THE USE OF DISPERSION-SHIFTED FIBER FOR CABLE TV APPLICATIONS

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ABSTRACT

As cable television operators deploy optical fiber in increasing volume, single-mode dispersion-shifted fiber has emerged as a viable transmission option in the 1550 nanometer (nm) window. This paper discusses the performance attributes of dispersion-shifted fiber, as well as the relative tradeoffs between it and standard single-mode fiber. The paper also outlines some potential cable television applications for dispersion-shifted fiber.

INTRODUCTION

Recent advancements in optical amplifiers and distributed feedback (DFB) lasers suggest that the 1550 nm operating window offers an opportunity for cost-effective cable TV architectures. While 1550 nm transmission over the long term is likely to complement, not compete with, existing 1310 nm technology, it has gained considerable momentum as an alternate operating wavelength.

Simply stated, 1550 nm transmission may help maximize many of fiber's benefits while reducing overall system costs.

Single-mode fiber's low attenuation rate, (the reduction in signal strength over the length of the fiber) at 1550 nm can enable cable operators to extend their link distances. In addition, the commercialization of 1550 nm optical amplifiers could enable more receivers to be shared by a common laser.

However, 1550 nm operation of amplitude modulated (AM) video over standard single-mode fiber presents its own challenges. Chief among these is reducing the effects of dispersion, a key fiber performance parameter.

UNDERSTANDING DISPERSION

Dispersion is commonly referred to in digital transmission as the key optical parameter that limits the maximum data rate or information-carrying capacity of a single-mode fiber link. It refers to the time-based spreading of each pulse of light as it travels along a fiber.

As the pulse of light travels along the fiber, it spreads due to the different wavelengths that make up the pulse traveling at different speeds. Eventually, the pulses can overlap one another and become unrecognizable, which leads to an increase in the bit error rate. If the bit error rate becomes excessive, the amount of received information or bandwidth becomes severely limited.

In analog transmission, the effect is slightly different. Dispersion can cause an analog waveform to become significantly distorted. The complex nature of an amplitude modulated (AM) video signal makes it very susceptible to any distortion impairment.

Dispersion induced distortion is a result of laser chirp. Laser chirp is created when the wavelength of the laser changes due to injection current modulation of the laser. Typically, as the laser injection current increases, and thus the laser ouput power, the center wavelength of the laser shifts towards longer wavelengths. A small amount of laser chirp can significantly distort the ouput of an AM optical video signal due to the presence of dispersion.

This distortion can be illustrated simply by imagining different wavelengths of light within the waveform, although very close, traveling at different speeds due to the index of refraction characteristics of single-mode fiber. The presence of dispersion significantly alters the traveling speeds of the wavelengths of light within the waveform and thus enhances this distortion effect.

In AM cable TV systems, this distortion shows up as second order harmonics and intermodulation (or "beats") and is commonly referred to as composite second order distortion (CSO). CSO distortion appears on a television monitor as rolling diagonal lines.

Fiber dispersion has been shown to create CSO distortion due to the chirp of a DFB laser interacting with the dispersion. Over standard single-mode fiber, the amount of dispersion is much higher at 1550 nm than at 1310 nm. This results in a reduction in picture quality, unless CSO compensation techniques are used.

For highly dispersive mediums like standard single-mode fibers at 1550 nm, CSO distortion due to dispersion can be compensated for through either electrical or optical means. Electrical compensation techniques typically employ the use of pre-distortion circuits to create CSO equal in magnitude, but opposite in sign to cancel the CSO created by the DFB laser.Optical compensation techniques most often try to offset the amount of dispersion in a system.

Several electrical compensation techniques have been demonstrated, but most are believed to be distance and/or bandwidth limited. One alternative to compensation techniques is the use of single-mode dispersion-shifted fiber at 1550 nm as the transmission fiber, instead of standard single-mode fiber.

WHAT IS DISPERSION-SHIFTED FIBER?

Corning developed the first commercially available single-mode dispersion-shifted fiber (SMF/DS™) in 1985. Historically, Corning's patented SMF/DS™ fiber has offered significant benefits for long-haul telephony and submarine cable applications.

