

# Central Tube Cable Ribbon Coupling

**Patrick Van Vickle, Lindsey Alexander, Steve Stokes**

Sumitomo Electric Lightwave

Research Triangle Park, NC

+1-919-541-8100 · pvanvickle@sumitomoelectric.com

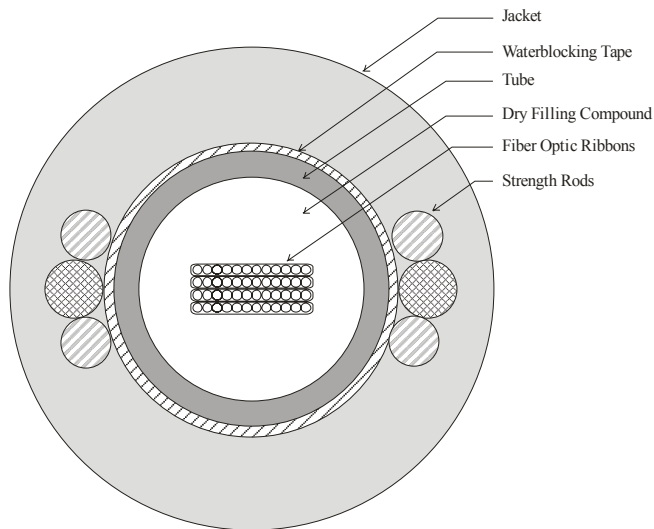
## Abstract

The advent of dry central tube ribbon cable has introduced challenges in evaluating key cable parameters that are not required for gel filled central tube cable. When developing new test methods and criteria it is important to directly relate the test method and criteria to functional cable requirements. Ribbon coupling has been one of the most challenging areas of activity. Through extensive experimental and theoretical analysis it is shown that an absolute ribbon coupling value does not ensure cable performance. In fact it is shown that for some designs an overly high coupling value may be detrimental. For each cable design and dry technology, an optimized ribbon coupling must be found through testing directly related to actual cable lifecycle events.

**Keywords:** Central tube; ribbon; coupling

## 1. Introduction

Dry central tube ribbon cables were introduced in 2001 [1]. Different methods to block the ingress of water in the central tube have been introduced, but all designs rely on a super absorbent polymer filling compound as a replacement for gel in the central tube as shown in Figure 1.



**Figure 1. Dry Central Tube Ribbon Cable Cross Section**

The time and material savings in cable preparation are the driving benefits to these cable designs. The industry realized however that with the new design, new performance issues may need to be addressed [1,2,3].

An exhaustive list of reliability tests was developed. These tests included aged water penetration, humidity aged water penetration and repeated water penetration. In addition to variations of water penetration testing and internal freeze tests a ribbon movement issue may need to be addressed.

Installed cables will likely be exposed to events or forces that cause vibration or movement during the installed lifecycle. These conditions may cause unwanted ribbon movement. For example, it has been demonstrated that cables with low ribbon to central tube coupling force may have ribbons pumped out of the tube during a galloping condition [2].

The industry has struggled to agree on a series of functional tests related to real world conditions a cable may undergo during installation and lifecycle. The primary focus is the test method and acceptable values for ribbon coupling to protect the cable from high cable strain events.

In the following sections each condition is discussed followed by testing methods that may be used to evaluate cable against these conditions. Finally, experimental results for the test methods are discussed.

## 2. Application and Environmental Conditions

The conditions that a cable may see during its life have been discussed previously in numerous papers [4,5,6]. For the purposes of this paper they have been separated into two categories, vibration events and high strain events.

### 2.1 Wind Induced Galloping and Environmental Vibration

An aerial cable may undergo two main categories of vibration, galloping and aeolian. The categories are separated by their frequency and amplitude. Galloping vibration is described by its high amplitude and low frequency. Aeolian vibration has a high frequency and very low amplitude, approximately half the cable's diameter. An illustration of these two types of vibration is shown in Figure 2. Lashed aerial cable may gallop with the proper conditions so it is important to test this specific condition. The conditions of aeolian vibration are rare in nature in lashed aerial cable installations. The multi-degree of freedom systems typically have too much damping to allow a resonance in the span with amplitude equal to half the cable diameter to exist. While lashed aerial cable is unlikely to resonate at frequencies required for aeolian vibration, it may simulate environmental vibration from sources such as railway beds or auto traffic on a bridge or slope.

