The Importance Of International Standards In The Evolution Of Telecommunications Networks

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Abstract

Networks and their associated technologies are fundamentally dependent on industry standards to ensure consistency and continuity among all the various elements. In this paper we discuss the overall environment of the industry standards relevant to standard single-mode fiber and their importance to the performance and evolution of optical communications networks. We devote particular focus to the most recent revisions of the definitive industry standards and explain why network operators are best served by specifying this classification of fibers in order to ensure network capabilities now and in the future.

Introduction

Optical fiber has a long history of evolutionary change, ranging from improvements in the quality of the fiber itself to significant development in the transmission systems it supports. As advancements were made in the manufacture of lower-loss single-mode fiber, and commensurate progress was made in longer-wavelength lasers and transmitters around 1300 nm, applications requiring transmission beyond just a few kilometers drove demand for single-mode fiber due to its low attenuation characteristics and dramatic reduction in distortions over distance. Later, development of transmitters in the 1550 nm window to exploit the low point of single-mode attenuation drove another shift in operating and deployment practice, particularly for longer distances. Erbium doped fiber amplifiers (EDFAs) and wavelength division multiplexing technology (WDM) were subsequently developed, leading to dramatic increases in total network bandwidth and distance capability. Those two developments then led to significant shifts in fiber design priorities, namely attenuation across the WDM operating windows and polarization mode dispersion. As WDM options continue to expand in scope and higher data rates are adopted at longer distances, attenuation and PMD are increasingly critical for network operators, to ensure that the appropriate optical fiber is chosen to support existing and emerging system technologies. Industry leading optical fiber manufacturers, in turn, ensure that fiber properties change to meet ongoing and future demands.

Industry Standards Lead Network Evolution

The optical fiber industry is well served by a detailed set of comprehensive standards, assuring at least a minimum level of product capabilities across the various manufacturers as well as rigorous objective evaluation of the relevant requirements. The standardization process for both fibers and systems deserves significant credit for fostering the growth and widespread commercialization of the evolutionary technologies described above. In most cases, practical application of networking technologies has been pre-dated by thorough evaluation in the standards organizations. Network operators have benefited over the years by regularly following the updated standards recommendations, particularly those for optical fiber, to guarantee their networks can meet the demands of current and future system capabilities.

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Standards are stable foundations jointly defined by network operators and equipment suppliers that allow for network evolution from both technological and operational perspectives. Initial concepts evolve into technologies, which then receive thorough evaluation in standards development. Commonly, the necessary reviews of technological implications in standards bodies will identify areas where future needs might arise, promoting further concept development, thus starting the cycle over again. Without industry standards, individual networks would comprise a host of proprietary technologies, rendering inter-connections between multiple networks unnecessarily complex, driving up network costs and limiting the rate at which technological evolution can occur.

Decisions based on the most recent revisions to international optical fiber standards represent one of the critical junctures in the optical network timeline, where network operators are faced with the decision to adopt optical fibers compliant with the most stringent standards recommendations or risk limiting the future capability of their long-term infrastructure investment.

Network operators have increasingly relied on the two leading international fiber and cable standards organizations, the International Electrotechnical Commission (IEC) and the International Telecommunications Union (ITU), to set the minimum requirements for fiber and cable. The ITU is an industry organization with a "demand" perspective representing end users and the IEC is an industry organization with a "supply" perspective representing system vendors, so alignment between the two standards bodies on particular specifications is indicative of broadly accepted understandings. Both the ITU and IEC continue to evolve fiber and cable requirements over time to reflect the changing needs of optical communications networks. For the most commonly deployed fiber type, standard single-mode fiber, both standards organization updated their requirements in 2000 to include not only conventional standard single-mode fiber, but also a current-generation version known inter-changeably as "reduced-water-peak", "low-water-peak" or "full-spectrum fiber." The introduction of reduced-water-peak standard ITU-T G.652.C (and subsequently G.652.D) was intended to, in the ITU's words, "…maintain the continuing commercial success of this fiber in the evolving world of high-performance optical transmission systems." For the IEC, the reduced-water-peak standard IEC 60793-2-50 B1.3 was designed to "…extend the range of possible transmission signals, using 1310 nm band power budgets, to portions of the band above 1360 nm and below 1520 nm."

