Study of Mode Characteristics of Glass Optical Fibers

LABORATORY MANUAL: TESTER MCS-04

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1. Definition and Computation of Numerical Aperture

Numerical Aperure of an optical fiber is the measure of its Acceptance Angle.

Acceptance Angle is defined as the maximum angle at which the optical fiber accepts and transmits light through its core.

Numerical Aperture (NA) is also defined by the equation given below:

$$NA = n_0 \text{Sin } \theta_C$$

where n_o = 1 (refractive index of air), θ_c is half the Acceptance Angle of the fiber.

Numerical Aperture (NA) is also defined by the refractive indices of the optical fiber as given below:

$$NA = (n^2_{core} - n^2_{cladding})^{1/2}$$

where n_{core} and $n_{cladding}$ are the refractive indices of the fiber core and the fiber cladding

Qualitatively, NA is a measure of the light gathering ability of a fiber.

A number of optical parameters of the optical fiber are dependent on NA.

2. Definition and Computation of V Number & N

The normalized frequency, V of a fiber (also called the V number or the cut-off frequency) is given by the equation:

$$V=2\Pi a/\lambda\ (NA)$$

where a is the core radius, λ is the wavelength of light, NA is the numerical aperture and n_{core} & $n_{cladding}$ are the refractive indices of the fiber core and fiber cladding respectively

V number is also related to the number of guided modes, N, in a fiber.

For a step index fiber $N = V^2/2$.

For a graded index fiber (with a parabolic refractive index core profile), $N = V^2/4$.

If V is less than 2.405 for a given wavelength, the fiber is single mode.

If V is greater than 2.405 for a given wavelength, the fiber is multimode.

3. Specifications of 9/125 Single Mode SI Glass Fiber

Fiber Type	Glass Single Mode Step Index (9/125)
Numerical Aperture	0.11
Core Diameter	8.3 microns
Cladding Diameter	125+/- 1 microns
Secondary Coating	250 microns
Attenuation @ 1310 nm	0.34 db per Km
Attenuation @ 1550 nm	0.20 db per Km
Effective Group Refractive Index	1.4675 @ 1310 nm 1.4681 @ 1550 nm
Cut- off wavelength	1260 nm
Mode Field Diameter @ 1310 nm	9.2 +/- 0.4 microns
Mode Field Diameter @ 1550 nm	10.4 +/- 0.6 microns
Refractive Index Difference	0.36%

4. Specifications of 50/125 Multimode GI Glass Fiber

Fiber Type	Glass Multi Mode Graded Index (50/125)
Operating Wavelength	750-1450 nm
Numerical Aperture	0.20+/- 0.015
Core Diameter	50 +/- 2.5 microns
Cladding Diameter	125+/- 1 microns
Secondary Coating	250 microns
Bandwidth @ 850nm	Greater than 500 MHz-Km
Bandwidth @ 1300 nm	Greater than 1000 MHz-Km
Attenuation @ 850 nm	Better than 2.8 db per Km
Attenuation @ 1300 nm	Better than 0.9 db per Km
Effective Group	1.480 @ 850nm
Refractive Index	1.479 @ 1300nm

