10 Gb/s LAN Networking: Optical Fiber LAN Design Considerations

By Richard Perron, Eng., RCDD-LAN specialist
Belden

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The purpose of this paper is to guide premise wiring telecommunications specialists through the decision making process regarding future optical fiber cabling implementations for LAN environments. We will go through the latest technology updates and information to simplify the process and assist the reader in making the wisest decisions for both near and long term requirements.

As in most telecommunications articles, there is a classic networking introduction, which sets the stage for what is to come. This paper will not deviate from this approach but will proceed rather quickly.

Introduction

The exploding demand for Internet access to WEB based applications as well as integrated multimedia applications (voice/data/video) has fueled the need for higher bandwidth networks. Rapid advances in microelectronics and optical networking technologies are enabling the increased bandwidth capacity. The quite rapidly growing need for faster networks leads us from 10 Mb/s to 100 to 1000 Mb/s and now to the most anticipated 10000 Mb/s or 10 Gb/s.

Why bother to plan now for 10 ***GIGA***-bit transmission rates in LAN environments when most of what is still being used today is dedicated 10/100 ***MEGA***-bit transmission to the desktop? The answer to this question has two dimensions; one philosophical and one practical.

Philosophically, we live in high-pressure, rapid-paced times where we tend to neglect planning for productivity. As good business managers we must strike a balance between the tactical activities that affect near-term results and strategic planning activities that affect the efficiency, competitiveness and long-term viability of the enterprise. Simply put, “Plan Ahead!” to anticipate and accommodate key future technologies; and, “Plan Ahead!’ to be in a position to take full and swift advantage of these key technologies as they become available.

Practically speaking, it is especially important to plan ahead when it comes to your network cabling infrastructure. Unlike active networking components where performance and capacity upgrades can be often accomplished through comparatively simple software and hardware upgrades, cabling infrastructures have finite performance envelopes which cannot be increased without physically replacing the cables, connectors, or both. Such upgrades are disruptive and costly, both in the direct costs associated with re-cabling and the indirect costs of lost productivity due to cabling related network performance problems.

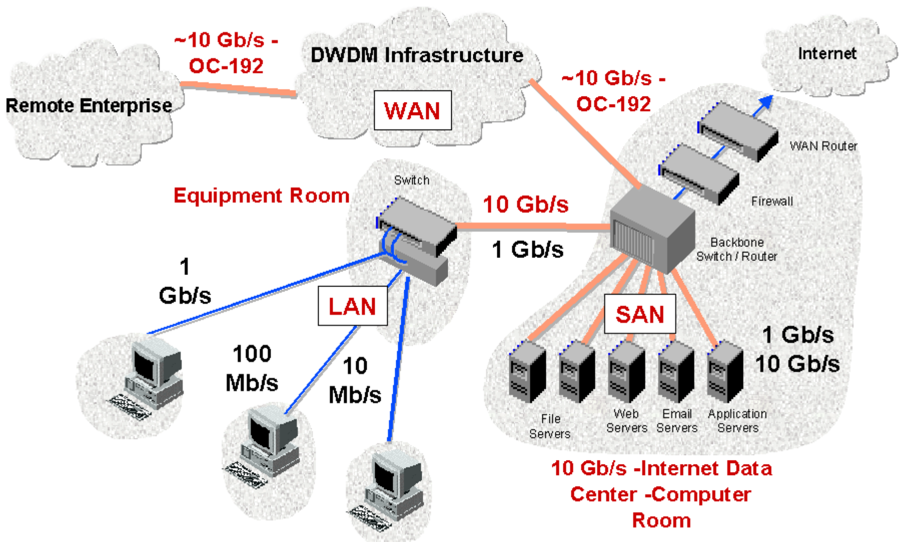
So although some might argue that today’s installed base of 10/100BASE-T makes planning for 10 Gb/s LANs a little premature, informed network managers are recognizing that emerging technologies such as gigahertz clock-rate workstations, gigabit LANs, and ‘bit-heavy’ multimedia applications will be realities in their networks, possibly sooner than later. Forward-thinking managers will want to consider 10 Gb/s LAN technologies today in order to ensure that their networks have the capacity and performance required to allow a graceful and rapid migration to these new technologies when required.

In the following pages, we will review the latest 10 Gigabit Ethernet technologies and standards. We will have a look at some key market information that will help us through the decision making process. Finally, we will zoom-in on the crucial design factors and potential solution options. Occasionally, the information will flow in a Question and Answer format, which becomes easier to follow and much clearer to the reader.

The Technologies

With several media and multiple technologies to choose from, the network upgrade paths for enterprise and service provider network managers are numerous. For enterprise LANs, 10 Gigabit Ethernet will enable network managers to scale their Ethernet networks from 10 Mb/s, 100 Mb/s or 1000 Mb/s to 10000 Mb/s, while leveraging their investment in Ethernet as they increase network performance. As a rule of thumb, it is important to keep in mind that the networking speed in the backbone should to be at least 10 times higher than the speed to the desktop. This allows the minimization of the bottleneck effect.

For service provider metropolitan and wide-area applications, 10 Gigabit Ethernet will provide high performance, cost effective links that are easily managed with familiar Ethernet tools. 10 Gigabit Ethernet matches the speed of the fastest technology on the WAN backbone, OC-192, which runs at approximately 9.6 Gb/s.



