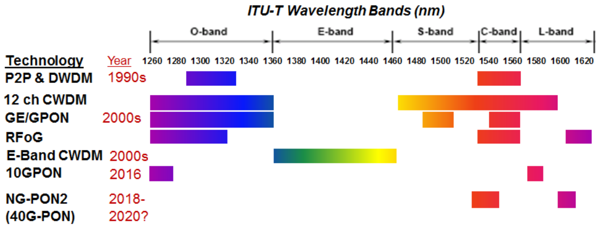
How to Speak "Fiber Geek"

Article 2 – Critical Optical Parameters – Attenuation

Welcome back, Fiber Geeks!

Article 1 in this series highlighted some bandwidth demand drivers and introductory standards information. The article also highlighted how the demand for additional bandwidth is driving the need for wavelengths across the optical spectrum, and how this trend is just beginning.

As a quick refresher, we discussed in the last article how wavelength use has grown through the past three decades, as illustrated in the graph to the right.



Applications for the first 30 years were centered in the 1310 nm and 1550 nm regions. Given the explosive demand for bandwidth, it's reasonable to expect that the next 30 years will require many more wavelengths, with potential applications across the entire optical spectrum.

This article will focus on critical optical parameters starting with attenuation, or loss in the fiber. Attenuation is a very important optical parameter, and there are many aspects to it. Additional articles in this series will focus on other optical parameters, including chromatic and polarization mode dispersion, splice loss, and an introduction to non-linear effects.

Attenuation is typically measured in terms of optical dB, a logarithmic measurement, ((Loss dB = 10*log (Power in/Power out)), so that every 3 dB of loss corresponds to the signal strength being cut in half.

Attenuation of fiber is typically measured in terms of dB/km. Attenuation varies with wavelength. One of the most prominent features in the attenuation curve for an optical fiber is that it has a relationship of attenuation proportional to $1/\lambda^4$.

There are three main loss mechanisms in fibers, and we'll briefly discuss each. Those mechanisms are:

- Scattering
- Absorption
- Bending

Scattering

The first mechanism is "Rayleigh scattering" of light in fiber. This mechanism contributes most to the baseline attenuation of fiber. A certain amount of light is scattered in the glass. In the simplest of terms, scattered light is simply light that is no longer guided through the optical fiber, but instead propagates in some other random direction (an interesting side note is that OTDRs measure loss by using the light that is scattered backwards in a fiber so the device only needs to be connected to one end of the optical fiber). Since some light doesn't transmit forward through the glass, loss occurs. The classic attenuation curve has a relationship of attenuation proportional to $1/\lambda^4$ and is driven by the properties of Rayleigh scattering. Rayleigh scattering is the result of small fluctuations of glass density in an optical fiber and is the same mechanism responsible for the blue color of the sky, when sunlight scatters off molecules in the atmosphere.

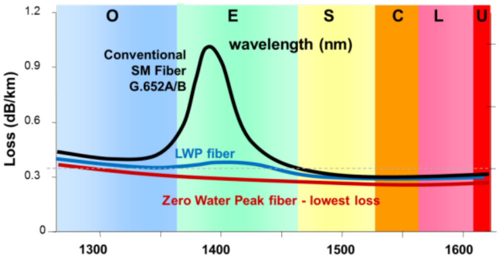
The scattering-related attenuation properties of the glass are determined by the materials used in the glass, and are frozen in during fiber manufacturing.

Absorption

Impurities may absorb or reflect light. This is why fiber manufacturers pay such close attention to the quality of materials used in the glass and to cleanliness during manufacturing. Particles as small as a fraction of a micron can be large enough to absorb enough light to increase loss.

Besides particles, impurities in the raw materials used in the fiber manufacturing process itself can increase loss. That's because the hydroxyl (OH) ion is a by-product of the manufacturing process. It absorbs light in the wavelength range around 1383 nm.

The graph to the right shows the loss performance across the wavelength range with three different grades of fiber.



Conventional single-mode fiber that meets the G.652.D standard can have high loss in the 1380 nm wavelength window, even > 1dB/km. This type of loss could render a network basically inoperable due to the short range caused by the high loss. Fiber with this type of performance is available on the market and can significantly reduce the long-term capability of the network.

Low water peak fiber is also available with a typical loss of 0.35-0.40 dB/km.

OFS AllWave® fibers are classified as Zero Water Peak (ZWP) fibers.

In these fibers, the hydroxyl ion has been reduced and deuterium gas added to interact with unreacted bonds, to essentially serve as a barrier to the ion for excellent long-term attenuation performance in this region of the optical spectrum.

For the most part, scattering and absorption properties are locked into the fiber during manufacturing. If the cable is deployed in normal environments using typical installation techniques and materials, the attenuation due to these mechanisms will remain similar to that at installation.

Bending, however, is another story.

Bending

Bending is a very important mechanism. The cabling process and installation in the field can affect attenuation caused by bending.

