Key Parameters for Testing Multimode Fibre Optic Cables and Transmitters

Principles on the measurements related to the Mode Transfer Function, 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.

A parameter, known as the Coupled Power Ratio (CPR), is sometimes used to qualify the degree to which light is distributed between the modes of the fibre. This should enable loss measurements made with different test sets to be properly compared, but it has been shown the CPR value is only of real value for monotonic modal distributions where the low-order modes are more fully-filled than high-order modes. For modal distributions where there is a dearth of low-order modes the CPR value can be erroneously high which makes the fibre appear to be well filled when, in fact, high-order modes may not be present.

International standards bodies responded to the need for more accurate characterisation of mode-filling by introducing a qualification template based on the Mode Power Distribution (MPD). A direct measurement of mode-filling by the Arden *MPX Modal Explorer* provided a real-time measurement of MPD, enabling sources to be qualified against this template. It was subsequently found, however, 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 for Ethernet compliance, 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 centre to unity at the core boundary. The exact shape of this curve has been the subject of much debate in the IEC standards community, but it is expected that a definitive set of templates, for 50um and 62.5um fibre, at 850nm and 1300nm, will be published in 2009. The *MPX Modal Explorer* provides a real-time measurement of Encircled Flux, against both the IEEE and IEC templates, enabling rapid characterisation 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, shown in Figure 1, and those that travel in a helical fashion, not crossing the axis, known as ‘skew’ modes, shown in Figure 2.

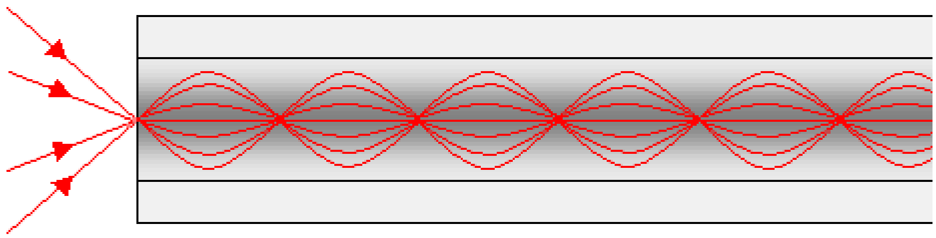

Figure 1. Meridional rays in a graded-index fibre.

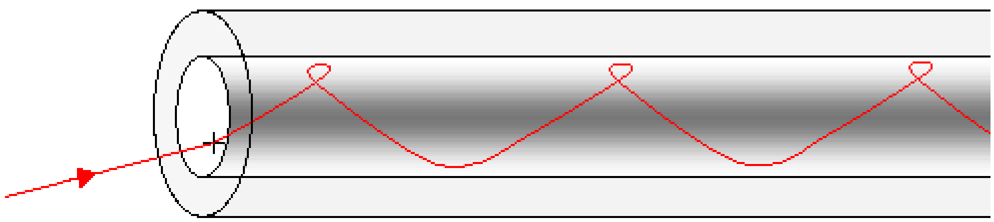

Figure 2. Skew ray in a graded-index fibre.

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.

