ULTRA BEND-INSENSITIVE SINGLE-MODE FIBER
FOR ACCESS AND IN-BUILDING NETWORKS

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Synopsis: Some service providers have requested a new category of ultra bend-insensitive fibers, to be designated as G.657.A3, to be deployed in metro and long haul applications. OFS studies have demonstrated that ultra bend-insensitive fibers, while an excellent choice for FTTH, have attributes that may be detrimental to metro and long haul systems.

Ultra bend-insensitive fiber, with its 5 mm minimum bend radius as described in the ITU-T G.657.B3 specification, has found wide acceptance in the fiber-to-the-home (FTTH) market. In multi-dwelling units (MDUs), these fibers are routed through new and existing structures with low-cost, easy-to-use fasteners. These products, such as OFS’ EZ-Bend® technology, are compatible with G.652.D requirements.

Recently, some service providers have requested a new category of ultra bend-insensitive fibers, to be designated as G.657.A3, which would be G.652D compliant as well. Fibers in this category would be deployed in metro and long haul applications.

Studies conducted by OFS have shown that G.652.D compatibility offers more value than G.652.D compliance, from a system perspective as well as a reliability perspective. What’s more, all existing ultra bend-insensitive fibers have attributes that may be detrimental to metro and long haul systems. Therefore, it is recommended that these fibers only be
deployed in the FTTH systems for which they were developed. This paper explains why.

Compliance vs. Compatibility

Let’s begin by defining the terms compatible and compliant. While they are frequently used interchangeably, there is an important distinction. A fiber is said to be compliant to a standard when it meets all of the requirements or specifications given in that standard, regardless of how it performs in a system. Fibers are said to be compatible when they interoperate seamlessly; in other words, when the fiber is introduced into a system, it adds no system penalties such as high splice loss, a dispersion penalty, or noise that would degrade system performance.

Thus, the key difference: compatibility is a metric that describes how well the product will interoperate with the existing base of product, while compliance is merely a comparison of specifications that might be relevant to system performance.

What the Standards Say

ITU-T G.657 recommendations for bend-insensitive single-mode fiber:

This Recommendation describes two categories of single-mode optical fibre cable which are suitable for use in access networks, including inside buildings at the end of these networks. Both categories A and B contain two sub-categories which differ in macrobending loss.

Category A fibres are suitable to be used in the O, E, S, C and L-band (i.e., throughout the 1260 to 1625 nm range). Fibres and requirements in this category are a subset of ITU-T G.652.D fibres and have the same transmission and interconnection properties. The main modifications are improved bending loss and tighter dimensional specifications, both for improved connectivity.

Category B fibres are suitable for transmission at 1310, 1550 and 1625 nm for restricted distances. These fibres may have different splicing and connection properties than ITU-T G.652 fibres, but are capable at very low values of bend radius.
Or, put more simply:

- All G.657 fibers are for the access network; they are not recommended for metro or long haul applications.

- Category A fibers have the same transmission properties as G.652.D fibers and also have improved macrobend performance for access applications. Category B fibers, a niche product in the access network, are suitable for short distance links such as in-building applications.

**Enhancing Ultra Bend-Insensitive Fibers for Access Applications**

With this as prologue, let’s take up the question at hand: Is there a need for a G.657.A3 fiber or is the current G.657.B3 specification sufficient? Currently, it appears that compatibility with the embedded base of G.652 fibers is more important than compliance to the G.652.D specification. Here’s why.

The ITU-T recommendation describes category B fibers for short reach applications. Cables in this application space include single-subscriber drop cables and in-building cabling. The links for this portion of the access system are less than 1 km. What’s required for these links is a fiber that is compatible with the G.652.D link and does not add any unnecessary impairment to transmission. The following enhancements are being considered to improve the compatibility of G.657.B3 fibers:

- An MFD range that is equivalent to G.652.D (it has been agreed that this change will occur in the next version of the G.657 document)

- An added dispersion specification of $1250 \text{ nm} < ZDW < 1350 \text{ nm}$ and a dispersion slope of less than $0.11 \text{ ps/nm}^2 \text{ km}$ (this will likely occur in future versions of the ITU-G.657 document)
• The addition of full spectrum performance (this does not have the support of the ITU-T, but is recommended by OFS and other US manufacturers)

All OFS G.657.B3 fibers meet these more stringent requirements.

System Modeling in FTTH Networks

OFS has modeled access systems including GPON and 10GPON networks using the accepted IEEE 802.3 transmission models for both upstream and downstream transmission. Our models show that if the fiber meets the current G.657.B3 specification, and has the compatibility requirements described in the previous section, the added transmission penalty of the G.657.B3 fiber is less than 0.1 dB if the fiber is part of a 20 km access link. This is the equivalent of four corner turns of 5 mm each.

In-building installations may have ten, twenty, or even more corner turns. Thus, this small transmission penalty is outweighed by the improvement in the attenuation budget. Table 1 shows a loss comparison of OFS EZ-Bend cable to a commercial G.657 B3 cable that is compliant with G.652.D (i.e., a so-called “G.657.A3” fiber).

