Key Parameters for Testing Multimode Fibre Optic Cables and Transmitters

Principles on the measurements related to Encircled Flux and Mode Power Distribution: Key parameters in the performance of Multimode Fibre, 10 Gigabit Ethernet Networks.

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Overview

The distribution of power among the various modes in a multimode fibre is known as the ‘mode profile’ of the fibre. The modal distribution plays a particularly important role in the performance of fibre in Local Area Networks (LANs). For example, the loss of a fibre link is often found to be smaller if the transmitter launches only low-order modes into the fibre.

International standards bodies have responded to the need for more accurate characterisation of channel loss, required for high bandwidth systems, by introducing a qualification template based on the Mode Power Distribution (MPD). However it was subsequently found that the channel loss repeatability using sources compliant to this template was not sufficient to meet the very stringent requirements on loss budget necessary for 10Gbit Ethernet.

To overcome this shortcoming a parameter called Encircled Flux, which had previously been adopted by the IEEE for qualifying VCSEL sources was adapted for channel loss test instrumentation. Encircled Flux is a radial integration of the power distribution in the fibre, going from zero at the core centre to unity at the core boundary. The exact shape of the Encircled Flux distribution has been defined by a series of templates giving upper and lower boundaries at various radial positions. The MPX Modal Explorer provides real time measurement of Encircled Flux against both IEEE and IEC templates, enabling rapid characterization on a pass/fail basis.

Mode Theory

Light travels along a multimode fibre through a series of reflections at the interface between the core and the cladding. From a geometrical point of view it would be thought that any ray angle would be possible but when electromagnetic theory is applied to the fibre it is found that only certain angles are permitted, these are known as the ‘modes’ of the fibre. Broadly speaking there are two types of mode, those where light passes through the axis of the fibre, known as the ‘meridional’ modes, and those that travel in a helical fashion, not crossing the axis, known as ‘skew’ modes.

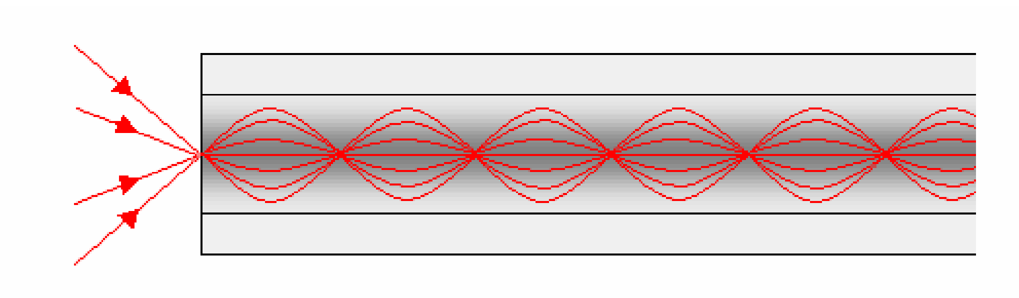


Figure 1: Meridional rays in a graded-index fibre.

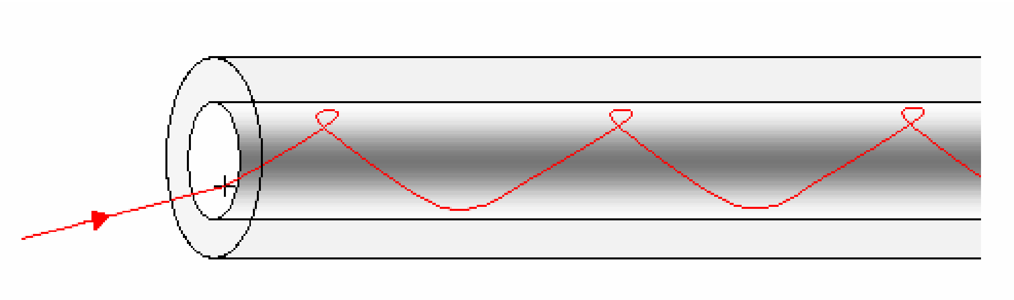


Figure 2: Skew ray in a graded-index fibre.

It can be seen in Figure 1 that the index gradient causes rays which are traveling at steeper angles in the fibre, the ‘high-order’ modes, to catch up with rays traveling at shallow angles. This is because that, although the steeper rays have further to travel the refractive index they experience near to the core/cladding boundary is less than at the centre of the core and so they travel faster in this region. It is this feature of graded-index fibre that gives it much less pulse dispersion than step-index fibres and hence superior bandwidth performance.

A useful parameter to calculate the number of modes in a fibre is the normalized frequency, or V-number, defined as

$$V = \frac{2 \cdot \pi}{\lambda} \cdot a \cdot NA \qquad (1)$$

where: a is the fibre core radius.
NA is the numerical aperture of the fibre.
λ is the wavelength.

The total number of modes, N_m, in a graded-index fibre is given by

$$N_m \approx \frac{V^2}{4} \qquad (2)$$

As an example, for a 50um core diameter and a numerical aperture of 0.21, there are approximately 376 possible modes in the fibre at 850nm.