5. Specifications of 62.5/125 Multimode GI Glass Fiber

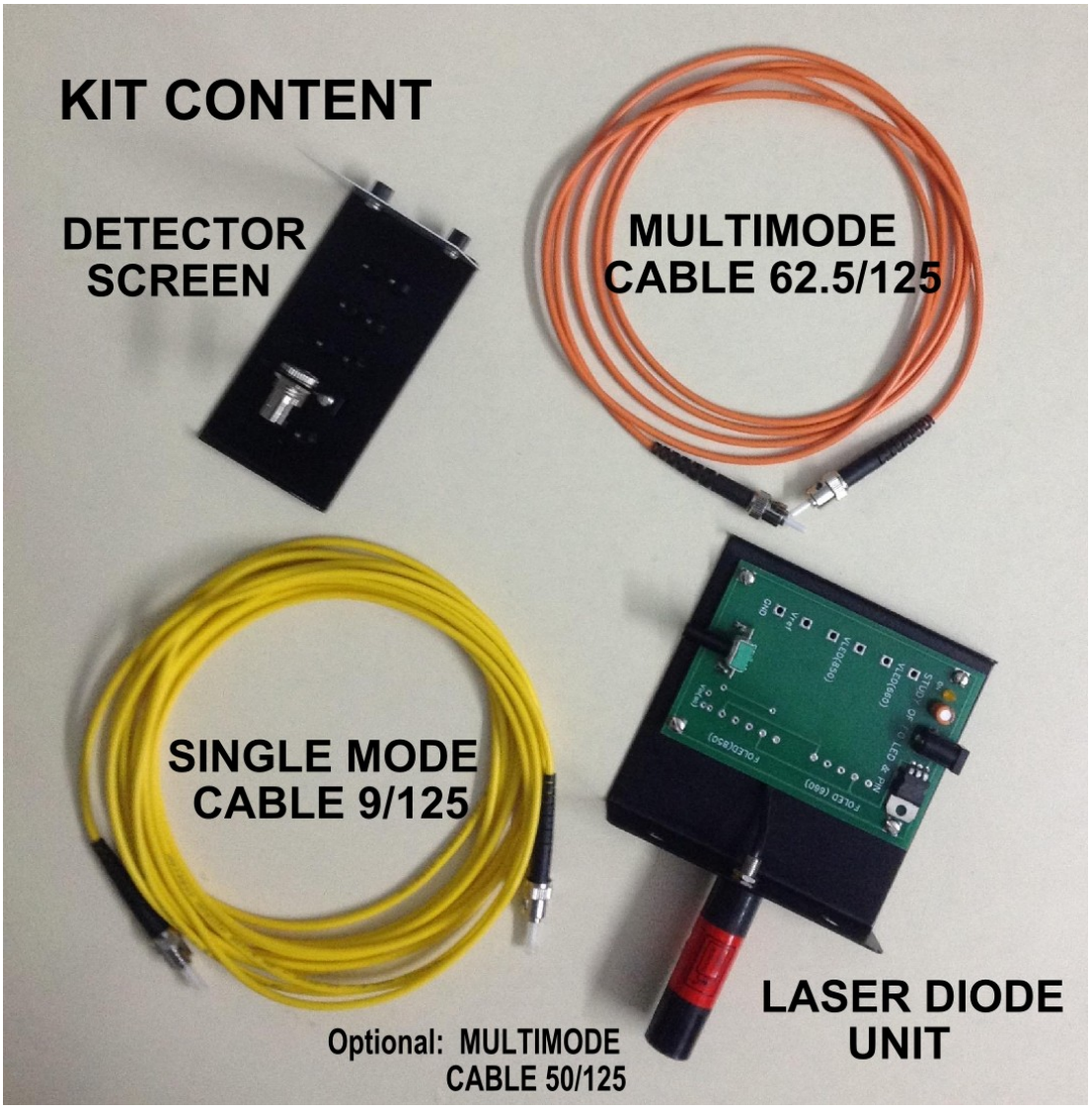
Fiber Type	Glass Multi Mode Graded Index (62.5/125)
Operating Wavelength	800 - 1350 nm
Numerical Aperture	0.275 +/- 0.015
Core Diameter	62.5 +/- 2.5 microns
Cladding Diameter	125 +/- 1 microns
Secondary Coating	250 microns
Bandwidth @ 850nm	Greater than 200 MHz-Km
Bandwidth @ 1300 nm	Greater than 800 MHz-Km
Attenuation @ 850 nm	Better than 3.2 db per Km
Attenuation @ 1300 nm	Better than 1.0
Effective Group Refractive Index	1.496 @ 850nm 1.491 @ 1300nm

6. Contents of Tester MCS04

6.1 Laser Diode Unit: This comprises a laser diode operating at 650nm with a peak output power of 3 mw. Optical power from the laser is coupled to the fiber through the ceramic 2.5 mm ferrule. The ferrule is the precision cylindrical ceramic part at the tip of the cable. Optical power coupled into the fiber may be adjusted by positioning the ferrule suitably, back or forth. Please note that cable connector fits into the notch provided on the Laser Diode Unit, when the ferrule is fully inserted. Rotating the ferrule will result in variation of the pattern observed on the display screen.

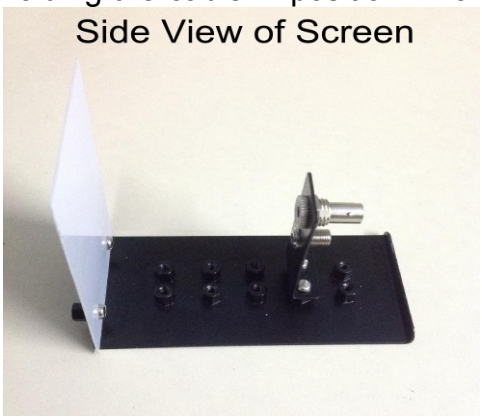
The output power of the laser is settable through the potentiometer provided. One needs to set the laser output to the desired intensity. As the coupled power into the 9/125 single mode fiber will be very small, the lighting in the room may have to be dimmed, to observe the patterns with clarity.

An external 9 Vdc/500 mA power supply is required.

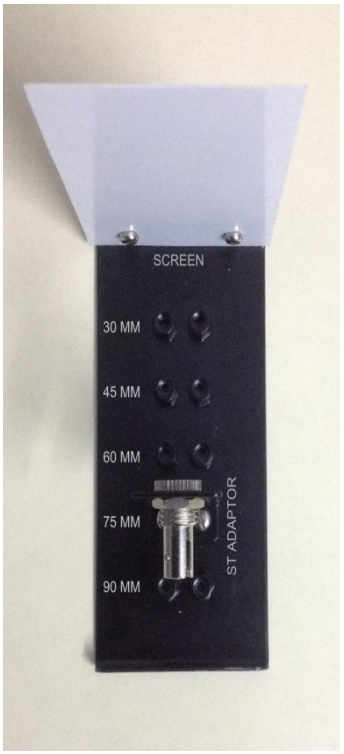


6.2 Detector Screen: This comprises a fixed a white screen, 54 mm wide and a cable holder on a solid metal frame. The position of the cable holder is settable at fixed distances of 30, 45, 60, 75 and 90 mm from the screen. Two M3 screws facilitate mounting of the cable holder on the frame. The actual distance between the cable end and screen needs to be measured accurately.

The cable holder has an ST adaptor that provides for holding the cable in position. Provision is also made for an SMA cable adaptor, in case one desires to study PMMA cables with SMA connectors too.



