Performance of Fiber Optic Cables in AM CATV Systems

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Abstract

Because fiber optics has quickly become an accepted technology in AM, CATV applications, the understanding of many component specifications and their impact on system performance has lagged behind. This paper examines current fiber optic cable specifications, and how cable made to these specifications can affect the performance of AM, fiber optic, CATV systems in the field.

It is shown that many of the currently applied telephony specifications are suitable for CATV applications. But, some specifications, in particular temperature performance, should be re-examined in order to meet the needs of the CATV AM video market place.

Fiber Cable Specifications

Although there are a number of specifications written by organizations such as REA, Sprint, and GTE that apply to outside plant fiber optic cable, the most comprehensive and critical specification is Bellcore's TR-TSY-000020, or for short, TR-20[1]. This specification was written by Bellcore for the Regional Bell Operating Companies (RBOCs) so that they could reference it when purchasing fiber optic cable from any vendor. The specification was written with the intent of being used to specify fiber optic cable for telephony systems. This paper investigates how those specifications apply to AM, CATV systems.

As mentioned above, TR-20 is the most comprehensive specification that is available to date. TR-20 cable specifications are summarized in Table 1. As shown in the summary, the attenuation measurements for the mechanical tests are all performed at 1550 nm. This is because the fiber is more sensitive to increases in attenuation at 1550 nm than at 1310 nm[2,3]. The bends that most likely occur during mechanical testing are referred to as macrobends. Macrobends range in size from 5-30 millimeters. Macrobends affect the longer wavelengths in fiber transmission before they affect the shorter wavelengths. The smaller the diameter of the macrobend the shorter the wavelength that the macrobend effects. But as shown in Figure 1, the effect on 1550 nm is apparent at far larger bend radii than at 1310 nm. When macrobends are the cause of attenuation increases, the effect is dramatic due to the severe slope of the loss curve. For this reason all systems should be proved into the field at 1550 nm as well as 1310, even if the intent is to only use 1310 nm as an operating wavelength. Potential problems with the long term stability of your system may not show up in a 1310 nm check out, but would if the system were checked at 1550 nm.

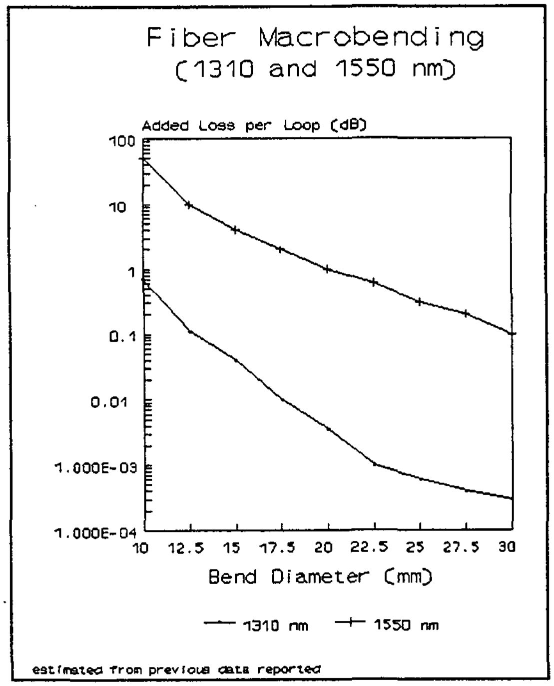

Figure 1

Mechanical & Environmental Tests			
Test	**EIA-455 Specification**	**Mechanical Requirement**	**Optical Requirement**
Tensile	FOTP-33A	600 lbs.	<.1 dB @ 1550 nm
Compression	FOTP-41	1000 lbs.	<.1 dB @ 1550 nm
Twist	FOTP-85	10 cycles	<.1 dB @ 1550 nm
Low Temp. Bend	FOTP-37	4 wraps @ -30 C	<.1 dB @ 1550 nm
Cyclic Flex	FOTP-104	15X cable O.D.	<.1 dB @ 1550 nm
Impact	FOTP-125	25 cycles	<.1 dB @ 1550 nm
Ice Crush	FOTP-98	24 hours @ -2 C	<.1 dB @ 1550 nm
Temperature Cycle	TR-20	-40 to +70 C	100% < 0.2 dB/km 80% < 0.1 dB/km

Table 1

Mechanical Testing

The mechanical tests consist of impact, crush, twist, flex, and ice crush, among others. Attenuation is monitored before, during, and after the tests. The level of acceptance is 0.1 dB allowable increase in attenuation on each fiber. In general, little or no attenuation increases at 1550 nm are experienced due to these tests. Which means, as per the above discussion, 1310 nm is not affected at all.

