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Analysis of Fiber Connection Loss Associated with Mechanical Tolerances

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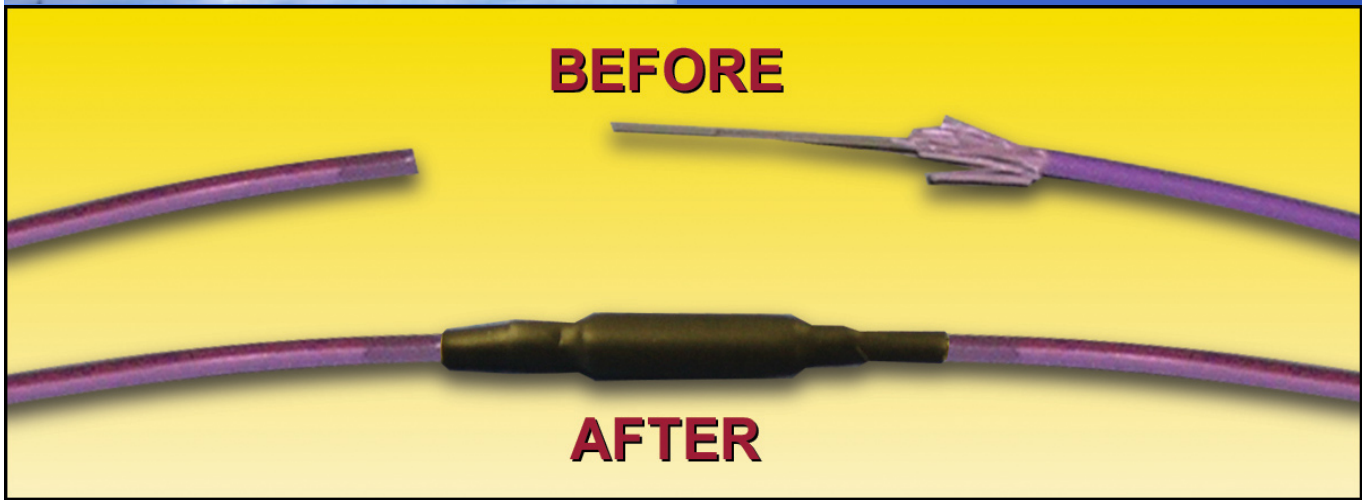
Outline

- Background
  - Polyimide fiber and mechanical splices
  - Fiber and capillary specifications
- Worst-Case Loss
  - Contributions to loss
  - Results for coated and uncoated fiber
- Statistical Analysis of Loss

All Optronics Fiber-Optic Splice

RuggedConnect™

For Permanent In-Field Repair



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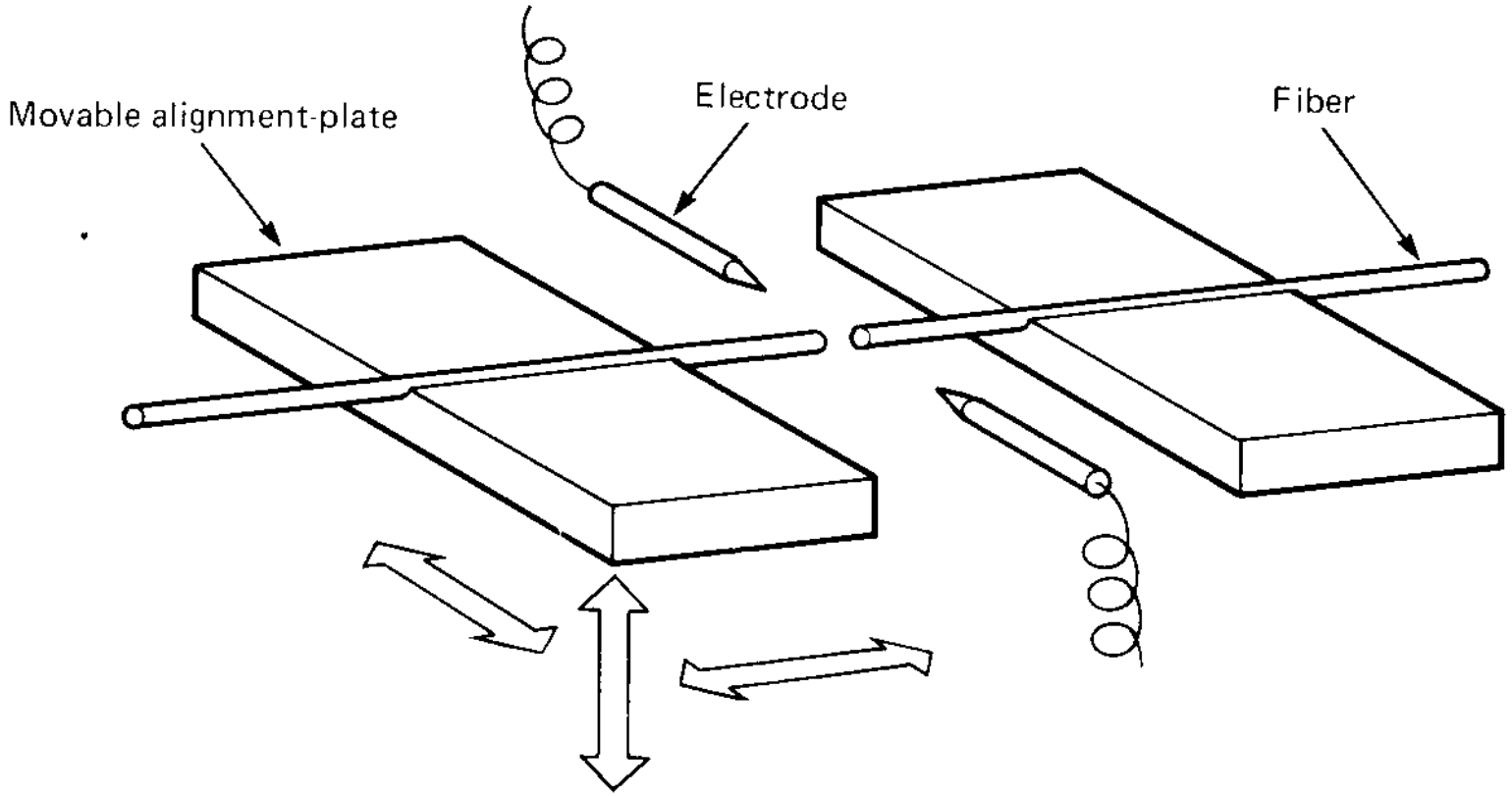
Fusion Splicing



