SubOptic 2007

*Enabling Global Communications*

# Advanced Fibers for Submarine Networks

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CORNING

# Presenter Profile

Sergey Ten was born in Rostov-on-Don, Russia and graduated with honors from the physics department of Moscow State University. He earned his Ph.D. from the University of Arizona in 1996 and joined Corning in 1997 as a Senior Scientist, concentrating on the physics of light propagation in optical fibers. Sergey worked for Tyco Submarine Systems Ltd. in 2000-2001 and in 2001, he re-joined Corning Incorporated as the manager of the transmission test bed group, investigating high data rate transmission in optical fibers. Currently, he is the Network Technology Manager, concentrating his efforts on market development for new fibers.

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# Outline

- Introduction

- Advanced fibers for submarine systems

- Technology trends in transmission systems and implications for submarine fibers

- Summary

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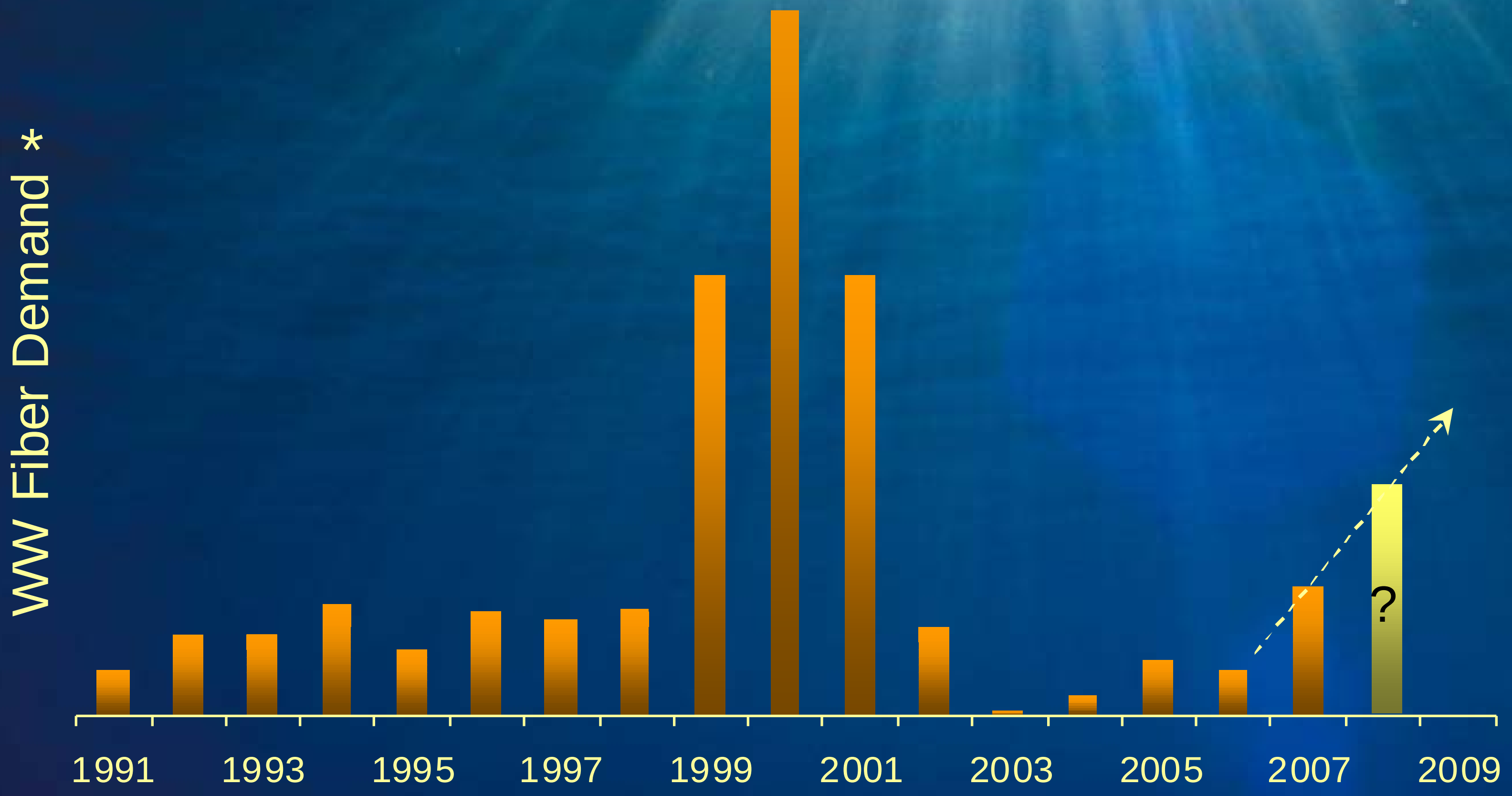
# Submarine Fibers - Recent Growth



**Corning estimate*

YEAR

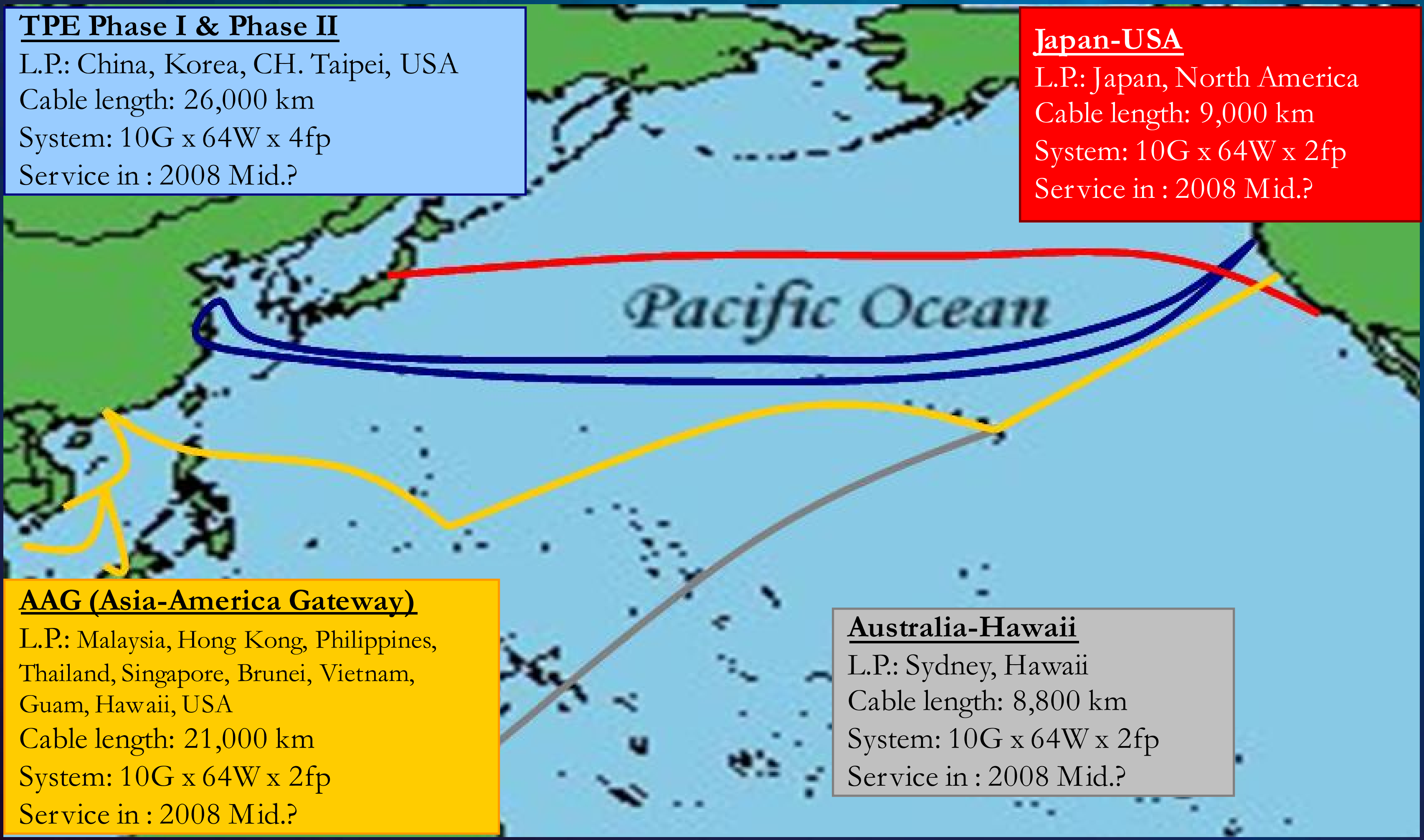
- Submarine fiber demand has been growing, however:
  - it will not likely match the demand during the bubble
  - it will have cyclical nature

# Drivers for Growth

- Growth of broadband terrestrial infrastructure leads to more intercontinental demand
  - Mostly (>80%) Internet traffic
  - Business driven data traffic
- Special events (e.g. China Olympics) and strategic considerations
- Demand for protection routes

# Bubble in the Pacific?

## *Cyclical nature will persist*



**TPE Phase I & Phase II**
L.P.: China, Korea, CH. Taipei, USA
Cable length: 26,000 km
System: 10G x 64W x 4fp
Service in : 2008 Mid.?

