Module 13 : Measurements on Fiber Optic Systems

Lecture : Measurements on Fiber Optic Systems

Objectives

In this lecture you will learn the following

- Measurements on Fiber Optic Systems
- Attenuation (Loss)
- Dispersion
- Cutt-Off Wavelength
- Laser wavelength and Spectral width
- Data Quality

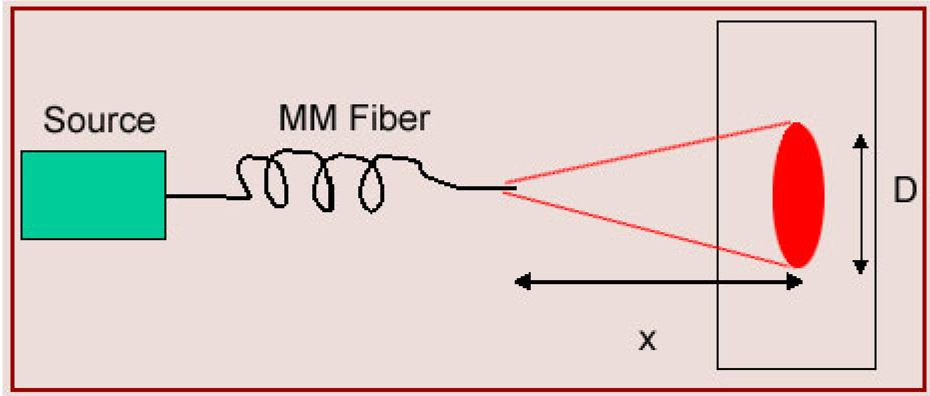
Measurements on Fiber Optic Systems

- A variety of measurements are to be carried out on optical fibers and the components connected to the optical fiber. Some important measurements are given in the following.

Numerical Aperture (NA)

- The numerical aperture (NA) is generally measured for a multi-mode optical fiber. Since the NA is related to the acceptance angle of the optical fiber, the NA can be obtained from the angle of the emerging light cone from the fiber.

- A fiber is excited with a source like LED or a visible laser. The light emerging from the other end of the fiber is projected on a screen as shown in Fig.



- The spot size and the distance of the spot from the tip of the fiber is measured go get the NA of the fiber.

- From the Fig we get,

$$\theta_{\max} = \tan^{-1}(D/2x)$$

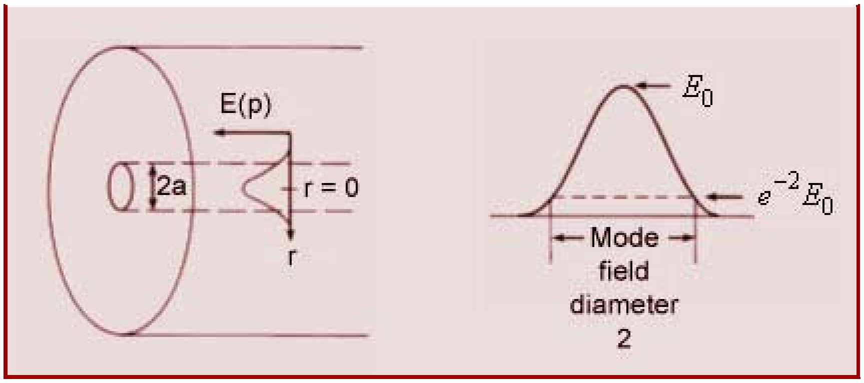
$$NA = \sin(\theta_{\max}) = \frac{D}{\sqrt{4x^2 + D^2}}$$

- Generally, near the input end of the optical fiber a large number of non-propagating modes are excited, which eventually die down along the length of the fiber. Very close to the input end of the fiber, the NA is higher compared to the true NA (some time called the saturated NA of the fiber).

- To get a correct estimate of the NA of the fiber, the length of the fiber should be sufficiently long. Alternatively, the fiber can be passed through a mode scrambler so that the non-propagating modes quickly radiate their power, leaving only propagating modes inside the fiber.

Mode Field Diameter (MFD)

- The mode field diameter is generally defined for the Single Mode (SM) optical fiber. The MFD gives the effective width of the field distribution inside the optical fiber.



- The measurement of MFD can be done in two ways :

1) By measuring far field distribution of the light emerging from the fiber.

2) Probing the optical field near the output tip of the fiber.

Attenuation (Loss)

- The attenuation of the optical fiber is one of the very important parameter as it has direct bearing on the length of the communication link. An accurate estimate of this parameter is very essential.

- The optical loss has two components:

1) Intrinsic loss in the fiber

2) Loss due to the environment through which the fiber is laid.