Diameter of light spots on the scale may be measured directly employing a suitable scale. Alternately, the spot diameter may be also be computed by capturing the image on a digital camera. The width of the screen (54 mm) or any other marking on the screen, also captured on the digital image, will serve as the reference distance in computing the actual spot diameter



6.3 One ST-ST 9/125 single mode step-index glass fiber patch cord.

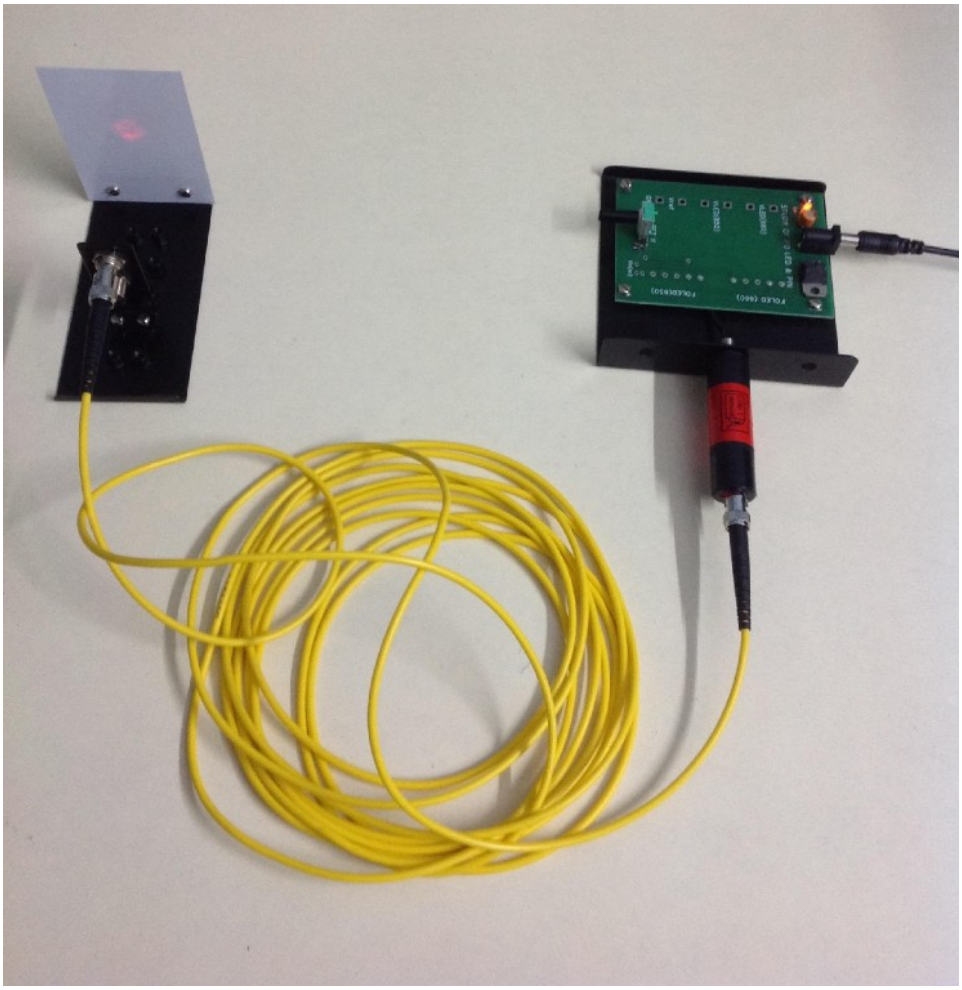
6.4 One ST-ST 62.5/125 multimode graded-index glass fiber patch cord.

6.5 One ST-ST 50/125 multimode graded-index glass fiber patch cord (optional)

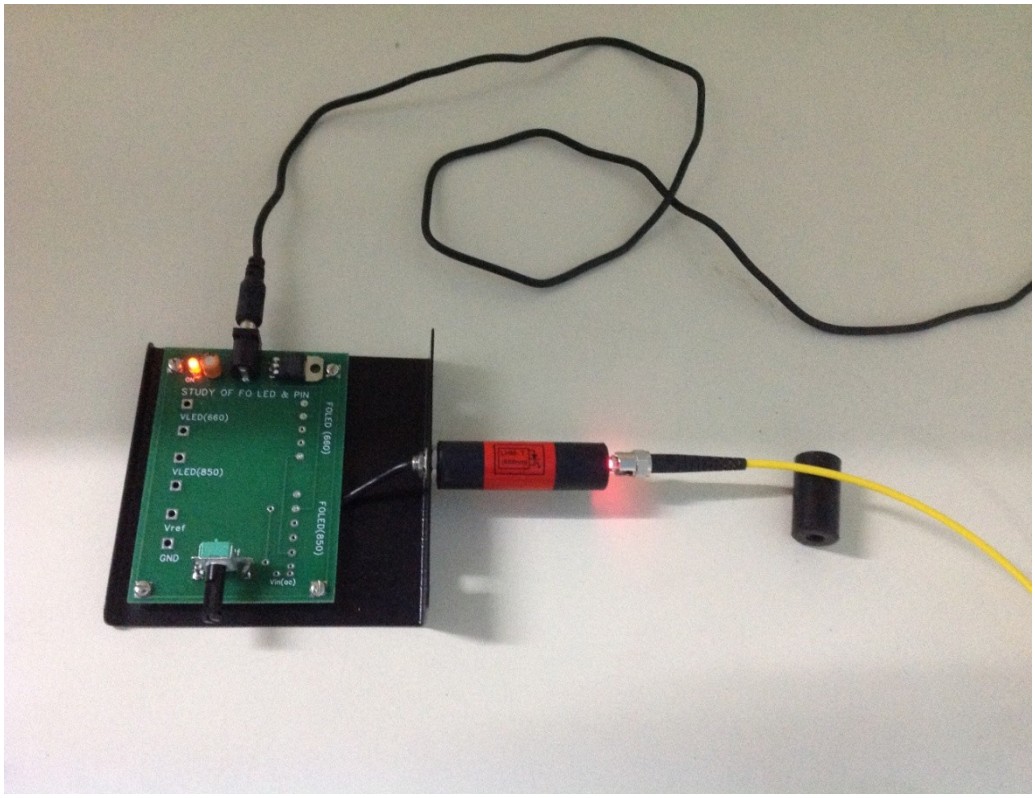
7. Full Set-up to Study Single Mode Fiber Characteristics