**Japan-USA**
L.P.: Japan, North America
Cable length: 9,000 km
System: 10G x 64W x 2fp
Service in : 2008 Mid.?

**AAG (Asia-America Gateway)**
L.P.: Malaysia, Hong Kong, Philippines, Thailand, Singapore, Brunei, Vietnam, Guam, Hawaii, USA
Cable length: 21,000 km
System: 10G x 64W x 2fp
Service in : 2008 Mid.?

**Australia-Hawaii**
L.P.: Sydney, Hawaii
Cable length: 8,800 km
System: 10G x 64W x 2fp
Service in : 2008 Mid.?

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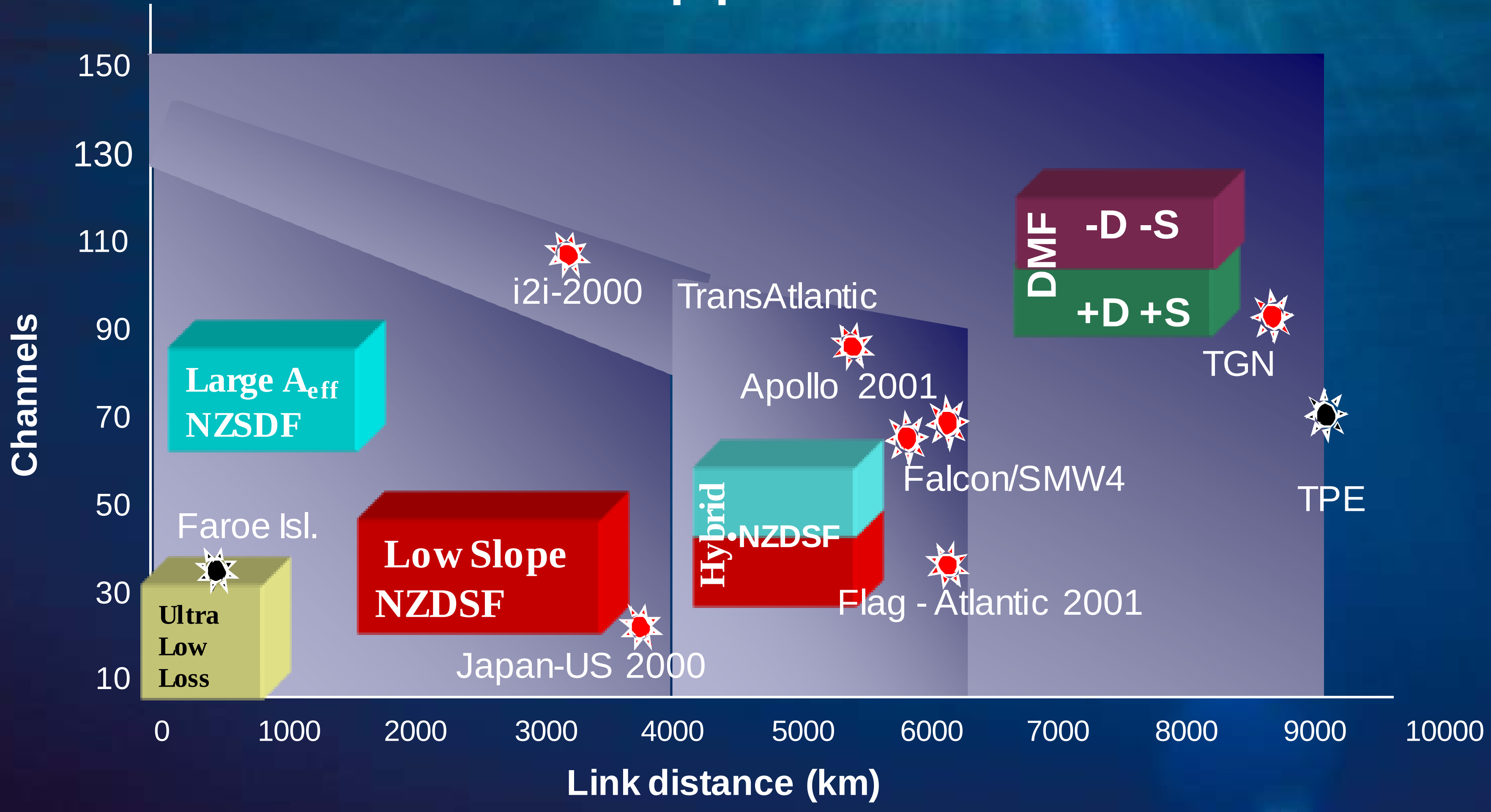
# Submarine Network Characteristics and Fiber Types Used

| Network Type | Distance (km) | Network Requirements | Key Fiber Attributes | Fiber Solution |
|---|---|---|---|---|
| Transoceanic | 9,000-13,000 (Trans-Pacific) | High Capacity (0.4-1 Tb/s) | Flat Span Dispersion, Large Aeff and Low PMD | Dispersion Managed Fiber |
|  | ~6,500 (Trans-Atlantic) | High Capacity (0.4-1 Tb/s) | Low dispersion slope, Large Aeff and Low PMD | Hybrid Solution (Large Aeff NZDSF followed by Low Slope NZDSF) |
| Intra-continental | 3,000-6,000 | Moderate Capacity | Low dispersion slope and Large Aeff, Low PMD | Hybrid Solution *and* Large Aeff NZDSF |
| Regional | 600-3,000 | Moderate – Low Capacity | Low dispersion slope or High Aeff | Large Aeff NZDSF *or* Low slope NZDSF |
| Unrepeatered | <600 | Low Capacity | Low Attenuation or Large Aeff | Low Loss Fiber or Large Aeff Fiber |

- Large difference in the lengths and capacity requirements of submarine networks results in the need for different fiber types that cost optimize those networks

# Fiber Choice for 10 Gb/s Submarine Fiber Applications



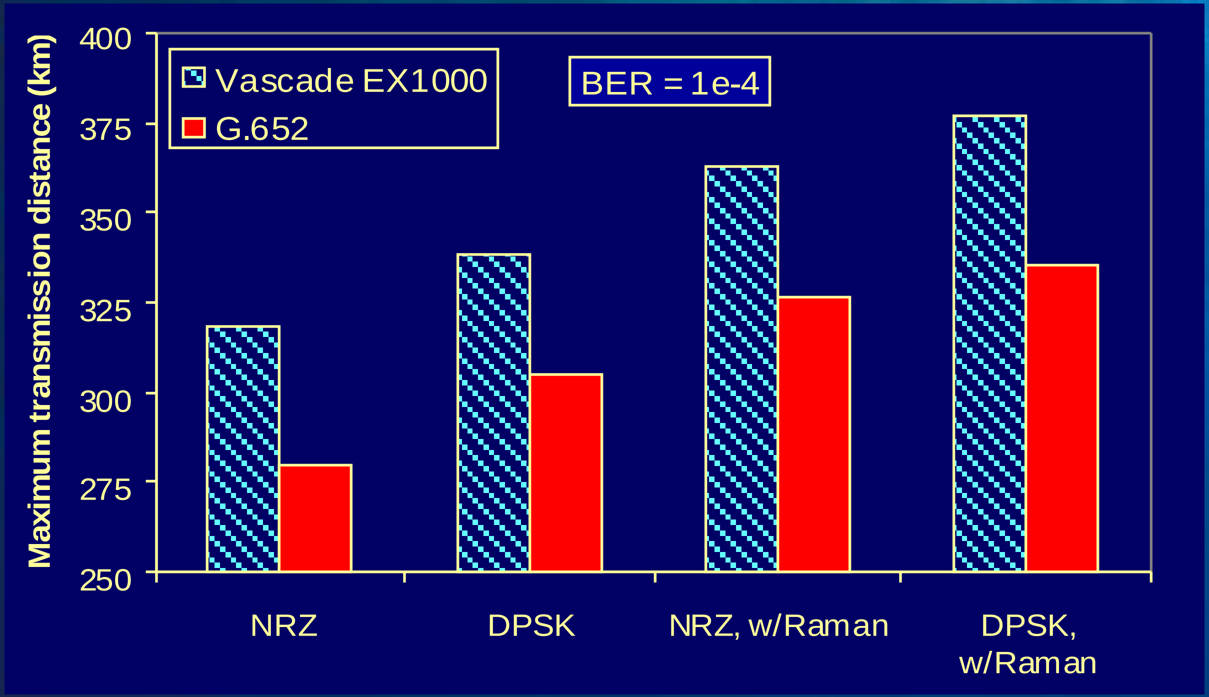
Fiber choice depends on customer specification and network design.