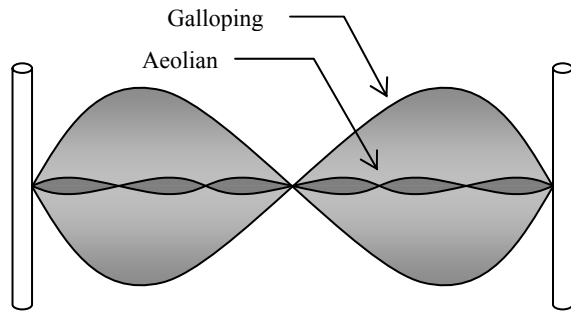


Figure 2. Cable Vibration Conditions

## 2.2 Strain Events

Strain events may occur in many different circumstances. Most cables strain during installation. Cables also see repeated strain from ice loading once installed or from accidental dig-ups.

In each case the amount of ribbon movement is important. The concern is that the ribbon movement does not translate down the entire length of the cable, consuming all ribbon excess length subsequently causing damage to the fiber. Installation procedures have required slack loops of cable, which are an ideal way to lock the ribbons to the cable in the event of an extreme strain event. However, as discussed in the following sections, the cable strain from these conditions is highly unlikely to lead to damaging ribbon strain.

**2.2.1 Ice Loading.** Fiber optic cable deployed in regions where ice buildup is likely must be capable of sustaining the loads and elongations likely to be encountered. The National Electric Safety Code (NESC) describes scenarios of ice buildup and wind conditions by region of the country [7]. From these inputs, elongation of a cable subjected to these conditions may be calculated and any resulting ribbon elongation may be predicted.

Under ice loading conditions cable will elongate. If the cable elongation exceeds the cable's intrinsic excess ribbon length, ribbon will be pulled in from an adjacent cable section as shown in Figure 3, Items 1 and 2. If the cable elongation resulting from the load event exceeds the intrinsic ribbon excess length of all adjacent spans, ribbon may be pulled tight against slack loops or closures if slack loops are not present. This condition exists for both gel and dry cables.

As the ice load is released, the ribbon pulled in from adjacent cable sections creates a new permanent excess ribbon length in the cable, as shown in Figure 3, Item 3. During the next ice loading event the cable will elongate, but since ribbon excess length equal to the strained cable length is already present, no further ribbon will be "pulled" into the section, as shown in Figure 3, Item 4. The cable has essentially reached a new equilibrium.

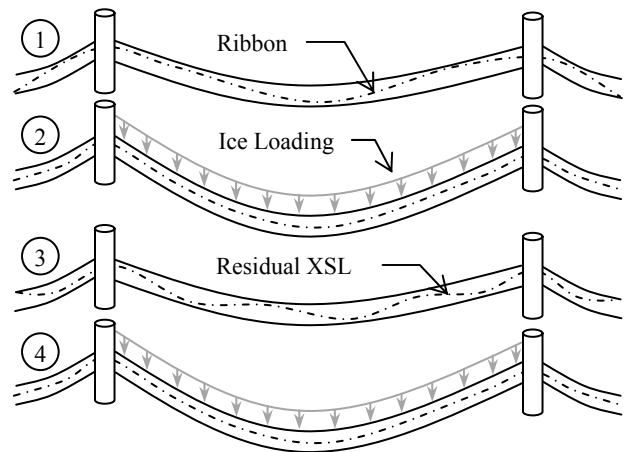
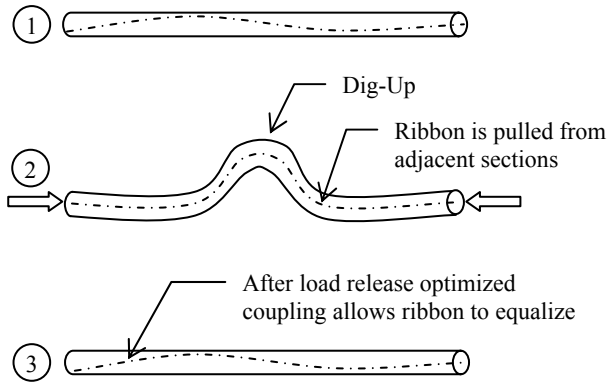


Figure 3. Ice Loading Conditions

Once this process is understood, the analysis of the magnitude of the cable elongation, induced ribbon excess length, and robustness of the cable design may be analyzed. Performing the catenary calculations for these scenarios on a "worst case" lashed aerial cable and span length the cable elongation achieved was less than 0.05% for NESC Heavy ice loading conditions [8]. With this knowledge it is imperative to ensure that the cable design is capable of accommodating this amount of ribbon excess length with neither attenuation loss nor imparting damage to the fibers. The intrinsic ribbon excess length value is designed to exceed this cable elongation.

