Optical Communications

Optics Review

Part2

Optics Review

RAY THEORY AND APPLICATIONS

We have three rules:

1- Ray travels at speed v

$$v = \frac{c}{n}$$

where *c* is the light speed in vacuum $(3 \times 10^{8} m/s)$

and *n* is the index of refraction or (refractive index) [in vacuum *n=1* and silica glasses used in fibers has a refractive index *n=1.5*). The speed of light for silica glasses as example is $2 \times 10^{8} m/s$.

Optics Review

RAY THEORY AND APPLICATIONS

2- Rays travel in straight paths unless deflected by some changes in the medium.

3- At a plane boundary between two media, a ray is reflected at an angle θ_r equals to an angle of incidence θ_i

$$\theta_r = \theta_i$$

$$\frac{\sin\theta_t}{\sin\theta i} = \frac{n_1}{n_2}$$ → Snell's Law of refraction

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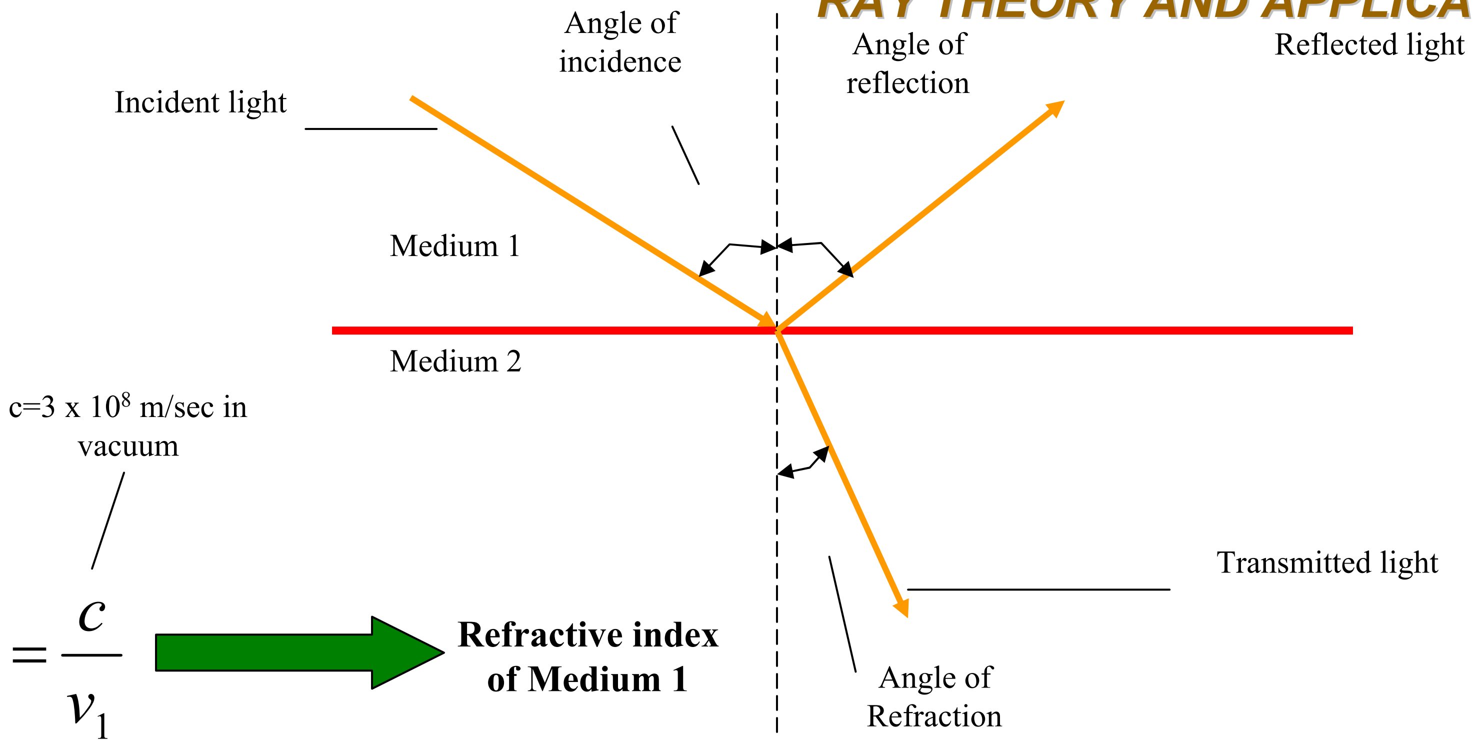
RAY THEORY AND APPLICATIONS



