What can Fibers do for Future Submarine Systems?

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What can Fibers do for Future Submarine Systems?

- **Status**
  - Dispersion Maps
    - NZDSF
    - DMF
- **Future**
  - Simplified Dispersion Maps
    - IDF x 1
  - Fibers for 40 Gbit/s
    - PMD
    - Effective Area
OFS
A Long History of Submarine Cable Innovations

1981 – First high strength single mode fiber for ocean applications
1984 – First Sea Trial using optical fiber
1987 – First application of fiber in trans-Atlantic TAT-8
1988 – First trans-Pacific fiber crossing TPC-3
1993 – First high speed ocean fiber
1996 – First WDM ocean fiber
1999 – First large area NZDSF ocean fiber
1999 – First reduced slope NZDSF ocean fiber
2001 – First dispersion slope matched ultra-long reach ocean sets
2006 – An improved dispersion slope matched product for TPE
Status on Long Haul

- **1988:**
  - **TAT8:**
    - 288 Mbit/s/fiber.
    - 6000 km cable.
    - O-E-O re-generation every 40 km

- **2008:**
  - **TPE:**
    - 64 x 10 Gbit/s/fiber
    - > 11000 km cable
    - optical amplification every 80 km
Primary Fiber Parameters for Current Systems

- Attenuation (long distance between amplifiers)

- Chromatic Dispersion (WDM)
  - Negative dispersion in transmission band due to Modulation Instability
  - Dispersion Slope

- Effective Area (Large Signal Power, lower non-linear impairments)

- Strength (deployment from ship)

- Reliability (25 years life expectancy)
Long Haul and Ultra Long Haul

- NZDF spans
  - Hybrid spans
    - Large effective area fiber near amplifier
    - Low effective area fiber (with low slope) at other end

- Dispersion and slope matched fibers
  - Hybrid spans
    - Large effective area fiber near amplifier
    - Compensating fiber, that compensates dispersion and slope at other end

- Accumulated dispersion
  - Dispersion compensated every 5 – 10 spans with SSMF or SLA
Dispersion managed spans versus conventional NZDF spans

Conventional: NZDF

Dispersion managed: SLA+IDF

Accumulated dispersion [ps/nm]

Distance [km]
What can Fibers do for Future Submarine Systems?

- **Simplified Dispersion Maps**
  - IDF x 1

- **Fibers for 40 Gbit/s**
  - PMD
  - Effective Area
Simplified Dispersion Map

- Symmetric dispersion and slope matched spans
IDF: Inverse Dispersion Fiber
Compensates dispersion and dispersion slope of the positive dispersion fiber in a span.
IDF x 1

**Advantages**

- **Simple cable lay-out**
  - Symmetry

- **Simple repair**
  - All cable segments have equal length of SLA and IDF

- **Lower PMD**
  - IDF x 1 intrinsically has lower PMD, which more than compensate the longer length of IDF in the span.

**Disadvantage**

- Slightly higher span loss
- Slightly higher non-linear impairment
## IDF Data Summary

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<tr>
<th></th>
<th>IDF x 1</th>
<th>IDF x 2</th>
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<tbody>
<tr>
<td><strong>Dispersion at 1550 nm</strong></td>
<td>-21 ps/nm/km</td>
<td>-44 ps/nm/km</td>
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</table>
| **Loss at 1550 nm**   | 0.222 dB/km  
Span with SLA 0.208 dB/km | 0.225 dB/km  
Span with SLA 0.206 dB/km |
| **Effective Area at 1550 nm** | 37 µm²                      | 32 µm²                      |
| **PMD**              | 0.02 ps/√km  
Span with SLA <0.02 ps/√km | <0.03 ps/√km  
Span with SLA <0.02 ps/√km |
Fibers for 40 Gbit/s

- PMD limit lowered by a factor of 4 with direct detection

- 6 dB improvement in OSNR is needed compared to 10 Gbit/s system
  - Span loss
    - Decrease loss of fibers
  - Increase signal power
    - Nonlinear impairments
    - Increased effective Area
What causes PMD?
(what makes a fiber –”non-perfect” ?)

“Internal causes” creating stress in the fiber:
- Non-perfect geometry
- Air void (“bubble”)
- Stress

“External causes”:
- Stress
- Bend
- Twist
PMD Reduction:

• The first step of PMD reduction is to identify and eliminate sources of PMD during manufacture, sources are plenty!

• This requires good control of all manufacturing processes and the ability to evaluate intrinsic PMD of a fiber.

• This, however, is not sufficient – bending resulting from stranding of the fiber in a cable will for instance always cause stress.

• So at OFS we use a patented spinning process in order to build-in a lot of mode-mixing (internal) during the manufacturing process.

• This further reduces PMD – and makes the fiber less sensitive to EXTERNAL mode-coupling changes.
PMD on Submarine Fibers

Ready for 40 Gbit/s long haul

- **NZDSF**
  - TrueWave
    - SRS  Average LMC PMD : < 0.02 ps/√km
    - XL    Average LMC PMD : < 0.02 ps/√km

- **Dispersion and Slope matched fibers**
  - UltraWave Link (SLA+IDF)
    - SLA  Average LMC PMD : < 0.02 ps/√km
    - IDF  Average LMC PMD:  < 0.03 ps/√km
    - SLA+IDF Average LMC PMD : < 0.02 ps/√km
Increase Effective Area

- A new positive dispersion fiber with increased effective area and low loss is required independent of the transmission format of the future.

- With coherent detection the dispersion compensation may not be needed.
  - This could lower the span loss with approximately 1 dB
Increased Effective Area

Cladding

Core

Primary Coating

Secondary Coating

Index profile
Model Calculation on SSMF

Effective Area [µm²]

Micro Bend Sensitivity A.U.

Core Size

Fiber Cut-off 1530 nm

Large Area NZDSF
Large Effective Area Fibers

- Effective area is limited by microbend sensitivity

- Optimized designs
  - Waveguide parameters
    - Currently experimental fibers are around 125µm² with 0.185 dB/km loss

- Increased fiber diameter
  - 125 µm -> 140 µm
    -> Decrease Factor of 2 in µBend

- Increased coating diameters (with 125µm fiber diameter)
  - POD / SOD from 190/250µm -> 225/285 µm
    -> Decrease Factor of 2 in µBend

- New coating materials: “Super Coatings”
  -> Decrease Factor of x in µBend

- Lower T_g of primary (better temperature performance)
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Model Calculation on SSMF

Effective Area [µm²]

Micro Bend Sensitivity A.U.

Fiber Cut-off 1530 nm

ECOC 09, PDP

Large Area NZDSF
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201x – Large effective Area fibers for coherent detection