The various internationally standardized fiber designations are summarized below in table 1. The relevant standard single-mode fiber standards, as noted above, are documented in ITU-T Recommendation G.652 and IEC 60793 Part 2-50.

Organization of IEC and ITU Fiber and Cable Standards
Table 1

Common Name	Previous IEC 60793-2-50 Notation (pre-2000)	Current IEC 60793-2-50 notation (post-2000)	Current ITU-T Notation
Conventional Standard Single-mode Fiber	A	B1.1	G.652.A G.652.B
Cut-off Shifted Single-mode Fiber	B	B1.2	G.654
Reduced-Water-Peak Standard Single-mode fiber	C	B1.3	G.652.C G.652.D
Dispersion Shifted Single-mode Fiber	D	B2	G.653
Non-Zero Dispersion Shifted Single-mode Fiber	E	B4	G.655.B G.655.C

A number of common parameter values are identical across the various single-mode fiber classifications, such as geometrical properties, mode field diameter, and chromatic dispersion characteristics. Where the classifications functionally differ is in attenuation with wavelength and polarization mode dispersion. Table 2 indicates the evolution of those values through the successive standard classes.

Evolution of Parameters Through Standards Designations
Table 2

	Maximum Macrobend Loss at 1625 nm (dB)	Maximum Attenuation Coefficient (dB/km)			Maximum Cabled PMD_Q (ps/√km)
		1310 nm	1383 ±3 nm	1550 nm	
ITU-T G.652.A	N/A	0.5	N/A	0.4	0.5
ITU-T G.652.B	0.5	0.4	N/A	0.35	0.2
ITU-T G.652.C	0.5	0.4	(see note)	0.3	0.5
ITU-T G.652.D	0.5		(see note)	0.3	0.2
IEC B1.1	0.5	0.4	N/A	0.3	0.5
IEC B1.3	0.5	0.4	0.4	0.3	0.5
Note: Attenuation in the 1383 nm range must be less than or equal to the value at 1310 nm after hydrogen aging.					

Since table 2 is comprehensive, addressing all parameters that have changed across the various standards recommendations, it subtly communicates a very significant point for network operators; namely, the most current ITU designation, G.652.D, is backward compatible with all previous designations. Optical fiber compliant with the specifications in ITU-T G.652.D will at least be compliant with, and in many cases be superior to, specifications in earlier designations (such as ITU-T G.652.B). Since relevant characteristics such as geometrical properties and mode field diameter are common and identical across the different designations, there is no impact on operational behavior (such as splicing) if ITU-T G.652.D and fibers compliant with earlier designations are combined in a network.

It is worth noting that the various standardized classes of standard single-mode fiber, as described in table 2, were not developed concurrently. Indeed, years passed between the introductions of some classes. Rather, the specifications evolved over time as system transmission technologies became viable and fiber manufacturing improved. A key example of this evolutionary trend is the shift from ITU-T G.652.B to G.652.C, where G.652.C includes a specification for attenuation around 1383 nm, also known as the "water-peak" region (note that IEC types B1.1 and B1.3, respectively, illustrate the same evolutionary trend). Historically, fiber manufacturers were limited to relatively high attenuation in this region due to defects introduced during the process, effectively rendering a broad swath of optical spectrum unusable. Moreover, attenuation in this region can increase over time if appropriate manufacturing procedures are not adopted. As aging induced loss increases at the "water-peak" performance at surrounding wavelengths is affected, which can measurably affect signal loss even above 1400 nm. Subsequent advancement in fiber manufacture allowed significant reduction in attenuation at the water-peak, opening the door for equipment manufactures to develop transmitters and passive devices capable of exploiting that spectral region. Standards kept pace with the fiber and system development, to ensure interoperability among different vendors and facilitate the specification process for network operators. ITU-T G.652.D represents the most comprehensive standard single-mode fiber specification, building on the low water-peak capability of ITU-T G.652.C while also reducing the allowable amount of polarization mode dispersion to ensure performance at longer distances and higher data rates. The ITU-T G.652.C and ITU-T G.652.D specifications, along with IEC B1.3, are commonly referred to as "full-spectrum" fiber due to the larger usable optical spectrum spanning the common communications wavelength range from 1310 nm to 1625 nm. While some manufacturers still produce fibers compliant with only the outdated lower-level designations (such as ITU-T G.652.A or B1.1) due to the difficulty in removing defects from the manufacturing process, multiple optical fiber manufacturers are now compliant with the up-to-date ITU-T G.652.D standard. It is also worth noting again that both ITU-T G.652.D and IEC B1.3 are completely backward compatible with all previous designations, allowing for deployment in both new and existing networks without additional integration complexity.

