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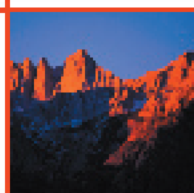
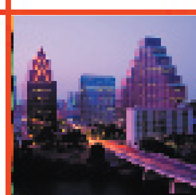
# Mixing TrueWave® RS Fiber with Other Single-Mode Fiber Designs Within a Network



OFS White Paper
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# Mixing TrueWave® RS Fiber with Other Single-Mode Fiber Designs Within a Network

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## INTRODUCTION

A variety of single-mode fiber types can be found in today's installed networks. Standards bodies, such as the IEC and ITU, recognize four categories of single-mode fiber: dispersion-unshifted (G.652), dispersion-shifted (G.653), cutoff-shifted (G.654), and nonzero dispersion (G.655). Furthermore, there are two varieties of G.652 fiber (conventional and low water peak), and numerous commercial varieties of G.655 fiber (small, moderate, and large effective areas; low, moderate, and high dispersion slopes; negative and positive dispersion), all of which may sometimes be found in a network.

This white paper discusses various topics that should be evaluated when mixing TrueWave® RS fiber with dispersion-unshifted and other nonzero dispersion fibers. These topics include: (1) joint loss, (2) one-way OTDR anomaly, (3) link chromatic dispersion, (4) link dispersion slope, (5) cutoff wavelength, and (6) nonlinear effects.

## JOINT LOSS

Whenever two fibers are joined to one another using connectors or splices, the joint loss can be influenced by differences in their mode field diameters (MFDs) and refractive index profiles. Although mode field diameter manufacturing tolerances (from ±0.4 to ±1.0 µm for commercial fibers) can increase the joint loss of nominally similar fibers from the same manufacturer, the increase in loss can become more pronounced when splicing different fiber types. The added loss due to joining fibers with two different MFDs can be calculated using:

$$\text{Loss(dB)} = -20\log\left[\frac{2MFD_1MFD_2}{MFD_1^2 + MFD_2^2}\right] \cdot (1)$$

This shows that a TrueWave RS fiber having a nominal MFD of 8.4 µm joined to an OFS depressed clad fiber having a nominal MFD of 9.7 µm at 1550 nm produces a theoretical increase in joint loss of 0.09 dB. When combined with the "normal" joint loss between like fibers, the expected joint loss of the mixed fibers is higher, and field data indicates this transition splice to be about 0.1 dB.

Although 0.1 dB is a significant additional loss (equivalent to about 750 m of fiber), such transition splices typically occur only twice in an amplifier span—once at each end—where the outside plant TrueWave RS fiber is joined to a premises depressed clad fiber in a hut or building.

Table 1 shows the calculated added losses and measured single-fiber fusion splice losses at 1550 nm when splicing TrueWave RS fiber to some other fiber types.

**Table 1. Single Fiber Fusion Splice Loss (dB) at 1550 nm**

| TrueWave® RS Fiber To: | Measured | Calculated Added Loss |
|---|---|---|
| TrueWave RS Fiber (MFD=8.4 µm) | 0.04 | 0.0 |
| LEAF* Fiber (MFD=9.6 µm) | 0.1 | 0.07 |
| Depressed Clad SM Fiber (MFD=9.7 µm) | 0.1 | 0.09 |
| Matched Clad SM Fiber (MFD=10.4 µm) | 0.1 | 0.2 |
| AllWave® Fiber (MFD=10.4 µm) | 0.1 | 0.2 |

This calculated added loss due to MFD differences occurs at connector joints as well as splice joints. Consequently, the number of transitions between different fiber types should be minimized.

## ONE-WAY OTDR ANOMALY

An Optical Time Domain Reflectometer (OTDR) measures reflected power—not transmitted power. Because the power reflected by an optical fiber depends on its MFD, an OTDR can produce an anomalous reading when trying to measure the attenuation of a joint. This OTDR error is given by:

$$\text{OTDR Error (dB)} = 10\log\left[\frac{MFD_2}{MFD_1}\right]. \quad (2)$$

This equation shows that the OTDR Error is positive if the MFD of the fiber after the joint ($MFD_2$) is larger than the one before ($MFD_1$). This positive error adds to the true joint loss to produce a fictitiously large reading.