Figure 3 shows schematic intensity distributions of some LPn,m modes,

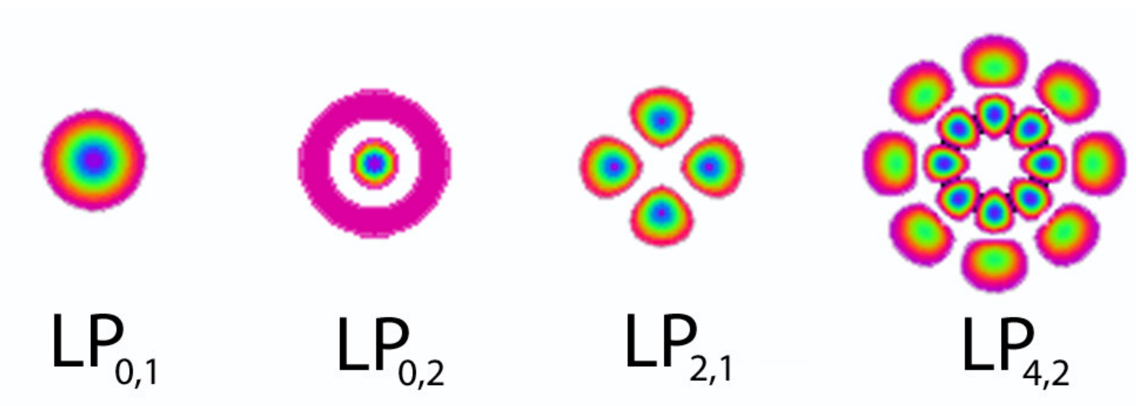

Figure 3. Schematic of LP mode intensity distributions, (not to scale).

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

Figure 4 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, where a compliant source would pass between the three marked areas. 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 Modal Explorer* enables the mode-filling of sources to be optimised using, for example, mode-scrambling devices.

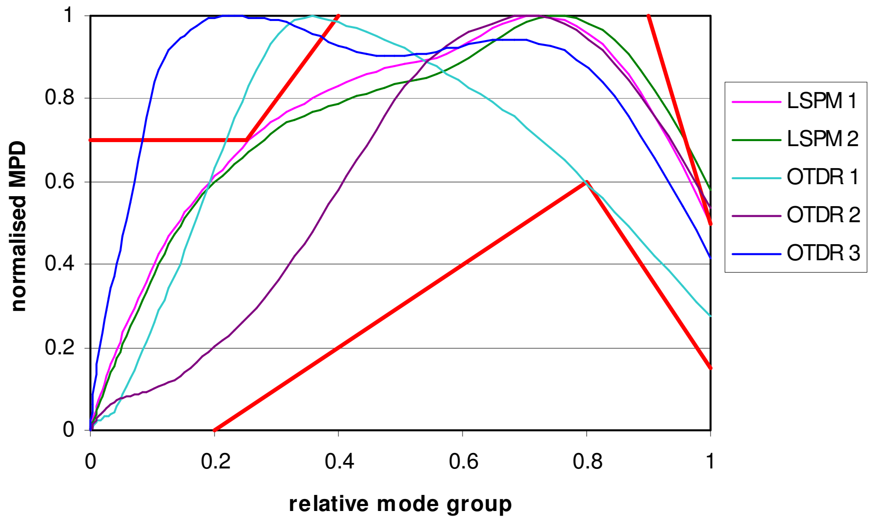

Figure 4. Examples of Mode Power Distribution of several sources

Encircled Flux

Encircled flux is a means of characterizing the modal filling of sources for use in Gigabit Ethernet (GBE) multimode fibre systems. For testing VCSEL sources, 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 in Figure 5.

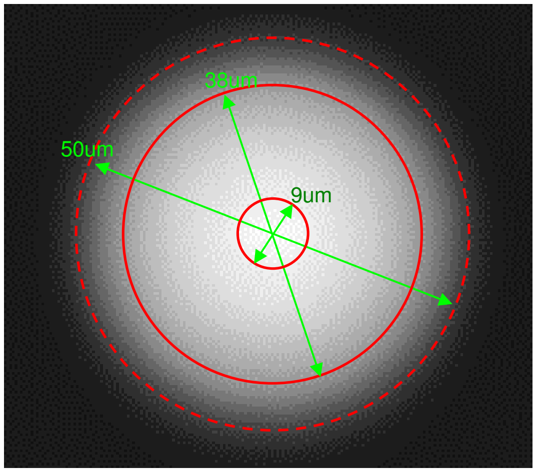

Figure 5. Encircled Flux template for 10Gbit Ethernet on 50um fibre at 850nm (IEEE 802.3ae)

The *MPX Modal Explorer* measures the encircled flux by a radial integration of the near-field image, according to standards IEC61280-1-4 and TIA/EIA FOTP-203. An example of an encircled flux measurement with the 10Gbit/s template superimposed is shown in Figure 6.