Note: DWDM: Dense Wave Division Multiplexing

Figure 1: Ethernet Enterprise Network -LAN/WAN/SAN

In the Premise environment, an emerging network architecture trend is the creation of data centers, where you find large concentrations of ultra-high performance devices (servers, routers, enterprise hubs, etc.) in a relatively limited area. With the more and more popular deployment of data centers, the need to implement a 10 Gigabit ready infrastructure is no longer an option, but a necessity!

The evolution of increasingly demanding network application technologies (see Figure 2) has led us from the use of earlier LED technologies to faster but more expensive laser-based technologies, to today's Vertical Cavity Surface Emitting Lasers (VCSELs), which provide the benefits of laser performance at comparatively lower cost.

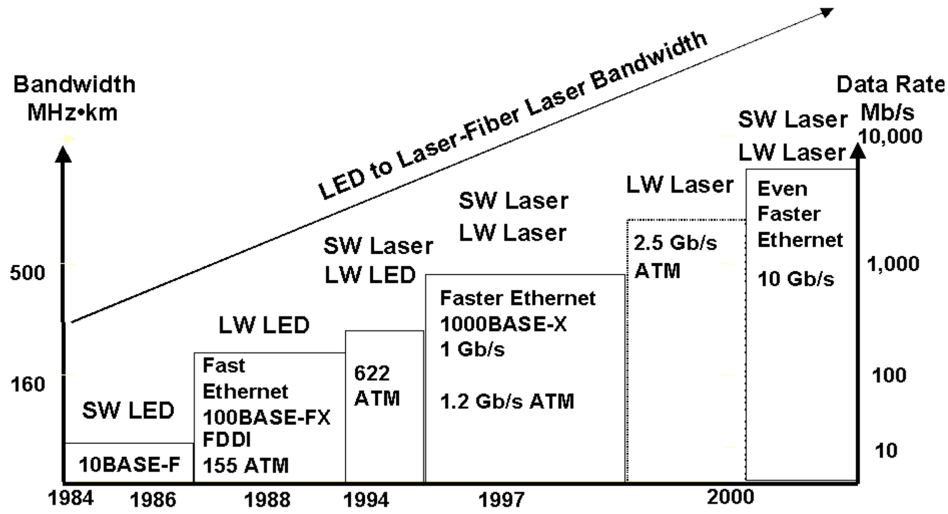


Figure 2: Fiber Bandwidth Evolution

As shown in figure 2, the light emitting diodes (LED) technologies have a switching limit of about 600 Mb/s where the limit for laser based technologies has yet to be reached.

<u>Some of the VCSELs' challenges…</u>

VCSEL technology, while bringing laser performance at lower cost, is not without certain challenges. Significant among these is the requirement for optical fiber cabling that provides the optical properties necessary to capitalize on VCSEL emitter technology. To better understand these and other technical hurdles lying ahead for 10 Gb/s networking and the associated physical layer, it is necessary to review some fiber optic basics.

Looking into the testing issues, most of the multimode fiber bandwidth characterization to date has been done using Overfill Launch LED based (OFL) methodology which uses all the modes (or light paths) available in the fiber strand. Laser type transmitters (e.g., VCSELs) use only a few of these modes located near the center of the fiber. Figure 3 illustrates the difference in light propagation for various light sources launched into the core of a fiber.

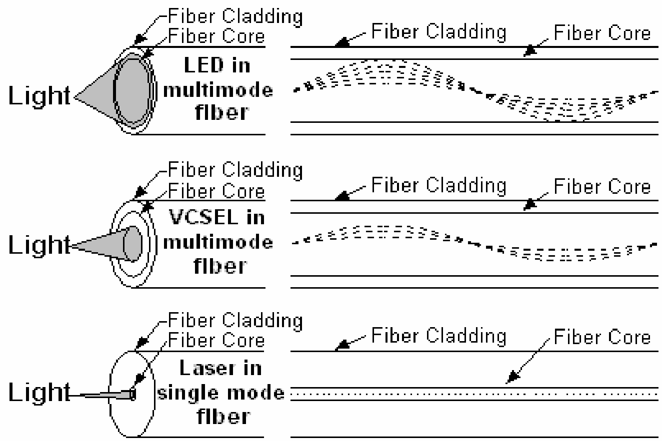


Figure 3: LED and laser technologies

LEDs disperse light in a pattern wider than the core diameter of the fiber, which overfills the fiber core. For laser technology, the light is dispersed only in the middle of the fiber core due to the precision of the launch.

A VCSEL launches light in a pattern that is contained within the core of the fiber. Because the core is not fully filled with light, less modal dispersion is created and the amount of information that can travel on the fiber tends to be increased, depending on the properties of the fiber.

On the fiber side…

During the multimode fiber manufacturing process defects in the index profile can occur. Ideally, the fiber refractive index should have a smooth parabolic shape.

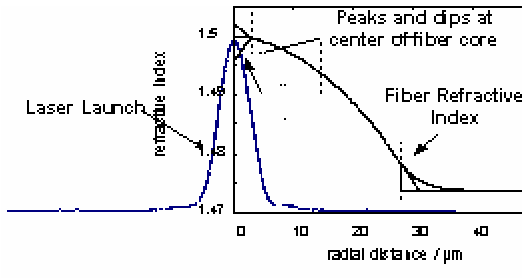


Figure 4: Laser launch and fiber refractive index

The laser launch, which is narrower than the LED, is more affected by the peaks and dips in the fiber refractive index. The peaks or dips in the refractive index at the center of the fiber core result in the most severe bandwidth degradation. The defects introduce a difference in delay between mode groups (see Note 1) called Differential Mode Delay (DMD), and results in a degradation of the fiber bandwidth. DMD is somewhat like delay skew in copper cables.

