



The premises and local area network (LAN) markets are strongly driven by standards and system capital costs. Until recently, the data rates in LAN and premises systems have traditionally been < 1 Gb/s and, as a consequence, the lowest cost and therefore most widely deployed solution was to use standard multimode fiber with light-emitting diodes (LEDs) as light sources. In time, as LAN and premises networks required 1 Gb/s data rates, the limited modulation bandwidth of LEDs became an issue. Then 850 nm vertical cavity surface emitting lasers emerged (VCSEL). VCSELs offered capability to operate at over 10 Gb/s and facilitated a low-cost solution for multimode fiber to upgrade to 1 Gb/s. VCSEL technology combined with the availability of laser-optimized multimode fiber further extends the bandwidth performance and reach capability of multimode fiber systems.

Legacy multimode fiber can exhibit non-smooth refractive index profiles, including “dips” along the center line of the fiber core; this localized imperfection negatively affects the bandwidth performance of the fiber, particularly when used with lasers. In laser-optimized multimode fibers, advanced manufacturing techniques are used to remove the perturbations in the refractive index profile and enhance the bandwidth performance of the fiber.

Laser-optimized multimode fibers, when used in conjunction with high data rate VCSEL technology, provide an economically feasible 10 Gb/s system solution for the cost-sensitive premises and LAN markets. Unlike systems using laser-optimized fiber, legacy premises and LAN systems, originally designed for 10 and 100 Mb/s data rates, operate over standard multimode fiber which is optimized for sub-gigabit LED operation. These legacy systems will not provide 10 Gb/s performance without system upgrades.

CORNING

**10 GB/S SOLUTIONS FOR MULTIMODE
FIBER PREMISES NETWORK**

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There are three main standardized options for providing 10 Gb/s capability in multimode fiber-based premises and LAN networks. They are 10GBASE-SR, 10GBASE-LX4 and 10GBASE-LRM. 10GBASE-SR is a simple 10 Gb/s solution that utilizes the benefits of low-cost VCSELs and high-performance laser-optimized multimode fiber to provide a cost-effective and uncomplicated solution for LAN and premises networks. 10GBASE-LX4 and 10GBASE-LRM are more expensive 10 Gb/s solutions that enable the upgrade of legacy multimode fiber to 10 Gb/s operation.

The 10GBASE-SR Solution

The introduction of 850 nm VCSELs provided a low-cost transceiver capable of providing a 1 Gb/s solution for premises systems. In time, continued improvement in manufacturing VCSELs enabled a solution for 10 Gb/s premises systems, using laser-optimized 50 μm core multimode fiber as shown in Figure 1. The 10GBASE-SR solution is a simple, low cost and elegant solution that uses 10 Gb/s capable VCSELs and laser-optimized OM3 multimode fiber, such as Corning[®] InfiniCor[®] SX+ and eSX+. In order to guarantee system performance over the fiber medium, it is necessary that the bandwidth of the deployed fiber be characterized with a laser-based measurement as defined by TIA/EIA-455-220A, such as is done with the minEMBc method.



Figure 1: The 10GBASE-SR system for 10 Gb/s transmission that uses a VCSEL transmitter and 50 μm laser-optimized multimode fiber.

The 10GBASE-LX4 Solution

10GBASE-LX4 provides an alternative for upgrading multimode premises network data rates to 10 Gb/s through the use of wide wave division multiplexing (WDM) technology. The 10GBASE-LX4 solution requires the use of four DFB lasers, each operating at 3.125 Gb/s and at wavelengths between ~ 1260 nm and 1320 nm, as well as four receivers, a multiplexer, and a demultiplexer, resulting in significant capital expenditure requirements. The basic schematic of a 10GBASE-LX4 system is shown in Figure 2. This solution enables 10 Gb/s data rates over 300 m of legacy multimode fiber with a specification of 160/500 MHz.km and a 62.5 μm core, as well as 10 Gb/s over 50 μm core fiber. However, it is not possible to reliably guarantee system performance over legacy multimode fiber as its bandwidth will have been measured using an

over-filled launch (OFL) method that is suitable for LED operation but inappropriate for characterizing laser operation. Another disadvantage of 10GBASE-LX4 is that along with the high active components cost, the 10GBASE-LX4 solution cannot be supported on small form factor transceiver designs like XFPs because of the heat load associated with running four lasers. Some 10GBASE-LX4 solutions have been deployed to upgrade existing premises networks, using XENPAK and X2 form factors, but these limit the blade density to 4-6 ports.