Coarse Wavelength Division Multiplexing (CWDM)

The most up-to-date standardized specifications for standard single-mode fiber (G.652.D and B1.3) depict the current evolutionary state of optical fiber manufacture. Beyond that, they allow for truly meaningful increases in system capabilities. The most readily apparent improvement is in the extended usability of coarse wavelength division multiplexing (CWDM). CWDM systems use uncooled distributed feedback lasers and wideband optical filters, providing pronounced advantages over their DWDM counterparts,such as lower power consumption and reduced capital and operating cost. By exploiting such system advantages, various system manufacturers suggest that CWDM allows for total system cost reductions on the order of 40% below conventional metro DWDM equipment, according to Wintergreen Research in a November 2003 report. The ease of use and low cost of CWDM has made it a popular networking option where the larger capacity of metro DWDM does not warrant the considerable cost difference. Nearly every major metro equipment manufacturer currently offers at least one product with CWDM interfaces, and some predict that CWDM equipment volume will overtake DWDM sales in the next few years. CWDM has received considerable interest from enterprises looking to build their own networks, such as storage network extensions, or as a cost-effective direct optical interface to larger carrier networks. Carriers who embrace CWDM and prepare their network for this technology are subsequently well-positioned to take advantage of this interest from potential customers.

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As suggested earlier, optical fiber standards evolved due to improvements in both fiber manufacture and system capability. As such, systems standards have similarly kept pace with technological development. CWDM technology is now standardized in two international specifications.

ITU-T recommendation G.694.2 specifies the CWDM operating wavelength grid, extending in 20 nm increments from 1271 nm to 1611 nm, including values within the water-peak region around 1383 nm. Although the standardized grid comprises 18 wavelengths, the usable range typically is cited as 16-wavelengths, avoiding use of the two lowest values (1271 nm and 1291 nm) due to excessively high attenuation.

CWDM Wavelength Grid, Specified in ITU-T G.694.2 and G.695

Table 3

Nominal Central Wavelengths (nm)	
1311	1471
1331	1491
1351	1511
1371	1531
1391	1551
1411	1571
1431	1591
1451	1611

To put the significance of this standard in context, ITU-T recommendation G.694.1 is widely considered to be one of the most significant optical networking standards to date, as it specified the DWDM wavelength grid and enabled interoperability between transmitters, receivers, and passive devices. This standardization enabled cost effective standardized components, allowing the DWDM equipment market to become economically viable ITU-T recommendation G.694.2 is now serving the same function for the CWDM market, allowing for the proliferation of standardized components and thereby lowering the cost of CWDM systems. An additional standard, ITU-T G.695, was recently ratified in late 2003. It provides detailed specifications for CWDM optical interfaces across 16 wavelengths defined by ITU-T G.694.2 (listed in table 3), further promoting the development of rigorously standardized components to reduce the cost of CWDM systems. As evidence of industry interest in CWDM, the ITU records indicate that the meeting where ITU-T G.695 was formalized had the highest participation level of any standardization meeting in the last 3 years. General industry interest in CWDM is illustrated in table 4, listing a sampling of the large number of system manufacturers who currently incorporate standardized CWDM interfaces into at least one of their product offerings. In many cases, an individual manufacturer has a large number of products supporting CWDM, frequently using interchangeable interfaces such as standardized form factor Gigabit Interface Converters (GBICs) to further reduce system cost and complexity.