Note 1: Basic fiber parameters

$v_1 = c / n_1$

v_1: Speed of light in the fiber medium path
c: Speed of light in a vacuum
n_1: Refractive index of the fiber medium path

Figure 5 (below) clearly illustrates the distortion caused by DMD. Lower modes (or light paths), closer to the center of the fiber core, will travel slower than the higher modes resulting in an incoherent blur of light pulses at the receiving end. This results in the inability to differentiate between the “On/Off” states (or ones and zeros) for the photodetector.

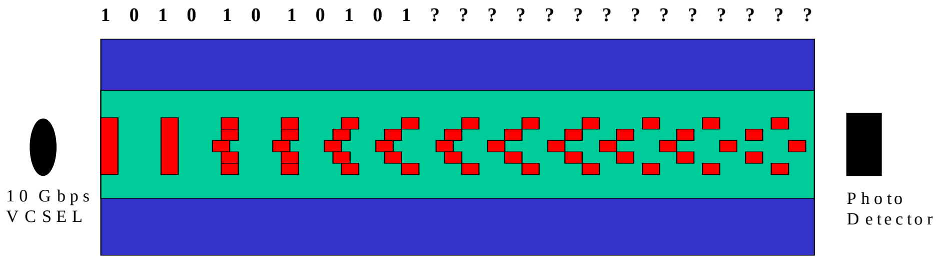


Figure 5: Conventional fiber Differential Mode Delay (DMD) phenomenon

An important breakthrough:

Optimizing the fiber manufacturing process to eliminate this problem has been accomplished with a new generation of multimode fibers where DMD response is flat and narrow, making the received pulse look as one energy peak easily detectable by the receiver. This new fiber is also compatible with existing LED based network devices.

Standards Update

Status of IEEE Ethernet

The 802.3ae Task Force developed and published in June 2002 an industry standard for 10 Gigabit Ethernet over optical fiber cabling systems. Today, the integral 10 Gigabit Ethernet standard is now part of the published Ethernet Standard 802.3-2005.

There are a number of available options that will support 10 Gb/s Ethernet over optical fiber. All of them are laser based technologies as described in Table 1.

Physical Layer Specification	Description	Fiber type	Number of wavelength(s)	Transmitter type
10GBASE-SR	850 nm Serial LAN	Multimode	One	VCSEL
10GBASE-SW	850 nm Serial WAN	Multimode	One	VCSEL
10GBASE-LX4	WWDM* LAN	Multimode	Four	Laser
10GBASE-LW4	WWDM* WAN	Multimode	Four	Laser
10GBASE-LR	1310 nm Serial LAN	Singlemode	One	Laser
10GBASE-LW	1310 nm Serial LAN	Singlemode	One	Laser
10GBASE-ER	1550 nm Serial LAN	Singlemode	One	Laser
10GBASE-EW	1550 nm Serial LAN	Singlemode	One	Laser

*:The four wavelengths of WWDM (Wide Wave Division Multiplexing) are 1269-1282.4 nm, 1293.5-1306.9 nm, 1318-1331.4 nm, 1342.5-1355.9 nm.

Table 1: Physical Layer Specification Technologies

The serial PMD uses one set of transmitter/receiver (transmission over one wavelength for each fiber) where any type of multiplexing technologies involves a number of sets of transmitter/receiver. In the case of 10GBASE-LX4/LW4, 4 sets (transmission over four wavelengths for each fiber) are required for the implementation.

Status of TIA/EIA

In parallel, the Telecommunications Industry Association (TIA) worked on a general specification for a next generation fiber (Table 2). Addendum 1 to the ANSI/TIA-568-B.3 ("Optical Fiber Cabling Components Standard") was created and published in April 2002. This addendum provides additional specifications for multimode optical fiber cabling optimized for laser operation at 850 nm in support of serial transmission at 10 Gb/s data rates for distances up to 300 meters.

Also, Addendum 3 to ANSI/TIA-568-B.1 was created and published in February 2003 to update the supportable distances and channel attenuation for optical fiber applications by fiber type.

To tie everything together, addendum 4 to ANSI/TIA-568-B.1 was created and published in February 2003. This addendum was created to recognize the use of the 850nm laser-optimized 50/125 μm in commercial environments.

Table 2 provides information on the 850 nm laser-optimized 50/125 micron multimode fiber cable.

Optical fiber cable type	Wavelength (nm)	Maximum attenuation (dB/km)	Minimum information transmission capacity for overfilled launch[1] (MHz•km)	Minimum information transmission capacity for laser launch (MHz•km) [1,2]
850nm laser-optimized 50/125 μm per TIA-492-AAAC	850	3.5	1500	2000
	1300	1.5	500	Not required

NOTE
1. The information transmission capacity of the fiber, as measured by the fiber manufacturer, can be used to demonstrate compliance with this requirement.
2. The laser launch bandwidth measurement takes into account the mode power distributions that occur within the fiber due to the effects of source characteristics and transverse offsets in connections

Table 2: Additional transmission performance specifications for Laser Optimized 50/125 μm optical fiber cable (Reference ANSI/TIA-568-B.3-1)

Premise Wiring Physical Implementation

Channel performance and cabling topology are key considerations in both the design and implementation of all networking infrastructures. In view of this, networking standards such as Ethernet include a physical layer specification, clearly indicating the minimum cabling transmission performance required to effectively support the networking application, as well as the maximum allowable cabling distances for design purposes.