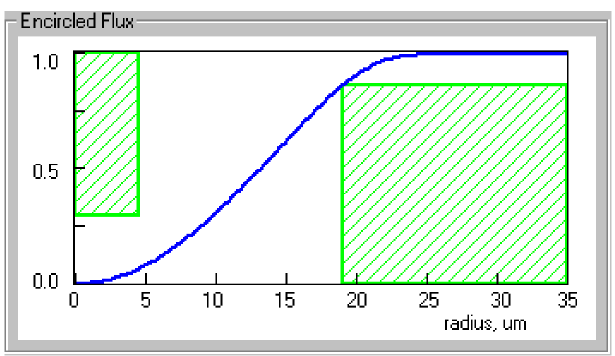

Figure 6. Example of Encircled Flux measurement with IEEE template.

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

For characterising sources to measure channel loss, the encircled flux template takes a different form to that shown above. In this case, the encircled flux curve has to pass between upper and lower tolerances, which are defined at several radial 'control points'. An example of the template, for 50um fibre, at 850nm, is shown in Figure 7. Here it can be seen that the blue encircled flux curve passes through the clear aperture at each control point and so, in this case, the source is compliant.

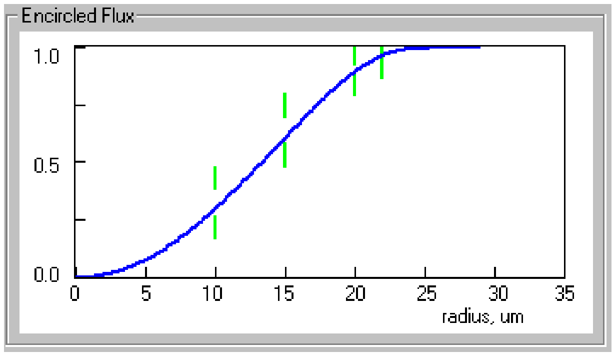

Figure 7. Example of Encircled Flux measurement with IEC channel loss template.

An alternative way of displaying encircled flux data is also offered by the *MPX Modal Explorer*, where the mean value of the tolerance at each control point is subtracted from the measured data. An example of this is shown in Figure 8. Here, a perfect source that passed through the centre of the template would be a horizontal line. In the example shown, the source fails the template at the 22um control point, indicated by the red tolerance bar.

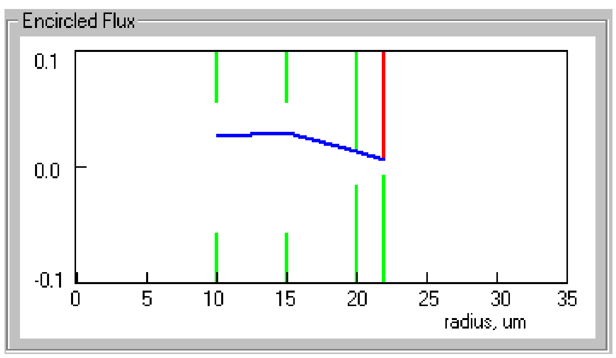

Figure 8. Example of offset Encircled Flux measurement with IEC channel loss template.

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 mode power distribution and 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 applicable to MPD and Encircled Flux measurements.

Mode Power Distribution

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

IEC 61300-3-43
Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-43: Examinations and measurements – Mode transfer function measurement for fibre optic sources.

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Encircled Flux

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Fiber-optic communication subsystem basic test procedures - Part 4-1: Test procedures for fiber-optic cable plant and links - Multimode fiber-optic cable plant attenuation measurement. Due to be published 2009.

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 802.3ae-2002
Amendment to IEEE 802.3-2002, 'Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation'.

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

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