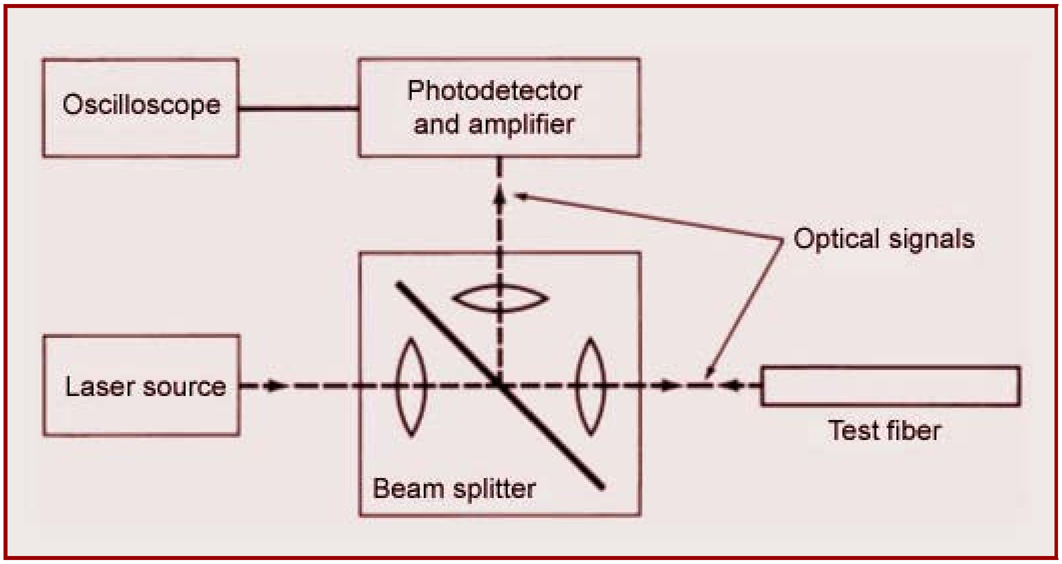
- The estimate of the intrinsic loss is obtained by the manufacturer. However, the second estimate has to be obtained by the user after the fiber is commissioned.

- The second estimate takes into account the losses due to micro-bending, radiation etc. Whereas the first estimate takes into account the intrinsic absorption of the fiber and the Rayleigh scattering loss.

- It should be noted that the loss measurement has to be carried out at the wavelength of operation.

- The most commonly used instrument for the loss measurement is the **Optical Time Domain Reflectometer (OTDR).**

- The basic set up of an OTDR is shown in Fig.



- The OTDR is essentially an **optical radar.** The laser source launches a narrow pulse of light inside the optical fiber and measures its reflection.

- The optical pulse when travels inside the fiber, gets Rayleigh scattred. The backward scattered light is collected by the photo-detector and displayed as a function of time.

- Now the intensity of the Rayleigh scattered light depends upon (1) Intensity of the light propagating at that location (2) the variation in the refractive index at that location.

- For a continuous fiber, the refractive index perturbation is same all along the fiber. The optical intensity however decreases along the fiber due to loss. The intensity of the back scattered light also then decreases in the same proportion. The back scattered travels along the fiber and gets further attenuated.

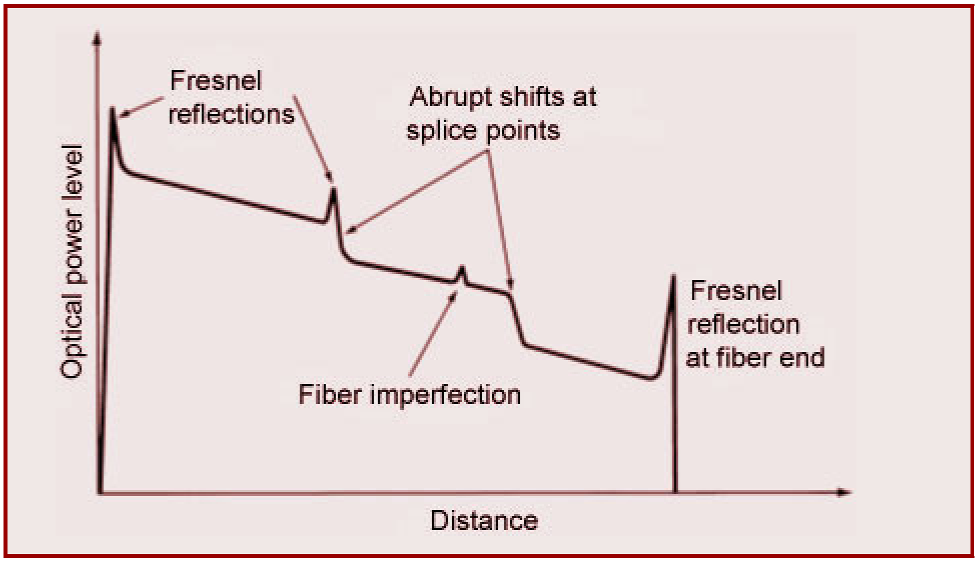
- The intensity of the back scattered light then is proportional to twice the loss of the fiber.