For design planning, let's start by talking about copper, believe it or not! Many users are using 10 Mbps and an increasing number of them are deploying their networks at 100 Mb/s to the desktop. Most of what is being installed today for horizontal distribution to the desktop is TIA/EIA specified category 5e cabling. Well, this cabling is designed to be Gigabit ready. Proper design planning suggests that if your horizontal cabling is Gigabit ready, your backbone cabling needs to be able to handle speeds that are a factor above, which leads to a 10 Gigabit ready infrastructure.

Unfortunately, the installed-base multimode LAN optical fiber infrastructure will not be sufficient to support 10 Gigabit Ethernet without using more expensive electronics (10GBASE-LX4). Most of what has been installed to date is the FDDI graded type (160/500 MHz-km, LED base applications) of fiber, along with some installations with better grades of multimode fiber “tuned” for Gigabit Ethernet and VCSEL technology. These fibers were not optimized (DMD) for the 10 Gigabit serial Ethernet (10GBASE-SR/SW) application.

The Table 3 summarizes distance performance characteristics of the various types of fiber currently installed or available in the market.

Fiber type	Bandwidth MHz	10GBASE-S 850 nm	10GBASE-LX4 1300 nm WWDM	10GBASE-L 1310 nm	10GBASE-E 1550 nm
Multimode					
62.5 micron	160	max. 26 m			
	200	max. 33 m			
	500		max. 300 m		
50 micron	400	max. 66 m	max. 240 m		
	500	max. 82 m	max. 300 m		
	2000	max. 300 m			
Singlemode					
10 micron	n/a	not supported	max. 10 000 m	max. 10 000 m	max. 40 000 m

Note: Links longer than specified for the same link power budget are considered engineered links.

Table 3: 10 Gigabit Ethernet distances

Relative economics

After our brief review of 10 Gb/s technologies and by referring back to Table 1, one can reasonably conclude that the more lasers (or wavelengths) that are used in a WWDM technology, the more expensive it gets. It is also known that 1300 nm laser applications are more expensive than the 850 nm VCSELs used for multimode applications. Without going into great detail, the Table 4 provides a quick overview of the relative active component costs associated with each of the different technologies.

PMD Option	300m MMF	300m nMMF	2-10 km SMF	40 km SMF	Relative Cost
850 nm serial		←→			X
1310 nm serial			←→		1.8X
1550 nm serial			←→	←→	5X
1310 nm WWDM*	←→	←→	←→		3X

*mode-conditioning patch cord required

MMF: Multimode Fiber

nMMF: new Laser Optimized Multimode Fiber

SMF: Singlemode Fiber

Table 4: 10 Gb/s PMD Options - Media, Distance, and Relative Cost

With this information in mind, we can see that the least expensive 10 Gb/s technology implementation uses a single serial laser source (VCSEL) operating over multimode fiber at 850 nm.

Is 300 meters sufficient?

Looking again at Table 3, the maximum distance limit for the new 10 Gb/s 50 micron multimode fiber is 300 meters for VCSEL lasers operating at 850 nm. A number of studies have concluded that approximately 85% of LAN backbones can be accommodated within this distance (see Figure 6).

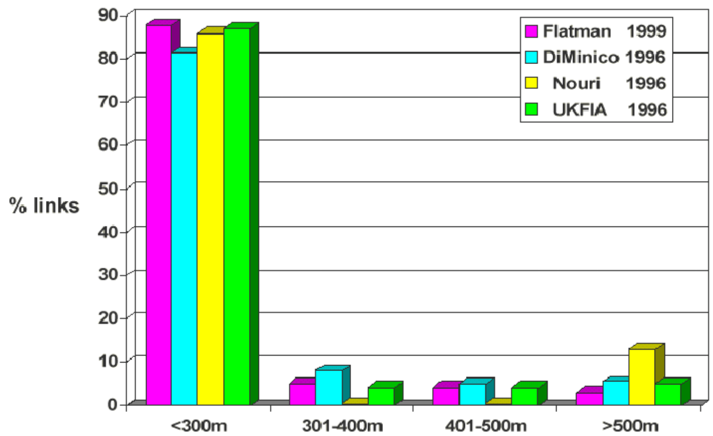


Figure 6: Installed Length Distribution in Building Backbones (Reference: contribution to IEEE)

In today's Market, one may hear about a number of performance offerings for shorter and longer distances on 850 nm laser-optimized 50-micron multimode fiber to support 10 Gb/s Ethernet. To date, the standards bodies only recognized one performance specification for this type of multimode fiber. It is the 850 nm laser-optimized 50-micron multimode fiber that supports 10 Gb/s Ethernet up to 300 meters. Although the other offerings will probably support 10 Gb/s Ethernet for a specific distance, it will impact the fiber cable design future proofing. These fibers should be used with caution.

Also, there is some talk about "engineered links". Engineered links allow longer distance than standardized distances. Although interesting, this avenue is a challenging solution. A high level of customization and expertise is required since longer distance are achieved based on the quality of the fiber cabling system. Not only does this solution have a high cost but, again, it may impact the fiber cable design future proofing.

