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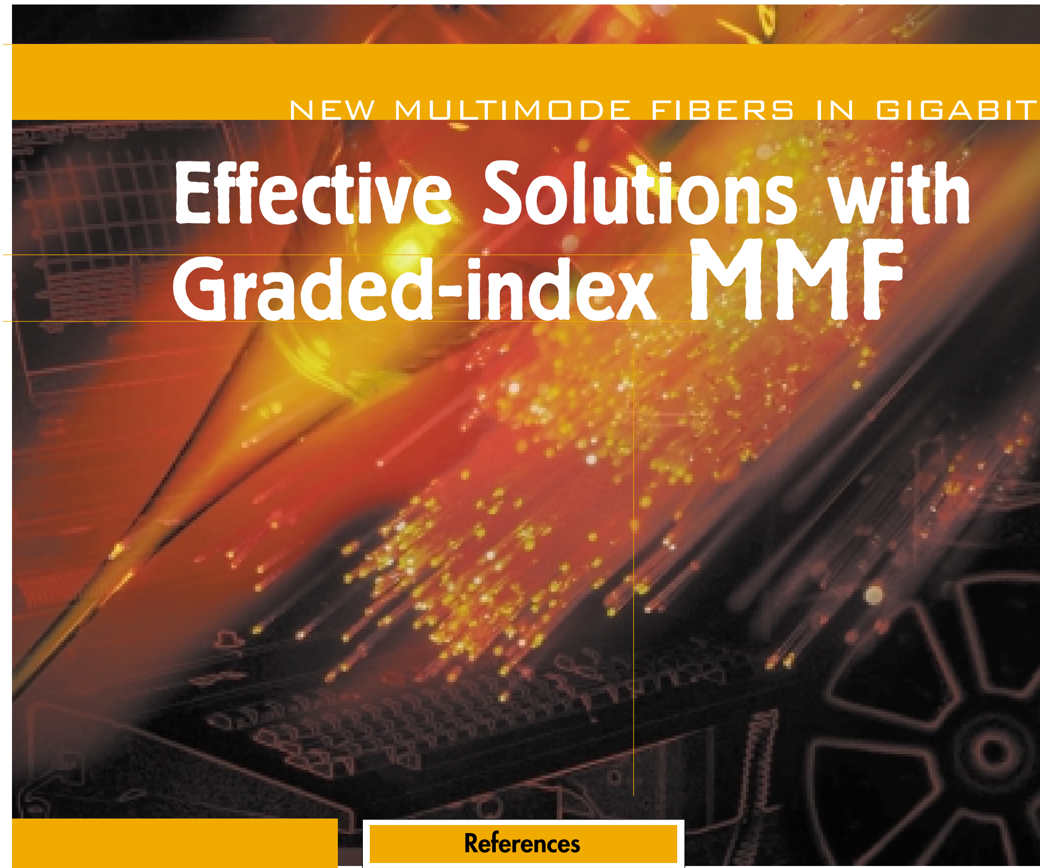
FiberCore Jena

NEW MULTIMODE FIBERS IN GIGABIT LAN SYSTEMS

Effective Solutions with Graded-index MMF



Multimode fiber cable is the solution of choice for handling the growing data volumes carried by modern LAN systems. First, it enables the use of inexpensive transmitter and receiver components not supported by single-mode fibers. Second, multimode fibers need considerably less exacting coupling technology. However, multimode fibers have a larger core diameter and significantly greater numerical aperture than the single-mode variety, and this leads to modal dispersion problems. The solution is to use graded-index multimode fibers.

References

/1/. A.Dhillon, C.DiMinico, A.Woodfin: Optical Fiber and 10 Gigabit Ethernet, Version 2, May 2002

/2/. Amann, M.C.: Long-wavelength VCSELs, European Conference on Optical Communications, Amsterdam 2001

The use of an approximately parabolic refractive index profile in graded-index multimode fibers reduces modal dispersion by more than two orders of magnitude as compared to step-index fibers. Graded fiber cable thus combines the advantage of practical coupling technology with high bandwidth. In graded-index fibers the effective bandwidth is limited by modal dispersion, i.e. propagation time delays between the modes. In addition the bandwidth depends on the launch conditions of the mode at the input end of the fibers. For example, a graded-index multimode fiber launched with a laser may achieve a higher bandwidth than one launched using a LED (light-emitting diode).

LED sources are used for transmission at the data rates of up to 100Mbit/s that are customary in Fast Ethernet networks. Laser sources are specified for the higher-speed Gigabit Ethernet (GbE) systems with data rates of up to 1Gbit/s. The new laser-optimized 50/125µm multimode fibers that have recently become available support serial transmission at 10Gbit/s over a link distance of up to 300m using a transmission wavelength of 850nm/1/.