Attenuation (Loss) - Contd

- From the delay of the back scattered we can find the location on the fiber.

- In addition to the Rayleigh back scattering, there could be local disturbance in the refractive index, like due to a splice or connector or a lossy bend. There will be stronger echo from these locations due to Fresnel reflections.

- A typical back scatter intensity variation as a function of time is shown in Fig.



- The slope of the line on the OTDR display gives twice the attenuation /Km of the fiber.

- Since the Rayleigh scattering is very week in the optical fiber, the back scattered light intensity is very small to be detected in the presence of electrical noise. Multiple pulses are therefore transmitted and the received signal is integrated to improve the signal to noise ratio of the OTDR trace.

- The separation between the pulses has to be more than the round trip delay on the fiber. If the maximum fiber length for which the OTDR is to be used is $L_{\max}$ and its effective index is n_{eff}, the minimum separation of the pulses should be $\leq L\, n_{eff} / c$, where c is the velocity of light in vacuum. The maximum pulse repetition frequency therefore is

$$\text{Max PRF} = \frac{c}{L_{\max} n_{eff}}$$

- The OTDR can also be used to monitor the status of the optical fiber while in operation. It can detect faults like tempering of the fiber as well as breakage in the fiber.

- The accuracy with which the faults can be located depends upon the width of the optical pulse. The minimum separation needed between two identical faults to be identified as the two faults is called the **resolution** of the OTDR.

- The resolution depends upon the laser pulse width as well as the dispersion on the fiber.

- If the laser pulse width is τ_i, the pulse width of the received back scattered light will be

$$\tau = \sqrt{\tau_i^2 + (DL\sigma_\lambda)^2}$$

where D is the dispersion on the fiber, σ_λ is the spectral width of the laser and L is the distance on the fiber.

- The spatial resolution of the OTDR is

$$\text{Resolution} = \frac{c / n_{eff}}{\tau}$$

- For short distance, the dispersion does not play much role and the resolution is independent of the distance. However, for longer lengths, the resolution worsens as a function of distance.

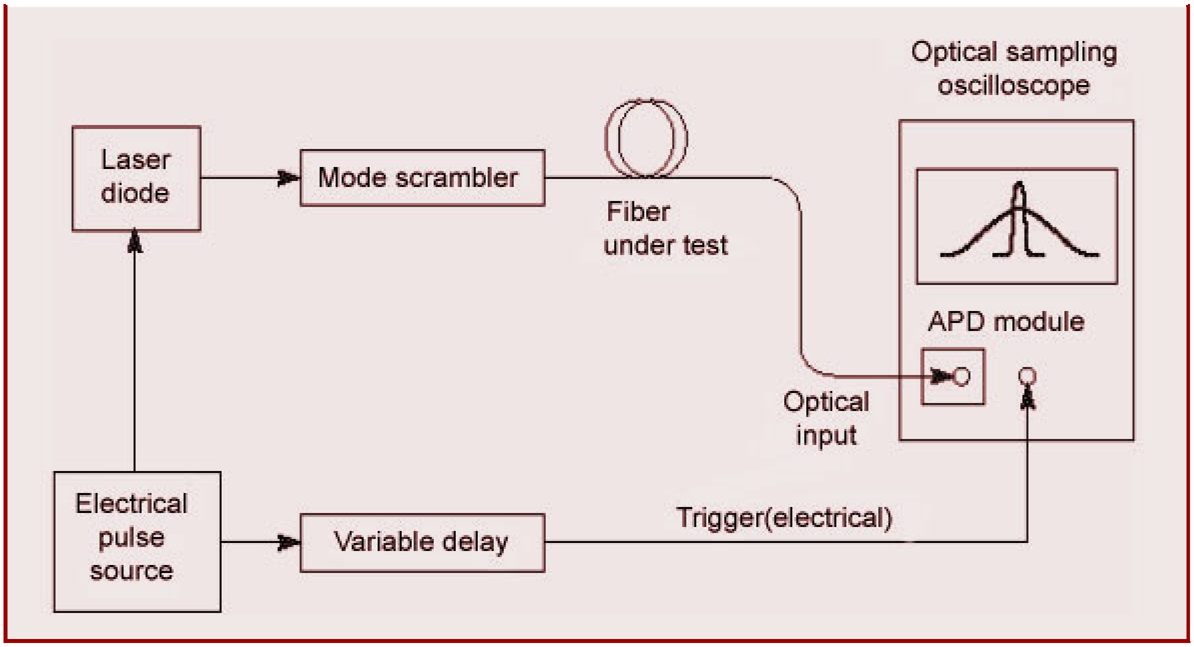
- **The most important aspect of the OTDR is, it requires access to only one end of the fiber and also it can monitor the fiber status on line while the fiber is in operation.**