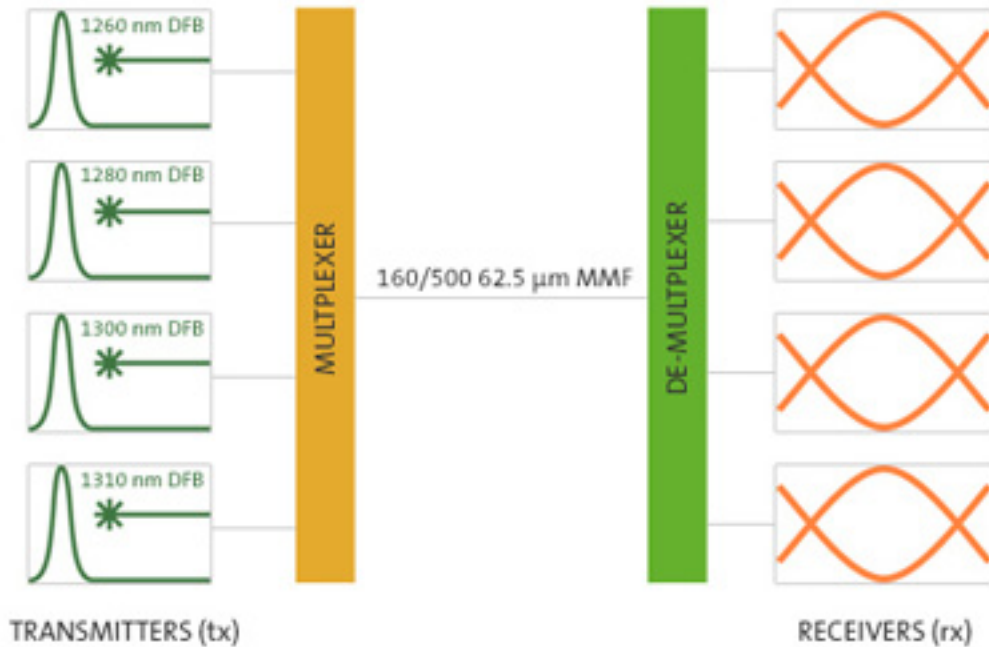


Figure 2: Schematic of 10GBASE-LX4 solution.

The 10GBASE-LRM Solution

A third alternative to the 10GBASE-SR and 10GBASE-LX4 solutions, is 10GBASE-LRM. This solution uses a 1310 nm Fabry Perot laser and an electronic dispersion compensation (EDC) chip at the receiver end of the network to deconvolve the 10 Gb/s signal to open the eye diagram and enable higher data rates as shown in Figure 3. The use of EDC to achieve higher bit rates over installed multimode fiber builds on the experience gained with the earlier 1000BASE-LX solution for 1 GbE as well as the 10GBASE-LX4 solution for 10 GbE. Like 10GBASE-LX4, 10GBASE-LRM uses more costly lasers but can be used to provide 10 Gb/s capability over legacy LED optimized multimode fiber. However, once again, the bandwidth of these fibers will have been measured with the inadequate OFL method, making it difficult to obtain reliable performance guarantees. With 10GBASE-LRM there is a trade-off at a given target distance between the bandwidth of the fiber (which depends on the fiber and the launch conditions) and the complexity of the EDC chip. Modeling suggests that the fiber bandwidth required for 10GBASE-LRM to operate, given current EDC chip design requirements, is ~700 MHz.km, making worst-case

installed fibers that have OFL bandwidth values near the 500 MHz.km specification a challenge. Limited system testing on these types of conventional fibers has confirmed the modeling results. The approach the 10GBASE-LRM standard has taken is to allow for a secondary launch position option, so that fibers have a statistically higher (but not guaranteed) likelihood of meeting the 700 MHz.km requirement. Even given the secondary launch option, a more complex (and inherently more expensive) EDC chip is required to reliably guarantee system operation. The 10GBASE-LRM standard is expected to be approved very soon for 10 Gb/s distances of up to 220 m, as compared to the 300 m enabled by 10GBASE-SR and 10GBASE-LX4.

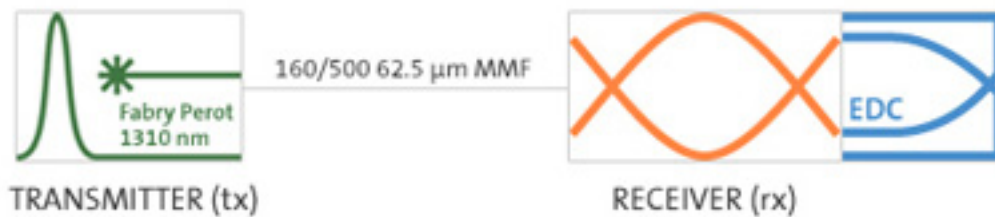


Figure 3: Schematic of a 10GBASE-LRM solution.

A summary of the main solutions for 10 Gb/s operation in LAN and premises networks is provided in Table 1.

	10GBASE-SR	10GBASE-LRM	10GBASE-LX4
Light Source	850 nm VCSEL	1310 nm FP	1310 nm DFB
Fiber Type	50 μm minEMB, ≥ 2000 MHz km	50 μm and 62.5 μm OFL 1300≥700 MHz km	50 μm & 62.5 μm OFL 1300≥500 MHz km
System Reach	300 m	220 m	300 m
Tx Form Factor	XFP, XENPAK, XPAK, X2	XENPAK	XENPAK, XPAK, X2
Cost	\$	\$\$	\$\$\$

Table 1: Summary of high data rate solutions for premises networks.

From a capital expenditure perspective, the 10GBASE-SR standard, through the use of low-cost 850 nm VCSELs, is the most attractive of the three 10 Gb/s multimode solutions discussed. However, because the system relies on VCSELs, and the light intensity pattern from a VCSEL is very different than that of an LED, 10 Gb/s VCSELs must be deployed with laser-optimized multimode fiber and, in order to guarantee fiber bandwidth performance, the fiber must have been characterized using appropriate laser bandwidth measurement techniques, like the minEMBc method.

Summary

There are a number of premises and LAN solutions available that enable 10 Gb/s data rates on both legacy and laser-optimized multimode fiber. However, the transition to 10 Gb/s data rates in LAN and premises networks ideally requires a move toward laser-optimized multimode fiber that has bandwidth specifications measured by advanced laser bandwidth measurement technique, like minEMBc. Deployment of such fiber enables the use of the lowest cost and robust 10GBASE-SR solution. 10 Gb/s solutions for legacy fiber exist but rely on more complex and therefore inherently more expensive systems. The most elegant 10 Gb/s solution for legacy fiber relies on EDC and because of the uncertainty surrounding the functionality of EDC units with legacy fibers characterized for use with LEDs, particularly for long length, high data rate applications, a laser-optimized fiber combined with 850 nm 10 Gb/s VCSELs provides the most robust, guaranteed solution for 10 Gb/s premises and LAN networks.