With recent developments in the commercialization of erbium-doped fiber amplifiers (EDFAs) and DFB lasers operating at 1550 nm, dispersion-shifted fiber is poised to be the fiber of choice for high-data-rate transmission systems over long distances. These same developments in EDFAs and DFBs have led the cable TV industry to consider its use for specific AM video applications.

Dispersion-shifted fiber was designed specifically to capitalize on fiber's inherent lower attenuation at 1550 nm by shifting the zero dispersion wavelength to 1550 nm as well. In order to center the zero dispersion wavelength at 1550 nm and still maintain similar performance characteristics as standard single-mode fiber, Corning manufactures its dispersion-shifted fiber with a unique refractive index profile (Figure 1). The refractive index profile represents the change in refractive index of the core glass relative to the cladding glass and typically defines the fiber's transmission characteristics.

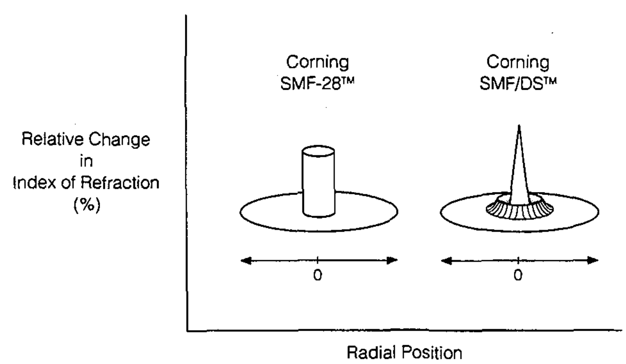

Figure 1. Refractive Index Profiles of Corning SMF-28™ and Corning SMF/DS™ Fibers

This design's advantage is that the attenuation at 1550 nm (~0.2 dB/km) is about half of the 1310 nm value for a standard single-mode fiber. However, a higher dopant level is required to change the refractive index profile for a dispersion-shifted fiber. Therefore, dispersion-shifted fiber theoretically will have a slightly higher attenuation at 1550 nm than standard single-mode fiber.

This is partially offset by SMF/DS™ fiber's improved resistance to macro- and microbending-induced attenuation from cabling, installation and handling. The smaller mode-field diameter (MFD) of the SMF/DS™ fiber - 8.1μm at 1550 nm vs. 10.5μm for SMF-28™ single-mode fiber, along with its unique index profile, results in this performance advantage. Table 1 compares the properties of Corning's standard and dispersion-shifted single-mode fibers.

		Corning SMF-28™	Corning SMF/DS™
Attenuation	@ 1300 nm	0.35 dB/km	0.39 dB/km
	@ 1550 nm	0.19	0.21
Mode Field Diameter	@ 1300 nm	9.3 μm	6.5 μm
	@ 1550 nm	10.5 μm	8.1 μm
Zero Dispersion Wavelength		1310 nm	1550 nm
Dispersion Slope		0.09 ps/nm²•km	0.08 ps/nm²•km
Dispersion	@ 1300 nm	≤ 3.5 ps/nm•km	~ -19 ps/nm•km
	@ 1550 nm	~ 17 ps/nm•km	≤ 2.7 ps/nm•km
Bend Performance		Good	Better

Table 1. Corning Single-Mode Fiber Comparison

PERFORMANCE TRADE-OFFS

To evaluate the relative performance trade-offs between standard and dispersion-shifted single-mode fiber at 1310 nm and 1550 nm, the following experiment was conducted.

The experimental setup consisted of a matrix generator with 40 channels, 55.25 to 325.25 MHz, offered to the input of the test laser. From the laser, various lengths of fiber were installed into the system to measure the effect on system performance over each length.

A variable optical attenuator was used after the fiber to maintain the same received optical power, thereby eliminating any contribution the receiver might make. The received optical power was kept at 0 dBm. Following the optical receiver were the RF bandpass filters, a post-amplifier, and a RF spectrum analyzer.