If a field problem subjected a cable to conditions similar to these mechanical tests, a resulting 0.1 dB increase in the fiber attenuation would result in a decrease in the CNR of 0.1 dB. Because, the majority of the noise in an AM fiber optic system is created in the transmitter and receiver, CNR varies inversely proportional with increases in attenuation of the passive part of the plant. Therefore, for every 1 dB increase in attenuation in the fiber, the CNR is decreased by 1 dB. In the case of the mechanical tests, a 0.1 dB increase, which, as discussed above is very rarely seen, would result in a 0.1 dB decrease in CNR. Distortions are essentially unaffected by an unpolarized, passive increase in system attenuation.

The conclusion is that the performance levels for the mechanical tests are in TR-20 are adequate for AM systems as well. Although, some consideration should be given to mechanical tests that are more applicable to an aerial plant. Most of the mechanical tests specified in TR-20 are applicable to buried applications, where the majority of telephony fiber optic cable is installed.

Lightning and Rodent Testing

There are no lightning or rodent testing requirements that fiber optic cable must pass in order to meet the TR-20 specifications. Although a lightning test must be completed and the results reported,

Table 2

Lightning Test Levels

Test Level	% of Strikes in U.S. below adjacent levels	TR-20 Rating
150 Ka	99%	
105 Ka	95%	A
80 Ka	90%	B
55 Ka	75%	C
< 55 Ka	N/A	D

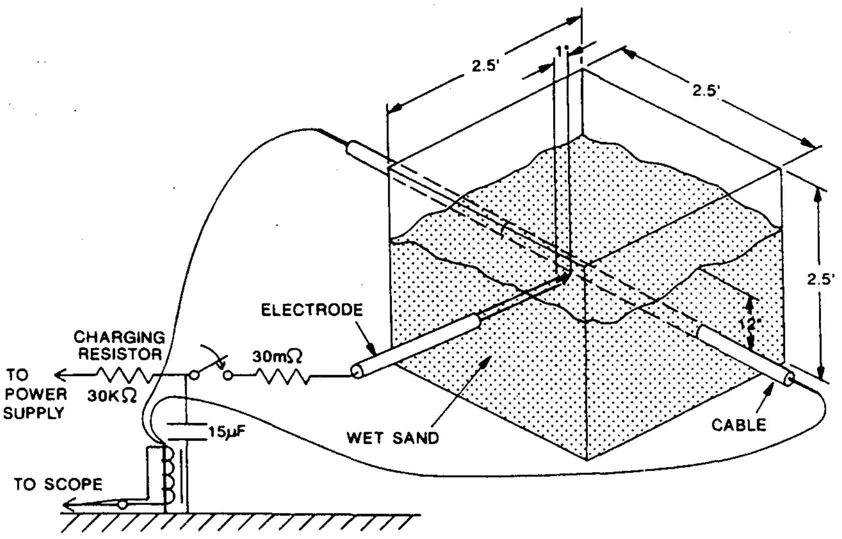

Figure 2

plastics in the cable shrink. The distribution of excess fiber in the tubes is such that the induced bend diameter of the fiber varies at low temperatures. As shown in Figure 1 the diameter of the macrobend does not have to decrease much in order to show a large effect on the attenuation of the cable. The effect, because it is a macrobend effect, degrades attenuation at 1550 nm before 1310 nm.

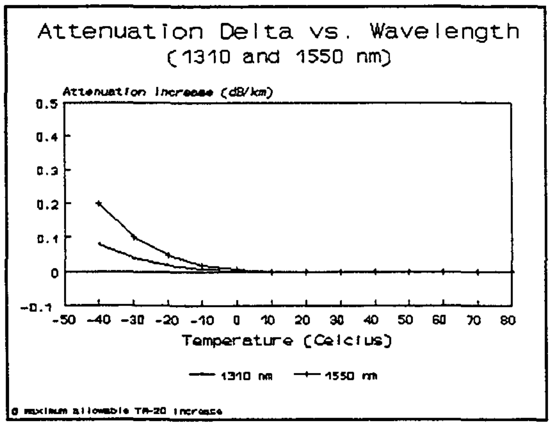

Figure 3

The potential effect on AM system performance due to the allowable attenuation increase, per TR-20 is shown in Figure 4[9,10,11,12]. A 0.2 dB/km increase in attenuation in the fiber corresponds to an identical decrease in CNR at the output of the optical receiver. That means for a 20 km run (12.4 miles), if the fiber were to increase in attenuation the allowable 0.2 dB/km, the net attenuation increase would be 4 dB and would decrease an original CNR at the optical receiver of 54 dB to 50 dB. For lower attenuation increases there would be a correspondingly smaller change in CNR.

