Name: Siddhesh Dilip Khairnar
Roll no: 1421
PRN no:22110398
Batch: N1

Experiment No. 5

Title: Numerical Aperture and attenuation in optical fibre

Aim: To determine the Numerical Aperture and attenuation in an optical fibre

Numerical Aperture

Theoretical Background:

Acceptance angle is defined as the maximum angle that a light ray can make with the axis of the fiber and propagate along with it. It is given by

$$\theta_0 = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right) \therefore NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2} \sim n_1\sqrt{2\Delta}$$

Numerical aperture is defined as the sine of the acceptance angle.
Where, fractional refractive index is

$$\Delta = \frac{n_1 - n_2}{n_1}$$

The output cone of light is identical to the input cone, as shown in Fig. 1.

RMS intermodal dispersion is given by

$$(\Delta t)_s \sim \frac{Ln_1}{2\sqrt{3}c} \sim \frac{L(NA)^2}{4\sqrt{3}n_1 c} = \frac{\quad}{4\sqrt{3}} \cdot - \cdot \frac{\quad}{n_1} \qquad \Delta \; 1 \; L$$

$(NA)^2$

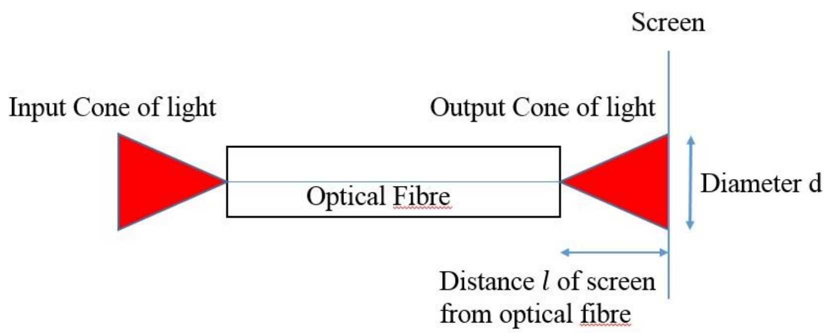

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Fig. 1 Input and output cones of light for an optical fibre

Design of the experiment:

The output cone is intercepted by a graph sheet at various distances (Fig. 2) to get circles of light (Fig. 3)

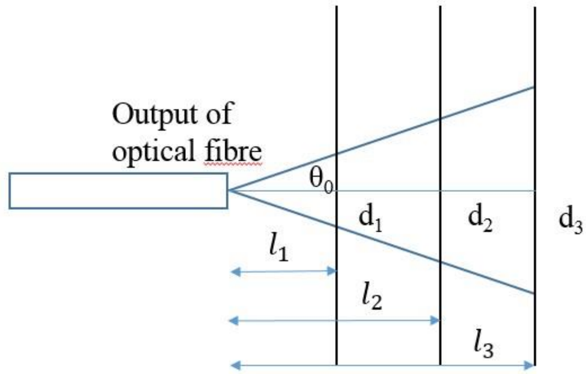

Fig. 2 The output cone of light intercepts the screen at distances l_1, l_2, l_3, etc. giving rise to circles of light with diameters d1, d2, d3, etc**.**

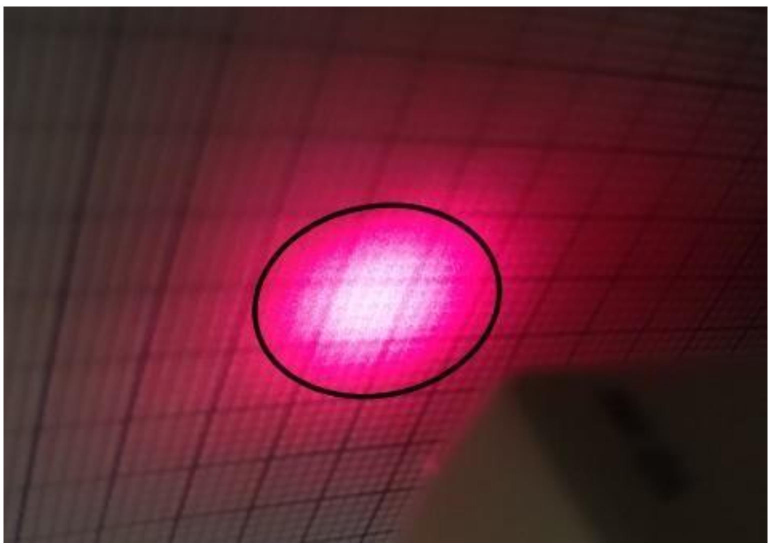

Fig. 3 A typical circular pattern of light on a graph sheet. The circle is shown schematically to define the diameter of the circular light pattern on the screen.

From Fig. 2

$$tan\theta_0 = \frac{d_{n+1} - d_n}{2(l_{n+1} - l_n)}$$

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The diameters d_n of the circles on the screen are plotted as a function of the distance l_n of the screen from the output of the optical fibre. The value of $tan\theta_0$ is then equal to half the slope. Calculate θ_0 and NA=sin θ_0. Since the cladding is air, $n_2 = 1$. Calculate n_1, Δ, $(\Delta t)_s$ and B_{max}.