The complete experimental set-up to study the mode characteristics of a single mode glass fiber is shown below and is self explanatory. The single mode fiber is connected to the laser diode unit and the detector screen. Laser intensity is adjusted by setting the potentiometer. Power coupled into the fiber is set by adjusting the depth of the ferrule in the laser unit. Slight tilt of the ferule may also be required for some cables

The pattern on the screen may be varied by gently distorting the cable in the mid-section, to change path length of the light propagating through the core. This has to be done carefully, without disturbing the power coupling. The spot on the screen will be more distinct if the lights are dimmed in the laboratory.

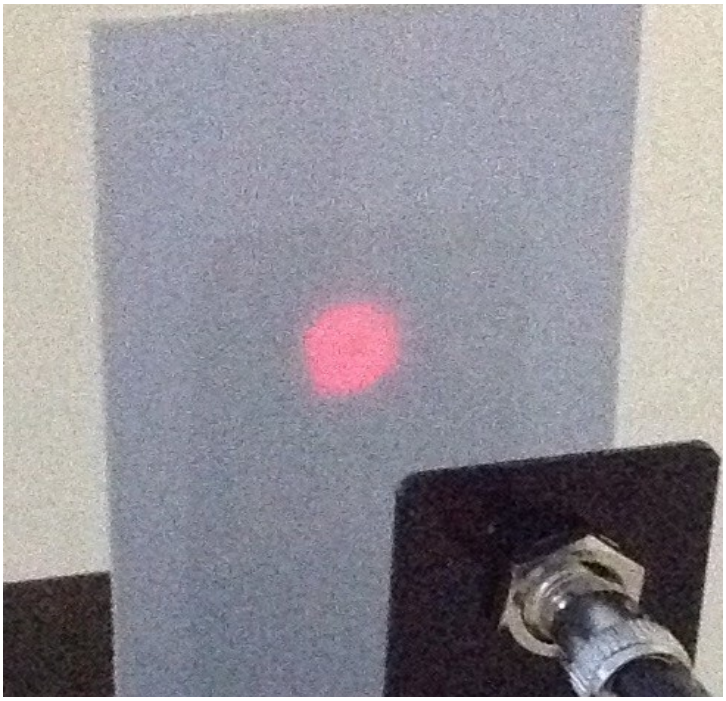


8. Close-up of Laser Diode Unit

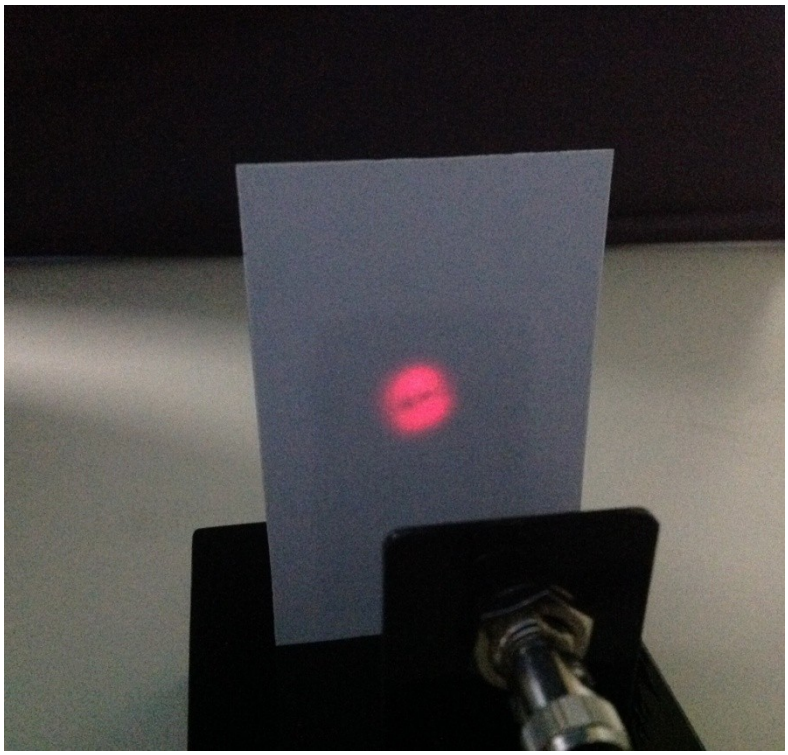


9. Close-up of Detector Screen

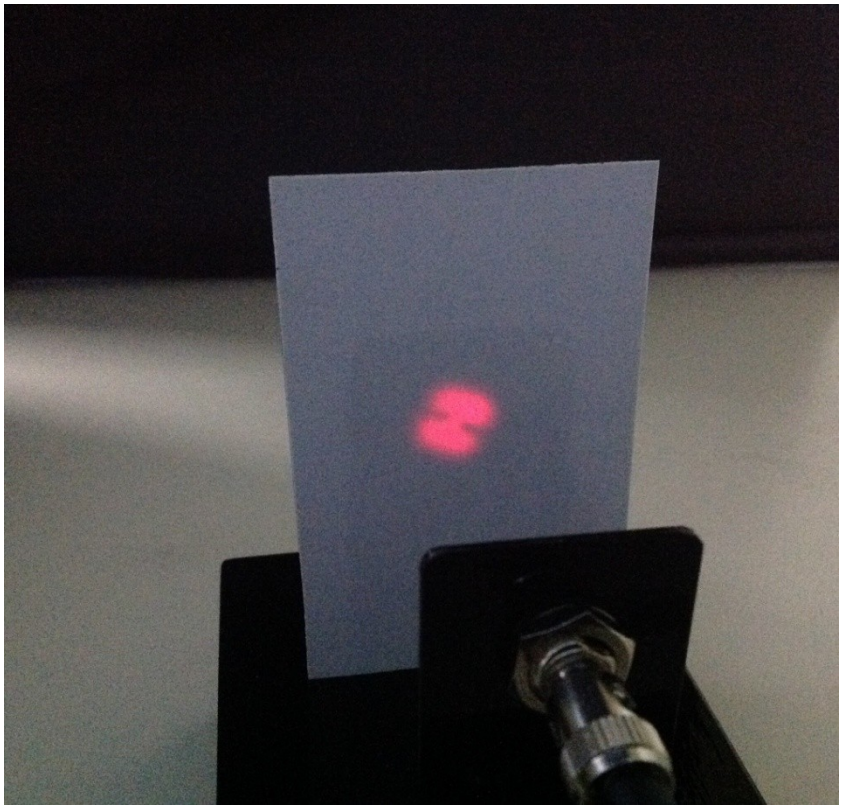
10. LP01 Intensity Pattern Observed on the Screen



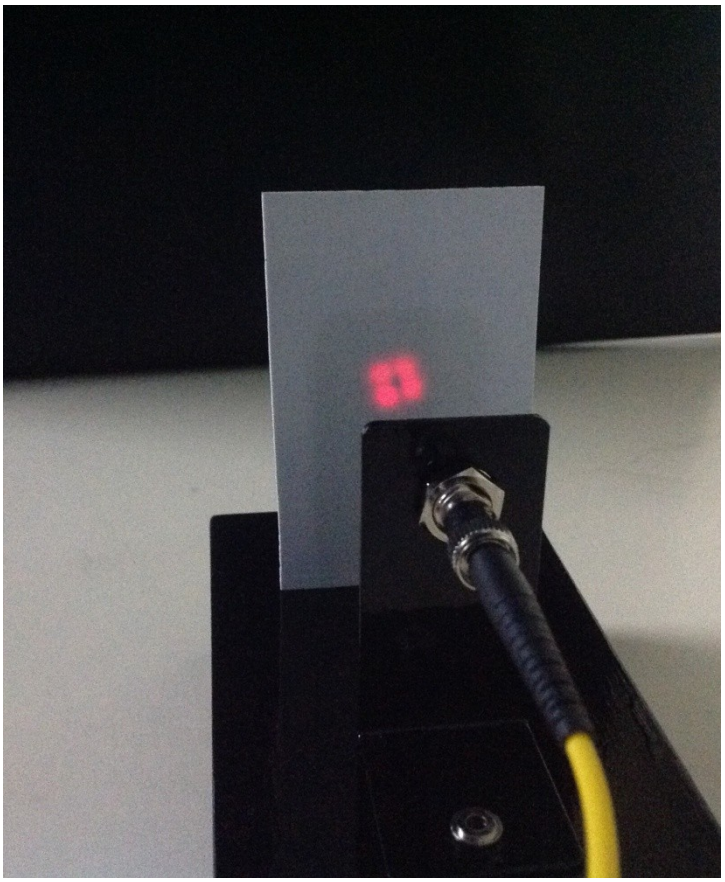
11. LP11 Intensity Pattern Observed on the Screen



12. LP11 Intensity Pattern Observed on the Screen



13. LP22 Intensity Pattern Observed on the Screen



14. NA Computation from Screen Shot of LP01 Pattern

Numerical Aperture of the 9/125 single mode step index fiber is computed using the screen shot captured during the study of the pattern. The method is described below:

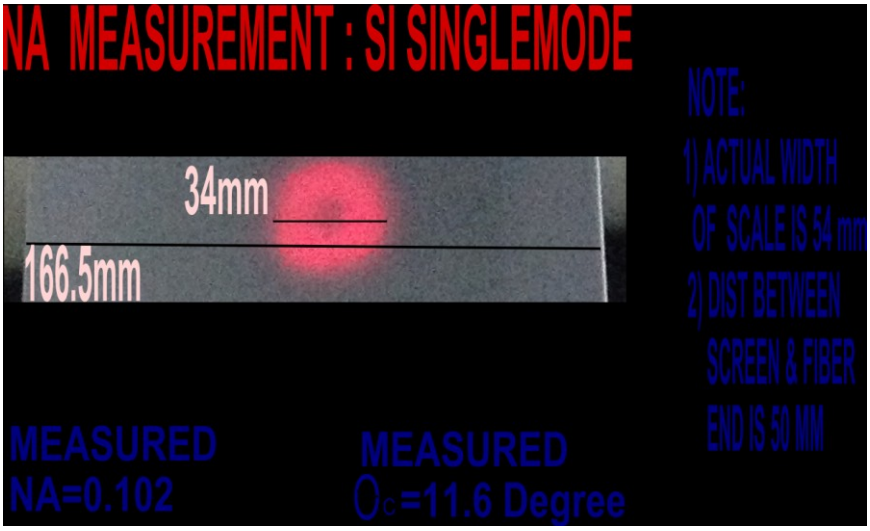
Step1 Open the screen image using a suitable software (we used Inkscape) to measure the spot diameter in relation to the screen width. The actual screen width is 54mm. In the case shown below, the spot diameter is (34X54)/166.5= 11.0 mm
The spot radius is 5.5 mm.

Step2: The spacing between the fiber end and the screen is fixed at 50mm.

Acceptance angle θ_c is given by 2 $\tan^{-1}(5.5/50)$ = 12.6 degrees

Step3: NA is given by Sin $\theta_c/2$ = 0.11. This matches the manufacturer's data.

Step4: V, N and other parameters of the optical fiber cable may be calculated from using the manufacturer's data and the NA obtained above. It may be noted that V is greater than 2.405 and hence at 650nm this fiber is a multimode fiber.