Two 1310 nm lasers and one 1550 nm laser were used for the tests. A 1310 nm laser (Laser 1) and a 1550 nm laser (Laser 3) were selected that had similar modulation index (MI), slope efficiency, laser output power, chirp, carrier-to-noise ratio (CNR), and CSO for 6 dB optical loss as shown in Table 2. Since the laser's distortion mechanisms (slope efficiency, linearity, and chirp) were accounted for, this allowed a better performance analysis based on the fiber's dispersion and attenuation characteristics.

	Laser 1	Laser 2	Laser 3
Modulation Index	4.1%	5.0 %	4.5%
Wavelength	1318 nm	1313 nm	1546 nm
Slope Efficiency	0.117	0.225	0.140
Laser Output Power	4.5 dBm	6.1 dBm	6.0 dBm
Received Optical Power	0 dB	0 dB	0 dB
Laser Chirp (MHz/ma)	370	92	350
CSO (55.25 MHz)	-72.7 dBc	-67.8 dBc	-72.5 dBc
CSO (325.25 MHz)	-66.4 dBc	-72.8 dBc	-61.5 dBc
CTB (55.25 MHz)	-73.6 dBc	-79.6 dBc	-74.9 dBc
CTB (325.25 MHz)	-71.8 dBc	-74.7 dBc	-69.7 dBc
CNR (55.25 MHz)	56.7 dB	58.2 dB	55.9 dB
CNR (325.25 MHz)	55.9 dB	56.0 dB	56.6 dB

Table 2. Relative Laser Performance Characteristics

Assuming the absence of any interferometric or receiver effects, the system CSO will degrade in relation to fiber dispersion, fiber length, channel frequency, chirp, and MI [1]. A second 1310 nm laser (Laser 2) was chosen whose chirp was significantly better than the first, and whose system performance is representative of today's cable TV DFB lasers. This was done to determine the impact on the resultant values of CSO and CNR.

The best CNR performance occurred when operating the 1550 nm laser over standard single-mode fiber. This was primarily due to the low attenuation of standard single-mode fiber at 1550 nm relative to any other combination of fiber and operating wavelength. As expected, operating at 1550 nm over dispersion-shifted fiber proved to have the next best CNR. A relative comparison of the CNR performance between standard and dispersion-shifted fiber at 1310 nm and 1550 nm is shown in Figure 2.

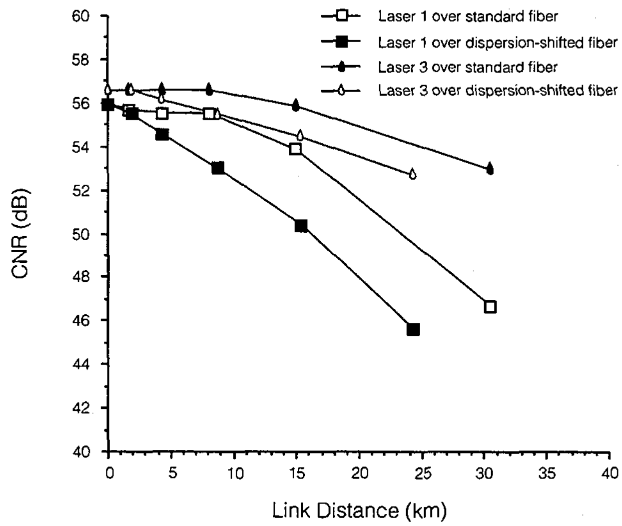

Figure 2. Relative CNR Performance Over Standard and Dispersion-Shifted Fiber

Laser chirp also impacts the overall system CNR. The more chirp a laser has, the lower the spectral density of the noise becomes, which results in a higher CNR [2]. This is a result of the noise due to Rayleigh backscattering within the fiber, coinciding within the same bandwidth as the laser chirp. The results indicated that, given equivalent laser output powers and similar fiber loss per length for the respective fibers, the best CNR performance at 1310 nm will depend upon which laser has the largest chirp. Figure 3 illustrates the effect of laser chirp on CNR performance.

