Optical Fiber Behavior in Radioactive Environments

Rob Gilberti - Draka Comteq
Advantages of Fiber Optic Systems

- Electromagnetic immunity
  - no cross talk between adjacent fibers
  - direct contact with high voltage electrical equipment and power lines / no ground loops of any kind

- Low attenuation, large bandwidth
  - much higher data rates / ability to carry much more information and deliver it with greater fidelity than either copper wire or coaxial cable

- Ideal for secure and safe communication systems
  - very difficult to tap but very easy to monitor / no possibility of a spark from a broken fiber.
  - even in the most explosive atmospheres, there is no fire hazard

- Chemical stability
  - impervious to corrosion / buried directly in most kinds of soil or exposed to corrosive atmospheres

- Low weight, low volume
  - much smaller than a wire / coaxial cable with similar information carrying capacity
  - easier to handle and install, and uses less duct space
- Attenuation reduction

  ➔ presently: <0.2dB/km @1550nm

- Strong increase of information-transmitting capacity

  ➔ Wider Wavelength range, Higher Data Rates/Laser Optimized

- Good mechanical resistance

  ➔ Lifetime > 25y; mainly mankind failures

- Large fiber production volumes

  ➔ Stabilization of fiber features & standards

- Radiation Resistance Performance Understanding
Uses of Optical Fiber in Radiative Environments

- Military

  no official data - classified; certifications (USA: MIL-PRF 49291)

- Nuclear Power Plants

- High Energy Physics Laboratories

  CERN (Geneva)
  Fermi National Accelerator Lab. (USA)

- Space industry

  NASA / ESA
# Uses of Optical Fiber in Radiative Environments

<table>
<thead>
<tr>
<th></th>
<th>Doses</th>
<th>Dose-rates</th>
<th>Typical applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military &amp; protection of strategic civil data (estimated – no official data)</td>
<td>From a few mGy up to $10^2$ - $10^3$ Gy</td>
<td>From $10$ Gy/h up to $10^9$ – $10^{13}$ Gy/h (pulsed irradiations)</td>
<td>Data transfer</td>
</tr>
<tr>
<td>Space</td>
<td>From $10$ up to $10^4$ Gy</td>
<td>From $10^{-2}$ up to $10^2$ Gy/h</td>
<td>Data transfer, gyroscopes</td>
</tr>
<tr>
<td>Nuclear power plants</td>
<td>Normal 40°C</td>
<td>~$5 \times 10^5$ Gy (over 40 years)</td>
<td>~1 Gy/h</td>
</tr>
<tr>
<td></td>
<td>Accident 120°C</td>
<td>~$10^6$ Gy</td>
<td>~$10^3$ Gy/h</td>
</tr>
<tr>
<td>High Energy Physics laboratories (CERN-LHC)</td>
<td>&lt; $10^5$ Gy (annual total dose) Up to $10^6$ Gy (future equipments)</td>
<td>&lt; 1 Gy/h Up to 10 Gy/h</td>
<td>Data transfer, fiber sensors</td>
</tr>
</tbody>
</table>
Uses of Optical Fiber in Radiative Environments

Typical doses and dose-rates for different radioactive environments (by S. Girard)

1 Gy = 100 Rad
What kind of fiber to choose?

Single mode fibers (SMF)

High data rates over long distances

- Current RadHard: SMF G.652 (MIL qualified: MIL - PRF- 49291/7)

Multimode fibers (MMF)

Short distance / Datacom

- Current: 50 µm OM2 RadHard (MIL qualified: MIL - PRF - 49291/1)
- Current: 50 µm OM3 RadHard (10Gb/s over 300m @850nm)
- Current: 62.5 µm OM1 RadHard (MIL qualified: MIL - PRF - 49291/6)
Single Mode Fiber behavior

Comparison of different commercial SMFs tested

Radiation-Induced Attenuation for different commercial SMFs – by Fraunhofer Institute

χ = 1310 nm, D = 10^4 Gy, D = 0.225 Gy/s,
T = 28°C, l = 100 m, P = 10/40 µW

1 Gy = 100 Rad
Comparison of different commercial MMFs tested for ESA by INO

**Draka-MaxCap 300 RadHard optimized**: recommended for space appl. [Thériault – 2006]


1 Gy = 100 Rad
Example of dose-rate dependency of RIA for a fiber of Pure Silica type (extracted from Kuhnhenn’s presentation - 2005, on CERN website: http://indico.cern.ch/conferenceDisplay.py?confId=a056455).
Example of temperature dependency of Radiation-Induced Attenuation (RIA) for MMF fibers (extracted from S. Theriault’s – Photonics North 2006, Quebec).
Dependence on Injected Power

- Low Power (1 μW - LED)
- High Power (7 mW - Laser)

Average dose rate = 429 Gy/h
Total dose = 500 Gy
Wavelength = 850 nm

Fibres outside irradiation setup

1 μW

7 mW

Accumulated dose [Gy]

Radiation-induced attenuation [dB]

1 Gy = 100 Rad
Dependence on Fiber Composition

- P-doped SMF (5 Gy)
- PSCF (100 Gy)
- Ge-doped SMF (100 Gy)

Wavelength [nm]

RIA [a.u.]
Radiation-Induced Attenuation or RIA

- **Impact of radiation conditions:** dose-rate, total dose, temperature, nature of radiation

  *RIA generally increases with increasing dose and dose-rate*

  ⇒ *Be aware that accelerated gamma-exposures (i.e. at higher dose-rates than the final operating dose-rate) will lead to much higher RIA. However, such trials can be very useful for fiber comparison.*

  ⇒ *Try to make the preliminary radiation-tests with conditions as similar as possible to the final in-situ radiation conditions.*

  **Nature of radiation (gamma, neutron, X, etc.) => seem to lead to quite comparable results (for same doses).**

  ⇒ *Note that $^{60}$Co sources are the easiest to use. Many radiation facilities (Fraunhofer Institute, INO, Tecnologica, CEA)*

  *RIA generally increases with decreasing temperature*
Radiation-Induced Attenuation or RIA

- Impact of dopants/Fiber Composition:
  
  Do not use P and B as dopants
  
  Formation of Phosphorus-defects that have strong absorption bands;
  one of them is located in the NIR => very bad for uses at 1310nm and 1550nm

  At very high doses (~MGy), use pure silica instead of Ge-doped fibers
  Ge-doped fibers: formation of Ge-defects (GeE’, Ge(1), Ge(2), GEC)

- Impact of manufacturing conditions:
  
  Coating: can be critical at high doses
  Radiation can cause crosslinking resulting in microbending
  – Special Coatings
More work to be done!

Effect of Radiation on Fiber Mechanical Properties
- Strength
- Bending
- Physical Dimensions

Temperature Dependence

Further Comparisons of Fiber Composition and Design
Summary - Conclusions

• Optical fiber offers important features in radiative environments

• Behavior of optical fiber in radiative environments can be complex
  Dependent on many variables including
dose rate, temperature, fiber composition and optical power

• Careful characterization of the radiation conditions is important

• Careful selection of fiber is very important, based on allowed loss
  budget, mechanical properties and fiber composition
Thank you for your kind attention!

Contact: rob.gilberti@draka.com