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>2 connectors</td>
<td>0.50 dB</td>
<td>0.50 dB</td>
</tr>
<tr>
<td>10 at ¼ turn 5mm radius bends</td>
<td>0.40 dB</td>
<td>0.20 dB</td>
</tr>
<tr>
<td>250 m cable</td>
<td>0.10 dB</td>
<td>0.10 dB</td>
</tr>
<tr>
<td>Dispersion penalty 10 GPON</td>
<td>0.00 dB</td>
<td>0.05 dB</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1.00 dB</td>
<td>0.85 dB</td>
</tr>
</tbody>
</table>

*Table 1*
The table clearly shows that, in the most demanding systems, the compatible G.657 B3 fiber adds more value than the G.652.D-compliant fiber. The advantage is due to the fact that the fiber is designed for the application, and therefore the focus is on the attributes that are significant to system performance (macrobend loss), rather than parameters that have been shown to add no value (e.g., dispersion). The bottom line for in-building systems: Compatibility with ultra-low bend loss adds the most value to the network.

Ultra Bend-Insensitive Fibers in Metro and Long Haul Networks

The previous section demonstrates why, from a systems perspective, a compatible G.657.B3 fiber is preferred for access network applications. But what about other parts of the network? If the bend loss is truly better, why not just make a fiber with a 5 mm bend radius that is fully compliant to the G.652.D specification and use the fiber anywhere in the network? The answer has to do with the design of ultra bend-insensitive fibers.

In a single-mode fiber, the fundamental mode of light travels a very long distance, while higher-order modes do not propagate. The lowest wavelength, where the fiber only has one mode propagating, is called the cut-off wavelength.

In ultra bend-insensitive fibers, the index profile is modified to improve macrobend loss. Unfortunately, the necessary changes made to the fiber’s light-guiding region results in a different cut-off behavior. The net result is a system impairment called Multi Path Interference (MPI).

This change has been tested thoroughly in access systems both experimentally and theoretically, and the data clearly shows that this change in cut-off behavior does not impact system performance. Unfortunately, metro and long haul systems are not as tolerant of this impairment because of amplification requirements. As a result, all ultra bend-insensitive
Reliability Considerations

Reliability of ultra bend-insensitive fiber can be divided into two categories: optical and mechanical. Optical reliability determines whether the signal will pass through the fiber in a usable form. The attenuation budget is an important part of this determination; macrobend-improved fibers deployed in systems with small bends improve the optical reliability. Other attenuation-limiting properties include microbend performance, connection loss, and splice loss.

Mechanical reliability determines whether an optical fiber will physically break in the intended application. Macrobend-improved fibers have done much to improve optical reliability but have done nothing to improve mechanical reliability.

Table 2 illustrates the mechanical reliability requirements for various applications. As shown, a system with bend radii less than 7.5 mm has an expected failure rate greater than 1 ppm in 30 years. Typical outside plant applications call for less than 1 ppm in 30 years, and for these applications the minimum bend radius needs to be limited to > 7.5 mm for single bends and 15 - 30 mm for slack storage. This differs from in-building applications, where the expected lifetime for a phone cord is on the order of 10 - 20 years.

Thus, from a reliability perspective, ultra bend-insensitive fiber is well suited for single-subscriber applications, where the benefit of easy installation outweighs the added risk of a mechanical failure. However, for other applications, ultra bend-insensitive fiber is not recommended.
### Table 2

<table>
<thead>
<tr>
<th>Application</th>
<th>MDU</th>
<th>FTTH</th>
<th>Trunks/Metro Applications</th>
<th>Long Haul Submarine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users per fiber</td>
<td>1</td>
<td>10-100</td>
<td>100-1000</td>
<td>100-10,000</td>
</tr>
<tr>
<td>Accepted reliability criteria</td>
<td>&lt; 10 ppm in 20 years</td>
<td>&lt; 1 ppm in 30 years</td>
<td>&lt; 1 ppm in 30 years</td>
<td>0 ppm in 40 years target</td>
</tr>
<tr>
<td>Cost of failure</td>
<td>1 customer down, truck roll</td>
<td>Several customers down, need for immediate repair</td>
<td>FCC reportable incident, need for immediate repair</td>
<td>FCC reportable incident. Failure extremely costly (Ship must be used)</td>
</tr>
<tr>
<td>Minimum design bend</td>
<td>5 mm radius</td>
<td>7.5-10 mm radius</td>
<td>15 mm radius</td>
<td>30 mm radius</td>
</tr>
</tbody>
</table>

### Conclusions

This paper explains how ultra bend-insensitive fibers, with their 5 mm bend radius, are designed for the access network. In this application, compatibility with G.652.D is of value, but compliance to that specification may not be a benefit. The use of 5 mm bend radius fibers, even if they are compliant to G.652.D, is not recommended for long haul and metro networks because 5 mm bend radius fibers generate more MPI, thereby decreasing the reach of the system, and have a reliability risk that is greater than what is accepted for these applications. As a result, there is no value to G.652.D-compliant G.657.B3 fiber. OFS recommends that for demanding drop cable applications of in-building deployments, the network provider choose a compatible ultra bend-insensitive fiber optimized for the application, such as OFS EZ-Bend products.