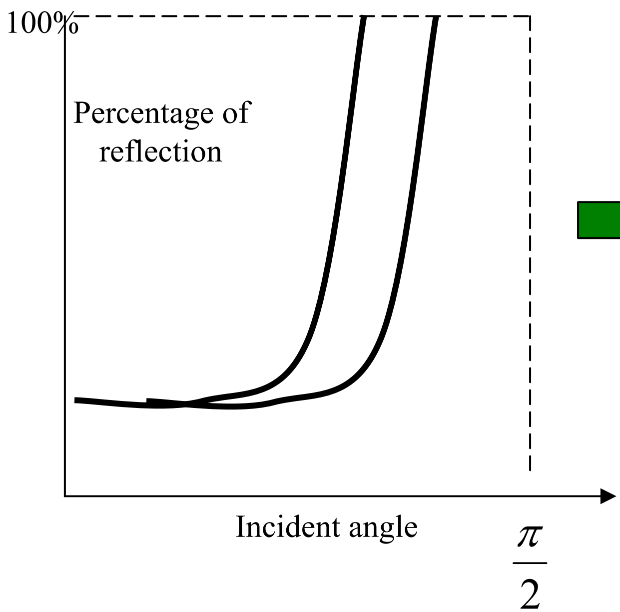
$$n_1 = \frac{c}{v_1}$$ → **Refractive index of Medium 1**

$$n_2 = \frac{c}{v_2}$$ → **Refractive index of Medium 2**

Velocity in medium two

If $n1<n2$ then $\sin\theta_t < \sin\theta_i$ which means that $\theta_t < \theta_i$

The transmitted ray is bent toward the normal when traveling from a medium having a low *n* into a medium with higher *n* .



Reflection as a function of the angle of incidence

Example 1:

Assume that the refractive index for medium 1 is n_1=1.3 and that for medium 2 it is n_2=1.5 .If a light ray is traveling in the Upper medium and impinging on the boundary surface at an angle of 45^0 to normal axis, determine the corresponding angles of reflection and refraction solution

Example 2:

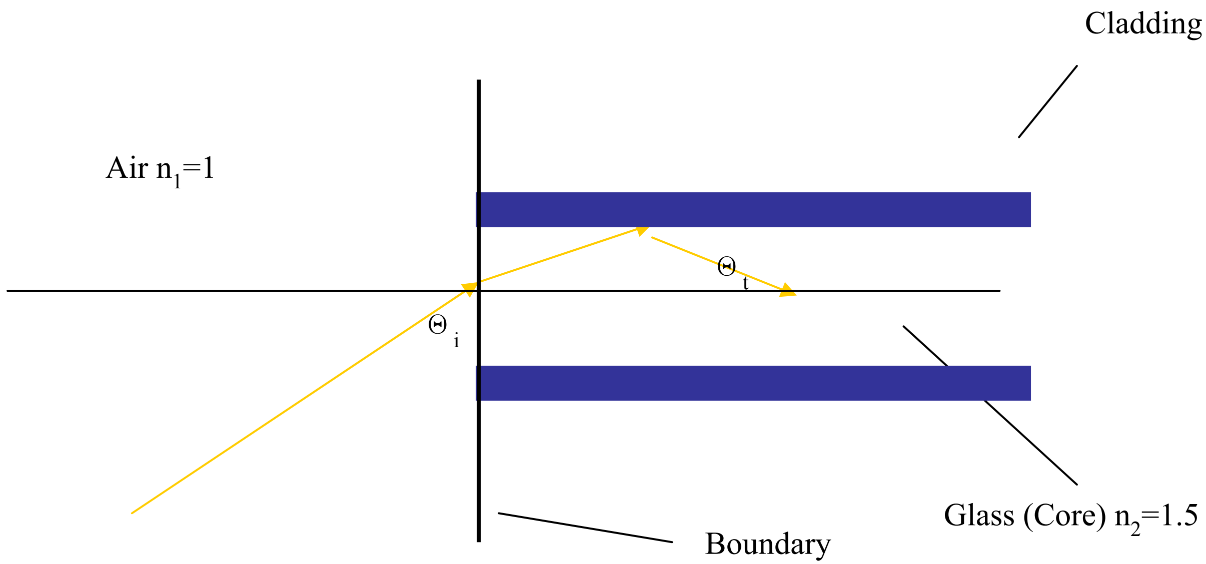
Given the two media described in example 1 and the light ray impinging from the lower on the boundary surface, at an angle of incidence equal 35^0, calculate the angle of refraction in the upper medium solution.

Optics Review

RAY THEORY AND APPLICATIONS

The transmitted ray is bent toward the normal when traveling from a medium having a low refractive index into a medium with a higher refractive index. If $n_1 > n_2$, then the ray is bent away.