What About Fiber-to-the-desktop (FTTD)?

One of the design topology options addressing FTTD is the "Centralized Optical Fiber Cabling Guidelines". Centralized Optical Fiber topology is recognized in the recently published TIA/EIA 568-B.1 standard. This topology facilitates the planning of a 62.5/125 µm or 50 µm fiber-to-the-desk cabling system utilizing centralized electronics versus the traditional method of distributing the electronics to the individual floors.

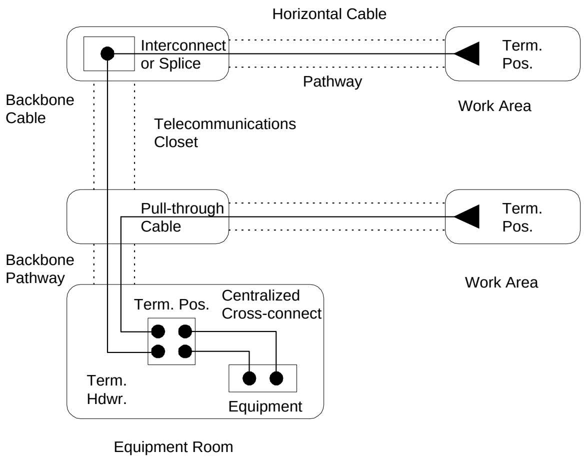


Figure 7: Centralized Optical Fiber Cabling

Under this design, the maximum horizontal cabling distance remains at 90 m (300 ft), while the maximum combined distance of horizontal and backbone cabling and both work area and cross-connect patch cords should not exceed 300 m (984 ft). By adhering to the 300 m (984 ft) distance, the 62.5/125 μm or 50 μm multimode cabling system can support future multi-gigabit applications. (1)

Therefore, a fiber cabling length of 300 meters addresses most of the application design requirements.

<u>“ Yes but, still, for the longer runs, what should I do?”</u>

Basically, there are a few options with different advantages, which have to be weighed properly:

1- Consider adding Telecommunications Rooms or using Telecommunications Enclosures
2- Consider relocating the Equipment Room and / or Telecommunications Room(s) in order to bring run lengths under 300 meters
3- Consider using repeaters or alternate technologies
4- Select singlemode fiber and associated electronics

This paper does not intend to go further in details for those specific aspects, although it is an interesting and challenging topic for designers.

<u>What about design considerations for legacy systems?</u>

With the increasing deployment of 50 micron fiber, many designers will be asking this question: Does this solution provide a good migration path taking into account the legacy systems already installed using the older types of fiber mainly being multimode 62.5 micron fiber?

The answer is that this new multimode 50 micron fiber is compatible with legacy systems (using 62.5 micron fiber interface), but a penalty of up to 5 dB in the link budget may occur. 5 dB is considerable but typically the fiber link budget for most FDDI type designs had an average of 7 or 8 dB margin, therefore allowing the backward compatibility. However, careful fiber link budget analysis is recommended.

(1) Additional information on this application can be found in the Belden’s IBDN Optical Fiber Design Guide.

Then, can I install this new 50 micron fiber with the existing 50 micron ones in the same link?

Multiple sources of information are indicating that one shall not mix the type of fiber cables with the same core diameter but with different performance specifications. In this mixing, it becomes very difficult to predict fiber cabling system performance.

The active component side:

The industry took an active part in the development of the IEEE 802.3-2005 Standard and has clearly identified the economic and technological advantage of 50 micron laser optimized fiber as the preferred option for the LAN segment.

It is comforting to know that this technology is not a proprietary one, eliminating most application risks factors.

10 Gb/s Fiber Link Budget

At this point, we have identified and answered many concerns about the technologies, the topologies and the potential impact on legacy systems. What about the 10 Gigabit Ethernet fiber link budget and connectivity specifications?

When designing a fiber cabling system, it is important to ensure that the total end-to-end attenuation of the passive fiber link is well within the operating parameters of the optical electronics to be used. If the end-to-end attenuation exceeds the difference between the strength of the transmitter and the sensitivity of the receiver, no signal will reach the far end of the fiber link.

The formula for calculating the end-to-end attenuation of a fiber link is as follows:

Attenuation = Fiber Loss + Connector(s) Loss + Splice(s) Loss

The information in table 5 is extracted from addendum 3 of ANSI/TIA-568-B.1. It provides the maximum channel attenuation to respect when designing an optical fiber cabling system.

Applications	**Wave length (nm)**	**Maximum channel attenuation (dB)** from ANSI/TIA/EIA 568-B.1 and IEEE 802.3-2005			
		62.5μm [1]	**50μm** [3]	**850 nm Laser-Optimized 50/125 μm**	**Singlemode**
10GBASE-S [6] (10 Gigabit Ethernet)	850	2.5 [2]	2.3 [4]	2.6	-
10GBASE-L [6] (10 Gigabit Ethernet)	1300	-	-	-	6.0
10GBASE-E [6] (10 Gigabit Ethernet)	1550	-	-	-	11.0
10GBASE-LX4 [6, 7] (10 Gigabit Ethernet)	1300	2.5	2.0 [5]	2.0	6.6