Optical Networking System Manufacturers Incorporating CWDM Interfaces Into at Least One Product
Table 4

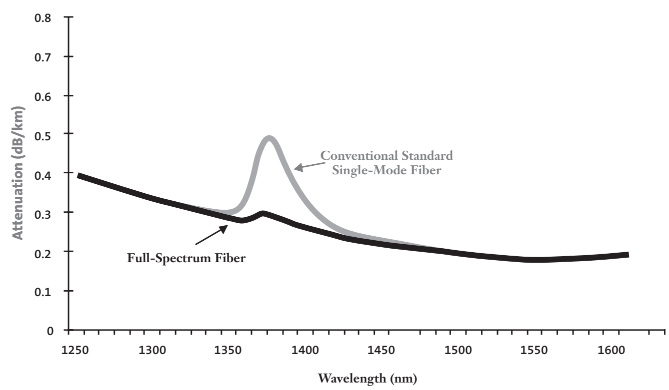
ADVA	Movaz
AFC	MRV Comm.
Alcatel	NEC
CIENA	Nortel
Cisco	Padtec
ECI Telecom	RBN
Ericsson	Siemens
Fujitsu	Sorrento
Hitachi	Tellabs
Huawei	Transmode
Internet Photonics	White Rock Net.
Marconi	

A number of CWDM-based systems currently support only 4 or 8 wavelengths, typically between 1471 nm and 1611 nm. As a result, in spite of the sizeable cost advantages, a network operator's decision to adopt CWDM rather than DWDM can be difficult due to the significant difference in total system capacity, with representative metro DWDM systems typically offering 32 wavelengths. If the full suggested 16-wavelength grid is utilized however, CWDM system capability more closely approximates the practical application requirements of most DWDM systems since very few DWDM systems are lit to full capacity. The primary factor limiting the ability to use all 16 standardized CWDM wavelengths is the relatively high attenuation of legacy standard single-mode fiber in the water-peak region. Figure 1 illustrates the difference in fiber attenuation in legacy fiber (complaint with ITU-T G.652.A, G.652.B, or IEC B1.1) and current-generation full spectrum fiber (compliant with ITU-T G.652.C, G.652.D, or IEC B1.3). System manufacturers commonly cite the high water-peak attenuation of legacy fiber as the reason for lack of full-spectrum system availability. However, a number of component manufacturers offer lasers, transmitters, and passive components (e.g., WDM mux/demux) to support the full 16-wavelength channel plan, and several system manufacturers do indeed offer complete 16-wavelength CWDM systems.

As full-spectrum fiber is increasingly deployed for new network builds and extensions, CWDM manufacturers will have obvious motivation to adopt full-spectrum system capability.

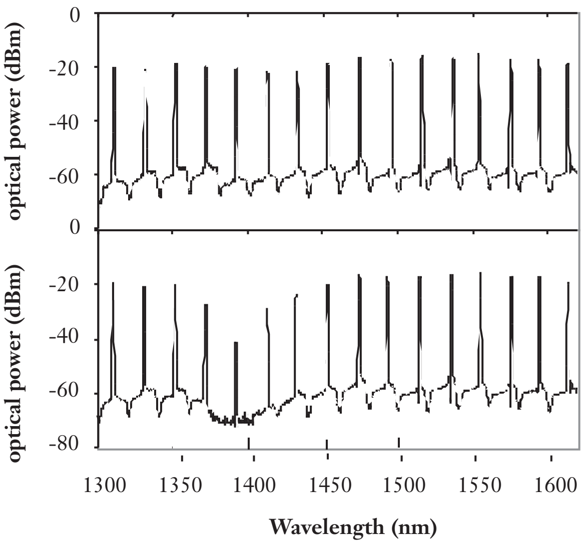
As older previously-installed legacy fibers are lit, and full-spectrum fiber is increasingly deployed for new network builds and extensions, the percentage of full-spectrum capable plant will shift to the point where all CWDM manufacturers will have obvious motivation to adopt full-spectrum system capability.

Comparison of Conventional and Full Spectrum Standard Single-mode Fiber
Figure 1



There are a number of published evaluations comparing various standards-compliant single-mode fibers coupled with 16-wavelength CWDM systems. Figure 2 illustrates one such comparison. At a representative metro distance of 50 km, the output of a full-16-wavelength CWDM system was monitored after propagation through both ITU-T G.652.D and G.652.B optical fiber. The upper graph illustrates ITU-T G.652.D fiber, showing no excess loss at 1383 nm. The bottom graph illustrates ITU-T G.652.B fiber, showing approximately 20 dB excess loss around the water-peak at 1383 nm, severely attenuating four channels between 1370 nm and 1430 nm, thus rendering them unusable.

