)
3. Imaging sphere (a larger spherical lens used to image the source on the core area of the fiber end)
4. Cylindrical lens (generally formed from a short section of fiber)
5. Spherical surfaced LED and spherical ended fiber
6. Taper ended fiber.

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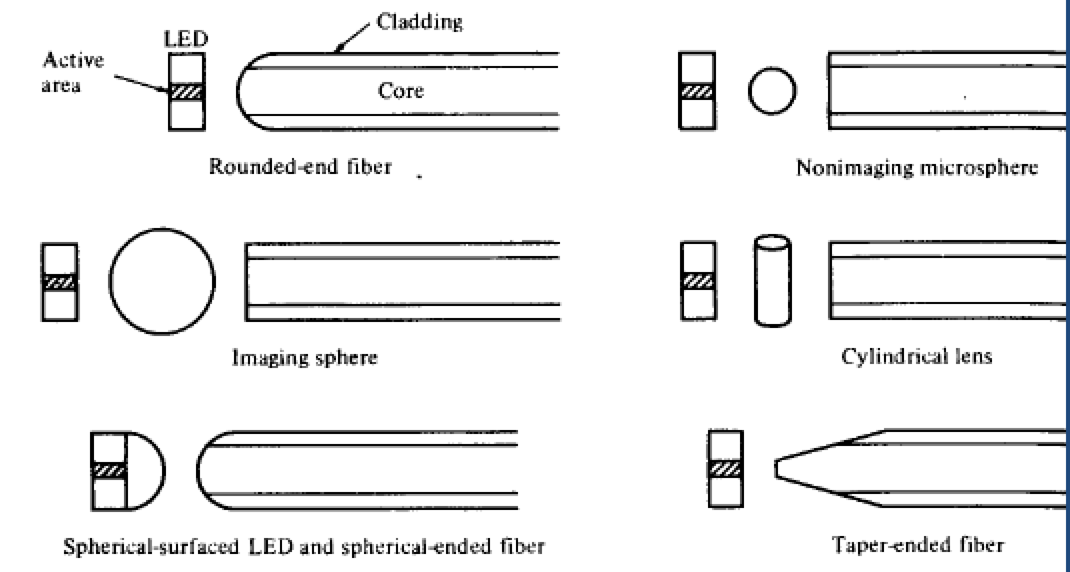
Lensing Scheme for Coupling Improvement



Fundamental Receiver operation

The design of an optical receiver is much more complicated than the optical transmitter.

In that , the receiver must first detect weak, distorted signals and then decide upon what type of data was sent depending on the amplified version of this distorted signal.

Digital Signal Transmission

- A typical digital fiber transmission link is shown in Fig.(next slide) The transmitted signal is a two-level binary data stream consisting of either a ‘0’ or a ‘1’ in a bit period T_b.

- The simplest technique for sending binary data is amplitude-shift keying, wherein a voltage level is switched between on or off values.

- The resultant signal wave thus consists of a voltage pulse of amplitude V when a binary 1 occurs and a zero-voltage-level space when a binary 0 occurs.