1. Application specifies 62.5 μm fiber with 200/500 MHz-km bandwidth at 850 nm.
2. For 62.5 μm fiber IEEE specifies 2.6 dB for 160/500 MHz-km modal bandwidth and 2.5 dB for fiber with 200/500 MHz-km modal bandwidth.
3. Application specifies 50 μm fiber with 500/500 MHz-km bandwidth at 850 nm.
4. IEEE 10GBASE-S specifies for 50 μm fiber 2.2 dB for 400/400 MHz-km modal bandwidth and 2.3 dB for 500/500 MHz-km modal bandwidth.
5. IEEE 10GBASE-LX4 specifies for 50 μm fiber 2.0 dB for 400/400 MHz-km modal bandwidth and 2.0 dB for 500/500 MHz-km modal bandwidth
6. This is a laser-based application. When not so noted, multimode applications are LED-based.
7. Mode launch conditioning patch cord may be required to obtain the maximum distance when using 62.5 μm fiber. A mode launch conditioning patch cord is a cord that focuses light in a specific area in the core of the fiber. This cord allows the distribution of the light in a multimode fashion to achieve optimum distances. For 10GBASE-LX4, IEEE recommends the use of a mode launch conditioning patch cord for all multimode fiber links.

Table 5: Worst case link power budget and penalties for 10 Gigabit Ethernet multimode applications.

Typically, two mated pairs (maximum of 0.75 dB per pair) are allowed in a standard fiber optic cabling link design, which are taking 1.5 dB off that budget, and this reinforces the need for the new specified fiber (identified as “850 nm Laser-Optimized 50/125 µm” in Table 5). The Standard only allows a 2.6 dB link power budget for that specific fiber. This leaves 1.1 dB for the fiber cable and patch cords loss, which equates to 300 meters.

It is important to note that because of fiber cable’s DMD properties (refer to “The Technologies” section), improving on components’ insertion loss will not provide additional cabling length within the power budget. However, it will give the designer far more flexibility in the number of connections/splices allowed.

Since the 10 Gigabit Ethernet fiber link budget is much tighter (most of us remember the good old 12 dB budget which could accommodate virtually any design and installation deviation possible!), the design options for 10 Gb/s Ethernet are very limited with the traditional cable and field installable connectors which will generally meet the budget restrictions limiting the connections to two mated pairs.

But for the numerous instances where real life requirements (rapid implementation, disaster recovery, physical design limitations, redundancy paths, corporate management demands, etc.) demand an effective and efficient solution, we need alternatives.

An interesting approach is the pre-terminated or pre-connectorized offering (pigtails, assemblies, multiple fiber MPO products) which can guarantee you controlled performance and high reliability without the variability often found in field connectorized installations.

<u>One may have heard about 10GBASE-LRM. What is it?</u>

At the time of printing this document, IEEE is working on an amendment to 802.3-2005 on 10GBASE-LRM. Based on the Ethernet history, when we see 10GBASE, we know that it is about the 10 Gigabit Ethernet application. Just like in 10GBASE-SR,10GBASE-LR and 10GBASE-ER, this new technology uses the same single-source encoding technique as the 10GBASE-R family of physical layer implementation, and it uses the longest wavelength for multimode fiber, 1300 nm.

The original intent of this amendment was to propose a less-expensive alternative to 10GBASE-LX4 – another way to support 10 Gigabit Ethernet over “FDDI-grade” fiber - 62.5-micron fiber with a bandwidth of 160/500 MHz-km. What exactly does this mean? It means that IEEE is trying to extend the life of old, installed-based fiber cabling infrastructure by using equipment that will compensate for the limitations of the fiber itself. But there are significant differences between 10GBASE-LX4 and 10GBASE-LRM. First, instead of using four sources to create four wavelengths, 10GBASE-LRM will use only one source and one wavelength, which in turn makes the 10GBASE-LRM equipment less expensive than the 10GBASE-LX4 (but still more expensive that 10GBASE-SR). Secondly, there is a length limitation. While the 10GBASE-LX4 application will support 300 m on this fiber type, the serial 10GBASE-LRM will support a maximum channel length of only 220 m at 1300 nm. Of course, compared to a maximum channel length of 26 m for 10GBASE-SR at the 850 nm, this solution is more interesting. But keep in mind that it does not meet the 300 m distance established for TIA cabling.

The design aspect of the optical fiber cabling network will require some comparison of the actual cost of the active equipment (since it is using the wavelength of 1300 nm) and on the cabling infrastructure due to the channel length and budget limitations. In some cases, it may be interesting to select this option, in other cases; it may be more appropriate and less costly to simply change the optical fiber cabling for a new version, as discussed earlier in this document.

If 10GBASE-LRM is of interest, table 6 will be helpful. But remember, this information was extracted from a draft document - it is still subject to change.

Multimode fiber type	Bandwidth (MHz)	Maximum length supported	Channel insertion loss budget [2]
62.5 micron	160 [1]	max. 220 m	1.9 dB
	200	max. 220 m	1.9 dB
50 micron	400	max. 120 m	1.7 dB
	500	max. 220 m	1.9 dB
	2000	max. 220 m	1.9 dB

1. The 62.5 micron fiber with a bandwidth of 160/500 MHz-km is also referred as “FDDI-grade” optical fiber.
2. The channel insertion loss budget includes the cable attenuation and 1.5 dB for 2 mated-pair connectors.

Table 6: Additional information on maximum length supported and channel insertion loss budget for 10GBASE-LRM (reference: IEEE draft 802.3aq/D1.0-February 2006).