Let’s go back to Fiber 101. Fibers use the concept of total internal reflection to guide light. The refractive index profile of the core and the cladding determine how light is guided, and the term “critical angle” is used to describe when reflection turns to refraction and light is lost from the fiber. In short, when fiber is bent tightly, light can be lost

All of the trends in fiber deployment point to the increased importance of fiber bending performance.

Rollable Ribbon Cable (1728 fibers)

Service providers increasingly want to put more fibers into a smaller space which means that, while buffer tube diameters keep growing smaller, the fiber counts used in these buffer tubes keep increasing. This leads to a situation where there is less room for fibers to move before touching a buffer tube wall, thereby creating a possible microbend.

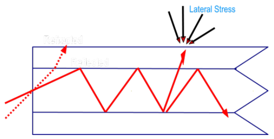
In addition, over the first 25-30 years of fiber deployments, service providers primarily installed cables in either the outside plant, the inside of central offices, or into remote cabinets. However, today’s fiber is going to places where it hasn’t gone before. It’s going inside homes and businesses to enhance the lives of users, and also up poles and onto rooftops to feed cellular and Wi-Fi sites.

Finally, the fiber being deployed to these new places is often being installed by inexperienced craftspeople, who can sometimes inadvertently make tight bends in splice trays, closures, and equipment racks/cabinets.

There are two main modes of bending – macrobending and microbending.

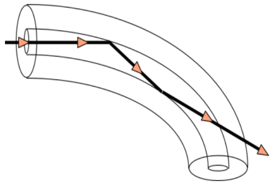
While the end result of both types of bending is attenuation, the mechanisms and how they manifest differ.

Microbends are caused by point stresses or loads on the fiber. As loads increase, loss increases.



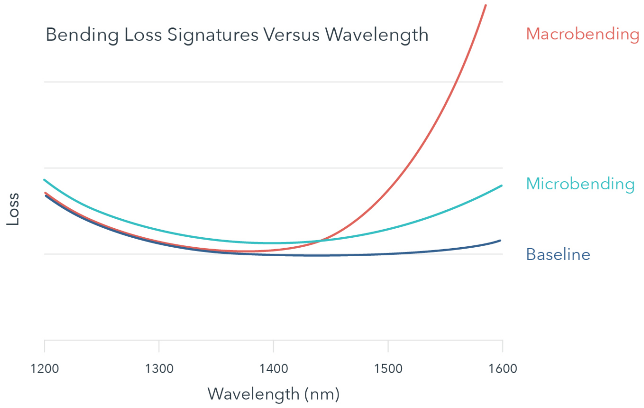
Microbending

Macrobends are caused when the fiber is bent too tightly. As bends get tighter, more light is lost.

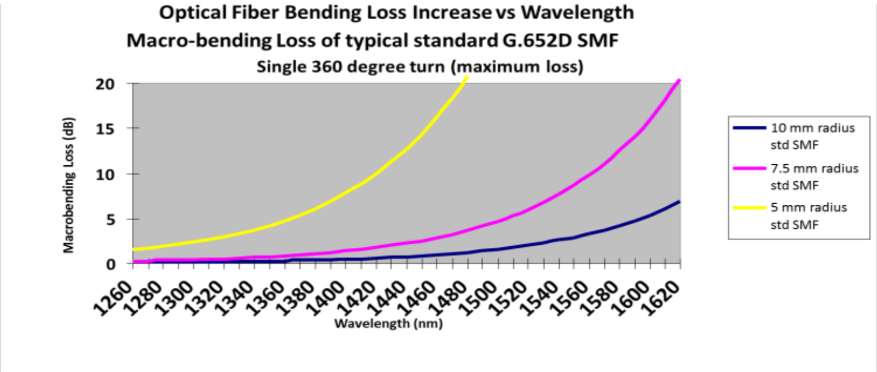


Macrobending

There’s a way to tell the two types of bending apart, as shown in the graph below. Although both mechanisms can cause loss to increase to the 1310 nm window, macrobending loss is much higher in the 1500-1625 nm area of the optical spectrum.



Macrobending performance is a very important fiber parameter. As shown in the graph below, the lighter the bends are in the network, the higher the loss. As wavelengths get longer, loss also increases.



Although the 1550 nm window is often used due to its lower loss, macrobends can significantly reduce the range of the network, unless the fiber is designed for use in an application with bends.

Other Ways Microbends and Macrobends Show Up in the Network

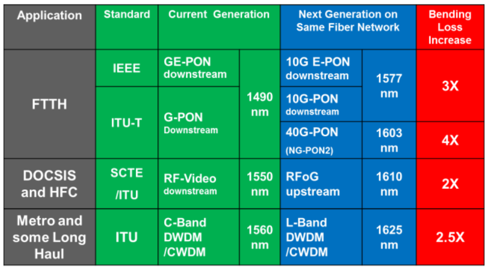
The concepts of micro and macro bends affect the network in ways that are not always obvious.