Comparison of 16-Wavelength Full-Spectrum CWDM System Propagation Over ITU-T G.652.D Fiber (upper graph) and G.652.B Fiber (lower graph)
Figure 2



Network operators can prepare themselves and the general industry for future wide-spread full-spectrum system availability by specifying full-spectrum fiber (ITU-T G.652.D) for current fiber deployments. Moreover, with several full-spectrum systems already available, operators can immediately take advantage of the increased fiber capability. Network operators delaying the transition to full-spectrum fiber run the pronounced risk of having significant portions of their outside plant incompatible with emerging system developments as they materialize in the near future.

Network operators delaying the transition to full-spectrum fiber run the risk of outside plant incompatible with emerging systems.

High Data Rates

Beyond the increased bandwidth capability discussed above, full-spectrum fiber also guarantees other performance advantages. At higher data rates (10 Gb/s and above), especially at longer distances, polarization mode dispersion due to optical fiber and network components can severely limit system capability.

With polarization mode dispersion, the two polarization modes which carry optical power in a fiber travel at slightly different velocities. Over distance, this leads to distortion when the two modes are recombined at a receiver since one will be delayed relative to the other. This can be expressed as a time delay, described as differential group delay (DGD). DGD is determined with PMD_Q and the square root of the link distance.

Considering the long-term investment that optical fiber represents, the best rule of thumb when considering maximum future data rate requirements is to “never say never.” Even if immediate requirements don’t demand the highest available data rates, fiber deployed today must support the needs that will arise 15 and 20 years from now. Both IEC and ITU specify a maximum allowable value of PMD in cabled fiber for the various fiber designations, in the form of “PMD_Q.” This is a statistical value representing the maximum upper limit of PMD for a series of multiple concatenated fiber cables, representing the situation which would be encountered in a real world deployment. ITU-T G.652.D specifies a full-spectrum fiber with the tightest requirement for PMD_Q, at ≤ 0.20 ps/√km. The ITU recommends this as the maximum level of allowable PMD for STM-256 (40 Gb/s) transmission. A number of network operators remember all too well the difficulties encountered when moving to 10 Gb/s transmission with some fibers installed in the early 1990’s, as some manufacturers at the time had difficulty in both predicting what future PMD requirements would be and in adequately controlling their own manufacturing process; as a result, today, some links only 10 years old are simply unusable for 10 Gb/s transport. As networks evolved to longer distances and higher data rates, non-zero dispersion shifted fibers (NZ-DSF) were developed to offer very low PMD and reduce the impacts of chromatic dispersion on optical nonlinearities. This family of fibers is also compliant with a set of industry standards, namely ITU-T recommendation G.655 and IEC 60793-2 type B4. Where high data rates and longer distances are encountered and NZ-DSF is not chosen as the preferred option, G.652.D-compliant fibers become the obvious next-best choice due to PMD characteristics superior to other standard single-mode fibers.

Table 5, taken from the ITU-T G.652 Appendix 1, summarizes the recommendationson maximum allowable DGD and the corresponding link length. Particularly with 40 Gb/s transmission, it is obvious that distance capability is severely limited at higher levels of PMD. With PMD_Q at 0.5 ps/√km, as specified in ITU-T G.652.A and IEC Types B1.1 and B1.3, link distances capable of supporting 40 Gb/s transmission are limited to no more than 2 km due to DGD! At the tighter specification of 0.20 ps/√km, as specified in G.652.D, distance capability significantly increases. Most G.652.D-compliant fiber cables in the marketplace have PMD_Q superior to the value specified in the standard, thereby allowing for further increases in network capability with emerging 40 Gb/s technology.

Network operators can prepare themselves by specifying full-spectrum fiber for fiber deployments.