($n1<n2$)

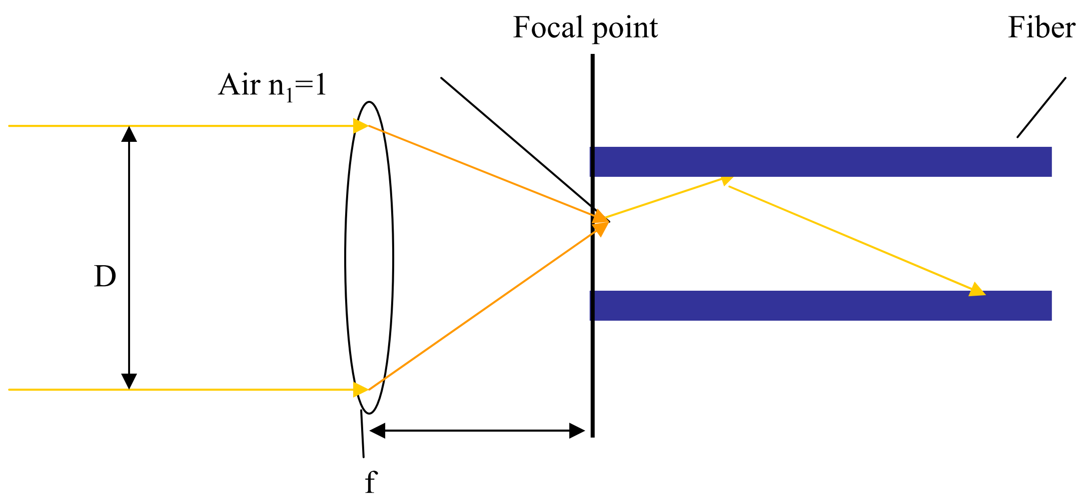


Optics Review

LENSES

Spherical lens

Fibers can be tested by making a continuity check by observing whether any light emerges from the end of the fiber using(Gas Lasers + Lens). Lens is used to focus the light onto the fiber end face. (See figure below)



D- Diameter of lens

n- Refractive index of lens

f- Focal length

Optics Review

LENSES

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (n-1)\left[\frac{R_1 + R_2}{R_1 R_2}\right]$$

R1,R2- Curvatures of spheres.
Thick of lens is being constructed by connecting the caps of two solid glass spheres.

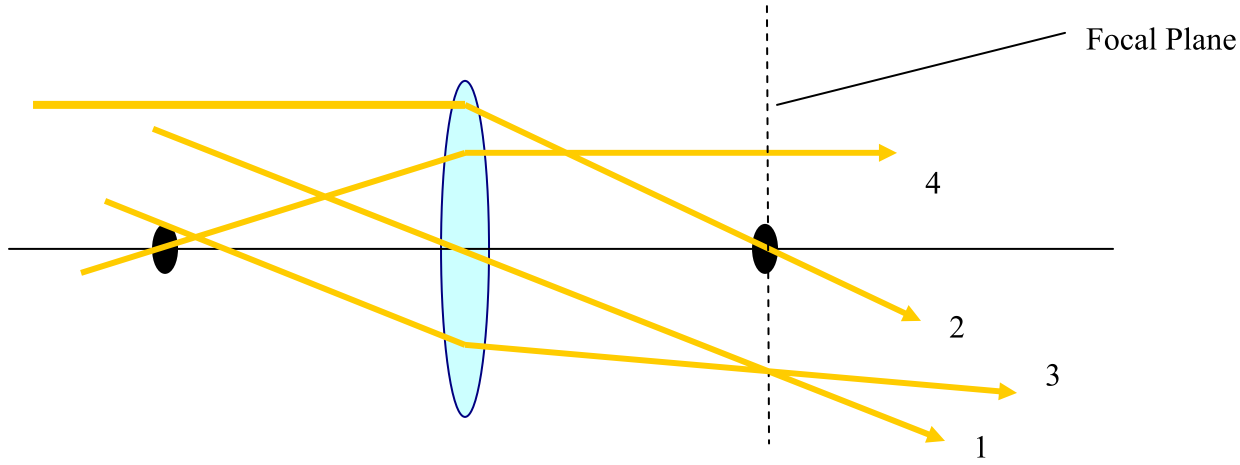
When R1=R2 =D/2 ➡

$$f = \frac{D}{4(n-1)}$$

For example, when n=1.5 the focal length f=0.5D (Small focal length requires a small lens diameter)

LENSES

Rules for tracing rays through a thin lens:

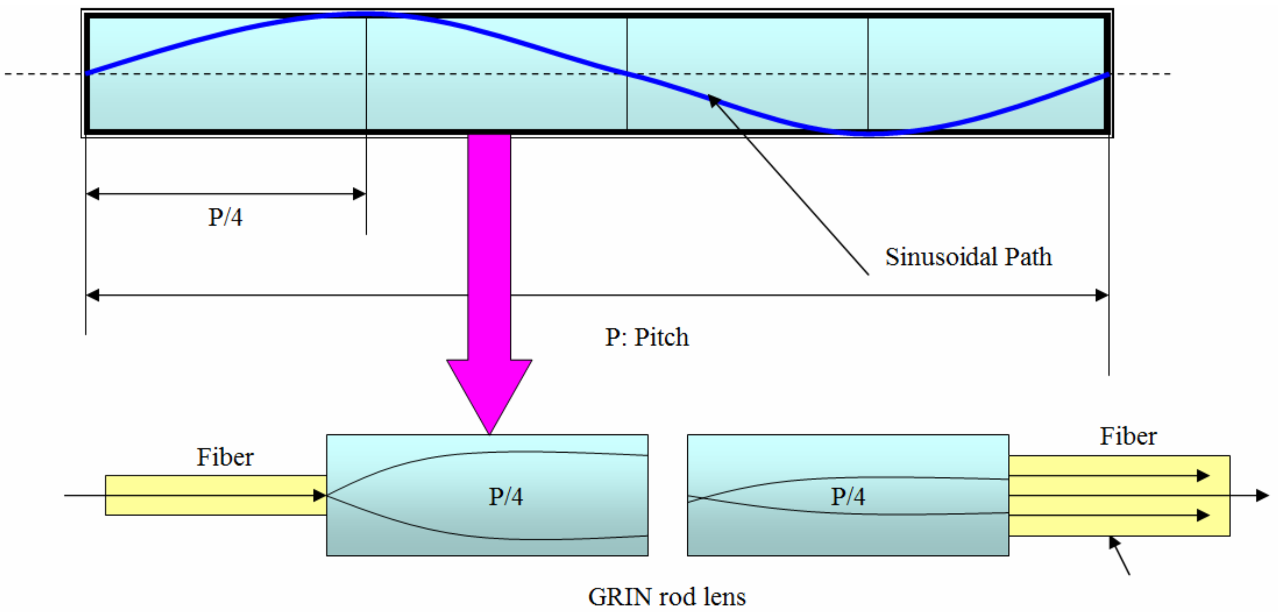


1. Rays traveling through the center of the lens are un-deviated.
2. Incident rays traveling parallel to the lens axis pass through the focal point after emerging from the lens.
3. An incident ray traveling parallel to a central ray intersects that ray in the focal plane after transmission through the lens.
4. An incident ray passing though the focal point travels parallel to the lens axis after it emerges from the lens.

Focal plane: The plane that passes through the focal point and is perpendicular to the axis of the lens

Graded-Index rod lens (GRIN) rod lens

It has a refractive index that decreases with distance from its axis. This causes light rays to travel I a sinusoidal paths.

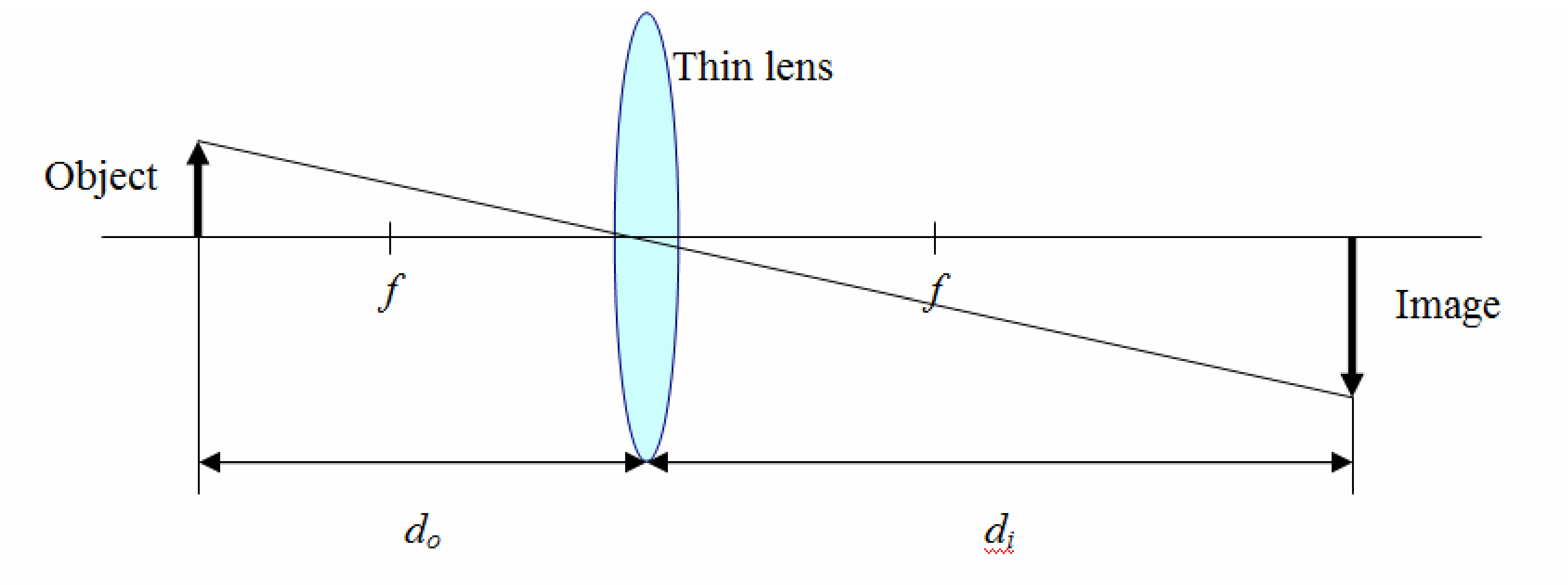


The GRIN rod lens has a solid mechanical structure with fiber. so it is easy to assemble, align and maintain.