# Fibers for Unrepeated System

- Three most important fiber attributes for very long unrepeated systems:
  - Attenuation, Attenuation and Attenuation
    - Example: at 300 km span 0.01 dB/km attenuation difference is equivalent to 3 dB!
  - For distributed Raman amplification lower attenuation in Raman pump band improves OSNR
- Pure Silica Core fibers with ultra low attenuation are the fibers of choice for long unrepeated systems

| *Fiber Solution* | *Corning Fiber* | *Attenuation (1550 nm) [dB/km]* | *Dispersion (1550 nm) [ps/nm-km]* | *Dispersion Slope [ps/nm²-km]* | *Aeff [$\mu m^2$]* |
|---|---|---|---|---|---|
| **Ultra Low Loss Fiber** | **Vascade® EX1000** | **0.17** | **+18.5** | **+0.06** | **76** |

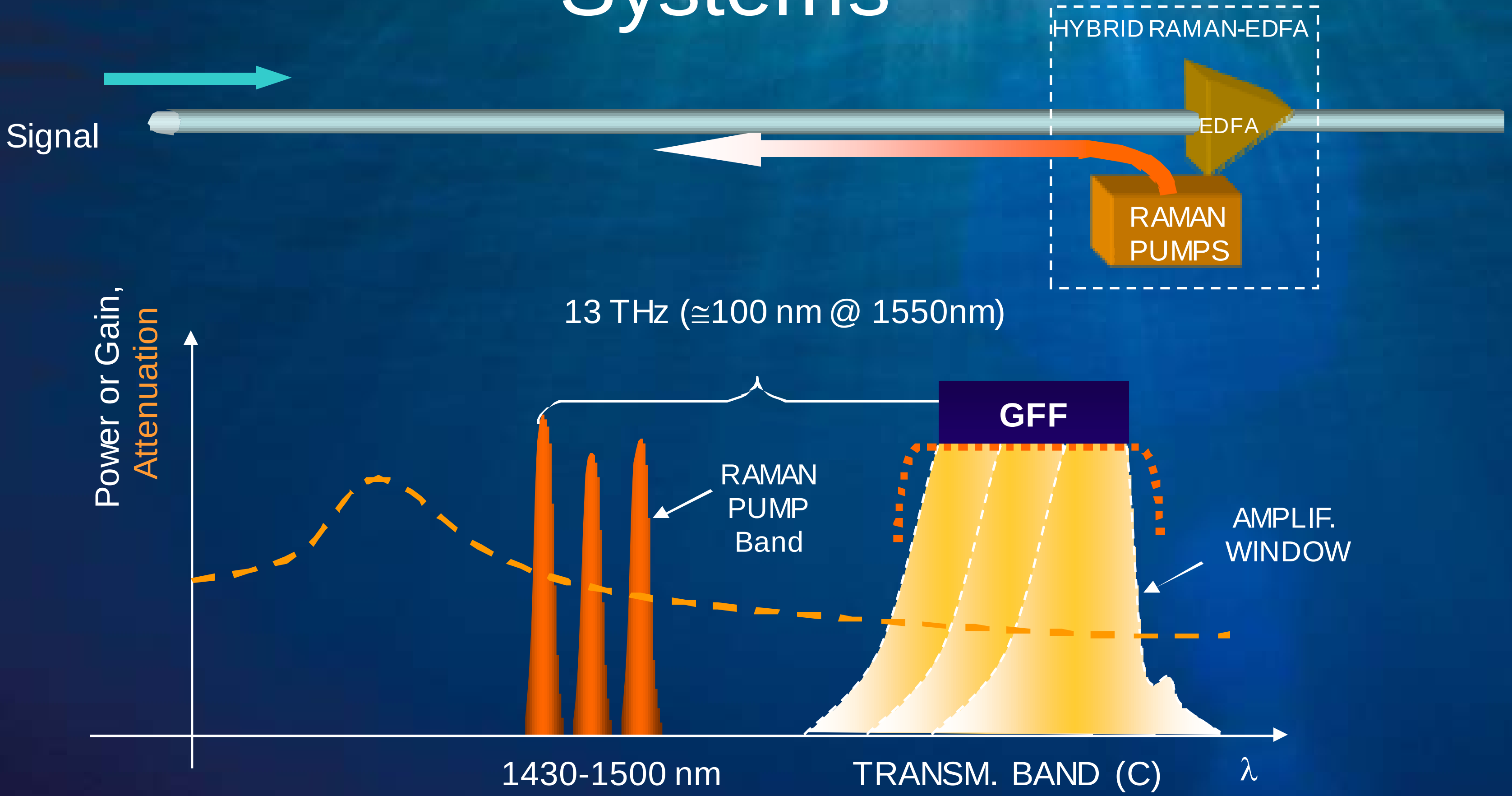
# Comparison of Unrepeatered Transmission Distances



*J. Downie et.al. ECOC 2006 Mo3.3.3.*

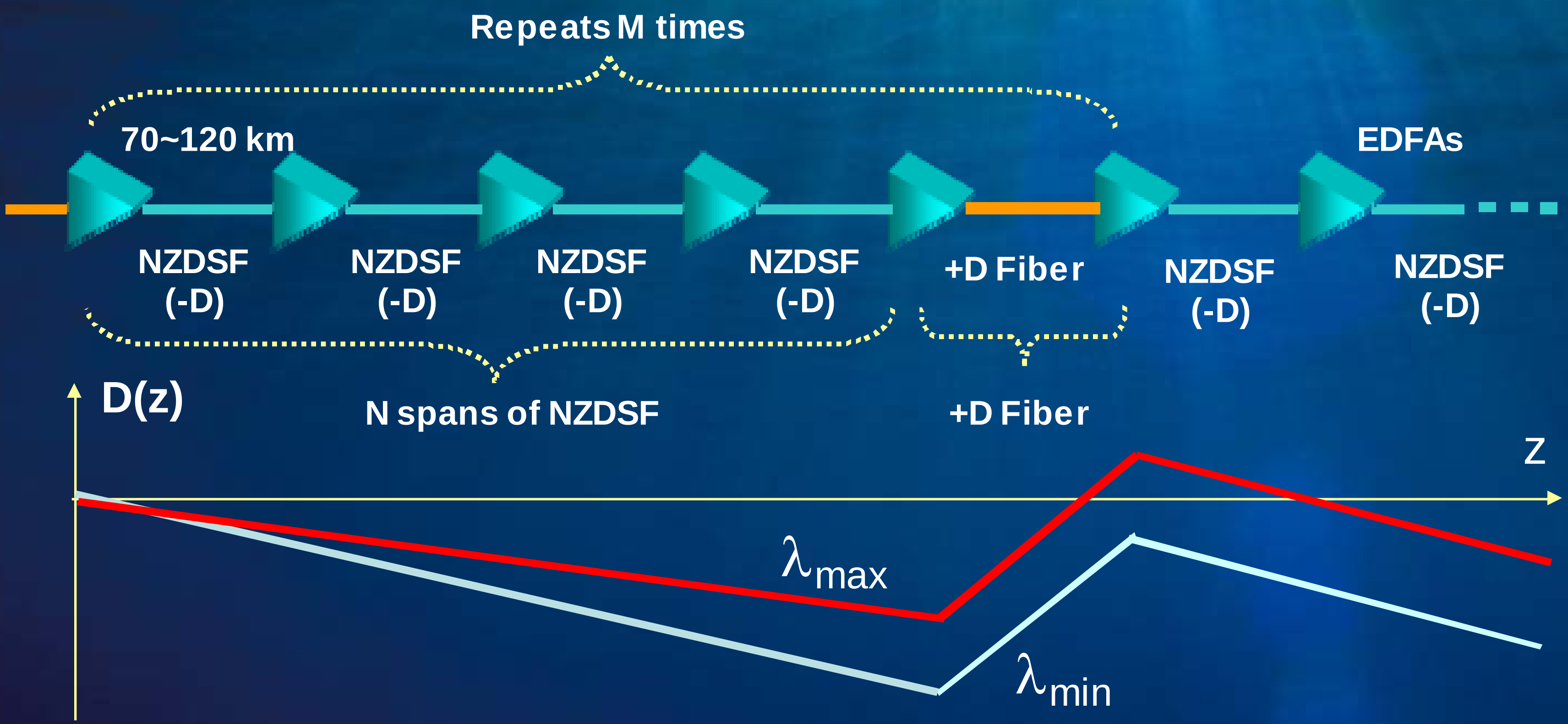
- Fibers: Ultra-Low-Loss fiber ($\alpha$=0.17 dB/km, $A_{eff}$=76 $mm^2$ and $D_{1550}$=18.5 ps/nm-km) and G.652 ($\alpha$=0.19 dB/km, $A_{eff}$=84 $mm^2$, $D_{1550}$=17 ps/nm-km)
- System: 8 x 10.7 Gb/s, NRZ and DPSK formats, 100 GHz channel spacing, Raman (18 dB gain)
- Reach advantage: ≥ 12% for each of the cases

# Raman Amplification in Unrepeatered Systems



Distributed Raman amplification in unrepeatered system is improved by lower attenuation in the Raman pump band.

# Repeatered Transmission Systems: Conventional Dispersion Map



Short wavelength and long wavelength channels accumulate significant dispersion by the end of the submarine link.