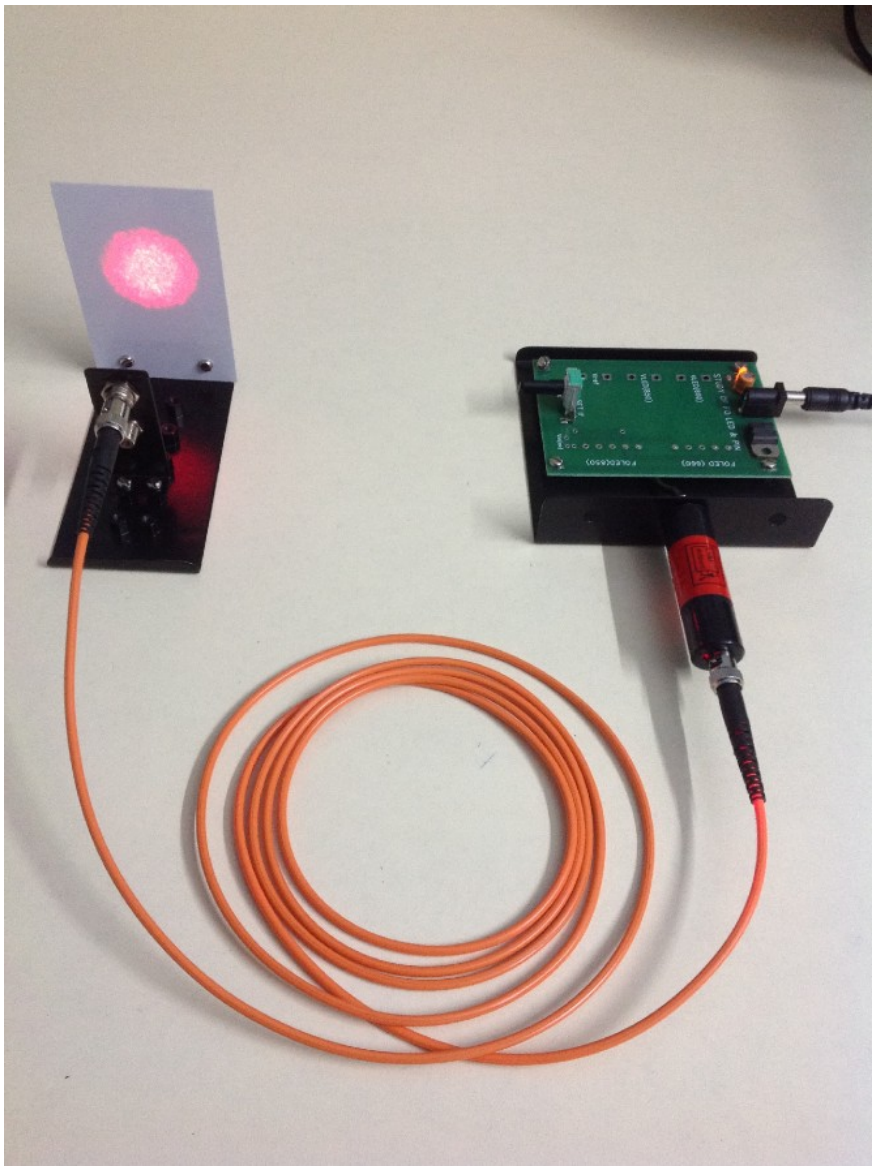


Note: This example refers to a screen-fiber end spacing of 50 mm

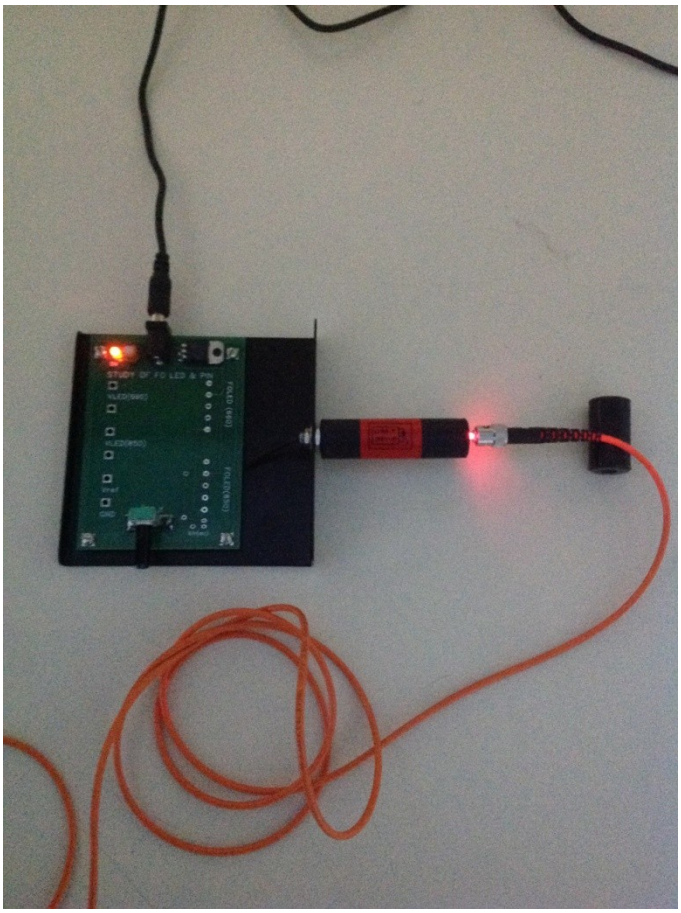
15. Full Set-up to Study Multimode GI Fiber Characteristics

The complete experimental set-up to study the mode characteristics of a multimode graded index glass fiber is shown below and is self explanatory. The multimode graded index fiber is connected to the laser diode unit and the detector screen. Laser intensity is adjusted by setting the potentiometer. Power coupled into the fiber is set by adjusting the depth of the ferrule in the laser unit. Slight tilt of the ferule may also be required for some cables

The pattern on the screen may be varied by gently distorting the cable in the mid-section, to change path length of the light propagating through the core. This has to be done carefully, without disturbing the power coupling. The spot on the screen will be more distinct if the lights are dimmed in the laboratory.

