Characterizing Bandwidth Length Uniformity in High Speed Data Communication Multimode Optical Fiber

White Paper

CORNING
Discovering Beyond Imagination

Optical
Fiber

WP4258
Issued: January 2005
ISO 9001 Registered

Phillip Bell
Global Product Line Management – Premises Fibers
Todd Wiggs
Department Manager – Multimode Preform Manufacturing
Karl Yngve
Supervisor – Optical Measurements Engineering

Overview

Multimode optical fiber is sold with a bandwidth specification provided in units of MHz*km, which is a frequency measurement normalized against the measured length. Manufacturing measurements are made on fiber lengths up to 17.6 kilometers, while the fiber is most often deployed in network link lengths shorter than 300 meters. Given the difference between measured fiber length and application fiber length, it is important to understand how the bandwidth measured in manufacturing relates to the bandwidth of fiber deployed in optical communication systems. This paper provides an overview of the work done by Corning Optical Fiber to ensure that every length of multimode fiber shipped meets bandwidth specifications, and that multimode fiber networks will function as designed 100% of the time.

The work accomplished included overfilled launch bandwidth (OFL BW) for legacy LED-based systems, restricted mode launch bandwidth (RML BW) for intermediate performance VCSEL-based systems, and minimum calculated effective modal bandwidth (minEMBc) for high-performance VCSEL-based systems. For each of these bandwidth measurement techniques, three items are considered when ensuring bandwidth-length uniformity:

1. The accuracy of manufacturing bandwidth measurements must be ensured
2. “Cutback gamma” measurement accuracy must be understood
3. Potential glass trends must be understood and accounted for

Manufacturing Bandwidth Measurement Accuracy

Corning measures every meter of every reel with the industry’s latest standardized multimode measurement methods, where all measurements are directly traceable to the world master reference benches at Corning’s Center for Fiber-Optic Testing (CFT). Multimode bandwidth manufacturing measurements are fully standards compliant, meeting all TIA and IEC requirements. Before introduction into production, measurement methods are qualified against targeted CFT artifacts and must demonstrate acceptable compliance based on analysis via TIA/EIA 455-204 Annex B. Measurements are also certified daily to CFT-targeted measurement standards. These procedures ensure that all Corning bandwidth measurements are reliable and accurate.

Cutback Gamma Measurement Accuracy

A common equation addressing the relationship between fiber bandwidth and length is shown below, where BW_L is the bandwidth of a long fiber length, BW_S is the bandwidth of a short fiber length, L_S is the short fiber length, L_L is the long fiber length, and γ(Gamma) is the length ratio exponent of interest. This unit-less length ratio exponent can be used to approximate the relationship between bandwidth and length.

$$\frac{BW_L}{BW_S} = \left[\frac{L_S}{L_L}\right]^{\gamma} \tag{1}$$

The equation above is used every day to compute fiber bandwidth performance by length. In a typical calculation, the known values are the BW_L and the L_L, which are measured and provided by the fiber manufacturer. The desired length, L_S, is also known, which is the application link length. If the value of γ is known, then the value for BW_S can be calculated. Generally, the value assumed for γ 1, where the BW_L value is assumed to be the same as the BW_S value, and is "passed through" to the shorter link length.

Regarding cutback gamma measurement accuracy, an experiment was conducted where six (6) 8.8 km fibers were measured for bandwidth at full length, then cutback and measured again at 4.4 km, 2.2 km, 1.1 km and 0.55 km. This testing produced a range of values for γ of [0.39, 1.59] for 186 data points. At a glance, this variability might cause some concern, but a careful consideration of the algebra in Equation 1 and a fundamental understanding of measurement systems finds that the actual range of γ is much closer to [1], as described in the balance of this section.

$$\gamma = \frac{LOG\left[\dfrac{BW_L}{BW_S}\right]}{LOG\left[\dfrac{L_S}{L_L}\right]} \tag{2}$$

Equation 2 shows the algebraic solution for from Equation 1. Equation 2 highlights the logarithmic change in bandwidth as length changes. Put simply, as length is decreased by half, the bandwidth doubles. This equation fits the form Y=mX + B, where γ is Y, one over the denominator is m, the numerator is X, and the Y intercept B is at the origin. This implies that the length ratio determines the slope of the line. In the experiment described above, there are only four possible length ratios, so all reasonable bandwidth ratios can be graphed to the corresponding γ value, which is shown in Figure 1.