# Typical Optical Parameters of Non-Zero Dispersion Shifted Fibers

| *Fiber Solution* | *Corning Fiber* | *Attenuation (1550 nm) [dB/km]* | *Dispersion (1550 nm) [ps/nm-km]* | *Dispersion Slope [ps/nm²-km]* | *Aeff [μm²]* |
|---|---|---|---|---|---|
| Ultra-Low-Loss Fiber | Vascade® EX1000 | 0.17 | +18.5 | +0.06 | 76 |
| **Large Aeff NZDSF** | **Vascade® LEAF®** | **0.21** | **-4.0** | **+0.12** | **70** |
| **Low Dispersion Slope NZDSF** | **Vascade® LS+** | **0.20** | **-3.0** | **+0.05** | **50** |

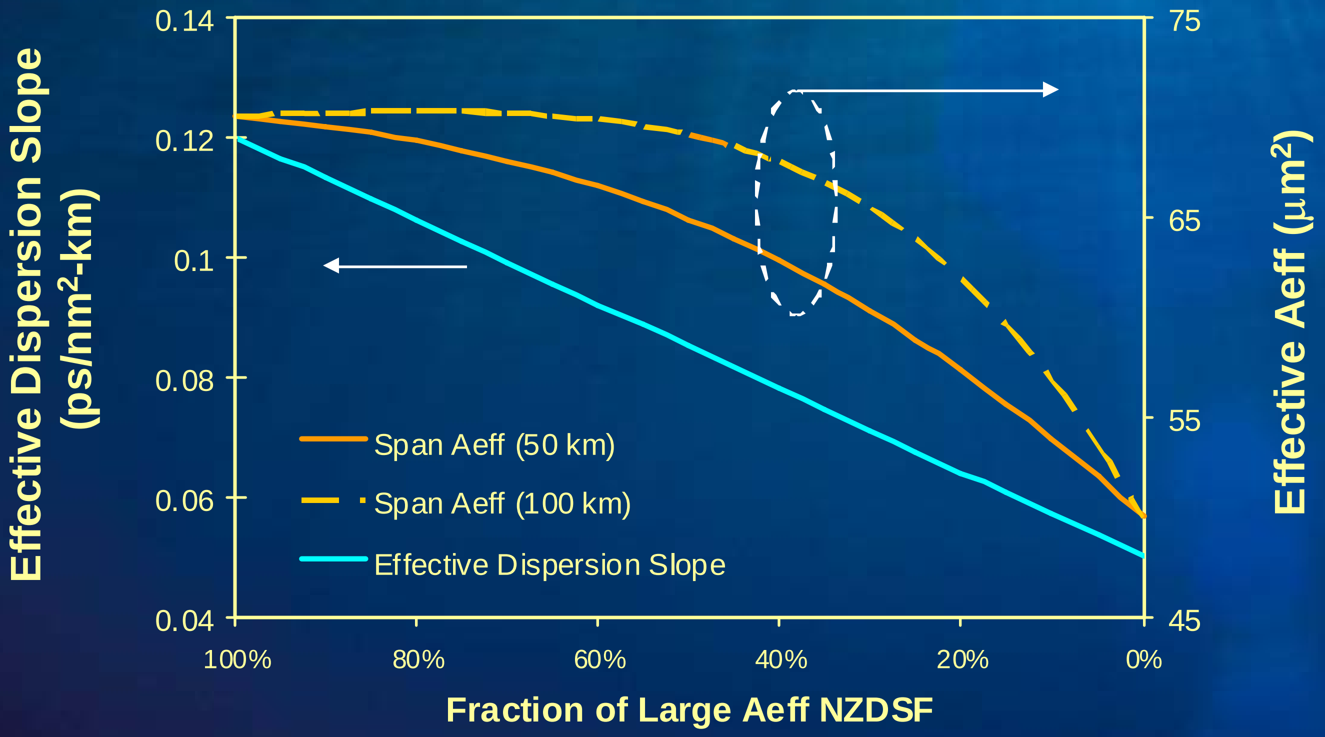
- NZDS Fibers have inherent trade-off between Aeff and Dispersion slope: Larger $A_{eff}$ results in higher dispersion slope
- System trade-off: Larger $A_{eff}$ reduces nonlinearities but higher accumulated dispersion for edge channel increases nonlinearities

# Hybrid Solution

**Large Aeff NZDSF**

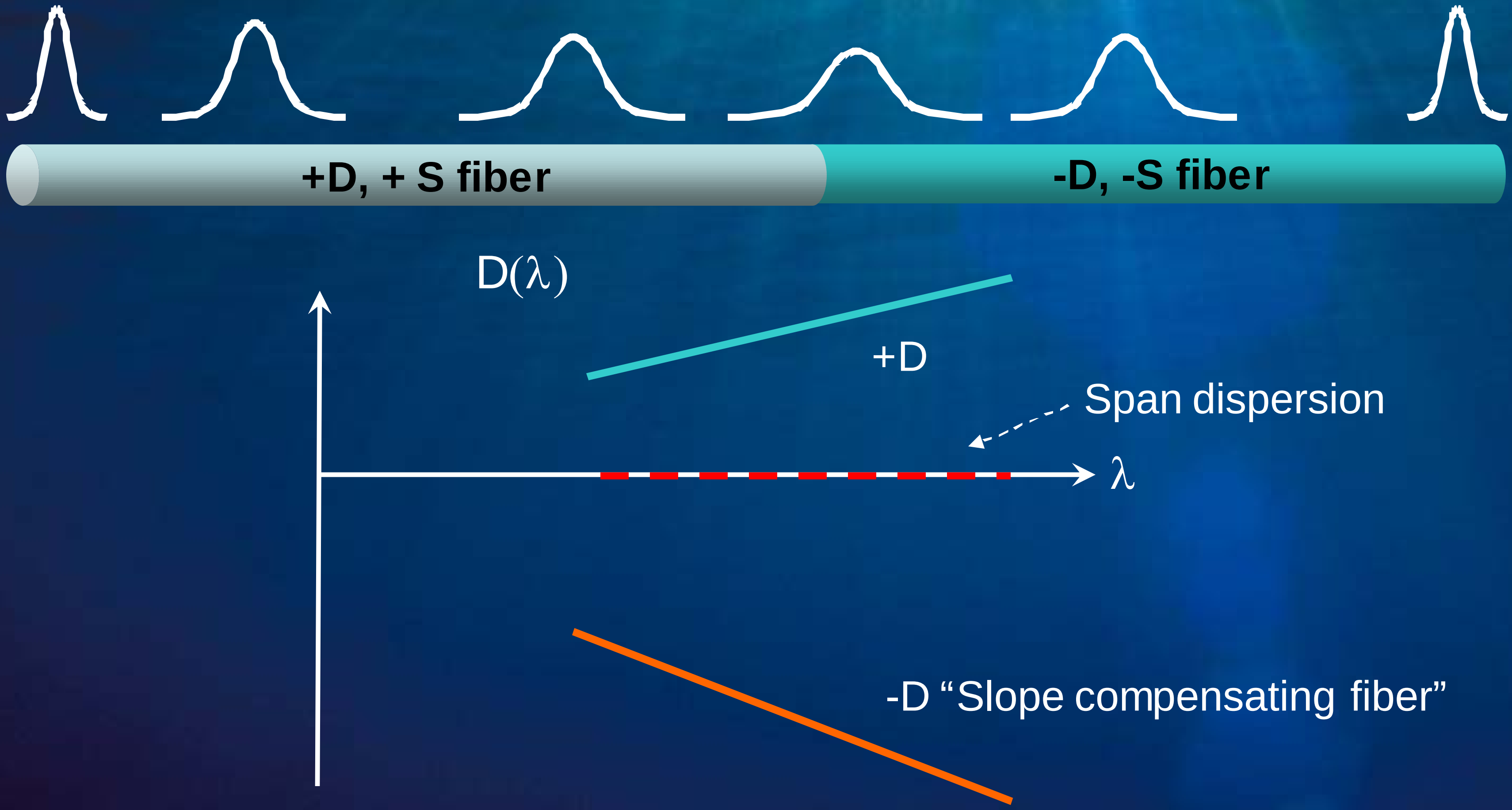
**Low Slope NZDSF**

**Signal**



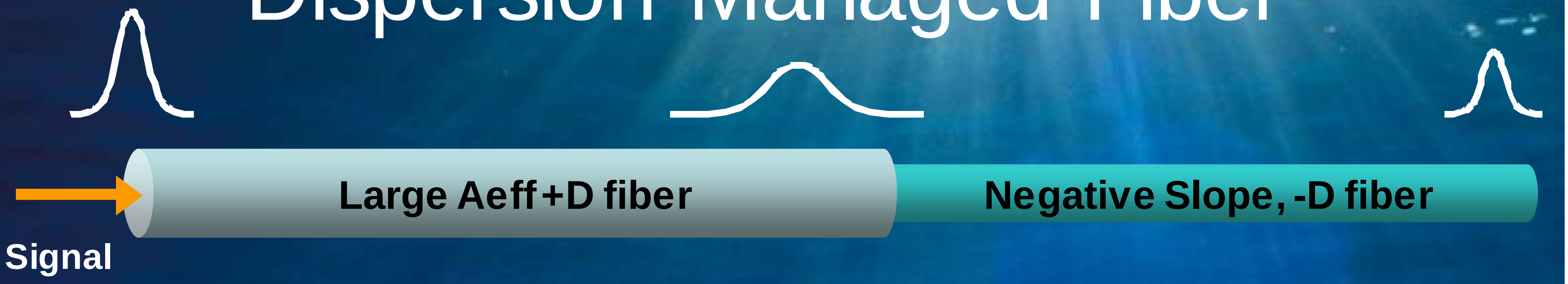
Hybrid solution enables lower effective dispersion slope and larger span Aeff , e.g. for 100 km span and 50/50 ratio dispersion slope =0.085 ps/nm$^2$-km and Aeff = 69 μm$^2$

# Concept of Dispersion Managed Fiber



Dispersion slope compensating fibers enable precise broadband dispersion compensation