Although these changes are seen at 1550 nm before 1310 nm, this allowable increase in attenuation may not be acceptable for some AM system performance criteria. If the performance specification for the fiber optic cable where cut in half (100% less than 0.1 and 90% less than .05), the "proposed specification " curve for AM video fiber optic cable performance shown in Figure 4 would result.

no minimum level is required. The results are reported by rating the cable as passing the test at certain amperage levels[4,5,6]. See Table 2. As shown, the highest TR-20 rating accounts statistically for 95% of all lightning strikes in the United States. Based on this information, an all dielectric fiber optic cable might be preferred in prominent lightning areas of the country. But, before rash conclusions are made, the test procedure should be examined in closer detail.

The test is designed to simulate not only the amperage of the lightning hit, but also the hammer effect of a lightning hit in an underground application. As shown in Figure 2 the cable is buried in wet sand before the simulated lightning hit is discharged. This is important because a great deal of damage can be done to the cable just due to the mechanical impact effect of a lightning strike. The question is: How applicable is this information to aerial applications of fiber optic cable? A modification to the sandbox test has been proposed for aerial applications[7]. The test set up is the same, except that there is no sand in the box and the cable is lashed to strand. All the metallic members in the cable, as well as the stand, are grounded to complete the circuit. Testing under these conditions shows that the strand takes the majority of the hit. See Table 3. Therefore, contrary to some claims, the construction of the cable is of diminished importance to lightning susceptibility in aerial fiber optic cable installations.

Table 3

Lightning Test Levels
Lashed to Strand

Fiber Optic Cable Construction	Test Level Passed
Core Tube, armored	200 Ka
Core Tube, dielectric	200 Ka
Loose Tube, armored	200 Ka
Loose Tube, dielectric	200 Ka
Coaxial Cable	200 Ka

On the other hand, the construction is important to lending rodent protection to the cable. The degree of rodent protection a cable has, is measured at the Denver Wildlife Center with the assistance of gophers. Gophers are used because of the large amount of damage done to buried telecommunications cable by gophers every year. Although a squirrel test might be more applicable to this industry, no such test exists to date. The results of the gopher rodent testing show that a gopher will chew through a non-armored cable during the seven day test, but will not penetrate the steel in an armored product within the same seven day period[8].

In summary, the choice of construction of fiber optic cable should be made with rodent resistance as the determining factor, with less emphasis on lightning resistance.

Temperature Performance

The temperature performance specifications for fiber optic cable as per TR-20 (See Table 1) allow an increase in attenuation as high as 0.2 dB/km across the operating temperature range of -40 to +70 degrees Celsius. The reality of the situation is very close to the specification[14,15,16]. Increases in attenuation are sporadic and non-linear. The specification reflects the inconsistency of the situation. One hundred percent of the fibers must have attenuation increases less than 0.2 dB/km and eighty percent must have increase less than 0.1 dB/km. The attenuation increases occur at the low end of the operating temperature range. See Figure 3. Attenuation increases typically begin occurring around -20 Celsius or approximately -4 degrees Fahrenheit. The increase is not the same on all fibers in a cable and also is not linear with respect to temperature. Some fibers may see the full 0.2 dB/km increase at -40 and other fibers in the same cable may see no measurable increase in attenuation.

This temperature dependent increase in attenuation is due to fiber macrobends discussed earlier. The fiber collapses into these macrobends at low temperatures as the

Again, as in the mechanical tests, non-polarized increases in attenuation due to temperature performance do not affect distortion parameters such as CTB and CSO.