Figure 1

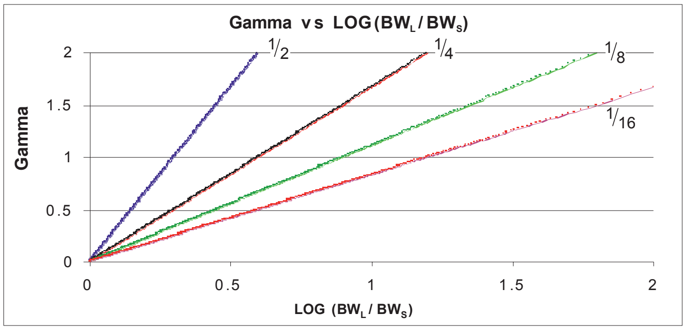


Figure 1 shows four possible length ratios from this experiment. A length ratio of 1/2 means that the fiber was cut in half, meaning the ratio of L_S/L_L = 4.4 km / 8.8 km (or 2.2 km / 4.4 km, 1.1 km / 2.2 km, etc.). Similarly, a length ratio of 1/16 means L_S/L_L is 0.55 km / 8.8 km, and so on. The slopes of the lines shown in Figure 1 are represented by length ratios of 1/2, 1/4, 1/8, and 1/16 from the highest to lowest slope. Figure 1 shows that the length ratio used will have a direct impact on the accuracy of the γ measurement. In other words, very small errors in the measurement of BW_L and BW_S will contribute to perceived variability in γ if the length ratio used is 1/2 (the steepest slope line) and a much smaller variability if the length ratio is 1/16 (the least positive slope line). Measurement variability can obscure this data, which was indeed the case for the [0.39, 1.59] γ range initially observed for this experiment. Figures 2 and 3 bear this out. Figure 2 shows the spread of values for each length ratio, demonstrating that the range of γ is largest on the largest length ratio. Figure 3 shows that even for the 0.5 length ratio, which has the largest range of , the exaggerated range exists in the length ratio .55/1.1, and 1.1/2.2. This is expected based on the non-linear variability of bandwidth measurement systems: as very short lengths of optical fiber are measured, the corresponding increased frequencies push the system to its physical limits and increase the variability of the measurements.

Figure 2

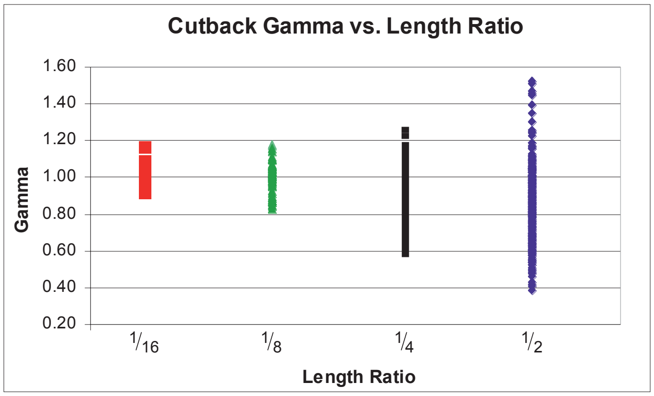
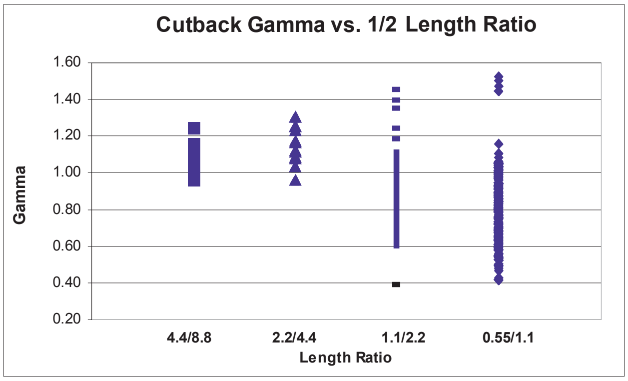