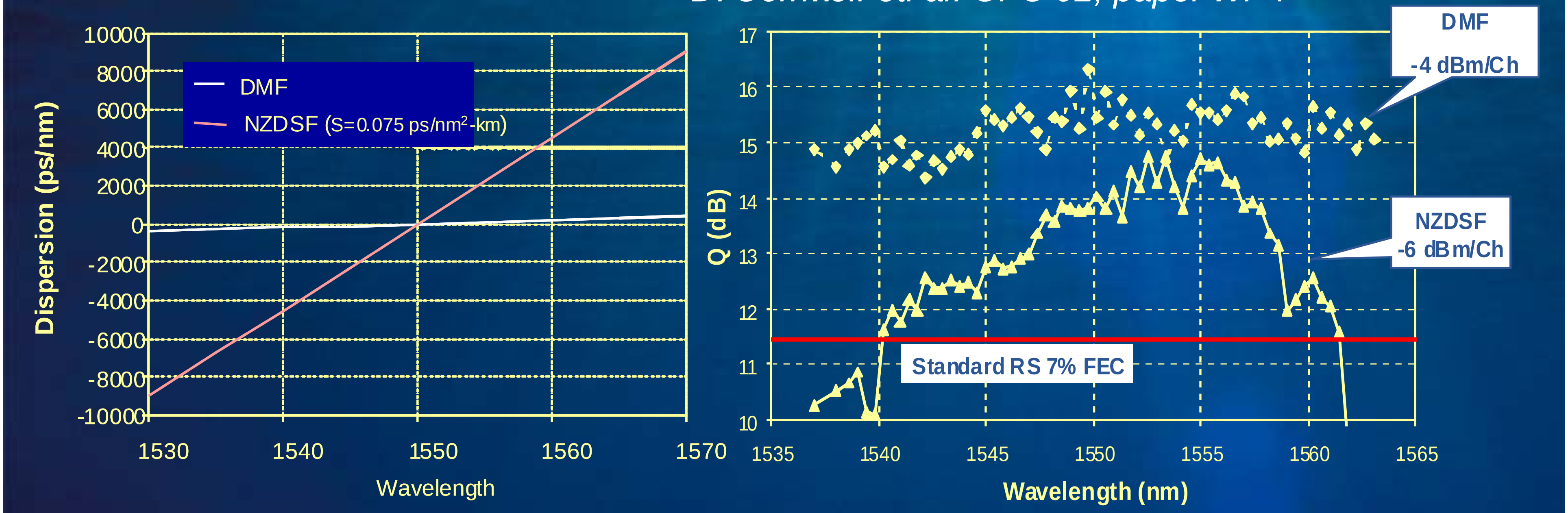
# Dispersion Managed Fiber



| Fiber Solution | Corning Fiber | Attenuation (1550 nm) [dB/km] | Dispersion (1550 nm) [ps/nm-km] | Dispersion Slope [ps/$nm^2$-km] | Aeff [$\mu m^2$] |
|---|---|---|---|---|---|
| Ultra Low Loss Fiber | Vascade® EX1000 | 0.17 | +18.5 | +0.06 | 76 |
| Large $A_{eff}$ NZDSF | Vascade® LEAF® | 0.21 | -4.0 | +0.12 | 70 |
| Low Dispersion Slope NZDSF | Vascade® LS+ | 0.20 | -3.0 | +0.05 | 50 |
| Hybrid | Vascade® Hybrid | 0.205 | -3.5 | 0.085 | 65-69 |
| **Dispersion Managed Fiber** | **R1000** **Vascade® L1000** | **0.187** | **+18.5** | **+0.06** | **101** |
| | **Vascade® S1000** | **0.24** | **-37.0** | **-0.12** | **27** |

- Dispersion slopes of +D and –D fibers cancel each other and transmission span has low residual dispersion.

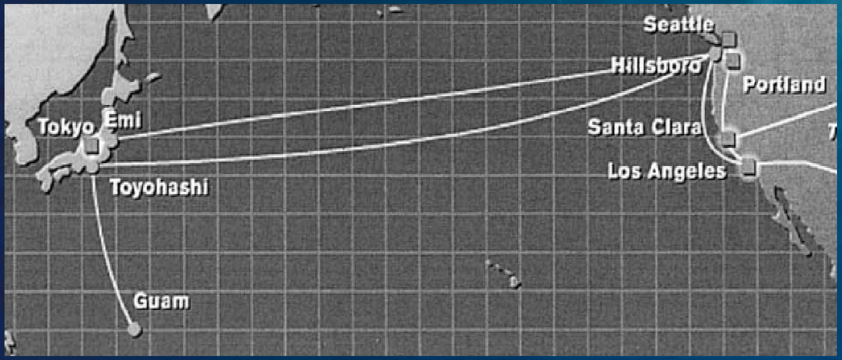
# Advantage of DMF over NZDSF in 6000 km Experiment

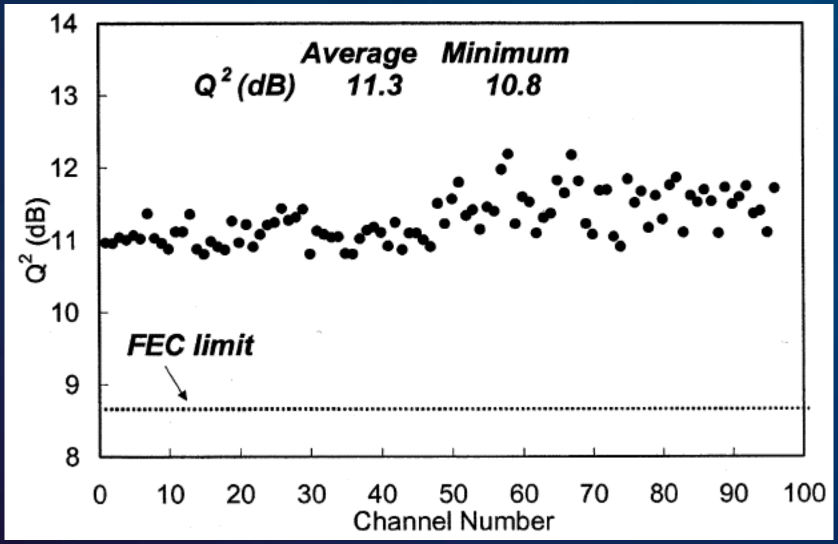


*D. Cornwell et. al. OFC 02, paper WP4*

- 64x10 Gb/s NRZ at 50 GHz channel spacing
- DMF dispersion slope is 0.0033 ps/nm$^2$-km!
- DMF improves performance of edge channels
- Enables wide band transmission >6000 km

# First Field Demonstration of DMF





| System Parameter | Value |
|---|---|
| System length | 8991 |
| Fiber | DMF |
| Number of Channels | 96 |
| Line Rate | 12.3 |
| Channel Spacing | 33 GHz |
| Maximum Dispersion Ripple | 250 ps/nm |
| Modulation Format | RZ |
| Repeater Spacing | 45 km |

B. Bakshi *et. al.*, J. of Light. Tech. v.22, p.233 (2004)

- First DMF solution from OFS (UltraWave) was deployed in Trans-Pacific Tyco Global Network route in 2003

# Submarine Fiber Portfolio

<table>
<tr><th>*Fiber Solution*</th><th colspan="2">*Corning Fiber*</th><th>*Attenuation (1550 nm) [dB/km]*</th><th>*Dispersion (1550 nm) [ps/nm-km]*</th><th>*Dispersion Slope [ps/nm$^2$-km]*</th><th>*Aeff [$\mu m^2$]*</th></tr>
<tr><td>Ultra-Low-Loss Fiber</td><td colspan="2">Vascade® EX1000</td><td>0.17</td><td>+18.5</td><td>+0.06</td><td>76</td></tr>
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<tr><td>Hybrid</td><td colspan="2">Vascade® Hybrid</td><td>0.205</td><td>-3.5</td><td>0.085</td><td>65-69</td></tr>
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</table>

- Wide variety of fiber attributes from submarine fiber portfolio enables system designers to meet lengths and capacity requirements in the most cost efficient way