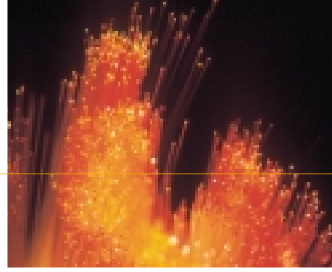
The modal bandwidth of conventional fibers

The product of the bandwidth and its length defines the information carrying capacity of a multimode fiber. Traditionally, when measuring the bandwidth of a multimode fiber, the overfilled launch (OFL) is used. Overfilled launch is assumed for all core modes when determining this modal bandwidth. This simulates the launch conditions achieved when a LED source is used. In the past, overfilled launch has always been postulated for all core modes in these calculations because a conservative determination of effective bandwidth is only possible for graded-index fibers under these launch conditions.

The standard measurement procedure for determination of the bandwidth of a multimode fiber with overfilled launch is summarized in IEC 60793-1-41 (*Measurement Methods and Test Procedures – Bandwidth*). The general transmission performance of a graded-index multimode fiber can also be characterized by determining the differential mode delay (DMD) across the core cross-section of the fiber.

VCSEL sources for Gigabit Ethernet LAN applications

Vertical-Cavity Surface Emitting Lasers (VCSELs) are a new type of surface-emitting semiconductor lasers. Their rotationally symmetrical active zone enables output that is likewise rotationally symmetrical. This facilitates better launching into glass fiber cable. The VCSELs are becoming increasingly popular as light sources in optical communications systems, especially for the first optical window at 850nm. It is because,



Template Number	Inner DMD Mask (R_{inner}=5µm, R_{outer}=18µm) (ps/m)	Outer DMD Mask (R_{inner}=0µm, R_{outer}=23µm) (ps/m)
1	≤ 0.23	≤ 0.70
2	≤ 0.24	≤ 0.60
3	≤ 0.25	≤ 0.50
4	≤ 0.26	≤ 0.40
5	≤ 0.27	≤ 0.35
6	≤ 0.33	≤ 0.33

Table 1
Specifications of the six DMD templates on the basis of ICE 60793-1-49 or FOTP-220

by the nature of their design, VCSELs can be processed and tested in a wafer, which makes them an inexpensive light source/2/.

Both the emitting surface and the numerical aperture of VCSELs are significantly smaller than those of an LED source. The emitted light can thus be coupled into the glass fibers efficiently and without expensive corrective optics. This makes them the ideal choice for transmission systems using multimode fibers. It ist well-known that LEDs have a relatively large numerical aperture (NA) and a relatively large emitting surface, lasers have both a significantly smaller numerical aperture and a smaller emitting surface. When an LED launches light into a multimode fiber it irradiates the entire fiber core and consequently excites all core modes. In contrast, lasers like the VCSEL only irradiate a section of the core center, thus exciting only a fraction of the possible core modes.

Graded-index fibers for data rates up to 1Gbit/s

On closer examination the bandwidth figures calculated on the basis of full excitation of a graded-index fiber prove to be less applicable to the behavior of transmission systems using lasers as the light source. If one assumes an ideal gradient refractive index profile the smaller number of excited modes should result in less modal dispersion, thus enabling a higher effective bandwidth.

This is not always possible, however, because of refractive index degradation in the important core center zone caused by dips (refractive index falloffs in the fiber center), flat tops (flattening of the profile curve in the core center zone) and peaks (profile peaks). If a radially limited laser signal is fed into a degraded profile area one can thus expect signal deformation and an increase in the bit error rate.

To solve this problem IEEE 802.3z suggests the use of mode conditioning patch cables. In these cables a graded-index fiber is spliced to a single-mode fiber with at a radial offset, so that the light to be transmitted is deflected into undegraded outer profile areas of the graded fiber. These mode conditioning patch cables are not needed when laser-optimized multimode fibers are used. Fibers used in GbE systems must be tested for system conformity. The standardized testing procedure calls for a defined, restricted mode launch (RML) in the core center area. The test procedure is documented in the FOTP-204 standard.

RML conditions are established by connecting a mode conditioning fiber patch cord with a numeric aperture of 0.208 and a core diameter of 23.5µm between the source and the receiver. This simulates the special, selective mode excitation conditions of a standard VCSEL and ensures that the application-specific transmission performance is maintained for the tested fibers at data rates of 1Gbit/s.

New graded-index fibers for data rates up to 10Gbit/s

The 10 Gigabit Ethernet Alliance has defined a minimum effective modal bandwidth of 2,000MHz*km at 850nm for 10Gbit/s transmission via multimode fibers, in order to ensure a link length of 300m/1/. When calculating the effective bandwidth in these systems – in contrast to the methods for determining bandwidth in systems with full core excitation – one must take into account the interaction between the launch characteristics of the source and the mode structure of the multimode fibers.