If the MFD of the fiber after the joint is smaller than the one before, the OTDR Error is negative. This negative error combines with the true joint loss to produce a fictitiously small reading, which in some cases, may even appear as a gain instead of a loss! This well-known one-way anomalous OTDR behavior requires a joint to be measured in both directions, and the two losses averaged, to obtain the joint's true loss.

Because of their different nominal MFDs, mixing TrueWave RS fiber with other fiber types can produce large OTDR errors. Table 2 shows the theoretical errors calculated using equation (2).

**Table 2. Nominal One-Way OTDR Error at 1500 nm**

| TrueWave® RS Fiber To: | One-Way Error (dB) |
|---|---|
| TrueWave RS Fiber (MFD=8.4 µm) | 0.0 |
| LEAF* Fiber (MFD=9.6 µm) | ±0.6 |
| Depressed Clad SM Fiber (MFD=9.7 µm) | ±0.62 |
| Matched Clad SM Fiber (MFD=10.4 µm) | ±0.97 |
| AllWave® Fiber (MFD=10.4 µm) | ±0.97 |

This table shows that one-way OTDR errors are very large and completely mask the true splice losses shown in Table 1. This dramatically emphasizes the need to make two-way measurements to obtain the true joint loss between different fiber types. True joint loss is then obtained by averaging the results of the two OTDR measurements.

## LINK CHROMATIC DISPERSION

In addition to MFD, another difference among single-mode fibers is their chromatic dispersion. Chromatic dispersion measures the tendency for different wavelengths to travel at different speeds in a fiber. Table 3 shows the nominal dispersion coefficients at 1550 nm for some single-mode fibers.

**Table 3. Nominal Fiber Chromatic Dispersion and Dispersion Limited Distance**

| | $D_{1550}$ (ps/nm*km) | Dispersion Limited Distance at 10 Gb/s (km) |
|---|---|---|
| TrueWave® RS Fiber | 4.4 | 240 |
| Depressed Clad SM Fiber | 17 | 60 |
| Matched Clad SM Fiber | 17 | 60 |
| AllWave® Fiber | 17 | 60 |

If the total dispersion between a transmitter and receiver is too large, digital pulses broaden and can interfere with those on either side—increasing the bit error rate. Consequently, chromatic dispersion limits the distance that a digital signal can travel before it requires regeneration or some form of correction. For digital systems using 1550 nm externally modulated distributed feedback (DFB) lasers with a Non-Return-to-Zero (NRZ) signal format, this maximum distance, the "dispersion-limited distance," occurs approximately when

$$Bit^2 * D * l = 104{,}000 \quad (3)$$

where:

Bit = bit rate in Gb/s

D = fiber dispersion coefficient in ps/nm*km

$l$ = link length in km.

Equation (3) shows that the dispersion-limited distance for matched and depressed clad fibers (with a dispersion of 17 ps/nm·km) is ~980 km when carrying a 2.5 Gb/s signal. This distance is usually long enough that fiber dispersion is not a limitation at such bit rates. However, at 10 Gb/s, the dispersion-limited distance becomes ~60 km, and unregenerated transmission over longer distances requires some type of dispersion management technique, such as dispersion compensation. Because some of these techniques introduce additional complexity and cost, TrueWave RS fiber and other nonzero dispersion fibers were developed that have lower dispersion than conventional single-mode fibers (G.652). Table 3 shows the nominal dispersion-limited distances at 10 Gb/s for various single-mode fibers.

Because different fibers have different dispersion-limited distances, a route containing a mixture of two fibers will have a distance limit between the limits for either one. A route comprised of $l_{TW}$ km of TrueWave RS fiber and $l_{MC}$ km of matched clad fiber will have an average dispersion coefficient of $(4.4\times l_{TW} + 17\times l_{MC})/(l_{TW} + l_{MC})$. For example, if a 100 km link (a concatenation of cables) consists of 75 km of TrueWave RS fiber and 25 km of matched clad fiber, the average dispersion coefficient is 7.55 ps/nm-km, which gives a dispersion-limited distance of ~138 km at 10 Gb/s.

Most long haul applications are >400 km in distance. Thus the 10 Gb/s dispersion-limited distances shown in Table 3 are too short, requiring that dispersion compensation be employed to extend the full distances. The compensation is typically accomplished by periodically inserting dispersion compensating fiber (DCF) modules with negative dispersion to cancel some of the positive dispersion in the transmission fiber. DCF modules are generally available with different magnitudes of dispersion. The proper module to use depends on the total dispersion of the link into which the module is to be inserted. Here is one way of looking at the effect of mixing TrueWave RS fiber and matched clad single-mode fiber on the selection of a DCF module.