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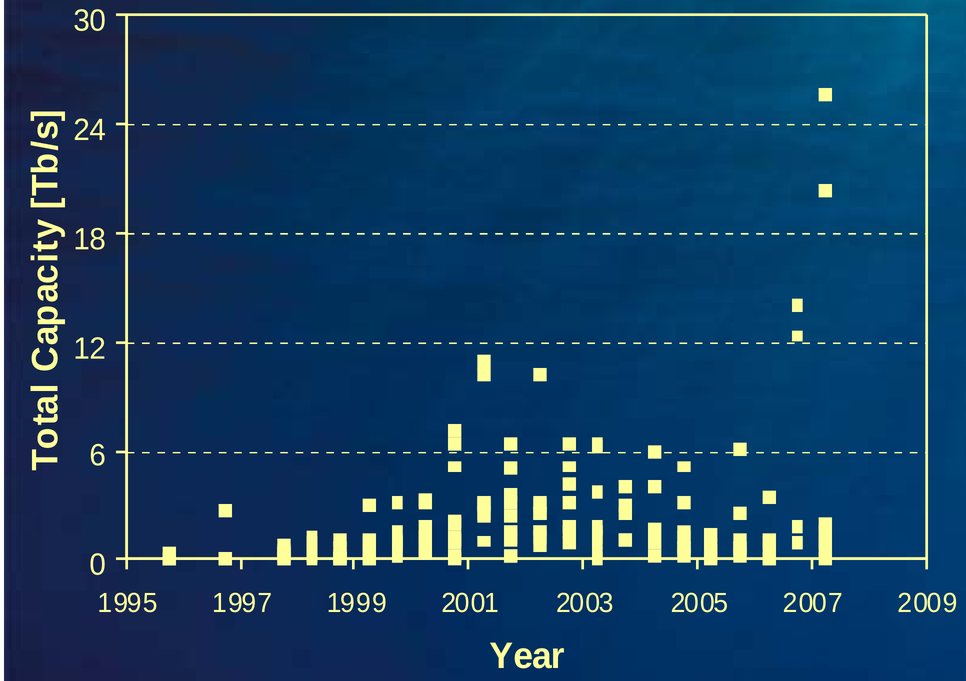
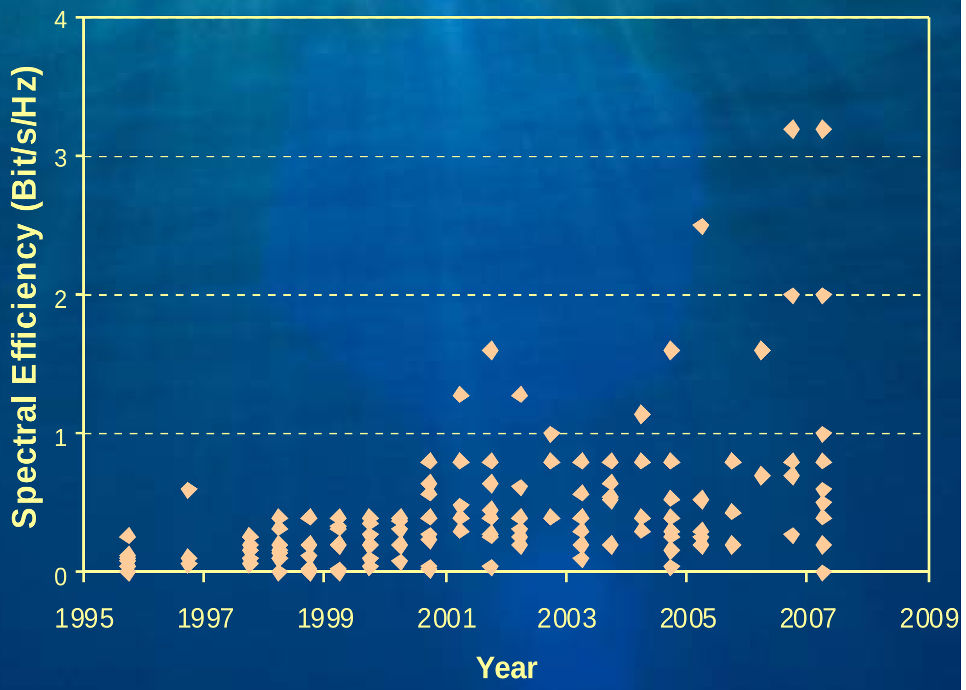
- Technology trends in transmission systems and implications for submarine fibers
- Summary

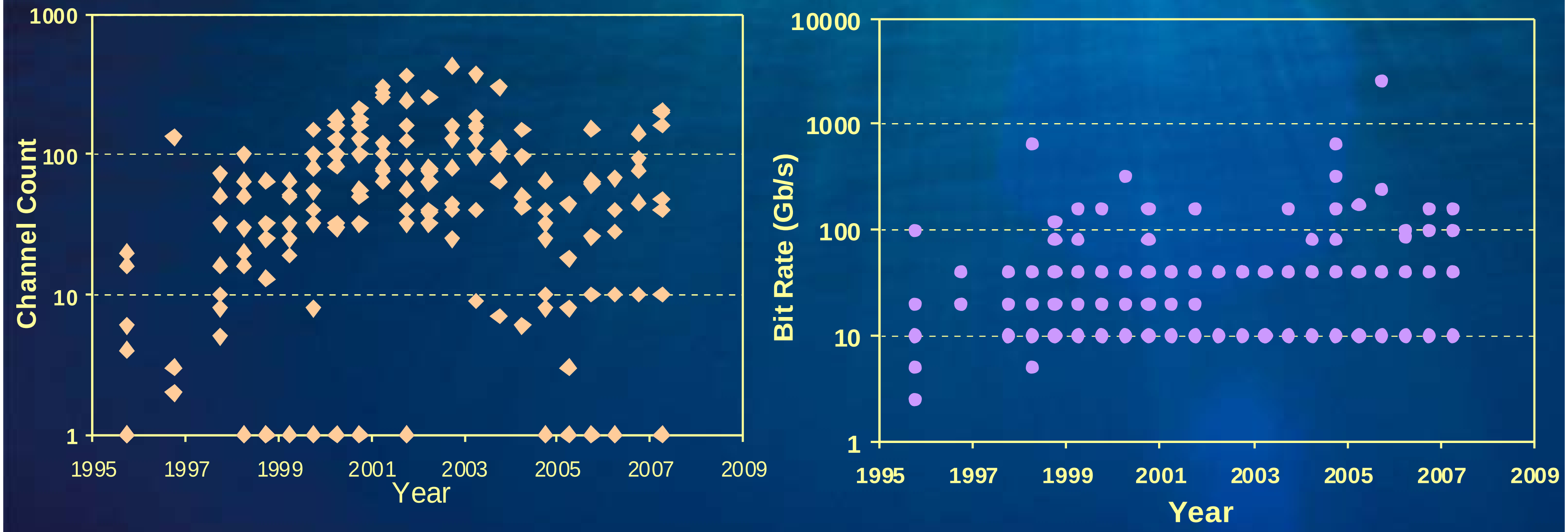
# Hero Results (OFC and ECOC): New Records in Capacity and Spectral Efficiency





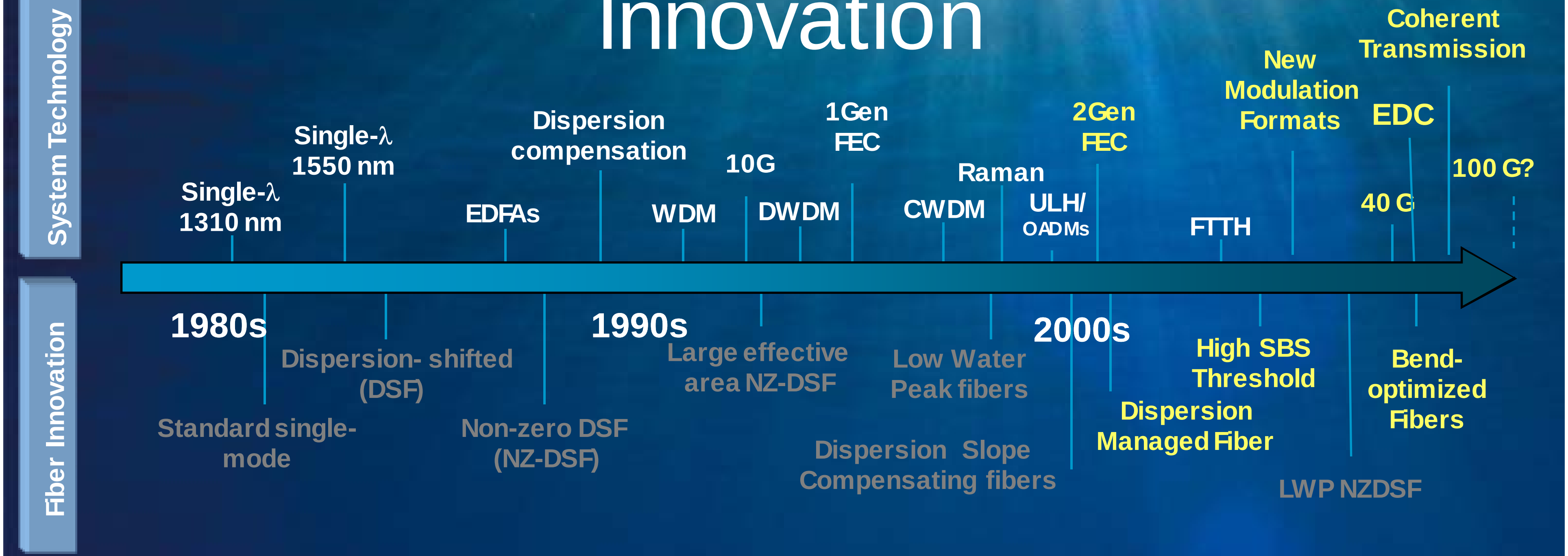
- After 5 calm years, the race for highest capacity per fiber continues. Enablers of high capacity experiments:
  - DQPSK - multilevel signaling for higher spectral efficiency
  - Polarization multiplexing

# Hero Results (OFC and ECOC): Number of Channel and Data rate



- The number of channels is likely to remain at the manageable level of ~100
- Data rate per channel will increase from 40 Gb/s to 100 Gb/s but not by direct TDM scaling

# Advances in Technology Drive Fiber Innovation



System Technology

Single-λ 1310 nm

Single-λ 1550 nm

EDFAs

Dispersion compensation

WDM

10G

DWDM

1Gen FEC

CWDM

Raman

ULH/ OADMs

2Gen FEC

FTTH

New Modulation Formats

40 G

EDC

Coherent Transmission

100 G?

Fiber Innovation

1980s

Standard single-mode

Dispersion- shifted (DSF)

Non-zero DSF (NZ-DSF)