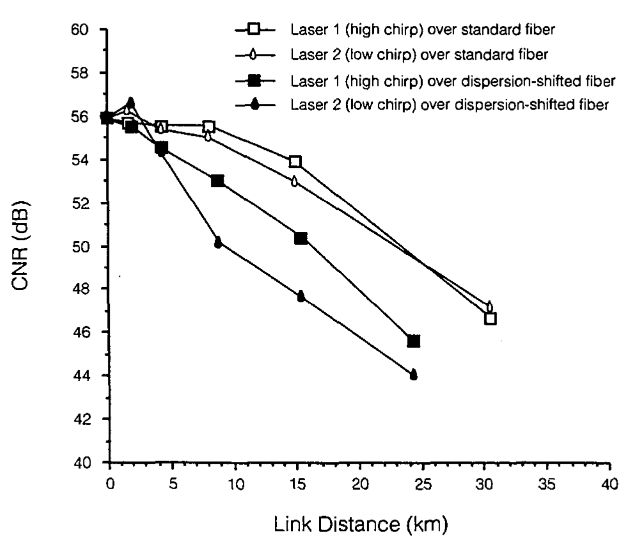

Figure 3. The Effect of Laser Chirp and Fiber Type on CNR

The best CSO performance occurred when operating at 1310 nm over standard single-mode fiber or when operating at 1550 nm over dispersion-shifted fiber. The worst CSO degradation occurred at channel 40 for both standard single-mode fiber operating at 1550 nm, and DS fiber operating at 1310 nm. Figures 4 and 5 show the CSO performance of channels 2 and 40 for standard and dispersion-shifted fiber for the two operating wavelengths, 1310 nm and 1550 nm, respectively.

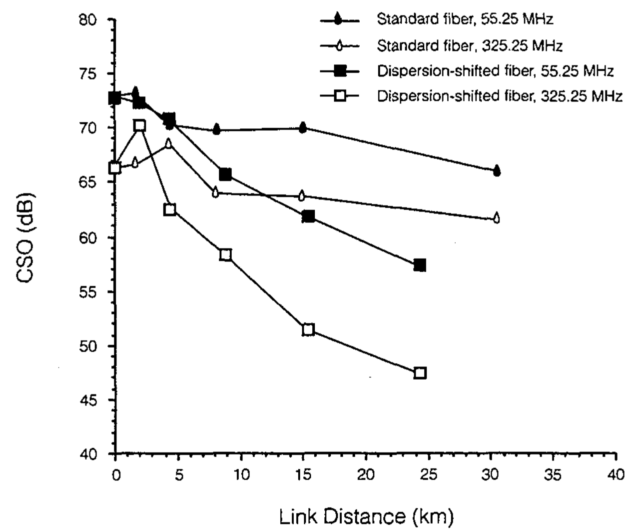

Figure 4. Laser 1 (1318 nm) Frequency Dependence of CSO

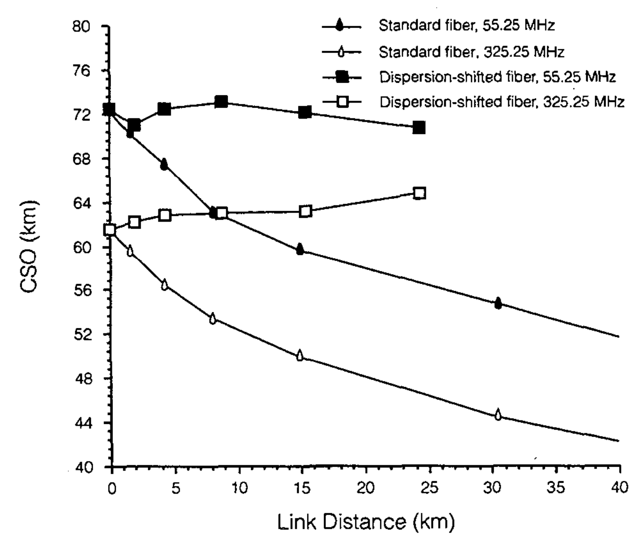

Figure 5. Laser 3 (1546 nm) Frequency Dependence of CSO

It was also observed that some amount of negative dispersion or dispersion compensation is required to improve CSO performance of 1310 nm operation over dispersion-shifted fiber. Figure 6 shows that when operating laser 1 (1318 nm) over dispersion-shifted fiber, the best CSO performance occurs at approximately 2 kilometers (km). It also shows that the CSO performance for laser 3 (1546 nm) over dispersion-shifted fiber appears to increase with length and is estimated to peak at around 50 km. In both cases, it appears that some amount of negative dispersion is helpful to partially cancel the laser or system CSO.