IEC Standard 61280-1-4 and the FOTP-203 standard define the output distribution of the VCSEL source in such a way that the core cross-section around the core center and the core in the core/cladding interface are not over-excited. This means that a source that is coupled to a 50µm fiber core is designated by the following encircled flux (EF):

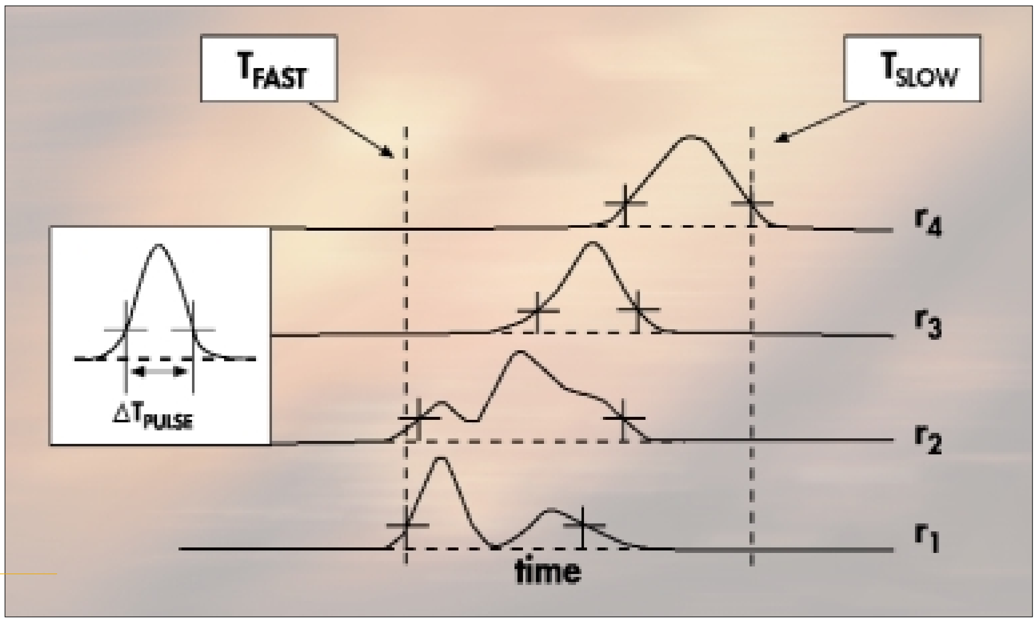
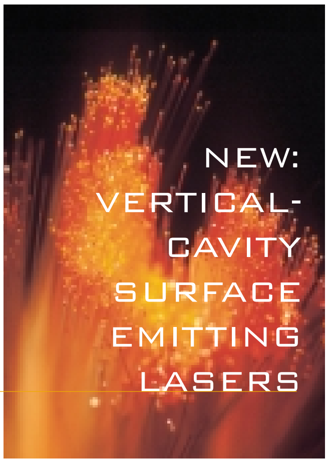


Fig. 1: Results of a DMD measurement (Differential Mode Delay)

Fiber Type	Core Diameter (µm)	Minimum Bandwidth*Length (850nm, OFL) (MHz*km)	Minimum Bandwidth*Length (1300nm, OFL) (MHz*km)	Minimum Effective Bandwidth*Length (850nm, RML) (MHz*km)
OM1	50/125 62.5/125	200	500	not spec.
OM2	50/125 62.5/125	500	500	not spec.
OM3	50/125	1500	500	2000

Table 2
The ISO/IEC 11801 classifications of glass fiber cables



- ≤ 30% of the total encircled flux lies within the radius interval from 0 - 4.5µm, and
- ≥ 86% of the total encircled flux lies within the radius interval from 0 - 19µm

The modal delay performance of the new multimode fibers for 10 GbE applications is characterized by six DMD templates. The measurement of the fiber's DMD and classification under the appropriate template are performed on the basis of IEC 60793-1-49 or FOTP-220.

For the DMD measurement the entrance end of the fibers to be tested is scanned radially with a single-mode fiber at a wavelength of 850nm (see Fig. 1). The corresponding output pulses at the other end of the fibers are recorded integrally on the basis of their locations in relation to the radial position of the single-mode fiber. This provides precise information on the modal delay differences between the selectively-excited mode groups at the various radial offsets. The DMD scans are then evaluated on the basis of the six predefined templates shown in Table 1, with a threshold of 25 percent. If the time differences lie below the specified limits in at least one of the six DMD templates there is a high probability that the tested multimode fiber conforms to the 10 GbE criteria. Modern, high-resolution DMD measurement equipment provides precise data on the time differentials between mode groups excited at the various radial offsets (see Figs. 2 and 3).

The Hamamatsu instrument used by FiberCore Jena emits very short light pulses (<100ps) that enable the performance of measurements with an extremely fine temporal resolution. When a streak camera is used as the receiver it is also possible to perform measurements on fibers with lengths >10km (see Fig. 4).