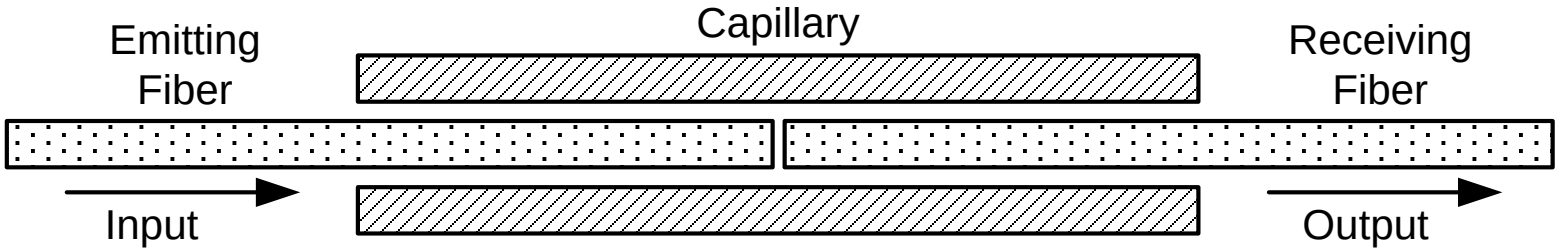
Fiber Optics Handbook for Engineers and Scientists, Frederick C. Allard, Ed.

Avionic Fiber and Splices

An analysis of loss is essential for estimating link budgets

Advantages

- Polyimide coating offers protection in harsh environments
- Fiber has a wide temperature operating range (-60 to 200 ºC)



Advantages

- Bulky, expensive equipment is not required
- There is no spark hazard, as in fusion splicing

Fiber & Capillary Specifications

OFS Polyimide-Coated, Multi-Mode, Graded Index Fiber

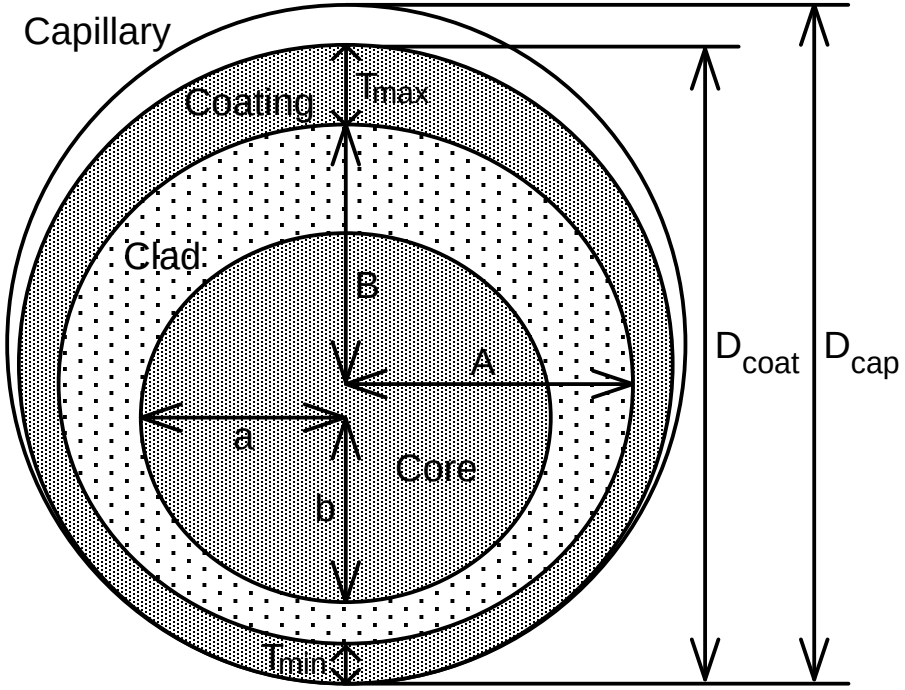
$$D_{core} = 2\sqrt{\frac{a^2 + b^2}{2}}$$