Imaging

Magnification (M):is the ratio of the size of the image to that of the object.

$$M = \frac{d_i}{d_o}$$



Optics Review

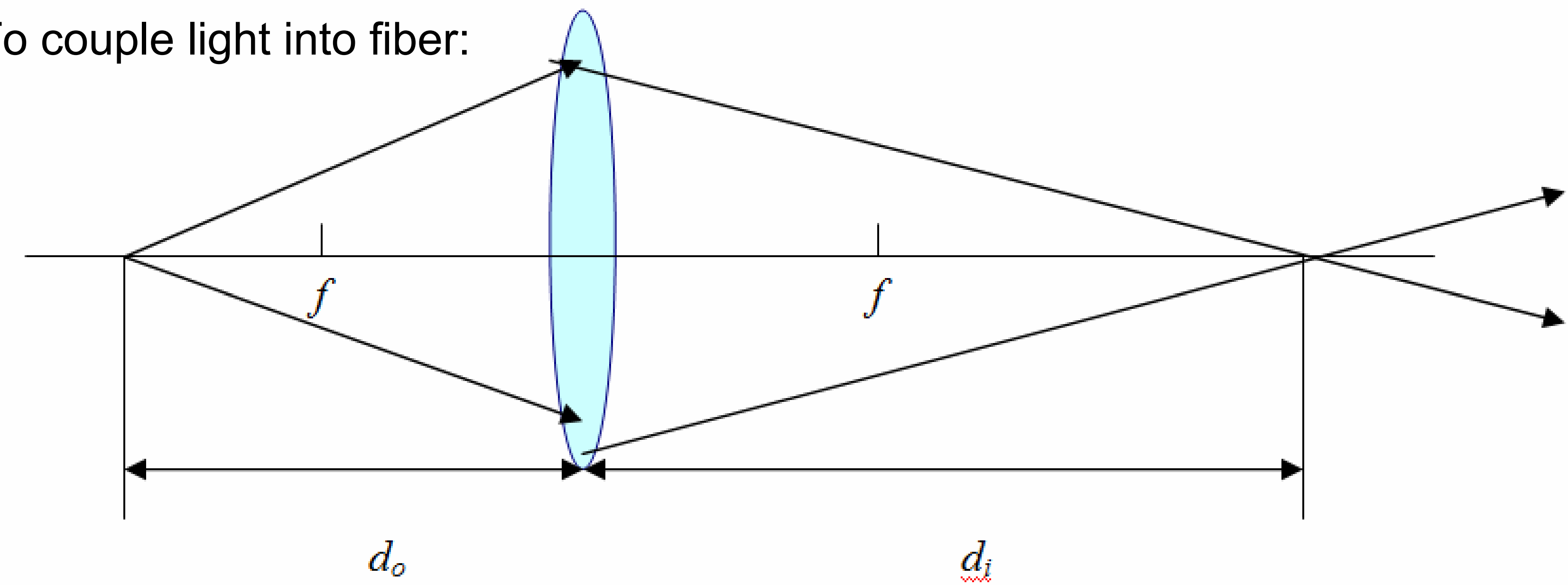
Imaging

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

or

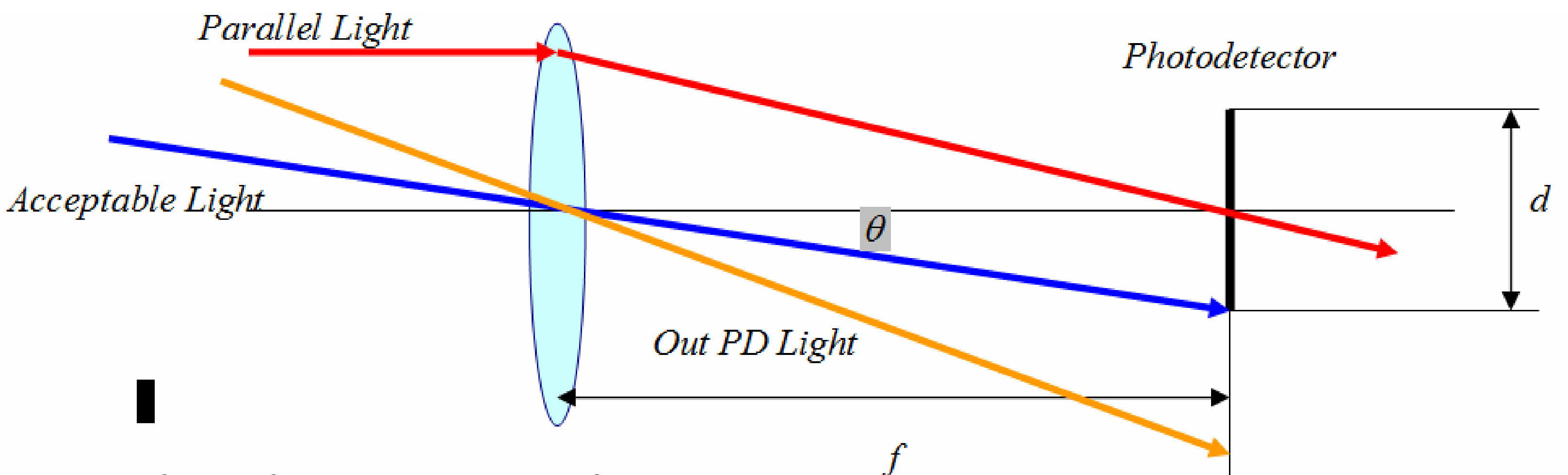
$$M = \frac{1}{\left(\frac{d_o}{f}\right) - 1}$$