Note: Mode conditioning patch cords may be required to obtain the maximum distance when using 62.5 μm fiber. A mode conditioning patch cord is a cord that focuses light in a specific area in the core of the fiber. This cord allows the distribution of the light in a multimode fashion to achieve optimum distances.

What is the best way to field test optical fiber cabling systems?

Even today, there are still some debates on how to field test optical fiber cabling system. There are three (3) standardized different methods available. Three different methods mean difference in results obtained. For efficient and accurate testing results in premises environments, Belden proposes the use of “Method B, One Reference Jumpers” as per ANSI/TIA/EIA-568-B.1 and TIA TSB-140.

Various types of testing equipment are available on the market, such as an optical loss test set (OLTS), a visual fault locator (VFL) set or an optical time domain reflectometer (OTDR).

- Optical loss test set (OLTS): The OLTS consists of a light source and an optical power meter. The main function of this equipment is to measure the optical power or loss.
- Visual fault locator (VFL) or tracer: The VFL is a red laser source; the tracer is an LED source. Either instrument can be used to trace fibers and troubleshoot faults on optical fiber cables. The main function of this equipment is to check continuity of the fiber, as well as to identify fibers and connectors in patch panels or outlets.
- Optical time domain reflectometer (OTDR): The OTDR is a more sophisticated measurement instrument. It uses a technology that injects a series of optical pulses into the fiber under test and analyses the light scattering and the light reflection. This allows the instrument to measure the intensity of the return pulse in functions of time and fiber length. The OTDR is used to measure the optical power loss and the fiber length, as well as to locate all faults resulting from fiber breaks, splices or connectors. For troubleshooting, the OTDR is recommended.

Here are some examples of the testing guidelines that promote efficient and accurate testing:

- Clean all connections and adapters at the optical test points prior to taking measurements
- The light source or OTDR (optical time domain reflectometer) used for multimode testing must operate within the ranges: 850 ± 30 nm and 1300 ± 20 nm.
- Test jumpers must be of the same fiber core size, performance and connector type as the cable system (e.g. 50/125 µm FX2000 jumpers for a 50/125 µm FX2000 optical fiber system) and shall be one to five meters long.

For additional information on field-testing optical fiber cabling system, refer to Belden's Optical Fiber Design Guide and the Acceptance Testing Notes Guidelines.

Optical Fiber Structured Cabling Solutions

In order to address all the previously mentioned issues and concerns about 10 Gb/s implementation, it is necessary to choose an experienced manufacturer who can provide quality products, support and knowledge to its partners, and reliable, proven solutions to its customers. A manufacturer who understands that the cabling system is the critical foundation of the customer's networking strategy.

Customers should look to a manufacturer with a history and reputation for technology leadership; an innovator who understands the technology challenges of optical networking infrastructure and has responded with complete, easy to implement high performance end-to-end optical fiber solutions.

Equally important, customers should expect their preferred optical networking solution to be fully supported by the manufacturer through a comprehensive documentation library including Design and Application Guides; Installation, Testing and Troubleshooting Manuals; and, Product Catalogs and Reference Guides to assist the customer in every phase of their system selection and implementation. Customers should also expect that the manufacturer's authorized business partners have been fully trained and qualified by the manufacturer to ensure that the system is implemented in full compliance with the manufacturer's recommendations to ensure optimal performance and reliability.

Belden is proud to offer its Fiber*Express* System solutions which address each of these requirements. The Fiber*Express* System is more than a simple assemblage of optical fiber products. It is a fully integrated optical fiber solution that provides a new approach to the methodology of fiber optic cabling; eliminating the problems traditionally associated with optical fiber networking. The Fiber*Express* System reduces conceptual complexities, simplifies installation procedures, reduces installation time and increases installation quality. These benefits combined with the advanced performance characteristics of the Fiber*Express* System to provide customers with cost-effective and reliable solutions for their high-performance optical networking needs.

Belden's history of technology leadership in communications cabling spans more than 100 years, and our continuing investment in research and development programs ensures our position as a leading provider of innovative products and system solutions. Unlike many manufacturers who must form alliances in order to provide all the products required for complete end-to-end cabling solutions, Belden conceives, engineers, and manufactures the complete range of cabling and connectivity products required to deliver fully integrated and tested end-to-end cabling systems solutions in both UTP and optical fiber media.

Belden's support tools and programs are considered industry benchmarks, providing customers with the industry, technology and product information that they require to make informed decisions regarding their network cabling infrastructures. Additionally, Belden offers a global network of authorized installation contractors; experts in their field who have been fully trained on the design, installation and maintenance of Belden's complete line of structured cabling system solutions.

Conclusion

This white paper discussed the current status of 10 Gigabit Ethernet and examined the technologies currently available to support this application today. Although 10 Gb/s Ethernet is a demanding application, the requirements can be narrowed down to a few critical issues, including:

a- The fiber cabling type and the performance at a specified wavelength: Attenuation, bandwidth and bandwidth measurement specification.
b- The network topology including operating distances and numbers of connector's i.e., the optical link loss budget.
c- The implementation of a cabling design that is compatible with LED and laser-based Ethernet network devices, which will allow the integration of current LED based 10 Mb/s and 100 Mb/s networks and laser-based 1 Gb/s and 10 Gb/s networks.

The 10 Gigabit Ethernet Standard for optical fiber cabling system has been published since June 2002 and enough solid information is available to make sound technical and economical decisions today. The new and improved 50 micron laser optimized fibers are more widely available, and network managers should consider the use of these optimized fiber optic cables as the most important element in their premise LAN cabling decisions and design strategies.