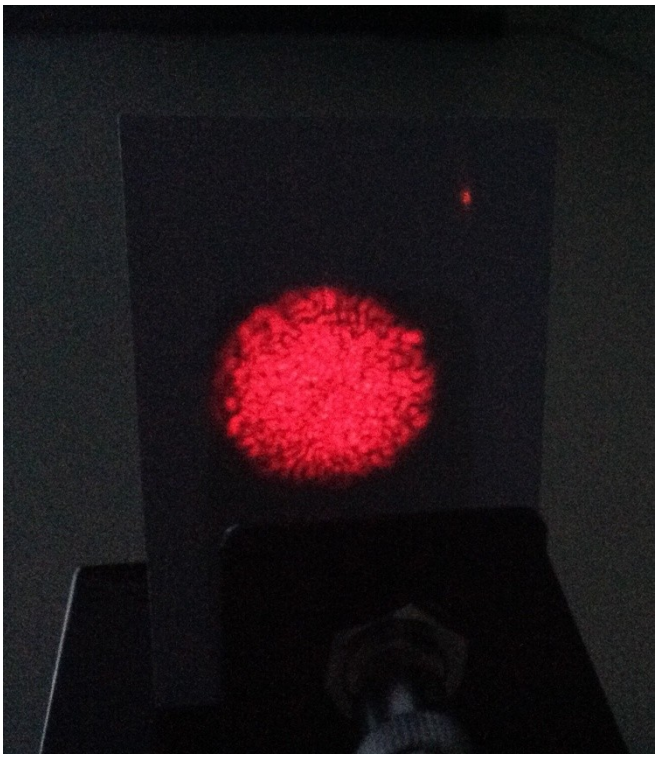


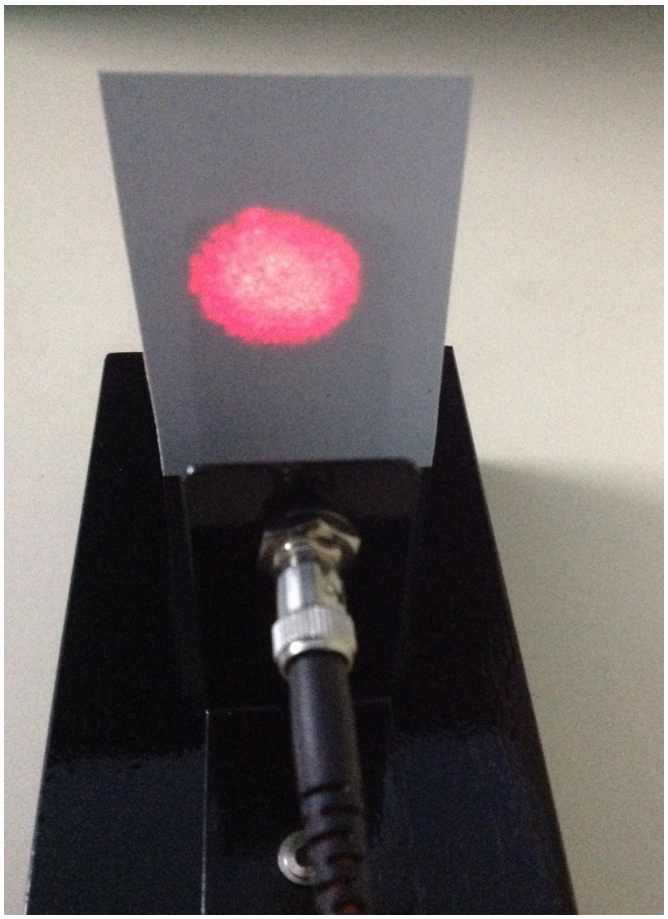
16. Close-up of Laser Diode Unit



17. Close-up of Detector Screen Diode Unit

18. Intensity Patterns Observed on the Screen





19. NA Computation from Screen Shot of Multimode Fiber Spot

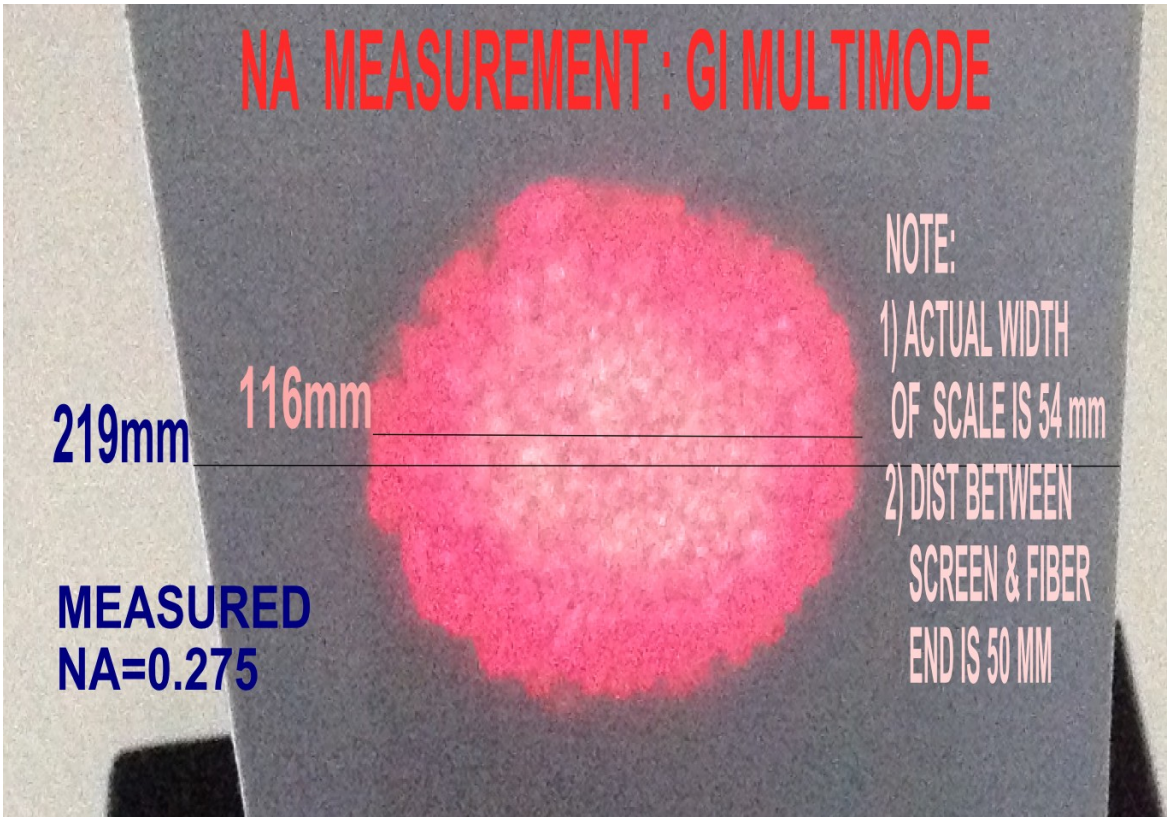
Numerical Aperture of the 62.5 /125 multimode graded index fiber is computed using the screen shot captured during the study of the pattern. The method is described below:

Step1 Open the screen image using a suitable software (we used Inkscape) to measure the spot diameter in relation to the screen width. The actual screen width is 54mm. In the case shown below, the spot diameter is (116X54)/219= 28.6 mm
The spot radius is 14.3 mm

Step2: The spacing between the fiber end and the screen is fixed at 50mm.
Acceptance angle θ_c is given by 2 $\tan^{-1}(14.3/50)$ = 32 degrees

Step3: NA is given by Sin $\theta_c/2$ = 0.275. This matches the manufacturer's data.

Step4: V, N and other parameters of the optical fiber cable may be calculated from using the manufacturer's data and the NA obtained above.



Note: This example refers to a measurement done with 50 mm spacing between screen and the fiber tip