To couple light into fiber:



Numerical Aperture

An important characteristic of an optic system is its ability to collect light incident over a wide range of angles.



The maximum acceptance angle

$$\tan\theta = \frac{d}{2f}$$

Imaging

The maximum acceptance angle

$$\tan\theta = \frac{d}{2f}$$

d is the diameter of the circular photo detector and f is the focal length. The photo detector will detect light within a cone having half angle θ

The numerical aperture (NA) can be defined as :

$$NA = n_0 \sin\theta$$

where θ is the maximum acceptance angle and n_0 is the refractive index of the material between the lens and the photodetector.

Example: f=10 cm , d=1 cm and n_0=1 then $\theta = 2.87$ and $NA = 0.0499$, where the full cone angle $= 2\theta = 5.74^0$

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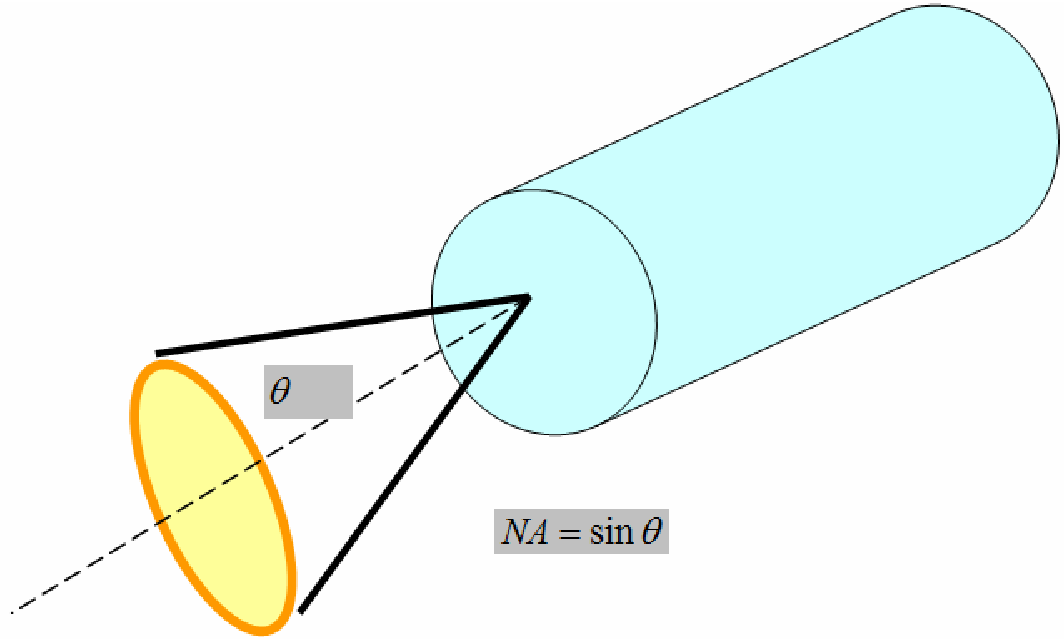