Dispersion

- The dispersion measurement is crucial since it has direct impact on the maximum data rate which the system can handled.

- A narrow pulse of light is launched inside the optical fiber and the output is displayed on an oscilloscope. One can then directly measure the output pulse width and calculate the dispersion.

- A schematic of the dispersion measurement set up is shown in Fig.

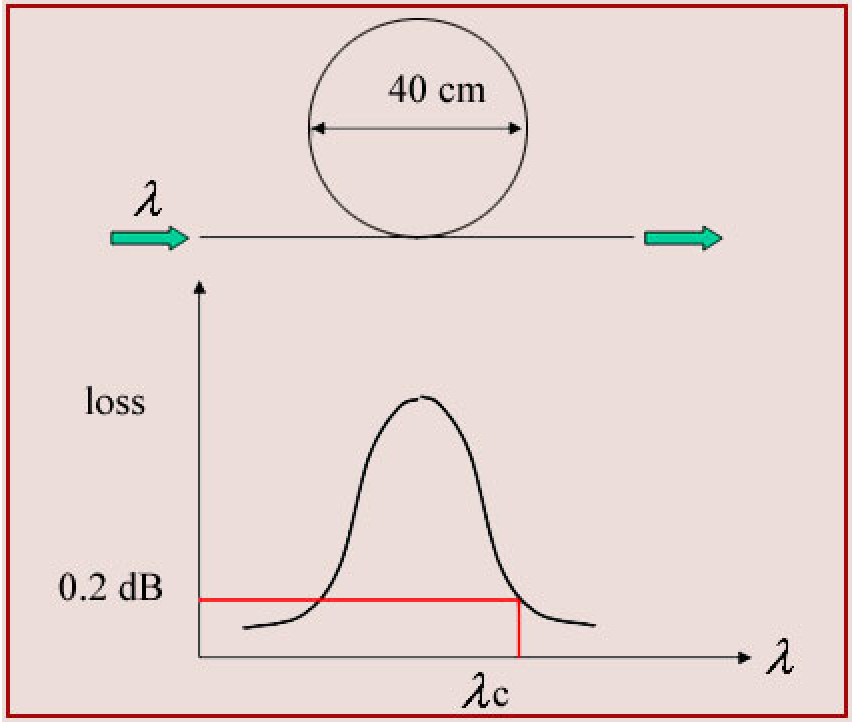


Cutt-Off Wavelength

- As seen during discussion on dispersion, the single mode optical fiber operate very close to the V-number 2.4. The cut-off wavelength is a wavelength at which the next higher order mode gets excited inside the fiber and the fiber does not remain a single mode fiber.

- The cut-off wavelength of a fiber should be far enough from the operating wavelength so that even with manufacturing tolerances on the V-number, the fiber remains a single mode optical fiber. Generally the cut-off wavelength is 30-40nm less that the operating wavelength.

- The cut-off wavelength measurement is done in the following way. A fiber forming a 40cm diameter loop is excited with a light source. The output of the fiber is measured as function of wavelength. A typical plot of output power vs wavelength is shown in Fig.



The output variation can be explained as follows.

- When the wavelength is much smaller than the cut-off wavelength, then both, the first mode and the next higher order get excited in the fiber and both are far from cut-off. So both the modes are well guided and there is not much loss in the fiber.

- As the wavelength increases, the higher order mode approaches cut-off and its energy spreads in the cladding. Due bending loss, this mode looses the power, so the power which reaches to the output is only the power with the first mode. The output then shows a higher loss.

- As the wavelength is increased further, the higher order mode does not get excited at all and the whole power is launched in the first mode which propagates without much loss. The loss on the fiber again reduces with the wavelength. The wavelength at which the loss reduces to 0.2 dB, is called the cut-off wavelength of the fiber.

- Cut-off wavelength is not as crucial parameter as the attenuation or dispersion. However its knowledge is useful in deciding the wavelength range of operation.