Although 10 Gigabit Ethernet and 10 Gb/s optical fiber networking may seem irrelevant to those with 10 Mb/s LANs, a more strategic view would indicate otherwise. CPU and IC clock rates have broken the multi-gigahertz barrier, user applications continue to demand higher and higher bit rates requiring more and more bandwidth, and well-defined standards are now in place for both Gigabit Ethernet and gigabit cabling systems. History tells us that these conditions will quickly create the competitive scenario that will bring reliable, cost-effective solutions to the marketplace at this technology level. In turn the business case for gigabit systems and networking will become increasingly easier to justify, resulting in broad acceptance and implementation in many market segments. Observing the 10: 1 backbone to horizontal design rule would indicate that 10 Gb/ps optical networking in LAN backbones is not so much a question of 'if, but 'when'.

Given this scenario, the case for strategic consideration, today, for 10 Gb/s optical fiber networking may have been best put forward by independent industry analysts The Gartner Group, in their statement, "The wiring plant is arguably the most important part of the network. Spend the time and money needed to ensure that what is installed today will be able to support the environment well into the future….Keeping in mind that upgrades to wiring systems can cost up to three times the initial installation expense."

The author:

Mr. Richard Perron is a IBDN FiberExpress Solutions Product Line Manager for Belden. Mr Perron has over 18 years experience in the Telecommunications and structured cabling industry.

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For further information, please visit our Web Site www.belden.com, or contact:

Division Headquarters–Americas
2200 U.S. Highway 27 South
Richmond, IN 47374
Phone: 765-983-5200
Inside Sales: 800-235-3361
Fax: 765-983-5294
info@belden.com
web: www.belden.com
Customer Service:
800-BELDEN-1 (800-235-3361)

CANADA
Cobourg
130 Willmott Street
Cobourg, Ontario K9A 4M3
Canada
Phone: 905-372-8713
Fax: 905-372-6291
salescobourg@belden.com

Montreal
2345 Boulevard des Sources
Pointe Claire, Quebec
Canada H9R 5Z3
Phone: 800-262-9334
Fax: 514-822-7968
ibdn.info@belden.com

LATIN AMERICA AND THE CARIBBEAN ISLANDS
Regional Office
6100 Hollywood Boulevard
Suite 110
Hollywood, Florida 33024
Phone: 954-987-5044
Fax: 954-987-8022
salesla@belden.com

Mexico
Insurgentes Sur 800, Piso 9
Colonia del Valle
03100 Mexico, D.F.
Mexico
Phone: 5255-5523-7733
Fax: 5255-5528-8077
salesmex@belden.com

Brazil
Av. Rebouças
1023 — 4 Andar
05401-300 Sao Paulo, SP Brasil
Phone: 5511-3061-3099
Fax: 5511-3061-3752
salesBRZL@belden.com

ASIA/PACIFIC
Australia
Level 10
369 Royal Parade
Parkville, Victoria 3052
Australia
Phone: 613-9341-0900
Fax: 613-9347-8274
australia.sales@belden.com

Beijing
Rm 1015
Office Tower Beijing Capital
Times Square
No. 88 West Changan Ave.
Beijing 100031
People's Republic of China
Phone: 8610-8391-5181-3
Fax: 8610-8391-5186
hongkong.sales@belden.com

Hong Kong
Unit 4401, 44F
Cosco Tower
Grand Millennium Plaza
183 Queen's Road Central
Hong Kong
Phone: 852-2955-0128
Fax: 852-2907-6933
hongkong.sales@belden.com

India
16th Floor, Tower B,
Unitech Cyberpark
Sector 39, Gurgaon
Haryana, India
Phone: 91-124-4509999
Fax: 91-124-4509900
india.sales@belden.com

Shanghai
Unit 2605
Harbour Ring Plaza
18 Xi Zang Zhong Road
Shanghai
200001
People's Republic of China
Phone: 8621-5385-3355
Fax: 8621-6249-0879
hongkong.sales@belden.com

Singapore
101 Thomson Road
#21-01 United Square
Singapore 307591
Phone: 65-6251-8211
Fax: 65-6251-5010
singapore.sales@belden.com

EUROPE/AFRICA/MIDDLE EAST
France
Immeuble le Cesar
20, Place Louis Pradel
69001 Lyon
France
Phone: 33-472-109-990
Fax: 33-478-298-409
venlo.salesinfo@belden.com

Italy
Via Paracelso, 26
Centro Direzionale Colleoni
Palazzo Cassiopea Ingr. 3
20041 Agrate Brianza (MI)
Italy
Phone: 39-039-656-0911
Fax: 39-029-656-0929
venlo.salesinfo@belden.com

Africa/Middle East
Dubai Internet City
Building One, Office 216
Dubai
United Arab Emirates
Phone: 97-14-391-0490
Fax: 97-14-391-8775
sales@belden.ae

The Netherlands
Division Headquarters – Europe
Edisonstraat 9, Postbus 9
5928 PG Venlo, 5900 AA
The Netherlands
Phone: 31-773-878-555
Fax: 31-773-878-448
venlo.salesinfo@belden.com

United Kingdom
3000 Manchester Business Park
Aviator Way
Manchester M22 5TG
United Kingdom
Phone: +44-161-266-1115
Fax: +44-161-266-1339
venlo.salesinfo@belden.com