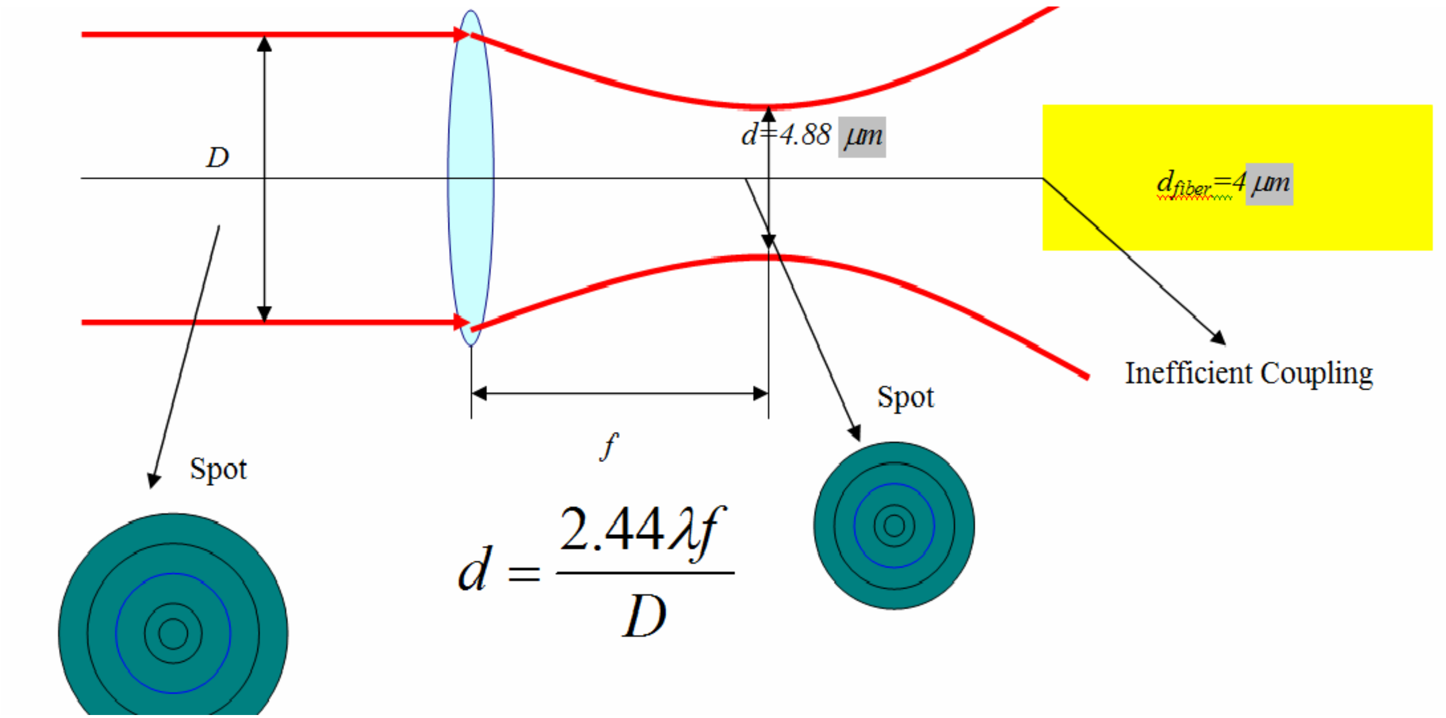
light rays incident at angles outside this cone will not propagate along the fiber but instead will attenuate rapidly.

The low NA does make coupling efficiency tend to be poor but imroves the fibers bandwidth..

Plastic fibers have high numerical aperture (0.4-0.5) to imrove coupling effiiecincy , partically offsetting the high propagation losses.

Diffraction

It is the deviation from the predictions of geometrical optics.
Transverse Plane .is the plane perpendicular to the direction of the wave travel .
Uniform beam .is one whose intensity (power) is the same at all points.



$$d = \frac{2.44\lambda f}{D}$$

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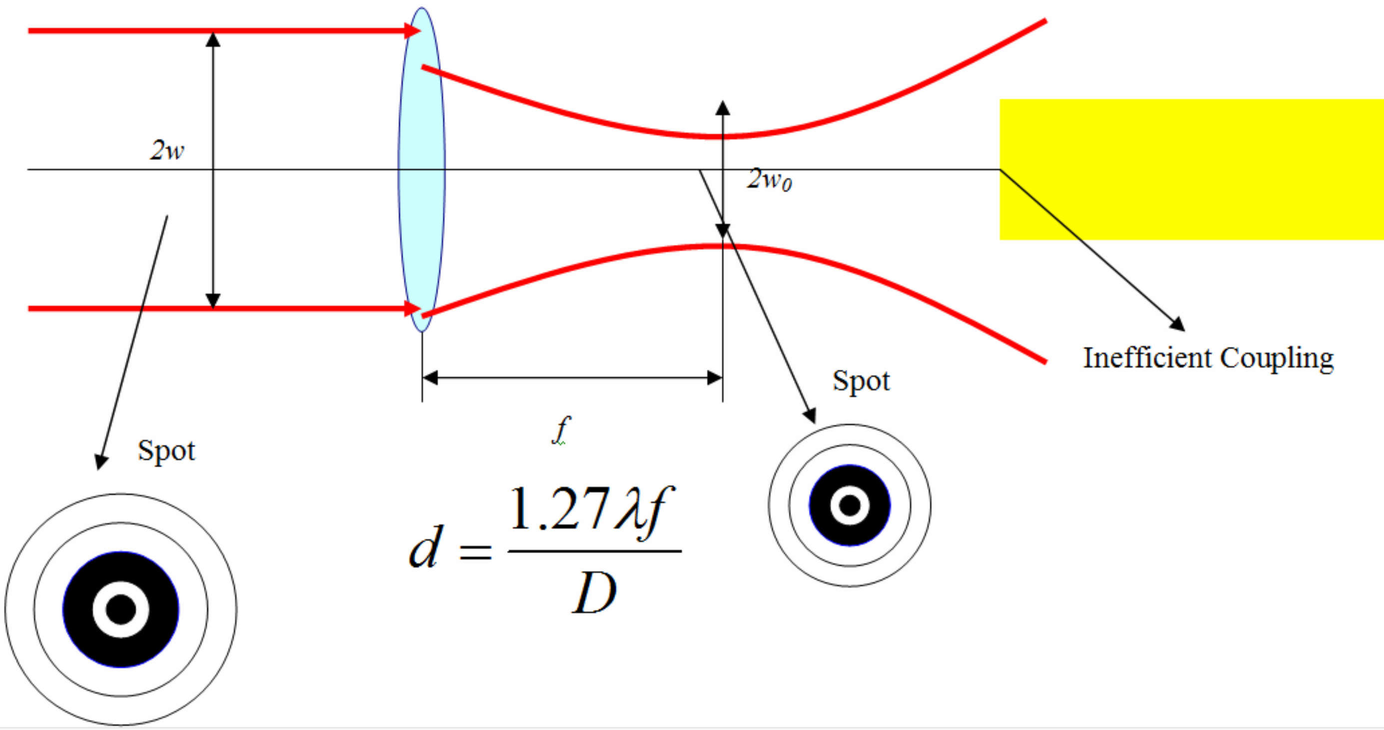
.***Nonuniform beam***:Actual light sources often produce nonuniform beams