1990s

Large effective area NZ-DSF

Dispersion Slope Compensating fibers

Low Water Peak fibers

2000s

Dispersion Managed Fiber

High SBS Threshold

LWP NZDSF

Bend-optimized Fibers

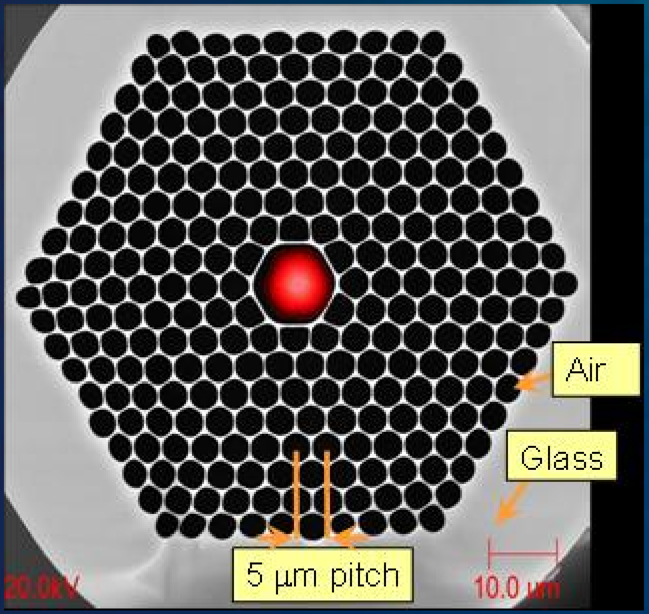
- System technologies that significantly influence submarine system design and have implications for fiber/span design
  - Channel rate and capacity per fiber is growing
  - Forward Error Correction (FEC) is approaching third generation
  - Advanced modulation formats: RZ-DPSK is commercially available
  - Span length gradually increases

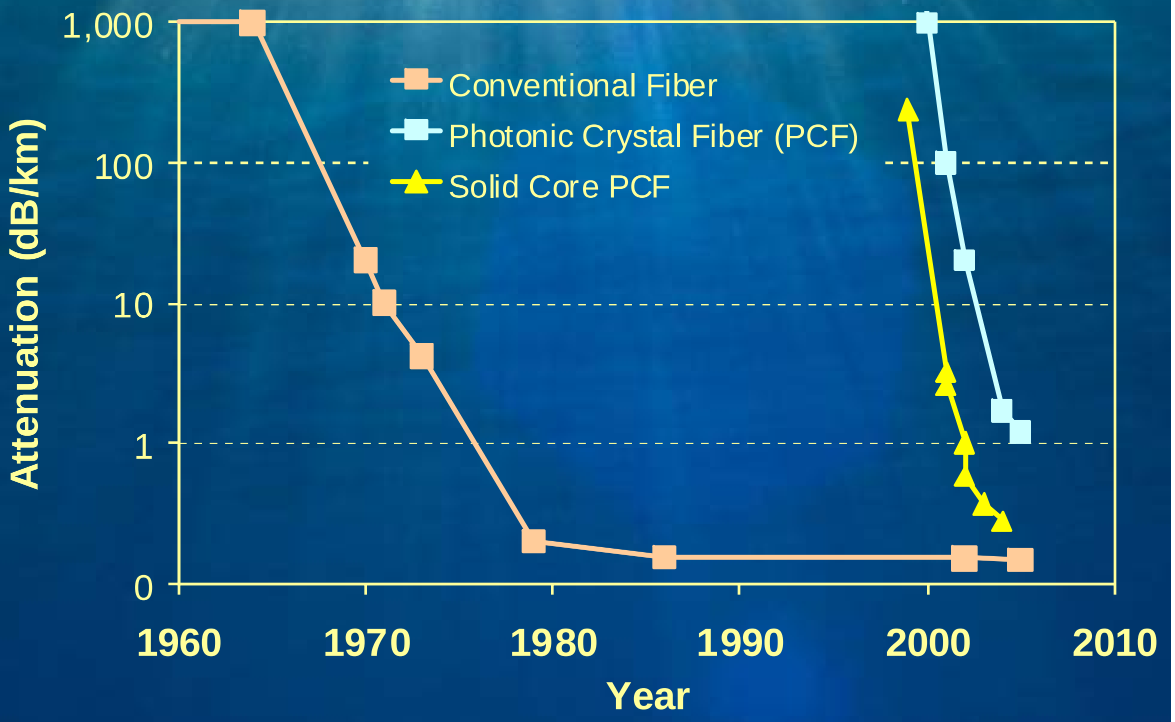
# Technology Advances and the Implications for Fiber

| ***Technology*** | ***Status*** | ***Implications for fiber or span/link design*** |
|---|---|---|
| Higher Data Rate | Transition to 40 Gb/s in terrestrial networks has begun, R&D efforts for 100 Gb/s | • Lower PMD<br>• Higher OSNR requires lower span loss or larger Aeff<br>• Precise dispersion compensation |
| Modulation Formats | RZ-DPSK has become commercially available, provides 3 dB improvement compare to OOK. No better modulation format has been demonstrated. | • Additional margin could be used for longer reach or longer span<br>• More robust to dispersion map |
| 3rd generation FEC | 3G FEC gives additional 2 dB advantage over second generation FEC (2G corrects Q=8.5 dB to error free level). Turbo code with soft decision threshold has been demonstrated. | Additional margin could be used for longer reach or longer span |
| Longer span between repeaters | Span length increased from 45-60 from the end of 90th to ~80-120 km today | Improved attenuation and higher Aeff may help to mitigate span length increase |

- Lower attenuation, lower PMD, and larger Aeff are critical attributes for fiber for future submarine networks

# Photonic Crystal Fiber: Status Update

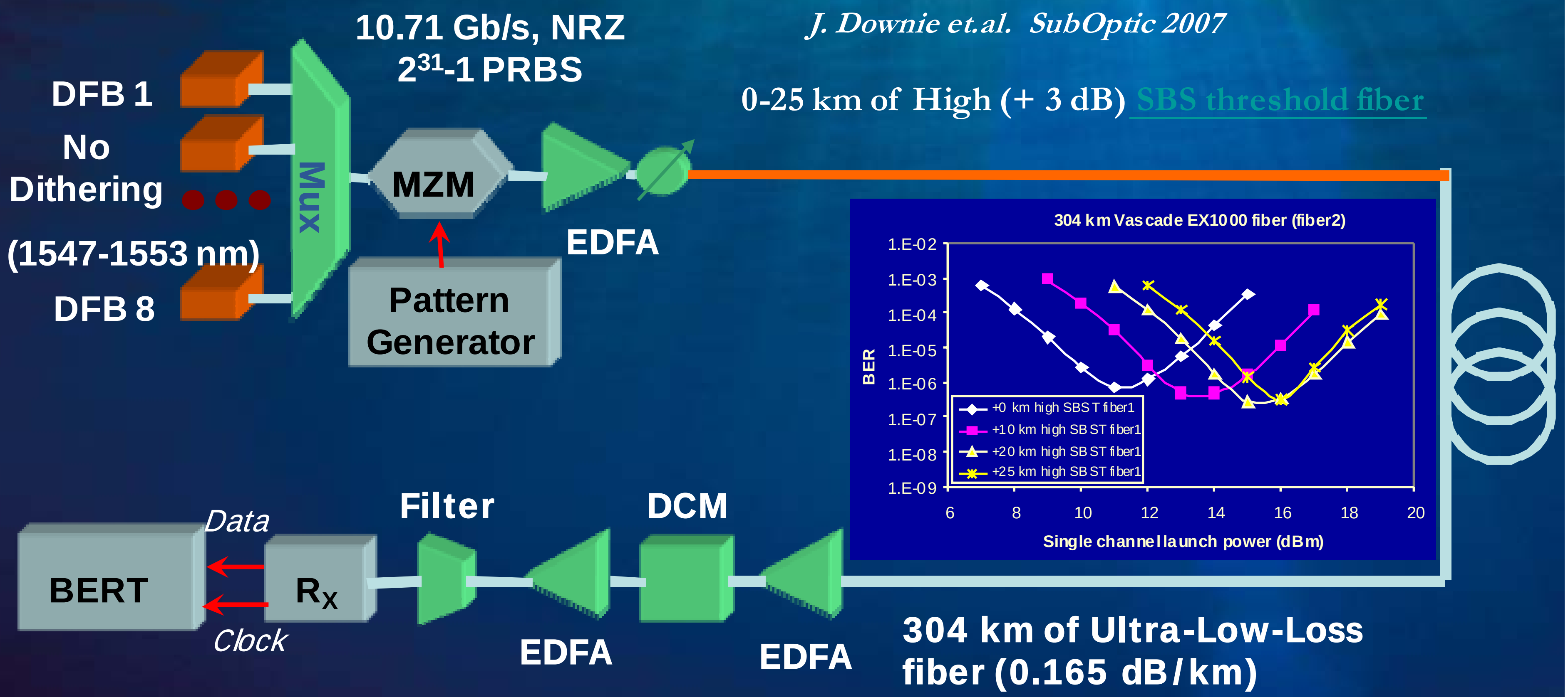




- Hollow core Photonic Crystal Fibers (PCF) (a.k.a. Photonic Bandgap Fibers) theoretically have a number of potential attractive features: large Aeff, low loss, very low nonlinearity. Currently PCF attenuation is too high for real world applications.

