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A New Generation of Multimode Fibers

Introduction

Historically, multimode fiber (MMF) optical channel links used light emitting diode (LED) transceivers for data communications up to 640 Mb/s and distances up to 2 km. Early MMF types included OM1 and OM2 as specified in IEC/ISO 11801 generic cabling standards. With the development of vertical cavity surface emitting lasers (VCSELs) in the mid to late 1990's, two new "laser optimized" fiber types emerged, OM3 and OM4. The development of laser optimized MMF enabled the transmission of optical signals at data rates of 1 Gb/s and beyond. Today, VCSELs can modulate optical signals up to 25 GBaud,[1] and with modifications to the VCSEL's resonant cavity and material system, VCSELs can be tuned to emit longer wavelengths.

Our journey will clarify the differences between OM3/OM4 and two MMF types called Signature Core™ fiber and Wide Band MMF (OM5). We will discuss the differences between Signature Core fiber and OM5, compare their performance in Ethernet and Fibre Channel standardized applications, and discuss future higher data rate Ethernet standards.

Laser Optimized MMF

The maximum distance or "reach" of multimode fiber is limited by three optical power penalties:

1. Modal Dispersion
2. Chromatic Dispersion
3. Optical Attenuation

When light from the VCSEL is coupled into the core of a MMF, due to the wave properties of light the signal propagates through the fiber core along multiple discrete optical paths, called modes. An ideal MMF has a graded index of refraction so that light traveling close to the core axis encounters a higher refractive index thereby slowing down the speed of the light taking the shortest optical path (low order modes). Conversely, light traveling along paths that come close to the outer regions of the fiber core and are reflected into the core spiraling around the core central axis traverses a longer overall optical path. Consequently, because of the variation in arrival times of the light traveling along these different optical paths (modes), the width of a pulse at the end of the fiber is broadened. This is called "modal dispersion." For traditional MMF channels, modal dispersion has been the primary optical penalty limiting the maximum reach.

Chromatic dispersion is caused by the wavelength dependence of the refractive index. Since a VCSEL emits a narrow spectrum of light (a spectral width on the order of 0.5nm) the different wavelengths (colors) of light comprising the optical pulse travel at different speeds thereby broadening a pulse transmitted down the fiber, in this case, due to chromatic dispersion.

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[1] Baud rate is defined as symbols per second, as opposed to bits per second.

In addition to dispersion, impurities in the fiber's silica glass core cause a small percentage of the optical signal to scatter and radiate out of the fiber core. This reduces optical power or on the order of 2.5 dB/km for 850nm transmission. The reduction in optical power at the receiver's photo-detector reduces the signal-to-noise ratio (SNR), thereby degrading the channel's performance.

Because of continued process improvements in the fabrication of MMF, laser-optimized OM3 and OM4 were introduced. They have a better-controlled core refractive index profile, providing significantly lower modal dispersion compared to OM1 and OM2. To better characterize the modal dispersion of OM3 and OM4, a new metric calculated from the modal dispersion measurement, Effective Modal Bandwidth (EMB) specified in units of MHz·km was introduced. In production, laser-optimized fibers with an EMB between 2000 MHz·km and 4699 MHz·km are sorted as OM3 and fibers with EMB greater than 4700 MHz·km are sorted as OM4.

New Generation of Higher Performance Multimode Fibers

In the development and specification of OM3 and OM4 fiber, it was assumed that VCSELs launched the same optical spectrum into each of the MMF modes. However, in 2008 Panduit® Labs researchers discovered that the spectral emission pattern of VCSEL caused different wavelengths to couple into different fiber modes. Consequently, in addition to modes undergoing modal dispersion due to the spectral differences between modes, the temporal separation between modes also undergo a chromatic dispersion. Therefore, the modal and chromatic dispersion of MMF cannot be treated separately. Instead, the channel bandwidth must be determined by the interaction of modal and chromatic dispersions.

This discovery gave way to a new generation of MMF with significantly higher total bandwidth. By selecting a subset of OM4 compliant fibers that have a uniquely specified refractive index profile, the modal and chromatic dispersions can be compensated, thereby reducing the total dispersion in a VCSEL-MMF channel. In 2008 Panduit introduced Signature Core™ MMF, which provides dispersion compensation enabling longer reaches and larger channel insertion loss.

Wide Band Multimode Fiber

Another important feature of Signature Core fiber is its ability to support wavelengths longer than 850nm as currently specified in application standards. In collaboration with Cisco's transceiver group during the development of the 40 GbE Bi-Direction (BiDi) transceiver, Signature Core fiber became the first multi-wavelength (dual-wavelength) MMF, supporting 850nm and 910nm transmission based on short wavelength division multiplexing (SWDM).

Industry recognition of the benefits of Signature Core fiber led to the standardization of wide band MMF in TIA 42.12, chaired by Panduit. The difference between Signature Core fiber and WBMMF is the specified EMB at the shortest and longest wavelengths specified for SWDM.

For 850nm applications, Signature Core fiber provides 17% higher EMB and equivalent chromatic dispersion compared to WBMMF/OM5. Since SWDM channel reach is limited by the fiber bandwidth at 850nm, Signature Core fiber will provide the highest channel performance for single and dual wavelength SWDM solutions for years to come.

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Future Proofing Your Network

Next-generation Ethernet supporting 50 Gb, 100 Gb, and 200 Gb/s transmission is currently being specified in IEEE 802.3cd and is based on 850nm transmission over parallel optics using two, four, and eight fibers respectively. This standard is scheduled to be ratified in September 2018. To date, Ethernet and Fiber Channel standards do not include SWDM solutions over multimode fiber.

For single-mode applications, CWDM (coarse WDM) and DWDM (dense WDM) technologies have been deployed for over two decades. However, to achieve higher data rates over MMF, parallel optics (using eight, 16, and 32 fibers) have been the technology of choice due to the simplicity of scaling the data rate. However, to achieve data rates beyond 200 Gb/s using eight fibers or less, will require the use of SWDM technology.

It is important to note that parallel optics is required to breakout high-density switch ports to four server I/O ports. The solutions shown in Table 1 all use the same structured cabling and support standards-based network architectures.

Table 1. Parallel Optics Solutions.

Data Rate Gb/s	Lane Rate Gb/s	Number of Fiber Pairs	Number of Wavelengths	Year Standardized
10 40	10	2 8	1	2002 2015
25 100	25	2 8	1	2016 2015
50 100 200	50	2 4 8	1	2018
100 (TBD) 200 400	50	2 4 or 2 (TBD) 8 or 4 (TBD)	N/A 2 or 4 (TBD) 2 or 4 (TBD)	~2021

Discussions and Conclusions

Currently, there is no industry standard specifying SWDM, and the development of a standard is not feasible before 2021. This is not to say non-standard solutions will not be available touting duplex structured cabling. Nevertheless, long-term SWDM will be required to achieve next generation 400 Gb and 800 Gb Ethernet. The demand for SWDM is uncertain since it will support the highest speed data center interconnects and therefore will compete with single-mode solutions on a cost basis.

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