Exp. No. 3
Measuring Numerical Aperture of Optical Fiber

Aim of experiment: In this experiment, we measure the numerical aperture.

Theory
Consider the geometry of Fig.(1), where a ray making an angle $\theta_i$ with the fiber axis is incident at the core center. Because of refraction at the fiber–air interface, the ray bends toward the normal. The angle $\theta_r$ of the refracted ray is given by:

$$n_0 \sin \theta_i = n_1 \sin \theta_r$$

(1)

where $n_1$ and $n_0$ are the refractive indices of the fiber core and air, respectively. The refracted ray hits the core–cladding interface and is refracted again. However, refraction is possible only for an angle of incidence $\phi$ such that $\sin \phi < n_2/n_1$. For angles larger than a critical angle $\phi_c$, defined by:

$$\sin \phi_c = n_2/n_1$$

(2)

One can use Eqs. (1) and (2) to find the maximum angle that the incident ray should make with the fiber axis to remain confined inside the core. Noting that $\theta_r = \pi/2 - \phi_c$ for such a ray and substituting it in Eq. (1), we obtain:

$$n_0 \sin \theta_i = n_1 \cos \phi_c = (n_1^2 - n_2^2)^{1/2}$$

(3)

In analogy, the numerical aperture (NA) of the fiber. It represents the light-gathering capacity of an optical fiber. For the NA can be approximated by[1]:

Fig.(1): Light confinement through total internal reflection in step-index fibers. Rays for which $\phi < \phi_c$ are refracted out of the core.
The most important parameter of a glass fiber is the numerical aperture. This value is very important to know for the design of coupling optics to get light into a fiber and it has influence on coupling losses e.g. of fiber connectors.

The numerical aperture is calculated with the index of refraction and the angle of acceptance at the face of the glass fiber. Due to the fact that the optical path is reversible the relations are valid for both, coupling of light into the fiber and radiant emitting at the fiber output. By definition the angle of acceptance is achieved if the emitted power is down at 5%[2].

**Procedure**
1. Adjust the system as shown in Fig.(2).

   ![](image.png)

   **Fig.(2)**

2. Release the locking screw G. then buckle the articulated connector (part 7) of the flat rails to defined angles.
3. Measure the output power of the fiber with an oscilloscope or with a digital voltmeter.
4. Vary the angle of the rails to find the maximum output power. At this variation, record the value angle $\Phi_1$. 

\[
NA = n_1(2\Delta)^{1/2}, \quad \Delta = \frac{(n_1 - n_2)}{n_1},
\]
5. Shift the rail to the value where the output power is dropped to 5% of the maximum value measured in previous step. This angle is $\Phi_2$.

6. Calculate the acceptance angle with following formula:

$$\Phi_a = \Phi_2 - \Phi_1$$

7. Calculate the numerical aperture by using measured acceptance angle as follows:

$$NA = n_0 \cdot \sin \Phi_a$$

Discussion
1. Comment on your results
2. Why we consider the numerical aperture is important characteristic of optical fiber?

References