**2.2.2 Cable Dig-Up.** Occasionally cable is mistakenly dug up by a backhoe or similar piece of digging equipment when the proper precautions are not followed prior to beginning work. When this occurs, a highly localized section of the cable span is subjected to high strains. The strained region has been estimated to be between 5m and 50m [4]. Generally this cable section is removed and replaced.

The question has been posed as to the effect of direct exposure to the high strain on the adjacent cable sections. Estimation of a 50m cable section exposed to a strain, with a load that is near the breaking strength of most cable designs, results in ribbon pulling in from the adjacent sections and may indeed pull tight against slack loops in both dry and gel filled cable. The ability of the cable and ribbon to absorb this strain depends on the cable design, the intrinsic excess ribbon length, and the length of the adjacent section of cable. Whatever coupling is present will either prevent or allow the ribbon strain from transmitting down the cable length and prevent or allow the cable to equilibrate after release of the load. Figure 4 illustrates this event.

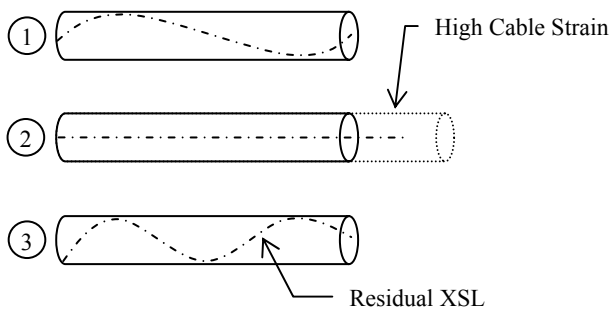


**Figure 4. Dig-Up Strain Event**

Viscoelastic gel filled cable has the unique ability to both couple the ribbons to the cable and allow the ribbons to relax over time. The time required to equilibrate may be long, longer than suggested pull rates for cable coupling testing. Temperature of the gel also plays a large role in the viscous drag imparted to the ribbons and may greatly affect the rate of relaxation. A dry coupling agent does not exhibit this property. Cable strains that result in a force that overcomes the dry coupling force, which is almost certain in this scenario, may not allow the adjacent sections to equilibrate. For this reason a direct correlation to gel filled coupling is hazardous, and testing related to real world cable lifecycle events is so important.

**2.2.3 Installation.** During installation a localized section of cable is subjected to a large strain. It has been reported with some cable designs that this will cause the ribbons to remain stationary while the cable is pulled over them, as shown in Figure 5. When the load is released there is no tensile force on the ribbons at the exposed end, so some length of ribbon remains within the cable. An installer is likely to be alarmed to see no ribbons exposed at the end of the cable after the cable pulling is complete!

This specific end condition also exists for some gel filled designs when subjected to certain installation conditions. The solution is to remove a small section of cable jacket, usually less than 1m, to recover the ribbons. The question again returns to what effect does this condition have on the cable section as a whole?



**Figure 5. Installation Strain Event**

The answer comes from the same factors mentioned earlier, the cable design, initial excess ribbon length and coupling. Clearly if the cable design was such that no cable strain resulted from the installation load then no ribbon movement issue is present, but this results in a large, overly stiff and costly cable. A balance of robust cable design and optimized coupling is the key.

### 3. Functional Test Development

#### 3.1 Vibration Test Method

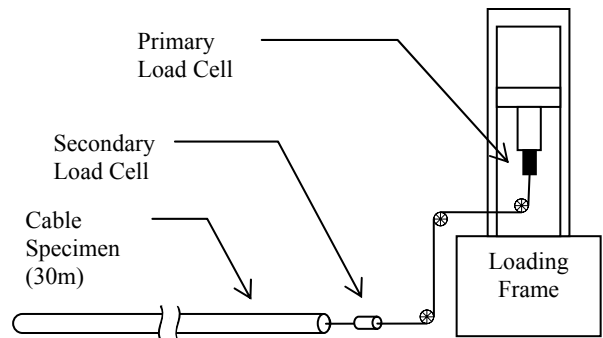
The tests that most accurately simulate the high and low frequency vibration seen in galloping and environmental vibration exist in the IEEE 1222 test method for All Dielectric Self Support Cable (ADSS) [9]. Attention was most recently paid to the low frequency vibration response in the galloping test, but the high frequency aeolian vibration test may also offer important information.