Consider a 100 km link of TrueWave RS fiber operating at 10 Gb/s. The total nominal dispersion of the link at 1550 nm is 440 ps/nm. One manufacturer of 10 Gb/s transmission equipment recommends choosing a DCF module that compensates for 85% of this dispersion $0.85\times440 = 374$ ps/nm. Because modules come with discrete dispersion values, it is necessary to choose the module that comes closest to the computed 374 ps/nm value, for example, a DCF-22.5 module from OFS.

Now consider a mixed route comprised of 75 km of TrueWave RS fiber and 25 km of matched clad fiber. The total nominal dispersion is $4.4\times75 + 17\times25 = 755$ ps/nm. Taking 85% of this value gives 642 ps/nm, which requires a DCF-40 module.

In summary, mixing TrueWave RS fiber with other fibers may require the use of a different DCF module depending on the amount of dispersion introduced by the other fiber type.

# LINK DISPERSION SLOPE

The previous section discussed the effect of mixing fiber types on the selection of a DCF module to match the link dispersion at 1550 nm. However, dense wavelength division multiplexing (DWDM) systems operate over a range of wavelengths, and the fiber dispersion at these wavelengths is different than at 1550 nm. Figure 1 shows how dispersion varies with wavelength for some fibers.

Dispersion variation with wavelength is quantified using the fiber's dispersion slope at 1550 nm, $S_{1550}$. Different fibers can have different slopes, and fibers with lower slopes are easier to compensate over a broad wavelength range. Table 4 lists the dispersion slopes of some fibers.

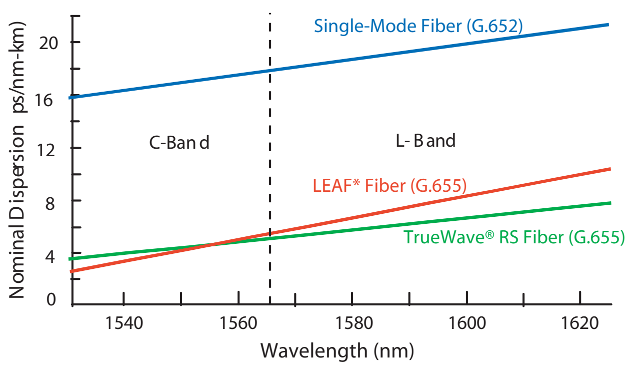


**Figure 1. Chromatic dispersion versus wavelength for some single-mode fibers.**

**Table 4. Nominal Fiber Chromatic Dispersion Characteristics**

| | $D_{1550}$ (ps/nm*km) | $S_{1550}$ (ps/nm$^2$*km) | RDS (1/nm) |
|---|---|---|---|
| TrueWave® RS Fiber | 4.4 | 0.045 | 0.01 |
| LEAF* Fiber | 4.3 | 0.085 | 0.02 |
| Depressed Clad SM Fiber | 17 | 0.060 | 0.0035 |
| Matched Clad SM Fiber | 17 | 0.060 | 0.0035 |
| Standard DCF | | | 0.0022 |
| Wideband DCF | | | 0.0035 |
| NZDF DCF | | | 0.0064 |
| TrueWave RS Fiber DCF | | | 0.01 |

Figure 1 and Table 4 show that the dispersion slopes of these transmission fibers are positive. Consequently, the dispersion slope of a DCF module should be negative so that it can compensate for dispersion over a broad wavelength range. The ability of a module to compensate for the dispersion slope of a transmission fiber can be quantified by Relative Dispersion Slope (RDS), which is the ratio of slope to dispersion at 1550 nm. Ideally, the RDS of a DCF module should be identical to the RDS of the transmission fiber. Mathematically,

$$RDS_{DCF} = \frac{S_{1550}}{D_{1550}} = RDS_{trans} = \frac{S'_{1550}}{D'_{1550}} \quad . \quad (4)$$

It's apparent from Table 4 that the RDS of DCF is often not the same as the transmission fiber. A measure of how well a given DCF compensates for the slope of a given transmission fiber is the Dispersion Slope Compensation Ration (DSCR), which is defined as:

$$DSCR = \frac{RDS_{DCF}}{RDS_{trans}} \quad . \quad (5)$$

Using this metric, standard DCF compensates for only about 63% of the slope of dispersionunshifted fibers, but wideband DCF compensates for 100%. NZDF DCF compensates for 65% of the slope of TrueWave RS fiber, but only 30% of the slope of Enhanced LEAF fiber. TrueWave RS fiber DCF compensates for 96% of the slope of TrueWave RS fiber, but only 44% of Enhanced LEAF fiber.