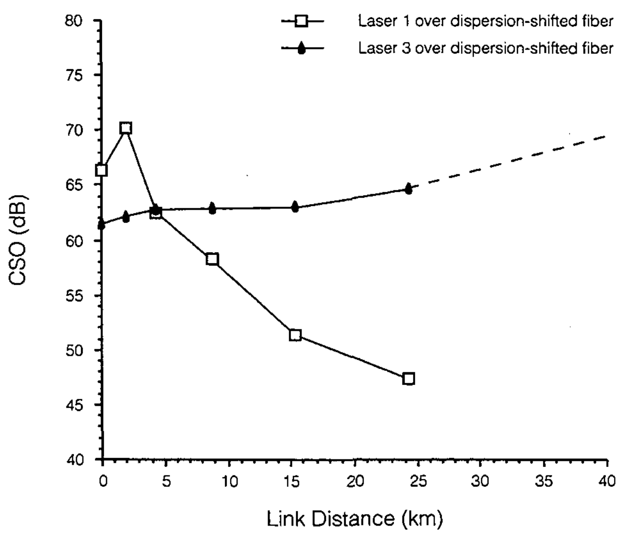

Figure 6. Channel 40 (325.25 MHz) CSO Performance Over Dispersion-Shifted Fiber

In conclusion, the results indicate that a performance tradeoff must be made between CNR degradation and CSO performance when considering 1310 nm and 1550 nm video transmission over standard and dispersion-shifted single-mode fiber.

POTENTIAL CABLE TV APPLICATIONS

Although, 1310 nm AM video transmission over standard single-mode fiber offers excellent CSO performance, transmission distances typically are limited to less than 30 km due to CNR degradation. Transmission at 1550 nm over standard fiber can extend the reach of cable TV links beyond 30 km, but will require some type of CSO compensation for links beyond approximately 4-5 km in length, depending upon system application.

By using 1550 nm transmission over dispersion-shifted fiber, link distances can be extended beyond 40 km with good CSO and CNR performances. Dipsersion-shifted fiber could also be used at 1310 nm without any form of CSO compensation to achieve good performance links up to 5-10 km and possibly further depending upon laser performance. Employing typical CSO compensation techniques would significantly enhance dispersion-shifted fiber's performance at 1310 nm over even longer distances. The 1310 nm window for dispersion-shifted fiber could conceivably be used to provide "narrow cast" programming, a return signal path, or other services with lower performance requirements.

Dispersion-shifted fiber could be included with standard single-mode fiber within the same cable and used for appropriate sections of the cable TV plant to provide 1310 nm/1550 nm system capability. For this hybrid cable design, the dispersion-shifted fiber could be used with optical amplifiers to provide the low cost solution for broadcast video. While the standard single-mode fiber could be used for narrow casting or other services with conventional 1310 nm equipment.

SUMMARY

In summary, dispersion-shifted fiber has been shown to be a technically viable option for 1550 nm window cable TV applications, particularly for longer distance AM links. In addition, dispersion-shifted fiber's 1310 nm performance enables good broadband AM video transmission up to 5-10 km or further, depending upon the laser performance, without CSO compensation. Distances could be extended and performance improved by CSO compensation techniques.

Dispersion-shifted fiber's acceptance and use within the cable TV industry will be determined by its performance tradeoffs relative to other technical alternatives.

REFERENCES

[1] E. E. Bergmann, C. Y. Kuo, and S. Y. Huang, "Dispersion-Induced Composite Second-Order Distortion at 1.5 µm," IEEE Photon. Technol. Lett., vol. 3, p.59-61, January 1991.

[2] H. A. Blauvelt, P. C. Chen, N. Kwong, and I. Ury, "Optimum Laser Chirp Range for AM Video Transmission," NCTA Technical Papers, (Dallas, TX), May 1992.