$$D_{clad} = 2\sqrt{\frac{A^2 + B^2}{2}}$$

$$\text{Coating Concentricity} \equiv \frac{T_{min}}{T_{max}}$$

$$\text{Core Non-circularity} = \frac{2a - 2b}{D_{core}}$$

$$\text{Cladding Non-circularity} = \frac{2A - 2B}{D_{clad}}$$



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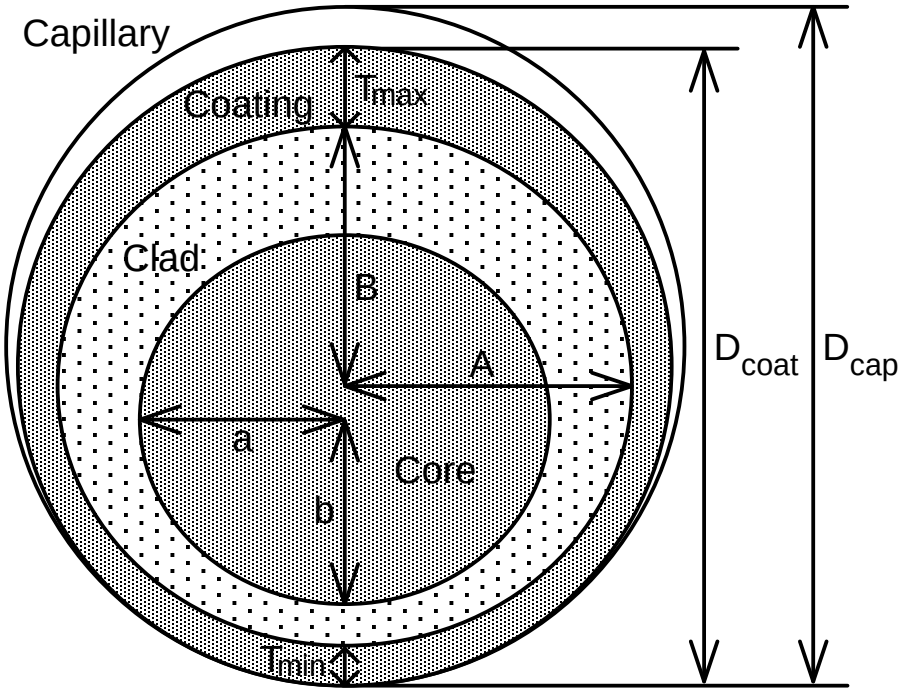
Fiber & Capillary Specifications

OFS Polyimide-Coated, Multi-Mode, Graded Index Fiber

Parameter	Specifications
Core diameter	100 ± 3 μm
Cladding diameter	140 ± 2 μm
Coating diameter	171.5 ± 1 μm
Coating concentricity	80%
Core non-circularity	2 %
Clad non-circularity	2 %
Core/clad offset	2 μm
Numerical aperture	0.29 ± 0.015
Capillary diameter (coated fiber)	173.5 μm + 1/ - 0 μm
Capillary diameter (uncoated fiber)	144.4 μm + 1/ - 0 μm