The RDS of a mixed fiber link can be found by taking the ratios of its length-weighted slope and dispersion. For a 100 km link comprised of 75 km of TrueWave RS fiber and 25 km of matched clad fiber, the length-weighted slope is $(75\times0.043 + 25\times0.060)/100 = 0.0475$, and the length weighted dispersion is $(75\times4.4 + 25\times17)/100 = 7.55$. Consequently, the RDS is 0.0063. Because this value is almost identical to the RDS of NZDF DCF, the mixed fiber route is better slope matched than the pure TrueWave RS fiber route.

## CUTOFF WAVELENGTH

Theoretically, cutoff wavelength describes the wavelength at which a fiber changes from multimode to single-mode behavior. For single-mode operation, the cutoff wavelength of a single-mode fiber should be lower than the system operating wavelength.

ITU recommends that the cable cutoff wavelength be no greater than 1260 nm for a dispersion unshifted (G.652) fiber, and 1480 nm for a nonzero dispersion (G.655) fiber. Consequently, whereas G.652 fibers have the ability to operate with legacy transmission equipment in the 1310 nm wavelength band, some G.655 fibers may not have this capability.

Although TrueWave RS fiber is optimized for use in the 1550 nm (C-Band) and 1600 nm (L-Band) windows, its 1260 nm cable cutoff wavelength permits it to also carry 1310 nm (O-Band) traffic. When mixed with matched or depressed clad fibers, this 1310 nm window is preserved. However, when mixed with a G.655 fiber that has a cable cutoff wavelength greater than about 1320 nm, the 1310 nm window is no longer available

## NONLINEAR EFFECTS

Optically amplified transmission systems can be affected by a variety of nonlinear stimulated scattering and phase refractive index effects that arise in optical fibers. These phenomena depend on the fiber's effective area, nonlinear refractive index, peak Brillouin and Raman gain coefficients, and chromatic dispersion. Because of complex interactions that occur among these parameters, detailed computer simulations are generally performed to assess fiber performance with a given transmission system, and the results are provided by transmission equipment vendors in the form of "engineering rules" for use in determining link lengths. Consequently, it is very difficult to assess how mixed fibers will affect the nonlinear characteristics of a link. With this caveat, here are some general considerations.

Fibers with large MFDs tend to have larger effective areas. Because this results in a lower optical power density, the fiber can carry more optical power. Since optical power is highest near the launch end, large area fibers offer benefits when placed within the first 20 km from a transmitter or amplifier.

Fibers with moderate effective areas tend to be more efficient at producing signal amplification in distributed Raman amplifier systems. Moderate area fibers offer the greatest benefit when placed near the receiver, which also functions as the power source for Raman amplification.

Because of the myriad nonlinear effects that can occur, the length of an amplifier span containing a concatenation of mixed fibers spliced to one another should be chosen using the more conservative engineering rules for the predominant fiber type within the first 20 km of the transmitter or amplifier. For example, for a route comprised of at least 20 km of TrueWave RS fiber on one end, and at least 20 km of G.652 fiber on the other end, the span length should be determined using the more conservative engineering rules provided by the transmission equipment vendor for the two fiber types.

## SUMMARY

With the variety of single-mode fibers on the market, it is almost inevitable that TrueWave RS fiber will occasionally be joined to another fiber type. In fact, TrueWave RS fiber is routinely mixed with short lengths of dispersion-unshifted fiber when outside plant TrueWave RS cables enter repeater huts or buildings.

Five topics to consider when mixing TrueWave RS fiber with other fiber types are: (1) joint loss, (2) one-way OTDR anomaly, (3) link chromatic dispersion, (4) link dispersion slope, (5) cutoff wavelength, and (6) nonlinear effects. Except for the last item, all these effects can be quantified. Because assessment of the last item, nonlinear effects, requires detailed computer analysis, it is recommended that the span be designed using the more conservative engineering rules for the predominant fiber type within the first 20 km of the transmitter or amplifier.

Original material developed by James R. Refi.

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