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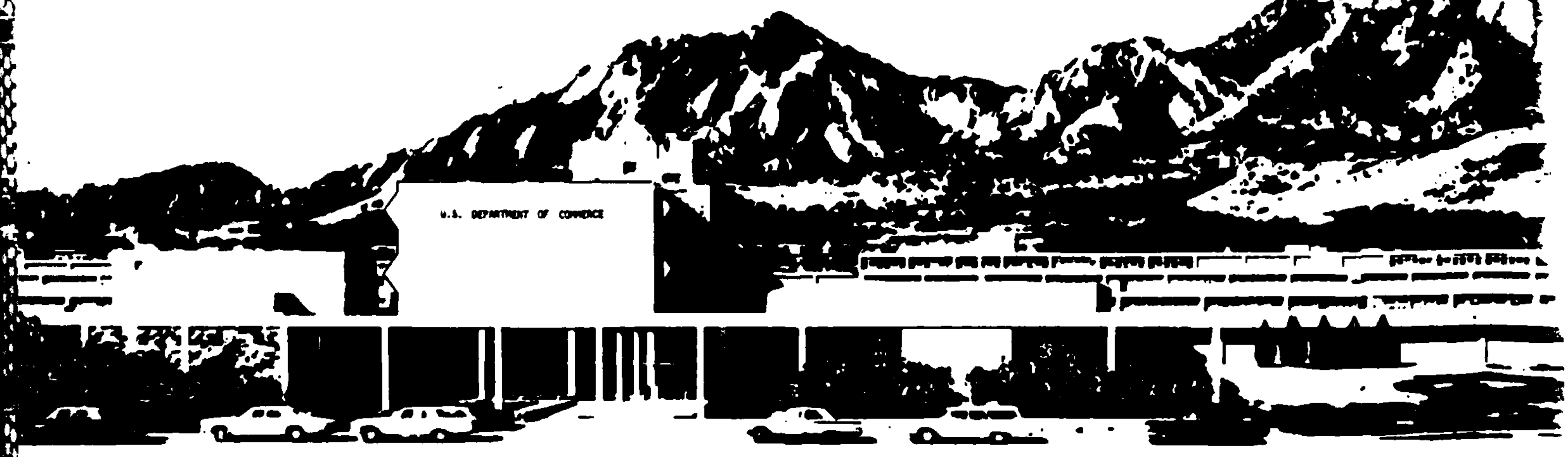

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PREDICTING MICROBENDING LOSSES IN SINGLE-MODE FIBERS

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INTRODUCTION. Conventional techniques for evaluating microbending resistance in single-mode fibers using basketweave [1], pin [2], drum [3], and sandpaper tests depend on excess loss measurements. These tests can evaluate one fiber against another, but the stresses induced in the fiber may not be representative of cable structures or other environments. An alternative evaluation method involves predicting excess losses using a model based on Petermann's microbending theory [4], which depends on mode-field radius, and geometry of the microbends. This method is demonstrated by predicting the excess losses in two precision-wound spools of fiber.

MODEL. The model shown below for periodic, Gaussian-shaped microbends that are separated by a distance L was derived from Petermann's theory. It relates excess loss in dB/km to fiber specifications and microbend geometry. Y_o is the maximum amplitude and A is average half-width at the 1/e amplitude, as shown in Figure 1. Variations in the half-width values can be described by a standard deviation, σ. The electric field distribution of the fundamental mode is also approximated by a Gaussian function with a radius W, which is defined at the 1/e value.

$$\alpha = \frac{13.644\, Y_o^2}{L W^2} \left[\frac{A^2 B^3}{(B^2 + \sigma^2)^{5/2}} + \frac{\sigma^2 B}{2(B^2 + \sigma^2)^{3/2}} \right] \exp\left[\frac{-A^2}{(B^2 + \sigma^2)} \right]$$

where $B = knW^2/\sqrt{2}$
$k = 2\pi/\lambda$
n = refractive index of the core

RESULTS. To demonstrate the model excess losses were calculated and measured in two precision-wound spools of fiber described in Table 1. Precision winding of fibers produces crossovers that can be approximated by the Gaussian-shaped microbends. Each layer of the precision-wound spool forms a helix with a lay angle nearly 90 degrees with respect to the axis of the mandrel. The next layer forms a helix in the opposite direction. As a result the fiber crosses over a fiber beneath it twice per turn so that the period of the microbends are equal to half the circumference of the mandrel ($L = \pi \times 5.72$ cm). The crossovers cause perturbations on the fiber axis and coupling of the fundamental mode to the lossy higher-order mode. This is assumed to be the primary physical mechanism for the microbending loss.

Table 1. Fiber and winding specifications

	Fiber 1	Fiber 2
LP_{11} cutoff λ (µm)	1.135	1.209
Mode-field radius (µm)		
@ λ = 1.3 µm	4.87	4.73
@ λ = 1.5 µm	5.65	5.32
@ λ = 1.55 µm	5.96	5.55
Delta (%)	0.27	0.30
Fiber OD (µm)	125	127
Coating OD (µm)	243	241
Length (km)	2.2	2.0
Mandrel diameter (cm)	11.43	11.43
Crossover amplitude (µm)	35	35
Winding tension (grams)	200	200
Average crossover half-width, A (mm)	1.05	1.05
Standard deviation σ (mm)	0.201	0.210

The fibers were wound onto 11.43-cm-OD mandrels in 17 layers under 200 grams of tension. Figures 2 and 3 illustrate the measured losses in the fibers before and after winding. Fiber 2 exhibits better microbending resistance at long wavelengths due to tighter mode confinement.