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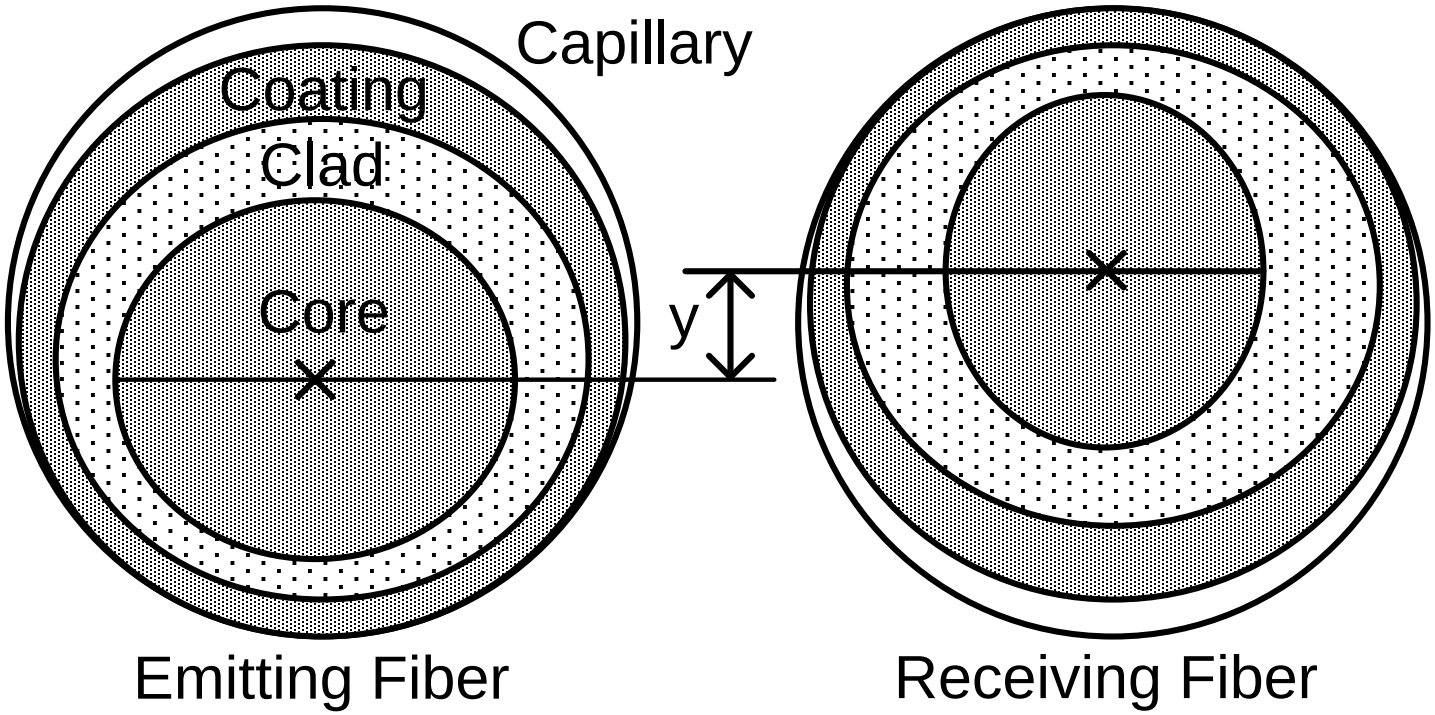
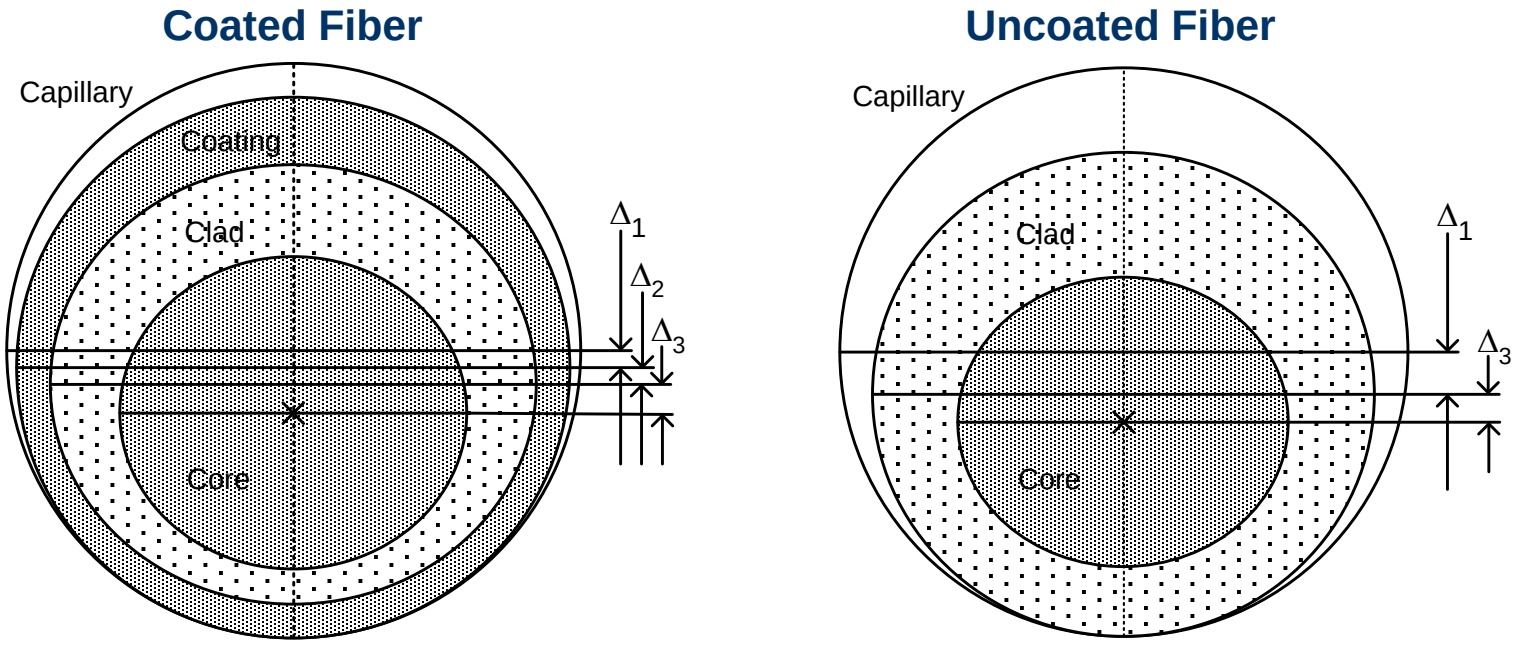
Loss from Fiber Core Offset

The worst-case offset occurs when displacements for and emitting and receiving fibers are in opposite directions.