To perform this test the cable was placed in a self supporting condition and strained to twice its rated installation load to meet the test setup requirements. The test does however allow a measurable span of cable to be vibrated with frequencies similar to what may occur if placed near railways or auto traffic. The duration of the test is also extensive, 100,000,000 cycles.

#### 3.2 Ribbon Coupling and Strain Event Test Methods

The test method published by a major telecommunications provider uses a fixed 30m cable specimen. The ribbons from this cable are then attached to a load frame and the force required to initiate movement of the ribbons within the fixed cable sheath and tube sample is monitored [10]. A fixed value of 0.036lbf times the number of fibers in the cable is the required minimum force for passing test results.

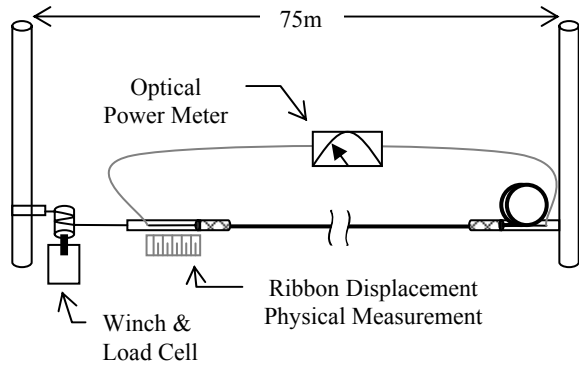
For some cables, especially with lower fiber counts, questions have been proposed about the interaction of the test apparatus given the inherent friction of the pulleys involved. A solution was proposed that elevated the cable sample from the ground to a tray to attempt to eliminate at least one pulley. We propose another solution that introduces a second load cell, located directly in-line with the cable sample. The loading frame load cell is still monitored and the frame controls the rate of movement fixed by the method at  $100 \pm 25$ mm per minute, but the absolute load is given by this in-line secondary load cell. This apparatus is shown in Figure 6.



**Figure 6. Ribbon Coupling Testing Apparatus**

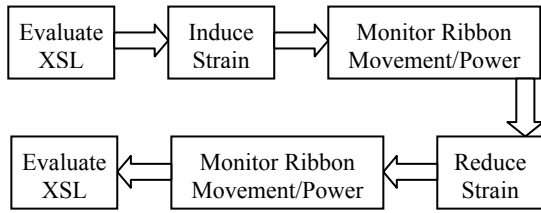
The update to the small scale cable testing apparatus helped ensure more accurate results for coupling force. It then became necessary to construct a test that could create a high strain event.

Using an electric winch and load cell, a cable was strained between two anchored poles 75m apart. By carefully gripping the cable, the ribbons were exposed at both ends and spliced to an optical power meter operating at 1550nm. The ribbons were also placed in such a way as to allow physical linear movement to be measured on one end while the other end was put into slack loops to simulate field conditions. The cable strain event apparatus is shown in Figure 7.



**Figure 7. Cable Strain Event Apparatus**

Prior to beginning and upon completion of the cable strain event test the cable sample is tested for ribbon excess length (XSL) to remove the possibility of excessive ribbon to cable length differences skewing the results. The cable sample then proceeds through the remaining testing procedure described in Figure 8.



**Figure 8. Ribbon Strain Event Testing Procedure**

#### 4. Cable Test Samples

To achieve a thorough understanding of the coupling phenomena, a large number of cable samples were tested. Some of the samples were variations of cables currently offered in the existing product line; others were custom created to achieve the best test resolution possible. Coupling fill ratio, the ratio of filled area to tube area, was a parameter applied for this analysis.