Differential Group Delay Caused by PMD
Table 5

Maximum PMD_Q (ps/ √km)	**Link length (km)**	**Implied Fibre induced maximum DGD (ps)**	**Channel bit rates**
0.5	400	25.0	10 Gb/s
	40	19.0	10 Gb/s
	2	7.5	40 Gb/s
0.20	3000	19.0	10 Gb/s
	80	7.0	40 Gb/s
0.10	>4000	12.0	10 Gb/s
	400	5.0	40 Gb/s

Emerging Technologies

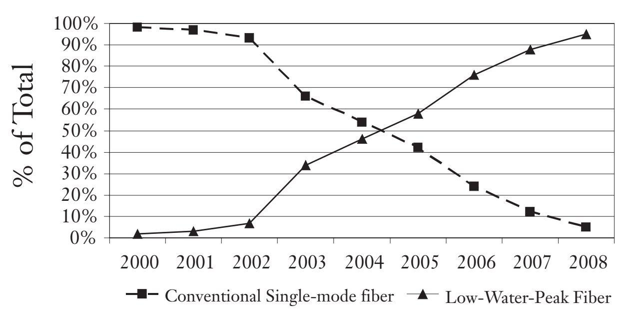
Beyond the opportunities that can be delivered today with full-spectrum fiber, there are potential future opportunities that can be advantaged. One promising technique enabling the possibility of ultra-wideband systems is the use of super-continuum sources with spectral slicing. In this technique a continuous spectrum spanning a large wavelength range is generated and then a simple passive filter is used to selectively transmit individual wavelengths. This eliminates the cost of integrating a large number of individual lasers. Several papers at the Optical Fiber Communication (OFC) conference in Atlanta, GA in March 2003 demonstrated supercontinuum generation spanning a full octave of frequencies, sufficient to cover all bands (O, E, S, C, & L) in an optical fiber. Raman amplification, already a viable technology in certain applications, utilizes pump lasers in the 1400 nm region to amplify signals in the C and L bands. In conventional legacy fibers, the high water-peak attenuation region can degrade the capability of pump wavelengths due to excessive loss, whereas full-spectrum fiber minimizes loss at the pump wavelengths, maximizing the amplification efficiency.

As emphasized several times already, the longevity of installed fiber as an asset demands that future network requirements be considered as much as possible. With the ever-present dynamics of the telecommunications market, and the potential for game changing technologies at any time, it is difficult to predict what will happen in the next year, much less in the next 10 to 15 years. As such, deployment of fibers meeting the most stringent specifications seems the obvious choice to best ensure future compatibility.

Market Momentum

Multiple fiber manufacturers currently offer full-spectrum fiber, with attenuation and PMD characteristics compliant with ITU-T G.652.D. As demand for this fiber grows among network operators, and other fiber manufacturers improve their manufacturing process, the volume of deployed full-spectrum fiber is expected to grow and rapidly overtake legacy standard single-mode fiber, as illustrated in figure 3.

Worldwide Fiber Market Forecast – Source: KMI Research 2004
Figure 3



For many of the reasons stated above, along with their historical experience with fiber and systems compatibility, a number of network operators are now exclusively specifying full-spectrum fiber for their new network builds as well as extensions of existing infrastructure.

The volume of deployed full-spectrum fiber is expected to grow and rapidly overtake legacy standard single-mode fiber.

Numerous incumbent carriers in North America, South America, Asia, and Europe, along with multiple Chinese provincial operators, now specifically require full-spectrum fiber for all new standard single-mode fiber deployments. They acknowledge the current and future CWDM system compatibility, the tight PMD specification to guarantee high-data-rate performance, and the overall peace of mind that comes with deploying the technology of today and tomorrow, rather than that of yesterday. As more networks are built and extended exclusively with full-spectrum fiber, technological momentum will shift to the point where system manufacturers no longer view the infrastructure as a limiting factor to full-spectrum system development. Consequently, it seems obvious that a large number of the manufacturers listed in table 4 will extend the capabilities of their offerings to take full advantage of the additional bandwidth capacity inherent in full-spectrum fiber.

Conclusion

Network operators around the world are specifying full-spectrum fiber compliant with ITU-T G.652.D as a requirement in both new network builds and extensions of existing infrastructure. This most recent standard specification allows full backward compatibility with all previous standard single-mode fiber, and significantly increases available optical system bandwidth and high-data-rate capability. As more operators convert network builds to full-spectrum fiber, displacing older generations of optical fiber, more and more systems will become available to take full advantage of the fiber attributes and allow for more cost efficient and capable networks.

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