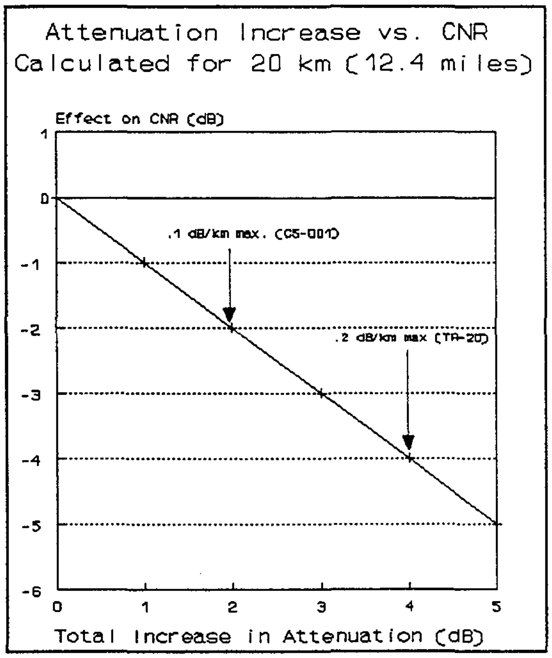

Figure 4

CSO in AM Fiber Systems

Chromatic dispersion is a general term describing the phenomena associated with pulse broadening of an optical signal in a single mode fiber.

Generally, chromatic dispersion can be broken down into two dispersion mechanisms; material dispersion and waveguide dispersion.

Material dispersion is a function of the chemistry used in the manufacture of optical fibers and waveguide dispersion is a function of the index profile of the fiber. They are both types of chromatic dispersion because both types spread the optical signal due to the finite spectral width of the optical source. Which means, different "colors" of light produced by any real optical source travel at different speeds creating a signal dispersion effect.

This dispersion effect in the fiber, combined with phenomena known as laser chirp, create an frequency modulating effect in AM fiber optic systems that manifests itself as CSO. This is the reason that in AM fiber systems CSO is the limiting distortion factor, not CTB[13].

Laser chirp is defined as the phenomena of the laser optical output wavelength changing linearly with the AM modulating signal input into the laser. This is why essentially no chirp is experienced in externally modulated lasers. The laser is not being directly modulated and therefore does not shift or "chirp" wavelength.

The telephony specifications for single mode fiber dispersion can also be referenced when purchasing fiber for AM fiber transmission. Standard singlemode fiber has it's zero dispersion point centered around 1310 nm. The dispersion at 1550 nm in a standard singlemode fiber is substantially higher. (maximum 18 ps/nm-km) Therefore, in many cases the limiting performance specification in 1550 nm systems is CSO, unless external modulation or precompensation for the chirping effect is used.

Time Varying CSO Effects

There have been isolated reports in the field of unacceptable levels of CSO that develop after fiber optic system istallations. These CSO levels can fluctuate in a matter of days or minutes. The effect is caused by a combination of parameters. One being the chirp factor of the laser and the other being polarization maintaining effects of the passive portion of the AM system, which include polarization sensitive loss and polarization dispersion. The passive part of the system consists of connectors, optical couplers and the fiber itself.

The problem occurs when the laser being used has a high chirp factor, and there is some polarization maintaining level of the optical signal in the passive part of the plant.

Two polarizations of the mode in a single mode fiber can be present and have a polarization sensitive loss as well as a polarization sensitive velocity of propagation. The amount of polarization separation is very sensitive to external changes on the fiber cable. Literally, if the wind were to whip a cable in the air, or the outside temperature change, the amount of polarization separation seen in the fiber can change. This change manifests itself as the time varying part of the time varying CSO effect. The actual CSO level is, in part, due to an frequency modulating effect caused by the laser chirp in conjunction with the passive polarization effects. This frequency modulating effect is much like the CSO distortions caused by chromatic dispersion described above.

If the two polarizations continually mix and are not separated, low levels of CSO are seen. As the two polarizations become more distinct for longer periods of time the dispersion levels, and therefore the CSO levels increase. Time varying CSO in AM systems can be controled by minimizing laser chirp, polarization dispersion and polarization sensitive loss.

Summary

At this point in time, there is no better specification to reference than Bellcore's TR-20, for the purchase of fiber optic cable for AM CATV systems. It has been shown, however, that the requirements of fiber optic cable for AM CATV systems differ from the requirements of telephony fiber optic cable.

The major installation method in CATV is aerial and the majority of telephony installations are buried. Due to this difference in predominant installation methods, some environmental test procedures, such as lightning resistance should be modified to better simulate application in the CATV industry. In other cases, such as attenuation increases with respect to temperature, and dispersion effects, the requirements for AM video fiber are more stringent than for digital telephony fiber optic cable and should be taken under consideration when specifying fiber optic cable for broadband AM systems.

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