Figure 3



The conclusion from this experiment was that generally $\gamma = 1$, and the utility of for predicting fiber uniformity is limited by a combination of normal measurement variability and cutback length ratio. This model is applicable for all bandwidth cutback experiments, and indicates that the preferred method to achieve accurate results would be to cutback in length ratios that have a lesser scaling effect. It was also learned that the effective use of γ as an all-purpose number speaking to bandwidth uniformity is limited, and that any thorough understanding of bandwidth uniformity must be accompanied by additional investigation.

Bandwidth Uniformity from the Outside Vapor Deposition Process

With this understanding of the applicability and limitations of cutback gamma measurements, Corning then evaluated the bandwidth uniformity capability of the vapor deposition manufacturing process. There are two primary vapor deposition processes capable of producing graded-index profiles for multimode fiber: outside vapor deposition (OVD) and inside vapor deposition (IVD). The first step in an OVD process is the manufacture of a soot fiber preform, which is consolidated (or "sintered") into pure glass in a separate step. Conversely, IVD processes will deposit soot and sinter it into glass as part of the same step – an important distinction for bandwidth uniformity that will be discussed. IVD processes vary in the industry according to their thermophoresis and sintering activation methods, such as an external chemical heat source ("modified chemical vapor deposition," or MCVD) or a plasma arc ("plasma chemical vapor deposition," or PCVD).

Corning invented both the OVD and IVD processes in the 1970's and ran them in parallel for 15 years to evaluate the advantages of each. Ultimately, Corning chose the self-contained OVD process due to its superior process and product performance. One of the key reasons Corning selected OVD technology was that it allowed complete start-to-finish control of fiber manufacturing, which in turn ensured that high-quality would be maintained throughout the entire glass fabrication process. Some IVD manufacturers, on the other hand, may only produce 20%-30% of the total glass that is contained in their optical fiber, while the rest of the glass is purchased from tube suppliers. Tube suppliers may not uniformly control the attributes necessary for reliable field performance of optical fiber, nor are their processes as sophisticated. Tube anomalies such as diameter and wall thickness variations, ovality, bow, and impurities can lead to significant performance problems in optical fiber, including bandwidth variability along the length of a multimode fiber.

In order to attain good bandwidth uniformity, a uniform soot deposition rate must be achieved, which in turn relies on well-controlled temperature gradients throughout the manufacturing process. The two fundamental manufacturing processes can be contrasted through a brief examination of the physics of vapor deposition. For most multimode fibers, germania is used as the principal doping agent to establish a refractive index profile in silica glass. A key component in the art of germania/silica glass synthesis is the sensitivity of glass composition to preform surface temperature. Since the dew point of silica is higher than the dew point of germania, it precipitates first to form nucleation sites for germania condensation. The germania gas condenses as the binary stream (solids and gas) approaches the cooler preform surface. The temperature of the preform surface determines the rate at which the germania gas condenses, and the number of silica particles available to serve as nucleation sites. This binary solid/gas transport system is responsible for proportions of germania and silica that are captured at any discrete axial location. In practice, cooler preform wall temperature will help maintain consistent temperature uniformity, which will in turn favor locally higher concentrations of germania and promote deposition uniformity.