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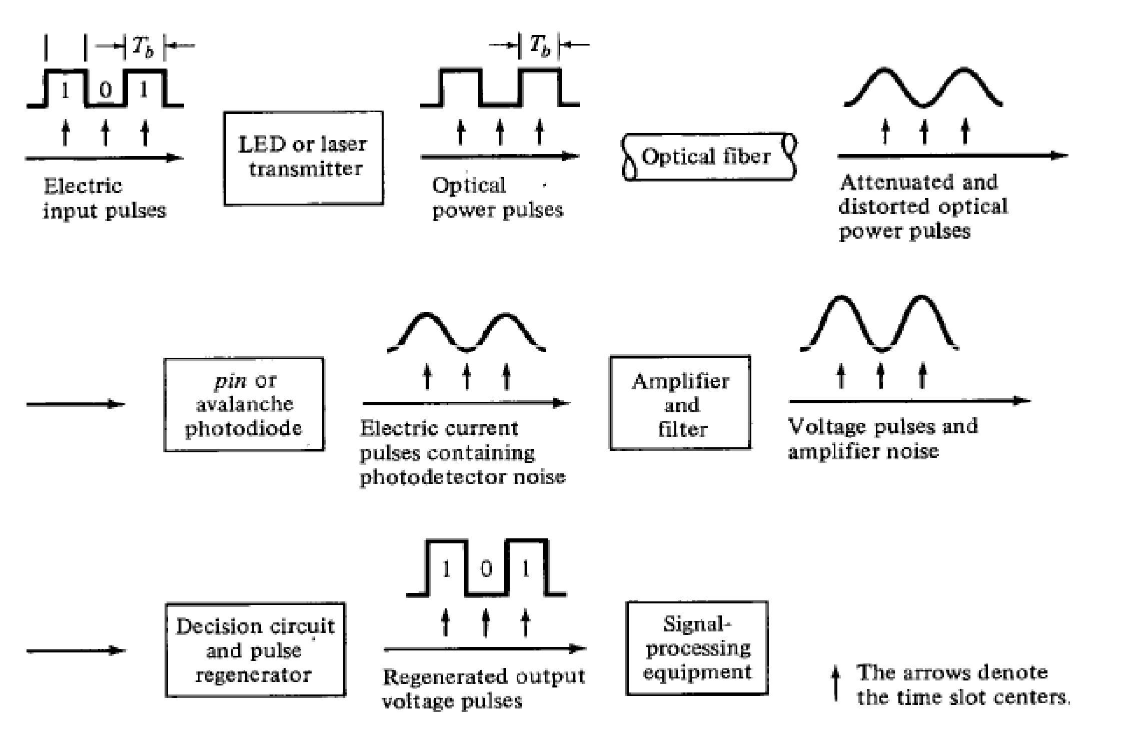
Digital Signal Transmission



Digital Signal Transmission

- An electric current *i(t) can be used to modulate* directly an optical source to produce an optical output power *P(t)*.

- In the optical signal emerging from the transmitter, a '1' is represented by a light pulse of duration *Tb*, whereas a '0' is the absence of any light.

- The optical signal that gets coupled from the light source to the fiber becomes attenuated and distorted as it propagates along the fiber waveguide.

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Digital Signal Transmission

- Upon reaching the receiver, either a PIN or an APD converts the optical signal back to an electrical format.

- A decision circuit compares the amplified signal in each time slot with a *threshold level*.

- If the received signal level is greater than the threshold level, a '1' is said to have been received.

- If the voltage is below the threshold level, a '0' is assumed to have been received.

Error Sources

- Errors in the detection mechanism can arise from various noises and disturbances associates with the signal detection system.

- The two most common samples of the spontaneous fluctuations are shot noise and thermal noise.

- Shot noise arises in electronic devices because of the discrete nature of current flow in the device.

- Thermal noise arises from the random motion of electrons in a conductor.

Error Sources

- The random arrival rate of signal photons produces a quantum noise at the photo detector. This noise depends on the signal level.

- This noise is of particular importance for PIN receivers that have large optical input levels and for APD receivers.

- When using an APD, an additional shot noise arises from the statistical nature of the multiplication process. This noise level increases with increasing avalanche gain *M*.

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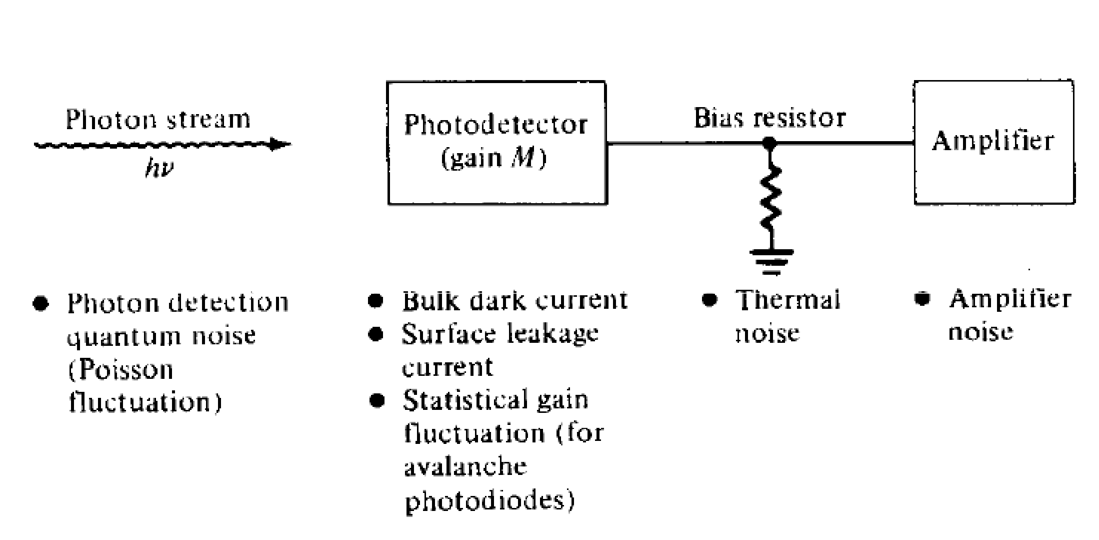
Error Sources