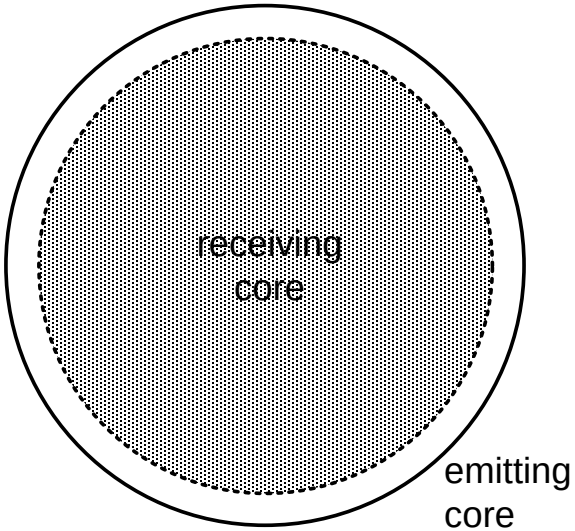
Fiber Core Offset Components



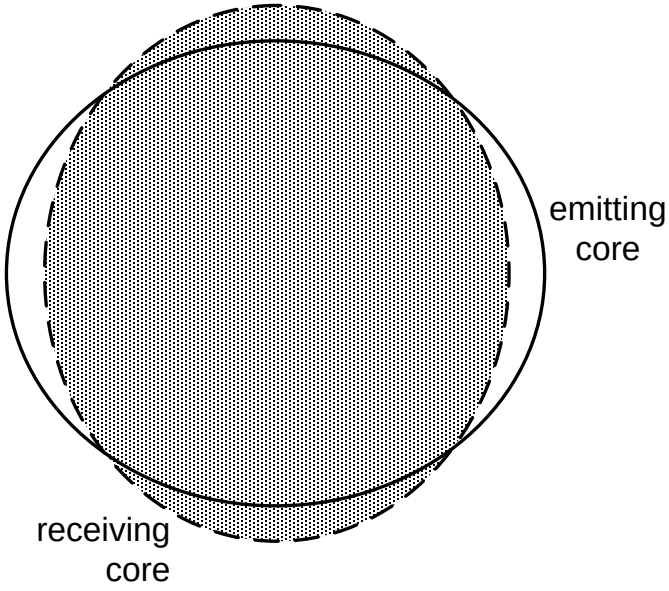
Δ_1 = Capillary/Coating Offset (coated fiber)
Δ_1 = Capillary/Cladding Offset (uncoated fiber)
Δ_2 = Coating/Cladding Offset
Δ_3 = Cladding/Coating Offset

Other Sources of Splice Loss

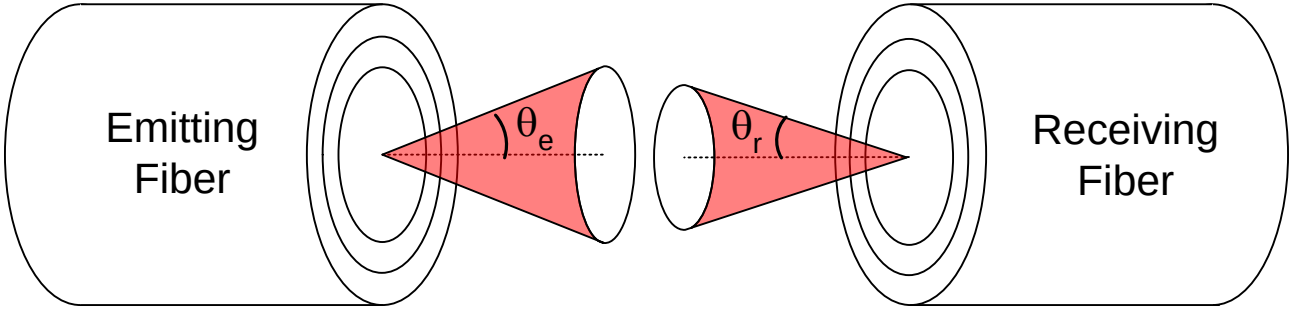
Core Diameter Mismatch



Core Ellipticity



Numerical Aperture Mismatch



“Textbook” Loss Expressions

$$Core\ Offset\ Loss\ [\mathrm{dB}] = -10\log\left[\frac{8d}{3\pi a}\right]$$

$$Core\ Diameter\ Mismatch\ Loss\ [\mathrm{dB}] = -10\log\left[\left(\frac{D_{core}^{rec}}{D_{core}^{emit}}\right)^2\right]$$

$$NA\ Mismatch\ Loss\ [\mathrm{dB}] = -10\log\left[\left(\frac{NA^{rec}(0)}{NA^{emit}(0)}\right)^2\right]$$

$$Ellipticity\ Loss\ [\mathrm{dB}] = -10\log\left[\frac{4}{\pi}\tan^{-1}\left(\frac{b}{a}\right)\right]$$