# Attribute Management: Flexible Span Design for Unrepeatered Systems

*J. Downie et.al. SubOptic 2007*



10.71 Gb/s, NRZ
$2^{31}$-1 PRBS

0-25 km of High (+ 3 dB) SBS threshold fiber

DFB 1
No Dithering
(1547-1553 nm)
DFB 8

Mux

MZM

Pattern Generator

EDFA

BERT

*Data*

*Clock*

$R_X$

Filter

EDFA

DCM

EDFA

**304 km of Ultra-Low-Loss fiber (0.165 dB/km)**

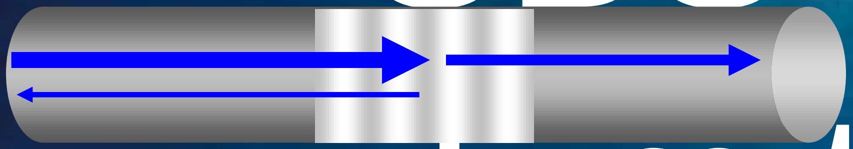
- Concatenation of high SBS threshold fiber with Ultra-Low-Loss fiber creates flexible span for unrepeatered systems: Can tolerate high launch power and increase span length by 25 km

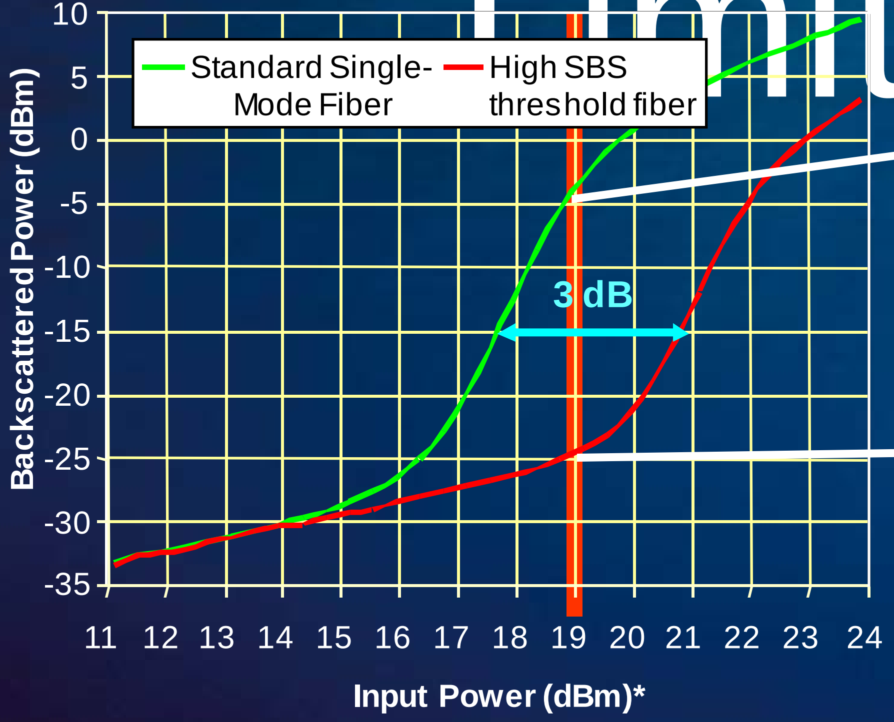
# Summary

- Portfolio of submarine fibers offers variety of optical attributes to enable optimization of submarine systems for different capacity and reach requirements.
- Major future trends that may impact requirements for optical fibers are higher data rates and higher spectral efficiencies
  - Lower attenuation, lower PMD and larger Aeff will be required/desired
  - There are no revolutionary concepts today that can create 10X improvement in fiber transmission properties
- Submarine system designers will utilize evolutionary improvement of attributes and smart management of fiber attributes in the span to meet challenging system requirements of future systems

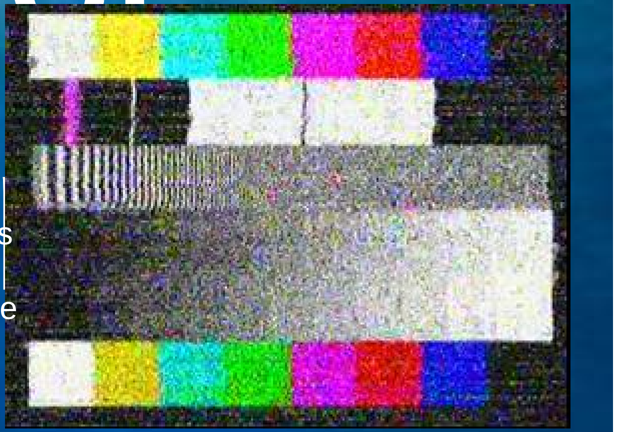
# Backup Slides

# SBS Effect Limitation

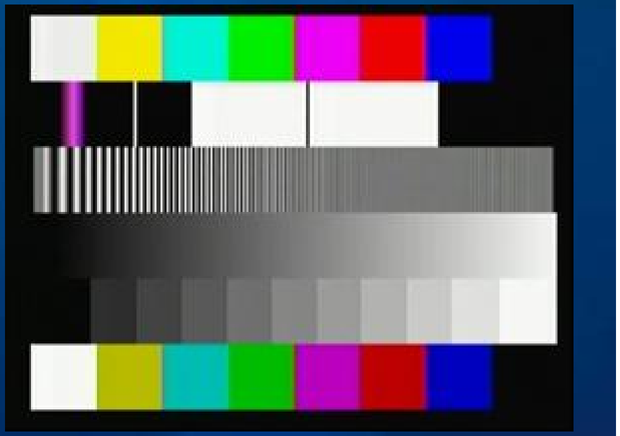




Picture quickly degrades above SBS threshold on standard single-mode fiber



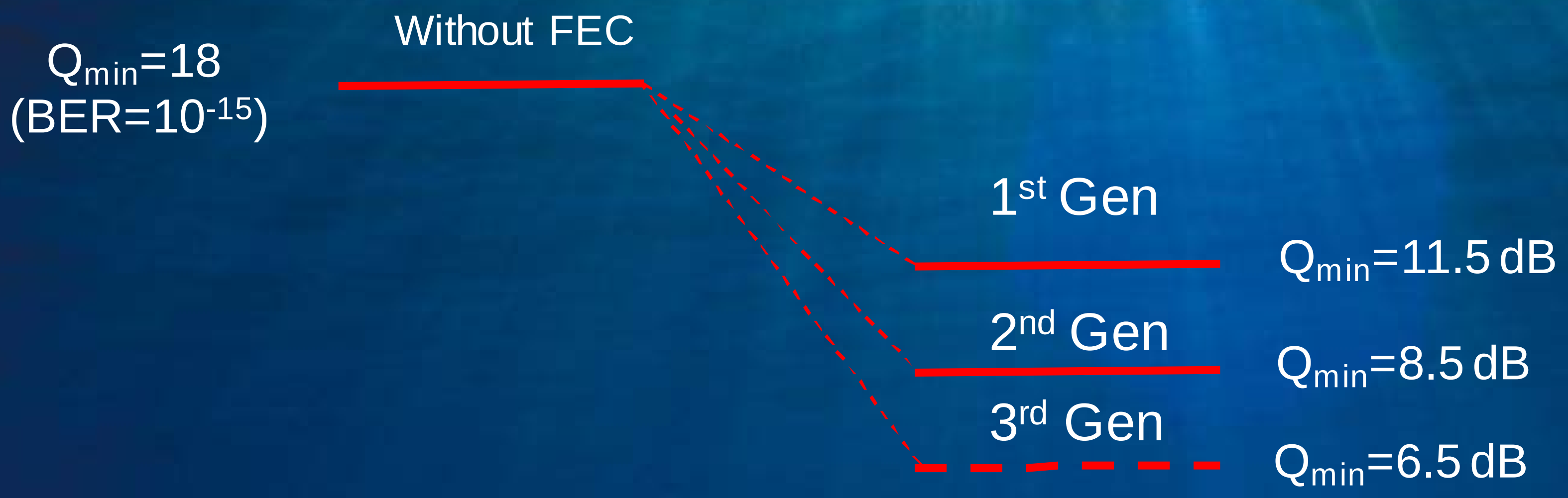
SMF-28e+™ fiber allows the same optical power with no degradation in picture quality



High SBS threshold fiber were designed for FTTH applications but can help to mitigate SBS for unrepeatered systems

# OSNR sensitivity improvement

## *Forward Error Correction Status*



$Q_{min}=18$
($BER=10^{-15}$)

Without FEC

1st Gen

$Q_{min}=11.5$ dB

2nd Gen

$Q_{min}=8.5$ dB

3rd Gen

$Q_{min}=6.5$ dB

| FEC Generation | Over-head | Code Type | FEC threshold (Q and BER) | Adoption |
|---|---|---|---|---|
| **1** | 7% | Reed-Solomon (RS) | 11.5 dB<br>($BER\sim10^{-4}$) | Standardized and adopted |
| **2** | 10-25% | Concatenated RS | 8.5-9.0 dB<br>($BER\sim4\times10^{-3}$) | Proprietary schemes that are not in standards. Implemented by Tier 1 systems houses |
| **3** | 20-25% | Turbo codes with soft decision threshold | ~6.2 dB<br>($BER\sim2\times10^{-2}$) | Development stage<br>chip has been demonstrated |