From an electromagnetic point of view, there are actually four different types of mode in a multimode fibre depending on the angle between the electric field vector and the axis of the fibre. For most communication fibres, however, where the refractive-index difference between the core and cladding is relatively small, the different types of mode can be grouped together into a single series of modes known as the Linearly Polarized (LP) modes.

The LP modes are normally designated by two parameters; these are the radial mode number, m, and the azimuthal mode number, n. For a particular mode m corresponds to the number of intensity peaks in the radial direction and 2n corresponds to the number of intensity peaks over 360 degrees in the azimuthal direction.

The following schematic intensity distributions are given as examples of some LPn,m modes, (not to scale),

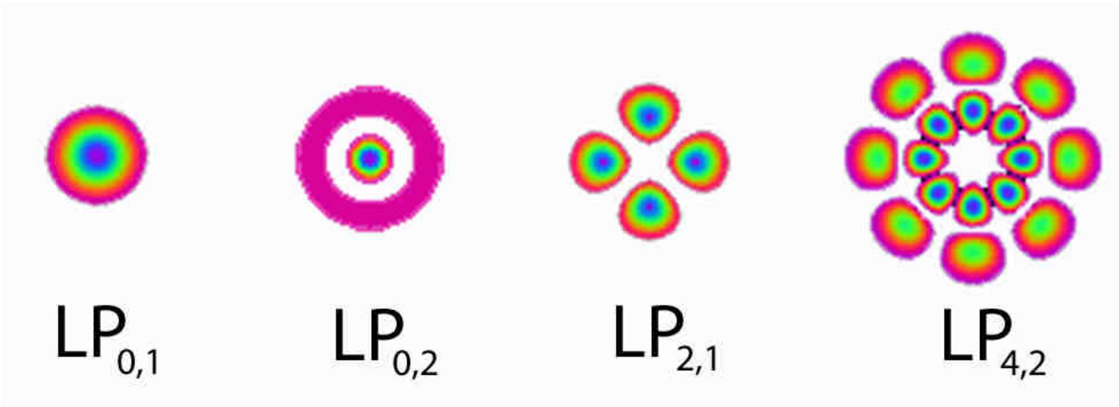


Figure 3: Schematic of LP mode intensity distributions.

The LP modes may be further classified into 'Mode Groups' where the mode group number, M_g, is given by

$$M_g = 2m + n - 1 \qquad (3)$$

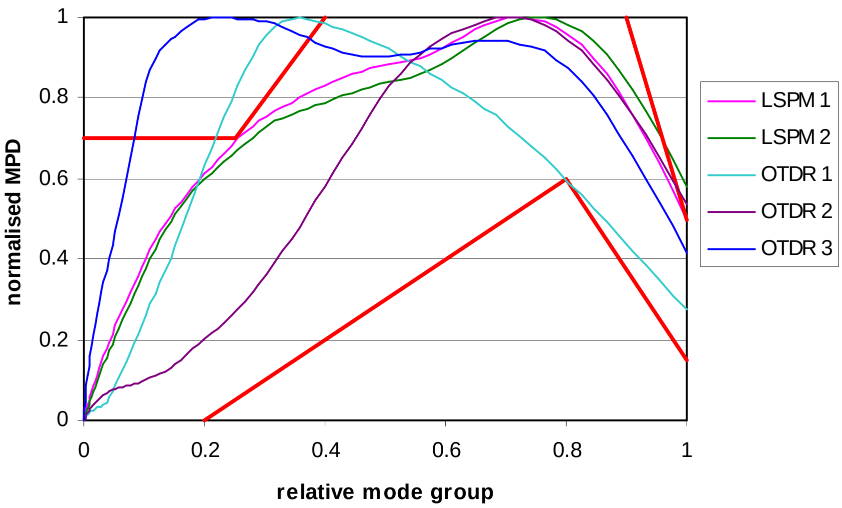
The total number of mode groups, N_g, is given by

$$N_g \approx \frac{V}{2} \qquad (4)$$

Now Nm is greater than Ng so clearly there several LP modes have the same mode group number. These modes are also characterized by having the same propagation constant. Including both polarisation states and azimuthal orientations, the number of modes in a particular group is numerically equal to twice the mode group number.

Mode Power Distribution

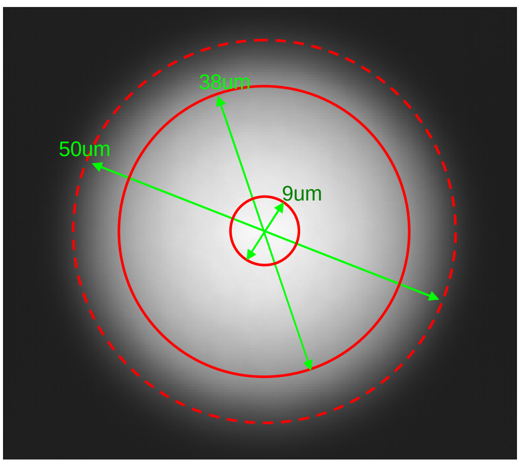
The figure below shows the measured MPDs of a variety of commercial LED and OTDR test sources, vs normalised mode group number. The red lines represent the MPD qualification template from the ISO/IEC14763-3 standard for link testing. Clearly, there is a lot of variation in the mode-filling between these sources and most of them fail to comply with the template. Through real-time MPD measurement, the MPX enables the mode-filling of sources to be optimised using, for example, mode-scrambling devices.