Modified Loss Expressions

$$Core\ Offset\ Loss\ [\mathrm{dB}] = -10\log\left[\frac{8d}{3\pi a}\right]$$

Stays the same

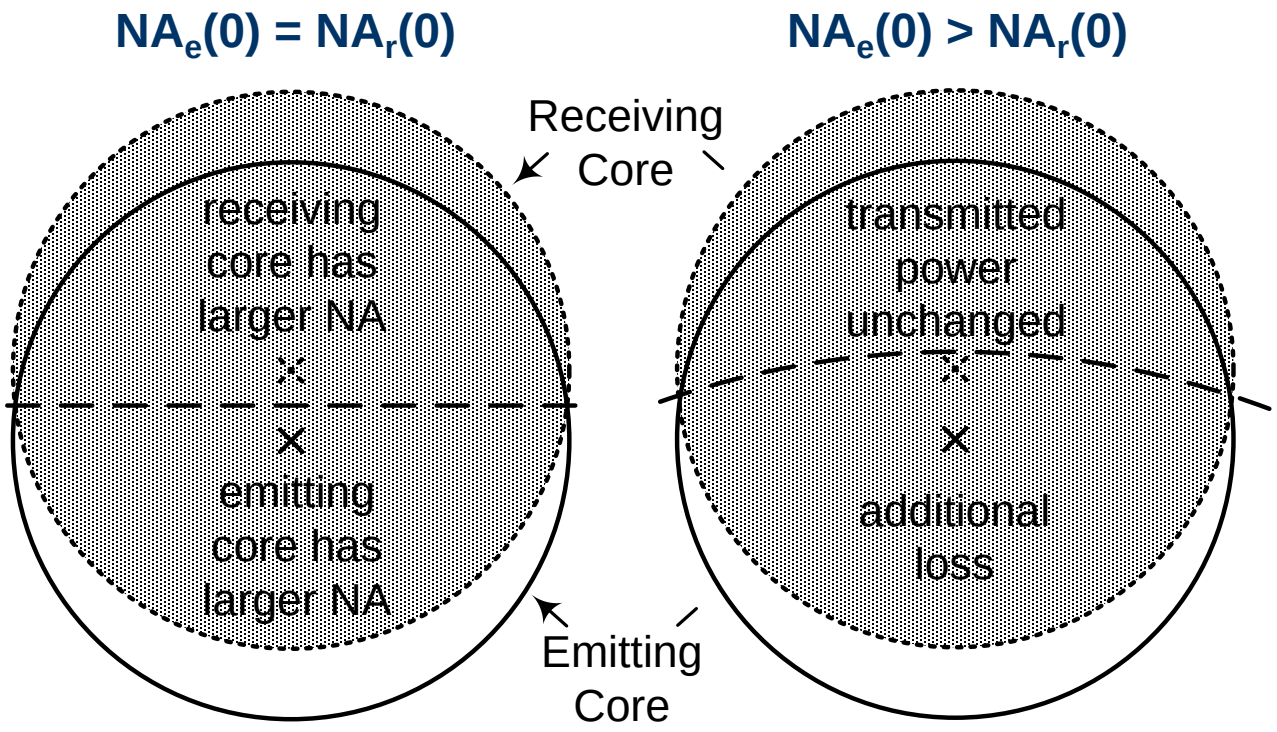
For other contributions to splice loss, linear loss is reduced by a factor of 1/2

$$Core\ Diameter\ Mismatch\ Loss\ [\mathrm{dB}] = -10\log\left[1-\frac{1}{2}\left[1-\left(\frac{D_{core}^{rec}}{D_{core}^{emit}}\right)^2\right]\right]$$

$$NA\ Mismatch\ Loss\ [\mathrm{dB}] = -10\log\left[1-\frac{1}{2}\left(1-\left(\frac{NA^{rec}(0)}{NA^{emit}(0)}\right)^2\right)\right]$$

$$Ellipticity\ Loss\ [\mathrm{dB}] = -10\log\left[1-\frac{1}{2}\left(1-\frac{4}{\pi}\tan^{-1}\left(\frac{b}{a}\right)\right)\right]$$

The Factor of 1/2



$$NA(r) = NA(0)\sqrt{1-\frac{r^2}{(D_{core}/2)^2}}$$

Worst-Case Loss

Loss	Coated Fiber Core Offset = 11.8 μm	Uncoated Fiber Core Offset = 12.8 μm
Offset	1.0 dB	1.1 dB
Core Diameter Mismatch	0.3 dB	0.3 dB
Numerical Aperture Mismatch	0.4 dB	
Core Non-Circularity	< 0.1 dB	
Total	1.7 dB	1.8 dB

A Monte Carlo Analysis of Loss

Statistical Assumptions

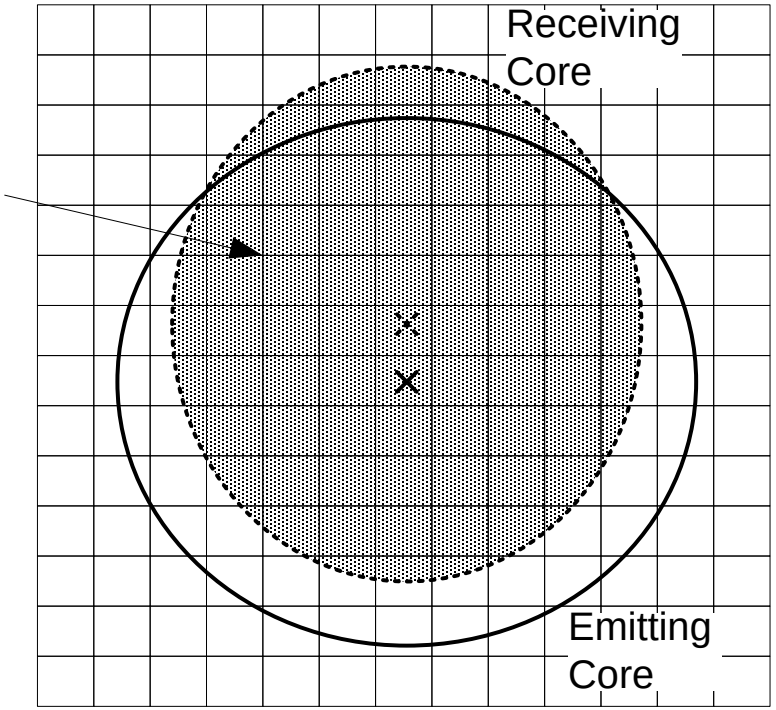
- **Quantities have normal or chi square distributions.**
- **0.27 % of fibers have values larger than the manufacturer's tolerance.**

  The probability is 0.27% that a normally distributed quantity will have a value greater than the "3 sigma value".