Laser wavelength and Spectral width

- The measurement of spectral width (also referred to as line width) is important because the pulse broadening due to chromatic dispersion is proportional to the spectral width.

- In a single channel optical transmission, an accurate measurement of the wavelength of laser is not that crucial as the fiber loss is a slowly varying function of the wavelength. However, in a WDM system, the precise measurement of the laser wavelength is necessary.

- In principle, the wavelength and the spectral width can be measured by passing the light through a tunable filter and measuring the output light intensity as function of wavelength. This not very easy.

- Generally, a system called the **Optical Spectrum Analyzer (OSA)** is used to measure the spectral characteristics of the light. The OSA displays the optical power as a function of wavelength. OSAs with spectral resolution of 0.001nm and power density of -70dBm are readily available.

Data Quality

- After measurement of characteristics of individual components of an optical link, finally one has to measure the over all system performance. The system performance would include, distortion of pulses due to system rise time, SNR, clock jitter, etc.

- The test which is conducted for this purpose is called the **Eye Pattern test.**

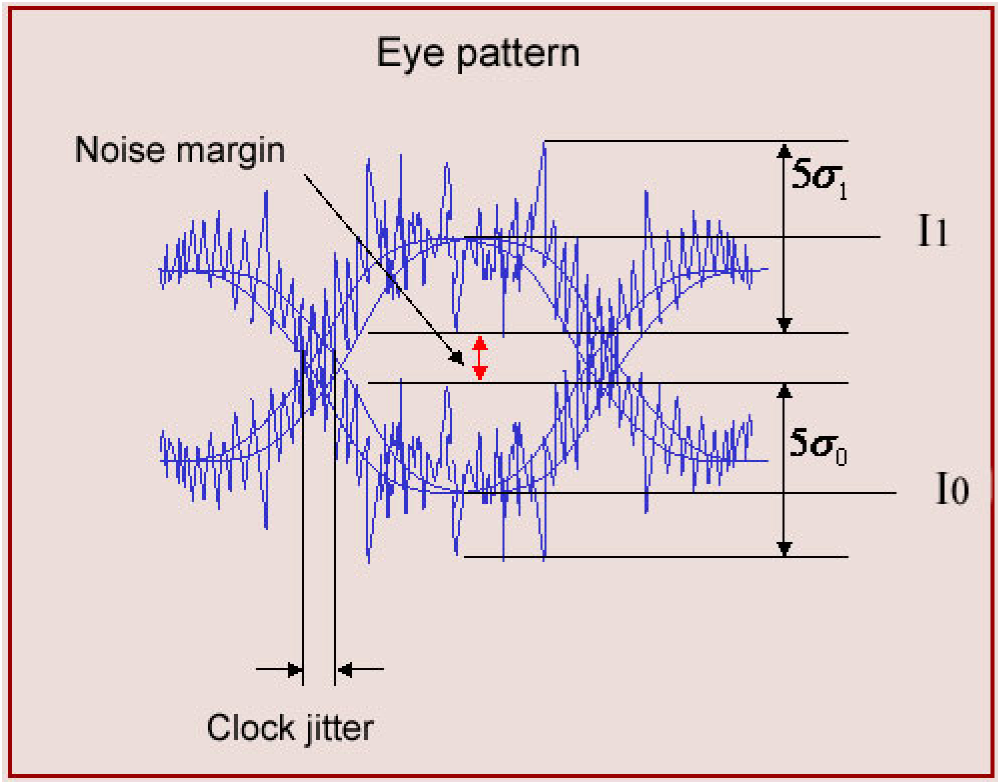
- The data received from the system is displayed on an oscilloscope with data folded over one or two bits. Since the data is random, the display shows all transitions between the two binary states giving details of the bit distortion.

- A typical display is shown in following Fig.

- The pattern appears like a human eye and therefore is called the eye pattern.

- The eye diagram gives the mean levels corresponding to the bit-0 and bit-1. Assuming that the noise is Gaussian, the peak to peak amplitude of noise is approximately 5σ. From the diagram therefore we can measure σ_1 and σ_0 and subsequently the parameter Q.

- The eye diagram clearly shows the noise margin in the data and it also shows the timing jitter.



- As the SNR of the data reduces, the eye closes vertically, whereas as the clock jitter increases, the eye closes horizontally.

- The system parameters are fine tuned to obtain the maximum opening of the eye.

- Since the eye diagram can give the value of Q, it can be used for estimating the BER without really running the system for long time.

Recap

In this lecture you have learnt the following

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- Dispersion

- Cutt-Off Wavelength
- Laser wavelength and Spectral width
- Data Quality

Congratulations, you have finished Module 13. To view the next lecture select it from the left hand side menu of the page