**Table 1. Cable Samples for Coupling Evaluation**

Coupling Fill Ratio	Fiber Count	No. Ribbons
19%	12	1
24%	12	1
25%	60	5
29%	48	4

Coupling Fill Ratio	Fiber Count	No. Ribbons
36%	48	4
37%	144	12
38%	108	9
41%	96	8
45%	144	12
51%	12	1
56%	48	4

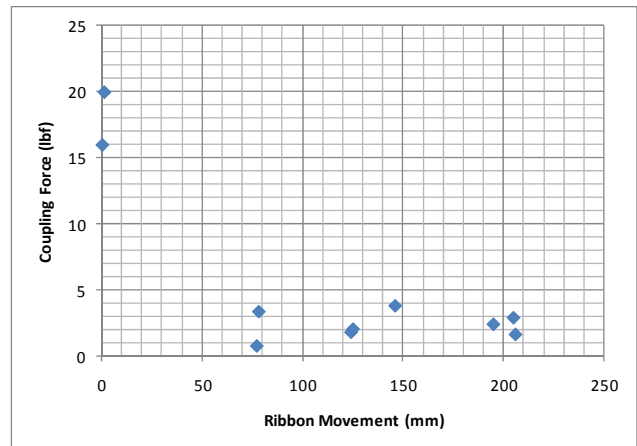
### 5. Experimental Test Results

#### 5.1 Aeolian Vibration

Aeolian vibration has been previously examined and shown to present no permanent attenuation or significant ribbon movement [3].

#### 5.2 Strain Event Ribbon Movement Vs. Coupling Force

To validate the correlation between coupling force and ribbon movement, the coupling force measured using the loading frame event apparatus was compared to the ribbon movement observed using the strain event apparatus.

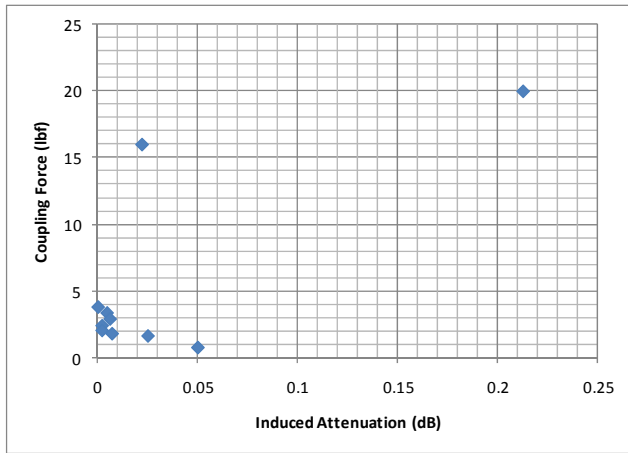


**Figure 9. Ribbon Movement vs. Coupling Force**

Figure 9 demonstrates that above a threshold of coupling force, ribbon movement is certainly retarded. Below this threshold the coupling force is not a good indicator of ribbon movement.

#### 5.3 Coupling Force Vs. Induced Attenuation

The next relationship of interest was the amount of attenuation change induced after a load release from a high strain event versus the coupling force from the loading frame apparatus.



**Figure 10. Induced Attenuation at Release vs. Coupling Force**

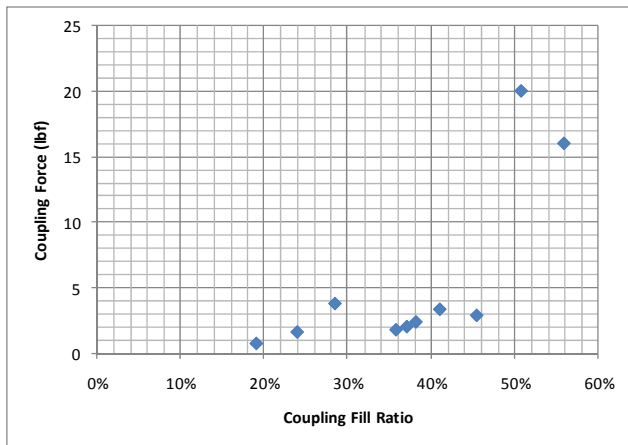
Figure 10 demonstrates that at very high coupling resulting in only a few millimeters of ribbon movement a large attenuation increase is possible. The high coupling does not allow the ribbons to redistribute or relax.

The one data point illustrating this phenomenon does not indicate that this is always the case. More testing at this coupling level would be necessary to better define the amount of coupling and exact circumstances that would cause this issue. This particular event occurred with a 48 fiber count cable comprised of four 12 fiber ribbons. Unlike gel filled cables, dry central tube ribbon cables do not have means to keep the ribbons in a uniform stack. The dependence on a uniform ribbon stack for antibuckling is suspect and this condition may also present itself for higher fiber count cables as well.