Attenuation

Theoretical Background

If the input optical power launched into an optical fibre is P_i and the output power is P_o, then attenuation is defined in decibels (dB) as

$$Attenuation\ A(dB) = 10log_{10}\left(\frac{P_i}{P_o}\right)$$

Fibre loss parameter α_{dB}, which represents signal attenuation per unit length in dB, is defined as

$$\alpha_{dB}L = 10log_{10}\left(\frac{P_i}{P_o}\right)$$

Definition of dBm

When the input power is assumed to be 1mW, the units of comparison of a given power is in dBm.

$$\therefore P(dBm) = 10log_{10}\left(\frac{P(mW)}{1mW}\right) dBm$$

For example, if the output power is 100µW, then the output power is

$$10log_{10}\left(\frac{100 \times 10^{-6}}{10^{-3}}\right) = -10\ dBm$$

Design of the experiment:

An optical power meter is used to measure the attenuation in three fibres of 1m, 3m and 10m length. A red LED emitting a wavelength 6500Å is coupled to an optical fibre with a core diameter of 1mm and the cladding is air. The light output from the optical fibre is measured using the optical power meter in the units of dBm.

Plot output power in dBm as a function of the length of the fibre. The slope will give attenuation in dB/m and the intercept will give the power of the source of light in dBm.

Observation Tables

Wavelength of the light: 6500 Å

Table 1: Diameter circle of light from the output cone of light for an optical fibre for various distances of the screen from the output of the optical fibre

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distance l (mm)	diameter (mm)
20	300
30	380
40	440
50	520
60	600
70	700
80	800

Table 2: Power in dBm at the output of optical fibres of various lengths

length L (m)	Power (dBm)
1	-37.90
3	-41.82
10	-44.79

Calculations:

Numerical Aperture:

Plot diameter d versus distance l in Excel. Add a linear trend line (y=mx+c) and display the equation.

$tan\theta_0 = \mathrm{m}/2 =$ 4.10715

Acceptance angle $\theta_0 = tan^{-1}(m/2)$ = 76.32 deg

Numerical Aperture $NA = sin(\theta_0)$ = 0.796676491

$NA = \sqrt{n_1^2 - n_2^2}, \therefore NA^2 = n_1{}^2 - n_2{}^2$

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$$n_{12} = NA_2 + n_{22}$$

$$\therefore n_1 = \sqrt{NA^2 + n_2^2}$$

= 1.278551

Fractional refractive index

$$\Delta = \frac{n_1 - n_2}{n_1}$$

= 0.217865

Intermodal dispersion

$$(\Delta t)_s = \frac{1}{4\sqrt{3}} \frac{L}{c} \frac{(NA)^2}{n_1}.$$

= 2.38838E-08

$$B_{max} = 0.2/(\Delta t)_s \ bits/sec$$

= 8373866.331
=8.37 Mbps

for optical fibre length L = 100m.

Attenuation
Plot Power(dBm) versus length(m) of the optical fibre in Excel. Add a linear (y=mx+c) trend line and display the equation.

Fibre loss parameter $\alpha_{dB} = -m$ in units of dB/m. = 0.6764

Attenuation for an optical fibre of length L (= 100meters) is $A(dB)$ =$(\alpha_{dB} \times 100\ )dB$

= 67.64

The intercept "c" is the power of the source of light P_i in dBm . Therefore, power of the source (or input power P_i) in mW is

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$$P_i(mW) = 10\hat{}((P_i(dBm)/10)$$

= 0.000146319

Attenuation $A(dB)$ after traveling a distance of L is

$$A(dB) = 10log_{10}\,(\text{Pi}/\ \text{P0})$$

Therefore, output power

$$P_0 = P_i 10\hat{}(\text{-A}/10)$$

= 2.51942E-11

Results:

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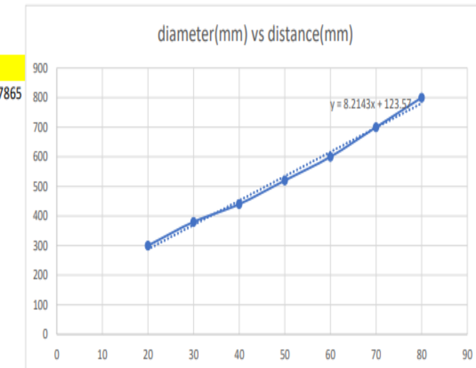
distance(mm)	diameter(mm)
20	300
30	380
40	440
50	520
60	600
70	700
80	800

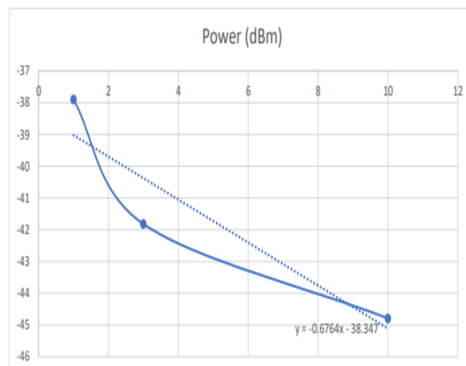
tan θ0	θ0	NA	n2	n1	Δ
4.10715	76.32	0.796676491	1	1.278551	0.217865

(Δt)s	NA^2/n1	L/C	Bmax
2.38838E-08	0.496416	3.33333E-07	8373866.331



length L (m)	Power (dBm)
1	-37.9
3	-41.82
10	-44.79

αdB	A(dB)	Pi(mW)	P0
0.6764	67.64	0.000146319	2.51942E-11



Conclusion: We determined Numerical aperture and attenuation in optical fibre.