Bend-related loss is also sometimes experienced in cold temperature environments. For this reason, fiber and cable qualifications should always include tests to see how products perform in cold temperatures. As a network designer, it's always a good idea to account for at least some optical margin for small potential attenuation increases in cold temperatures.

Some designs, especially very high-density designs, need bend insensitive fibers to reduce bend-related loss due to the inherent bends and lack of free space for fiber movement in the cable design itself.

Special care is sometimes required in above-ground pedestals using certain microcable designs for the reasons above.

While these issues are important today, they will become even more important tomorrow, as the next generation of many optical transmission protocols use longer wavelengths than the existing protocol. As highlighted earlier, longer wavelengths can result in higher loss. Theoretically, a GPON network operating today at 1490 nm, but with inadvertent bends in it, could have its reach reduced by almost half when it is upgraded to NG-PON2, operating at 1603 nm.



Application	Standard	Current Generation		Next Generation on Same Fiber Network		Bending Loss Increase
FTTH	IEEE	GE-PON downstream	1490 nm	10G E-PON downstream	1577 nm	3X
	ITU-T	G-PON Downstream		10G-PON downstream		
				40G-PON (NG-PON2)	1603 nm	4X
DOCSIS and HFC	SCTE /ITU	RF-Video downstream	1550 nm	RFoG upstream	1610 nm	2X
Metro and some Long Haul	ITU	C-Band DWDM /CWDM	1560 nm	L-Band DWDM /CWDM	1625 nm	2.5X

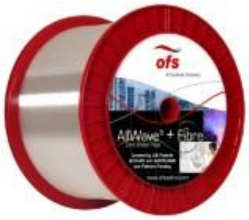
Help is On the Way

The good news is that fiber manufacturers have developed fibers that can withstand different amounts of bending while also reducing loss compared with traditional fibers meeting the ITU G.652.D Recommendation. These fibers are called bend insensitive or bend optimized fibers, and are defined by ITU Recommendation G.657.

While these fibers may have different index of refraction profiles from standard G.652 fibers, and guide the light in a different way than standard fibers, they are all compatible with the large installed base of G.652.D fibers.

There are three different main categories of bend insensitive fibers as defined by the ITU G.657 Recommendation. These fibers are often identified by the most applicable version of the ITU Recommendation. These three main categories are G.657.A1, G.657.A2, and G.657.B3. The performance differences between these categories are shown in loss when fibers are wrapped around mandrel sizes of different diameters.

G.657.A1 fibers are the closest to G.652.D fibers. G.657.A1 fibers have the least amount of bend insensitivity and are the primary choice for the vast majority of fiber networks. OFS has combined G.657.A1 and G.652.D performance with a 9.2 micron mode field diameter in our AllWave®+ and AllWave® One fiber types.


AllWave+ Optical Fiber

These fibers are ideal for most of today's typical short-distance (<1000 km) and low data rate (<400Gbps) applications, including standard outside plant (OSP) loose tube, ribbon, rollable ribbon, microcables, and drop cables.

The 9.2 micron mode field diameter splices seamlessly to the installed base of G.652.D fibers which feature the same mode field diameter.


Fiber Distribution Hub

G.657.A2 fibers can be bent more tightly with lower loss. They are most commonly used in central office and cabinet environments, such as Fiber Distribution Hubs (FDH). These fibers are also commonly used in building backbone networks and as tails for various pre-terminated panels and other devices.

In these environments, the fibers need to be bent more tightly than in typical OSP cable applications. One of the advantages of these fibers is that when they are bent tightly enough to potentially cause reliability concerns, the attenuation rises, thereby providing an "early warning" signal. This is especially important for central office applications where one fiber could provide the feed for thousands or millions of customers, and reliability is paramount. The main G.657.A2 product from OFS is AllWave® *FLEX*+ fiber.

G.657.B3 fibers are the third main category of bend insensitive fibers. These fibers are designed and recommended for use in the drop portion of a Fiber-to-the-Home (FTTH) network. Designed to be placed in very tight spaces, these fibers (including EZ-Bend® Optical Fiber from OFS), once cabled, can be tied in knots and stapled. EZ-Bend fiber is the basis for InvisiLight® products, which are used inside homes and buildings to provide service with a very small visual footprint.

Homes and buildings are very demanding places to deploy fiber, and unmanaged bends as small as 5 mm in radius (and even smaller) are not uncommon. Placing G.652/G.657.A1/G.657.A2 fibers in these environments will likely result in unacceptably high levels of attenuation, especially as longer wavelengths are deployed as new protocols come online.

For the network designer and installer, a thorough understanding of various attenuation mechanisms can assist with the network planning and installation processes, enabling proper loss budgeting and the use of appropriate products for the application.

In most situations, attenuation is the most important network parameter, and this article has provided enough background for you to be well on your way to fiber geekdom on this topic. However, fiber geekdom is a journey, not a destination, and there's always more to learn. OFS has multiple decades of experience with fiber optic networks. Please contact your local OFS representative if you would like additional information regarding any of the items in this article.