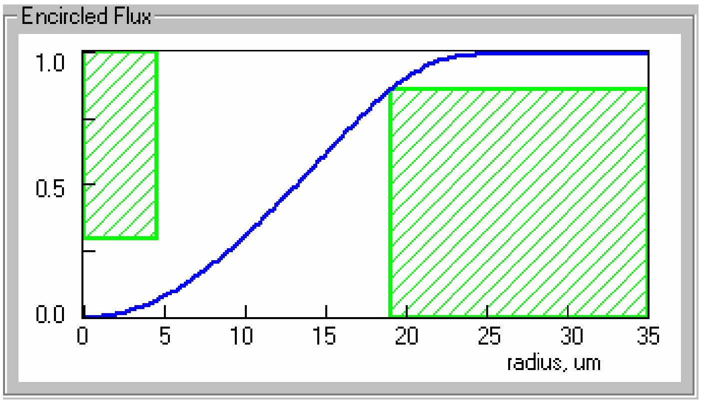
Encircled Flux

Encircled flux is a means of characterizing the modal filling of pigtailed VCSEL sources for use in Gigabit Ethernet (GBE) multimode fibre transmission systems. The IEEE has derived an encircled flux template which consists of specifying the maximum and minimum amount of light within concentric circles of given diameters centered on the fibre axis. Specifically, the requirement for 10Gbit/s is <30% of the power inside a 9um diameter circle and >86% of power inside a 38um diameter circle.

A pictorial representation of this specification superimposed on a near-field intensity distribution is shown below:

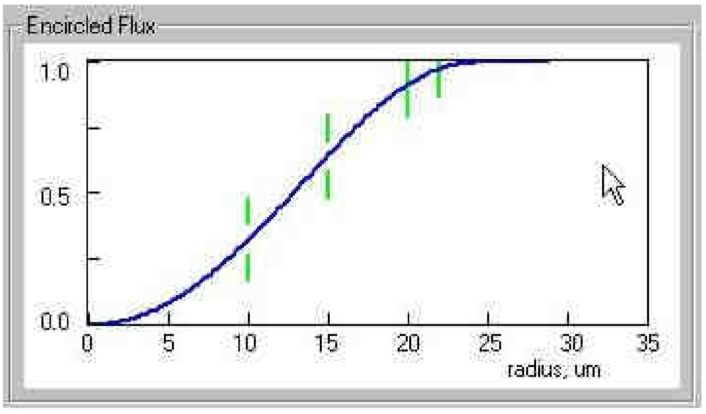


The MPX Modal Explorer calculates encircled flux by a radial integration of the near-field image, according to TIA FOTP-203. An example of an encircled flux measurement with the 10Gbit/s template superimposed is shown below:



In this example the blue encircled flux curve has just managed to avoid the hatched regions of the template and therefore passes the test.

An example of an IEC 61280-4-1 compliant source is shown below



Summary

Evolving standards for high performance multimode LAN systems are now putting requirements on the modal filling of operational sources and test equipment. Specification of templates for encircled flux necessitates accurate measurement of these parameters. The MPX Modal Explorer provides a complete measurement capability for compliance with these standards, in both the 850nm and 1300nm operating windows.

References

References for some standards and articles applicable to mode-field measurements.

Mode Power Distribution

TIA/EIA-TSB62-3
‘Mode Power Distribution and Mode Transfer Function Measurement’.

Calzavara M. et al., “Reliability of a new method for measurements of modal power distribution in optical fibres with application to mode scrambler testing”, Electronic Letts., pp543-545, v.17, no.15, 1981.

Rittich D., “Practicability of determining the modal power distribution by measuring near and far fields”, Journ. Lightwave Tech.,v. LT-3, no.3, pp652-661, 1985.

Daido Y. et al., “Determination of modal power distribution in graded-index optical waveguides from near-field patterns and its application to differential mode attenuation”, Applied Optics, v. 18, no.13, pp2207-2213, 1979.

ISO/IEC 11801
‘Information technology – Generic cabling for customer premises’.

IEC 61300-1
‘Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 1: General and guidance’.

IEC 61300-3-31
‘Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-31: Examinations and measurements - Coupled power ratio measurement for fibre optic sources’.

EN 50173
‘Information technology - Generic cabling systems’

EN 50346
‘Information technology - Cabling installation - Testing of installed cabling’.

Encircled Flux

TIA/EIA 455-203
‘Launched Power Distribution Measurement Procedure for Graded-Index Multimode Fibre Transmitters.’

IEEE 802.3ae-2002:
Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation 2002.

IEEE 802.3-2002:
Information Technology - Telecommunication & Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications 2002.

IEEE *Draft* P802.3aq
Draft amendment to IEEE 802.3-2002, 'Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-LRM'.

Link Testing

ISO/IEC14763-3
Information technology — Implementation and operation of customer premises cabling — Part 3: Testing of optical fibre cabling.

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