$$d = \frac{1.27\lambda f}{D}$$

Optics Review

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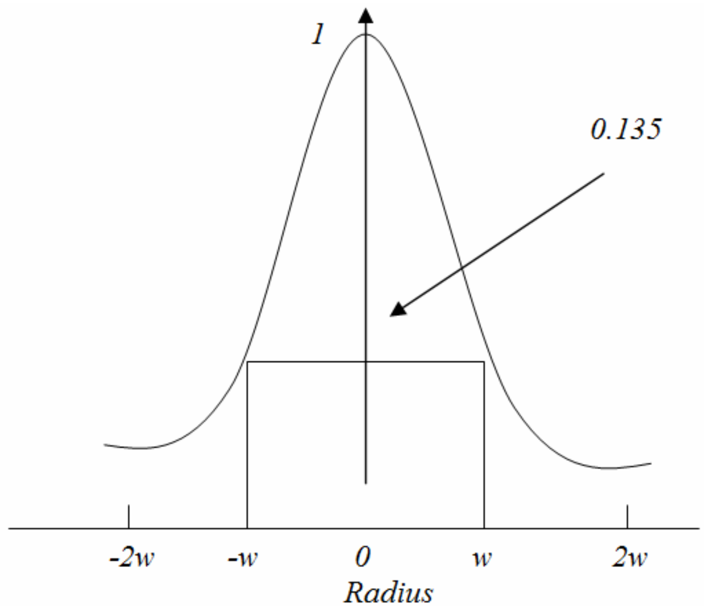
A oparticularly important transverse pattern is the Gaussian distribution. The Gaussian intensity distribution (before lens):

$$I = I_0 e^{(-2r^2)/w^2}$$

I_0 is the intensity at the center of beam ($r=0$). w is the spot size. The normalized Gaussian intensity (power) distribution is shown in figure below:

$$w_0 = \frac{\lambda f}{\pi w}$$



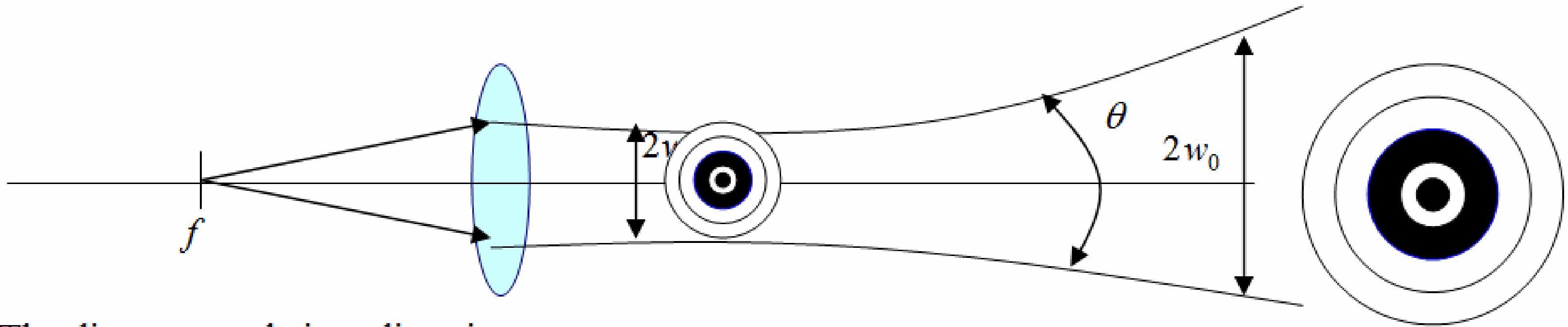
The normalized Gaussian Intensity distributaion

Optics Review

Imaging

Collimating Gaussian Beam

In case of atmospheric system, much transmitted power will be lost in this case.



The diverges angle in radians is

$$\theta = \frac{2\lambda}{\pi w}$$