Fiber classes and selection of fibers for GbE applications

Until recently 62.5/125µm graded-index fibers were the predominant choice for LAN applications in many locations, particularly in America, despite their higher price. The advantages of this fiber type over the 50/125µm graded-index fibers that are widespread in Europe are especially pronounced in LED-based transmission systems. In these applications more optical power can be launched into the larger core diameter. However, fiber attenuation is also higher, and this partially offsets the launchable power benefits. The higher numeric aperture and the larger core diameter mean that a larger number of core modes are excited, which generally results in greater modal dispersion and thus also lower bandwidth. The 62.5/125µm fibers still have certain advantages over 50/125µm fibers as regards sensitivity to microbending and macrobending.

In Gigabit Ethernet systems that use partial excitation by means of lasers the benefits of the greater launchable power are no longer significant. The IEC designation for the new laser-certified fibers for 10 GbE is A1a.2, and the new glass fiber type classification (see Table 2) designates them as OM-3 fibers.

Summary

The new multimode fibers for use in 10 GbE systems are characterized by optimization of the refractive index profile in the area close to the core center and the central radius area for a transmission wavelength of 850nm. This has made it possible to reduce the modal delay differentials so far that the fibers conform to the DMD templates of the IEEE 802.3ae standard. These new fibers, which are also known as laser-certified or laser-optimized, are the fibers of choice for new cable in LAN applications in the up to 300m ranges. These new fibers are also future-proof because they are equally suitable for LED and laser applications.

Fig. 2: Measurement results of a fiber suitable for 10 Gbit systems

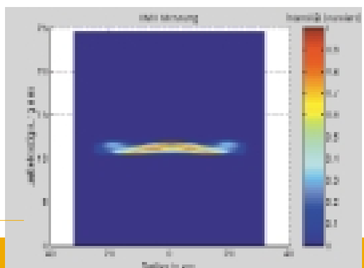
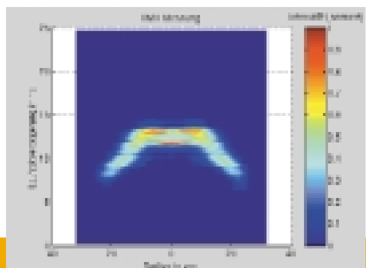


Fig. 3: Measurement results of a fiber not suitable for 10 Gbit systems



„GRADED MMF FOR USE IN 10 GBE SYSTEMS"

Traditionally, the transmission capacity of multimode fibers has been designated by their modal bandwidth, determined under overfilled launch conditions. With the transition to laser sources, which cause selective mode excitement, this method has proved to be inadequate as the sole characterization for the fiber media. The introduction of DMD measurement technology with exceedingly high temporal resolution and the definition of acceptable modal delay differentials in templates have now provided a reliable foundation for classification of MMF suitable for use in 10 GbE systems.

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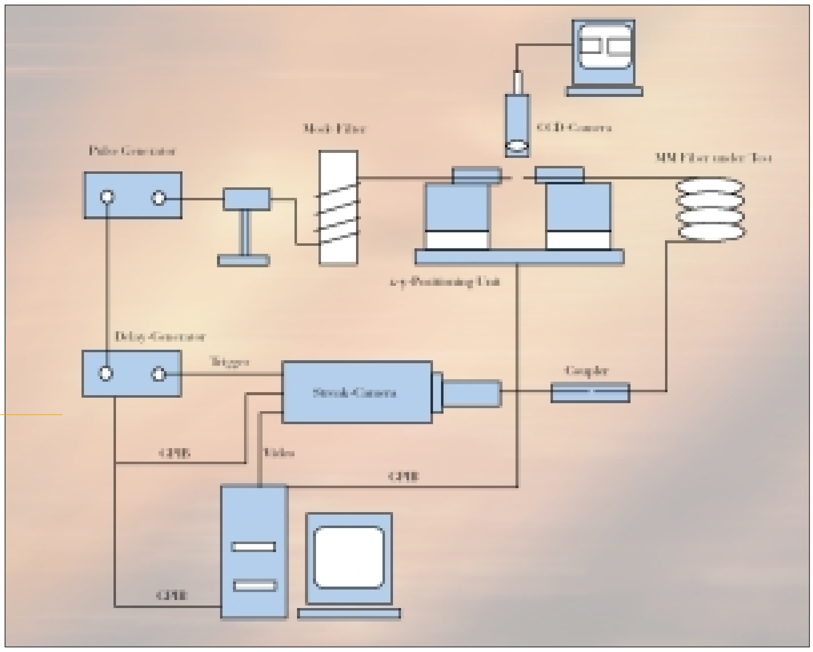

Fig 4: Schematic diagram of the Hamamatsu instrument setup