- **All positions and orientations for a fiber in a capillary are equally likely.**

Numerical Calculations

Grid Size = 100 x 100
Grid Spacing = 1 μm



$$\text{Loss[dB]} = -10\log\left(\frac{\sum_{i,j} P_r(i,j)}{\sum_{i,j} P_e(i,j)}\right)$$

$$P_r(i,j) = \begin{cases} P_e(i,j), & NA_r(i,j) \geq NA_e(i,j) \\ P_e(i,j)\left(\dfrac{NA_e(i,j)}{NA_r(i,j)}\right)^2, & NA_r(i,j) < NA_e(i,j) \end{cases}$$

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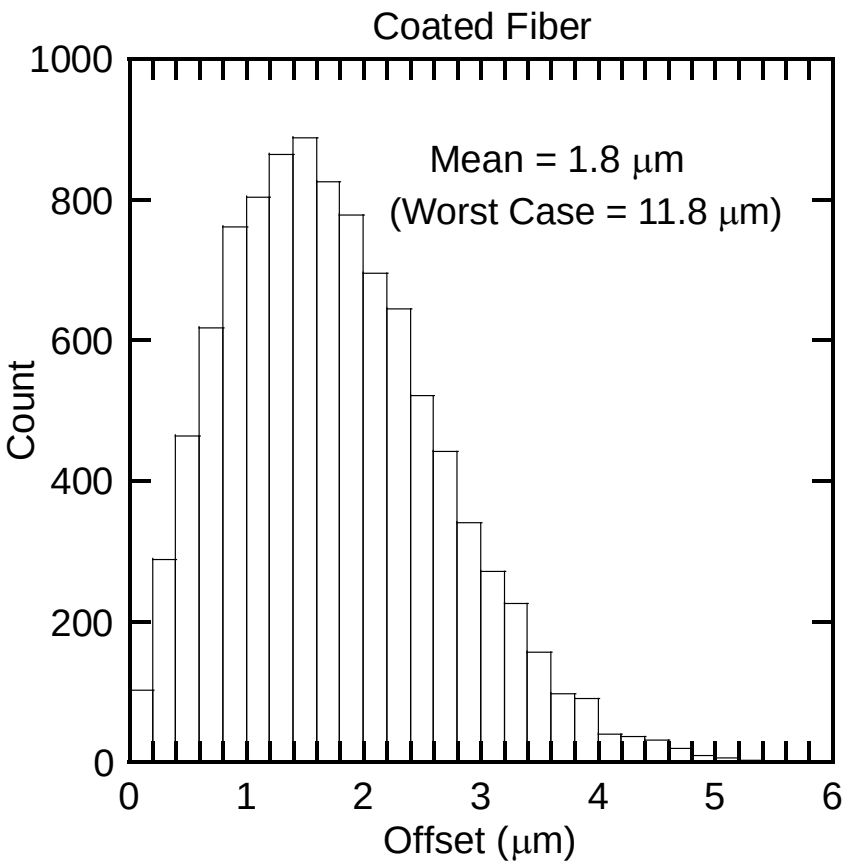
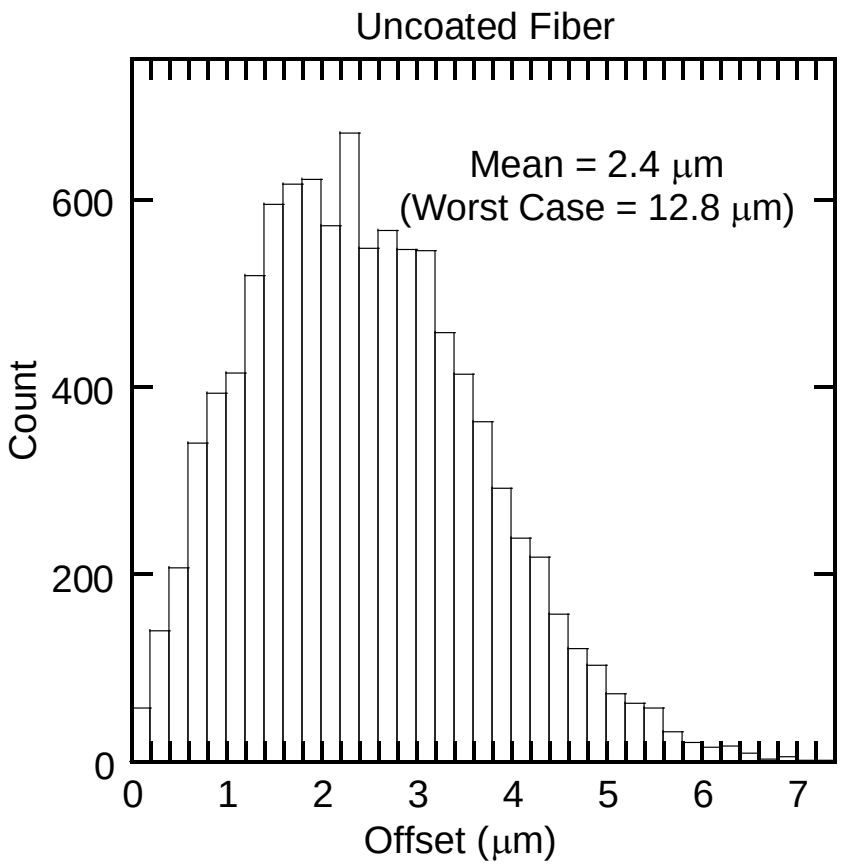
Distribution of Core Offsets

Of 10000 offsets, none were as large as the worst-case.