Y_0 was calculated to be 35 µm based on the fiber OD, and A was estimated to be 1.05 mm for both fiber spools by visual observation. The standard deviation values, σ, are 201 µm and 210 µm for fibers 1 and 2, respectively. These values were chosen for the best match between calculated and measured excess losses at 1.3, 1.5 and 1.55 µm. Table 2 compares the excess losses calculated using the model and measured excess losses at the three wavelengths. Errors in the calculated values are tentatively attributed to measurement errors in the mode-field radius, and visual observation of A. Winding imperfections also contributed to measurement and prediction errors.

Table 2. Calculated and measured excess losses in dB/km (Measurement errors are in parentheses.)

	1.3 µm	1.5 µm	1.55 µm
Fiber	calc/measured	calc/measured	calc/measured
1	.017/.001 (±.013)	.090/.086 (±.015)	.220/.202 (±.023)
2	.031/.008 (±.015)	.067/.044 (±.022)	.110/.110 (±.031)

CONCLUSION. Prediction of excess losses as a method to evaluate microbending resistance of single-mode fibers is a viable alternative to the other testing methods. Efforts are underway to improve the predictive capabilities of the model by including mechanical bending properties of the fiber.

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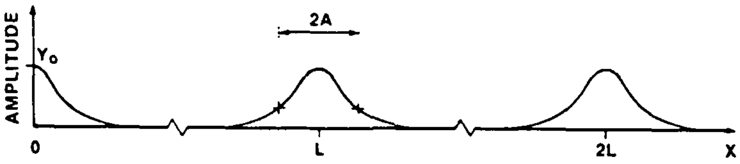

Figure 1. Gaussian-shaped microbends

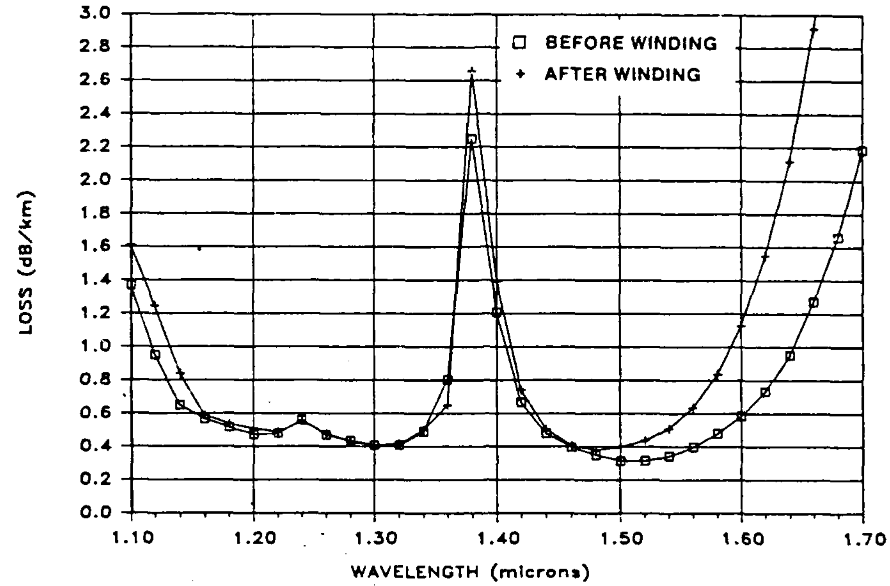

Figure 2. Spectral attenuation for fiber 1

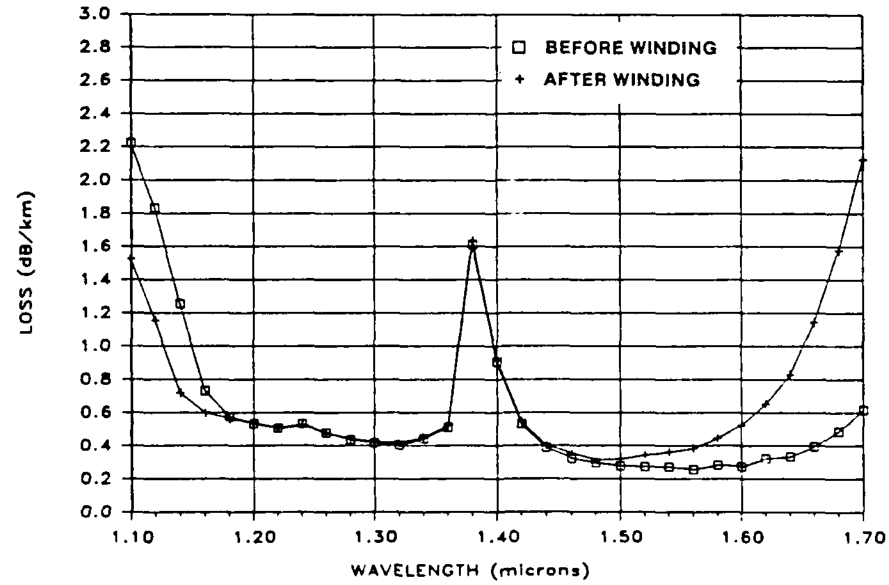

Figure 3. Spectral attenuation for fiber 2