The level of coupling that begins to cause this issue is higher than allowed by current design practice for commercialized cables of this design. To ensure robust design, the new design parameter was established that related the filled area of the tube to the available area. An upper limit on the new parameter, coupling fill ratio, would be set to limit induced attenuation.

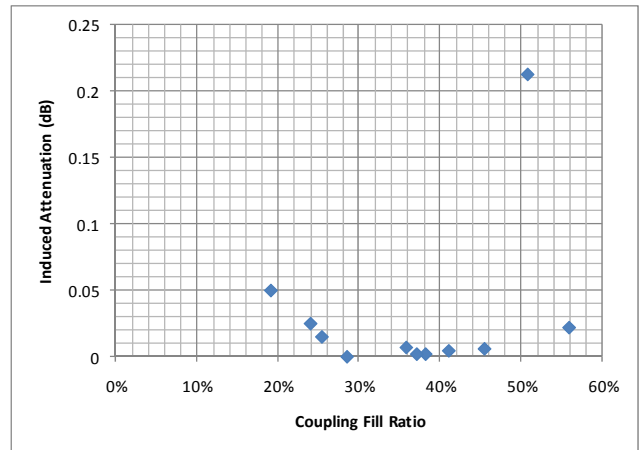
#### 5.4 Coupling Fill Ratio

The validity of the new coupling fill ratio parameter was analyzed against experimental results.



**Figure 11. Coupling Fill Ratio vs. Coupling Force**

Figure 11 shows that at approximately 50% coupling fill ratio the water blocking elements begin to compress and impart significantly higher coupling force. This indicates that there is a threshold below which this parameter does not correlate with coupling force. For this cable design a linear relationship of coupling force does not exist.



**Figure 12. Coupling Fill Ratio vs. Induced Attenuation**

Finally, Figure 12 demonstrates the need to set the coupling fill ratio parameter below 50%. All attenuation results below this level are 0.05dB or less.

## 6. Conclusions

Installation cost and time savings for dry central tube cables are obvious and these cables have been well received in the industry. The new technology however needs to be examined and new test methods developed. When this work is undertaken, it is of utmost importance to set the criteria to best match functional field requirements. The underlying technology for dry cable is common, but the delivery of the super absorbent polymer differs and not all cable designs behave alike. To ensure the most robust cable performance each design must be verified to meet functional requirements including vibration and high strain events.

The results of testing demonstrate that this design of dry central tube ribbon cable is robust. Designs that allow as much as approximately 200mm ribbon movement during a high strain event show no measurable attenuation effects, this indicates a robust cable with a balance between coupling and fundamental cable design. It was shown that a highly coupled cable may exhibit attenuation loss after high strain events. Since it is likely a design will undergo a strain event that will exceed even the highest coupling, it makes it imperative that in all designs a balance between ribbon coupling and overall cable design is achieved.

The criteria for ribbon coupling must be independently established for each dry technology and cable design. This should be accomplished through testing that is directly related to events likely to be experienced by a cable during its lifetime.

## 7. Acknowledgments

Special thanks to Amy Wilson and Mohammad Giahi of the Sumitomo Optics Lab for their work in collecting this data. Also thanks to Dean Dancy of Sumitomo Process Engineering for assistance in producing the cables for testing.

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## 9. Authors



**Patrick Van Vickle** is a Product Design Engineer at Sumitomo Electric Lightwave. His primary duties include optical fiber evaluation and design of premises and outside plant cable. He

received his BS and MS from North Carolina State University in Mechanical Engineering, and recently received a PhD, also from NCSU, with a dissertation titled "Photonic Bandgap Fibers for Transverse Strain Sensing." He is a licensed Professional Engineer in the state of North Carolina.



Lindsey M. Alexander received a B.S. in Electrical Engineering from Lafayette College and M.S. in Optics from the Institute of Optics at the University of Rochester. She is a Product Design Engineer at Sumitomo Electric Lightwave where her primary duties include R&D and production testing.



**Steve Stokes** is Director of Engineering at Sumitomo Electric Lightwave Corp. He holds a Bachelors of Science degree in Electrical Engineering from Virginia Tech. Steve's professional experience includes work in various capacities of optical fiber and cable research and development since 1980. He is currently responsible for fiber optic cable, air-blown fiber, and interconnect product development and process engineering activities at Sumitomo Electric Lightwave.