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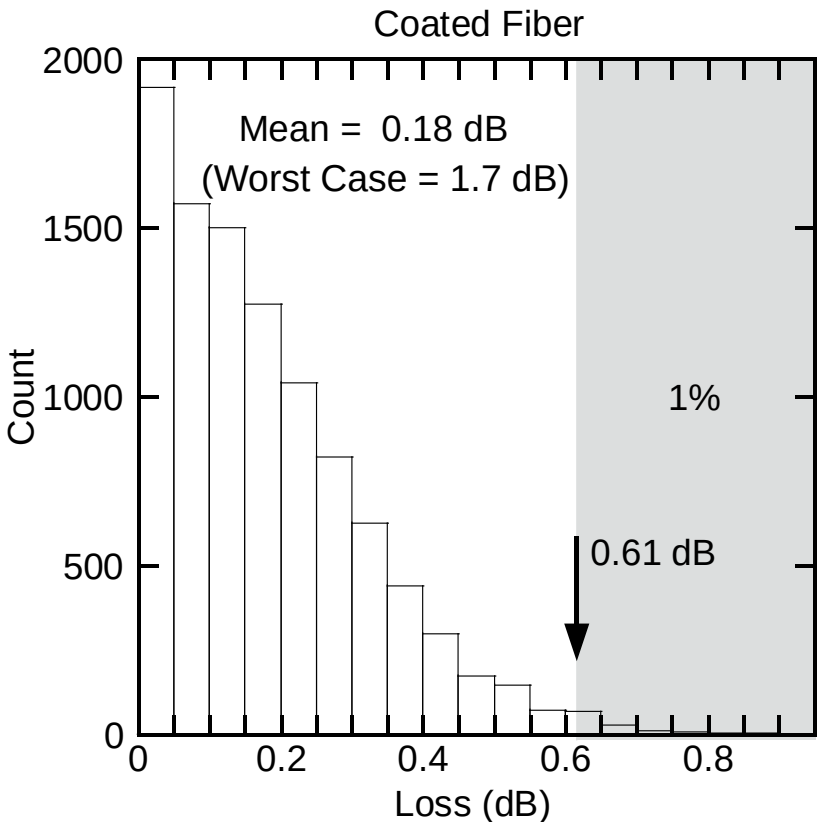
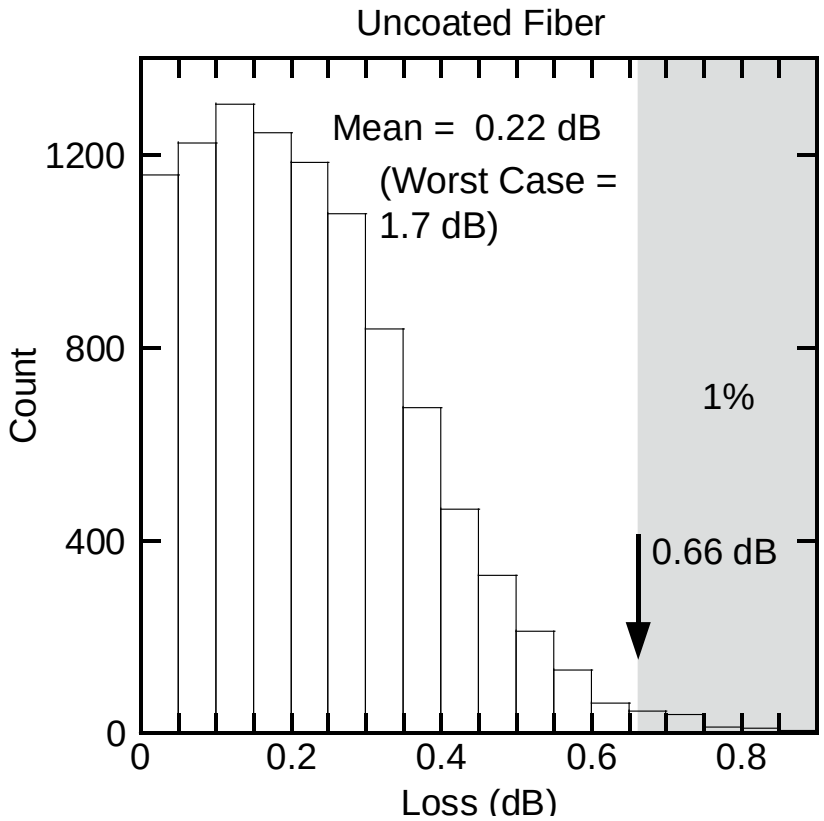
Loss Statistics

The worst-case loss is roughly 3 times the “1%” value.





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Summary

- A geometrical argument gives the rule of thumb:

  Divide loss (other than that due to core offset) by 2 for offset fiber cores

- A statistical analysis gives the rule of thumb:

  Divide the worst-case loss by 3 for the 1% value.