Receiver Configuration

- The three basic stages of the receiver are a photodetector, an amplifier, and an equalizer.

- The photo-detector can be either an APD with a mean gain M or a PIN for which M=1.

- The photodiode has a quantum efficiency and a capacitance C_d.

- The detector bias resistor has a resistance R_b which generates a thermal noise current $i_b(t)$.

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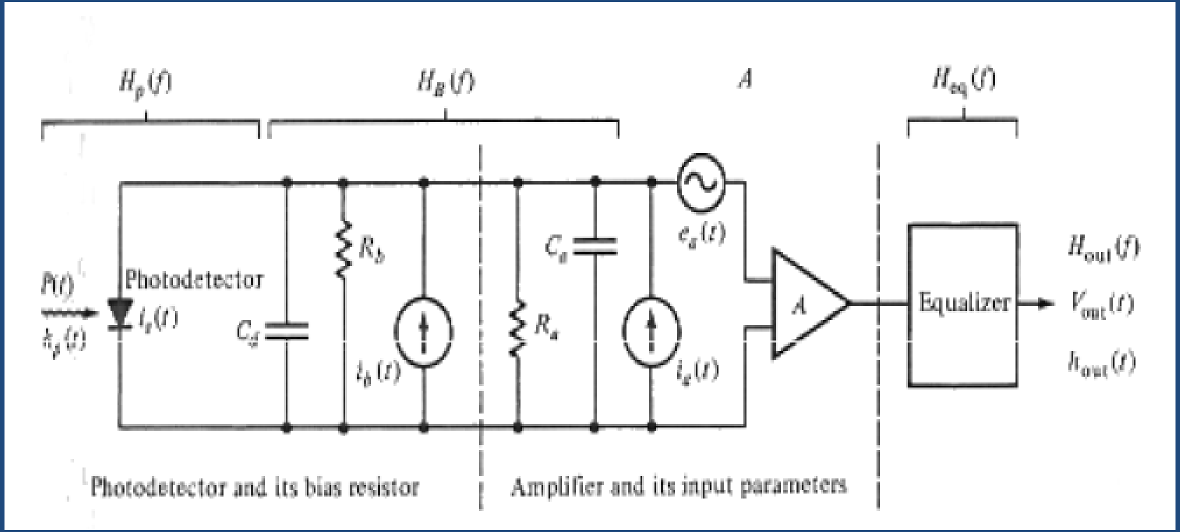
Receiver Configuration



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Digital Receiver Performance

- The performance of digital receiver can be evaluated by measuring the probability of error and quantum limit.

- Probability of error gives the number of errors occurred due to noise sources.

- While, quantum limit gives the minimum received power level at the input of the photo detector.

Probability of Error

- In practice , several standard ways are available to measure the rate of error occurrences in a digital data stream. One common approach is Bit Error rate (BER).

- BER is the ratio of number of errors (Ne) occurring over a certain time interval t to the number of pulses transmitted (Nt) during this interval , **BER = Ne / Nt**

$$\mathrm{BER} = P_e(Q) = \frac{1}{\sqrt{\pi}} \int_{Q/\sqrt{2}}^{\infty} e^{-x^2}\, dx$$

- **Where Q is** $Q = V/2\sigma.$

σ is rms noise and V/ σ is peak signal to rms noise ratio.

Quantum Limit

The minimum number of photons that are required per bit at a specified BER is called Quantum Limit.

If an optical pulse of energy E falls on the photodetector in a time interval T, then it can also be interpreted by the receiver as a ‘0’ pulse.

If no electron-hole pairs are generated then the probability than n=0 electrons are emitted in a time interval T is

$P(0) = e^{-N}$

Where average number of electron-hole pairs

$N = (\eta E) / (hv)$

Thank you