IVD axial and radial temperature uniformity is challenged by soot stream heating effects, wall thickness variability and natural sintering temperature fluctuations. First, the high-temperature soot stream will transfer heat along the entire length of deposition tube as it travels, differentially heating the end of the tube and creating axial temperature variation. Separately, the burners and plasma arcs used for soot deposition are subject to natural temperature variations, creating random temperature discontinuities both axially and radially. This effect is compounded by potential changes in IVD tube thickness, where thicker glass insulates against outside temperatures and creates cool zones on the inside wall. Finally, IVD manufacturing processes operate at much higher temperatures in order to sinter the sooty silica and germania deposits into a solid glass preform. These higher temperatures are more difficult to maintain, and again naturally tend towards non-uniformity. Each of these possibilities for disjointed temperature gradients can lead to axial and/or radial compositional variability, which will in turn drive continuous changes in a multimode graded index profile and ultimately drive bandwidth non-uniformity in the multimode fiber.

OVD, on the other hand, operates at much lower preform manufacturing temperatures which are more easily controlled. The more uniform temperature gradient of an OVD perform lends itself to silica and germania deposition uniformity, which in turn promotes uniformity of the ensuing refractive index profile across the entire preform. Since multimode fiber bandwidth uniformity depends on uniformity of the graded index profile, the OVD process is fundamentally advantaged for ensuring the consistency of bandwidth along the fiber's length.

Finally, as mentioned above, the OVD process is a self-contained, synthetic manufacturing method that is free from potential supplier idiosyncrasies. As a result of over three decades of process and equipment innovations, Corning has developed the knowledge base and manufacturing skill to produce preforms with superior axial and radial uniformity and fibers with tightly controlled bandwidth uniformity.

Conclusion

As the world's leader of optical fiber manufacturing, Corning has developed a tremendous amount of knowledge with respect to fiber manufacturing and consistency. This paper provides an overview of Corning's investigation and control of bandwidth uniformity, which is an increasingly important consideration with today's ultra high performance multimode fibers designed for bit rates of up to 10 Gb/s. Every meter of every reel of Corning® InfiniCor® fiber is measured for laser bandwidth performance, and can be relied upon to perform as specified. Corning stands apart from the crowd in manufacturing quality and measurement performance, and is committed to selling the world's highest-performance, most trustworthy multimode optical fibers.

Corning Incorporated
www.corning.com/opticalfiber

One Riverfront Plaza
Corning, NY 14831
U.S.A.

Phone: 800-525-2524 (U.S. and Canada)
607-786-8125 (International)

Fax: 800-539-3632 (U.S. and Canada)
607-786-8344 (International)

Email: cofic@corning.com

Europe

Berkeley Square House
Berkeley Square
London W1X 5PE
U.K.

Phone: 00 800 2800 4800 (U.K., Ireland, France,
Germany, The Netherlands, Spain and Sweden)

00 800 781 516 (Italy)

+44 7000 280 480 (All other countries)

Fax: +44 7000 250 450

Email: eurocofic@corning.com

Asia Pacific

Australia
Phone:1-800-148-690
Fax: 1-800-148-568

Indonesia
Phone: 001-803-015-721-1261
Fax: 001-803-015-721-1262

Malaysia
Phone: 1-800-80-3156
Fax: 1-800-80-3155

Philippines
Phone: 1-800-1-116-0338
Fax: 1-800-1-116-0339

Singapore
Phone: 800-1300-955
Fax: 800-1300-956

Thailand
Phone: 001-800-1-3-721-1263
Fax: 001-800-1-3-721-1264

Latin America

Brazil
Phone: 000817-762-4732
Fax: 000817-762-4996

Mexico
Phone: 001-800-235-1719
Fax: 001-800-339-1472

Venezuela
Phone: 800-1-4418
Fax: 800-1-4419

Greater China

Beijing
Phone: (86) 10-6505-5066
Fax: (86) 10-6505-5077

Hong Kong
Phone: (852) 2807-2723
Fax: (852) 2807-2152

Shanghai
Phone: (86) 21-5467-4666
Fax: (86) 21-5407-5173

Taiwan
Phone: (886) 2-2716-0338
Fax: (886) 2-2716-0339

E-mail: GCCofic@corning.com