Maximizing Network Capacity, Reach and Value
Over land, under sea, worldwide

Xtera Communications, Inc.

Raman + 100G Simplifies the Deployment of Terabit Networks

13 April 2011

Terabit Optical Networking Conference – Cannes, France

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- Raman by Xtera
- 100G by Xtera
- 100G + Raman Combination
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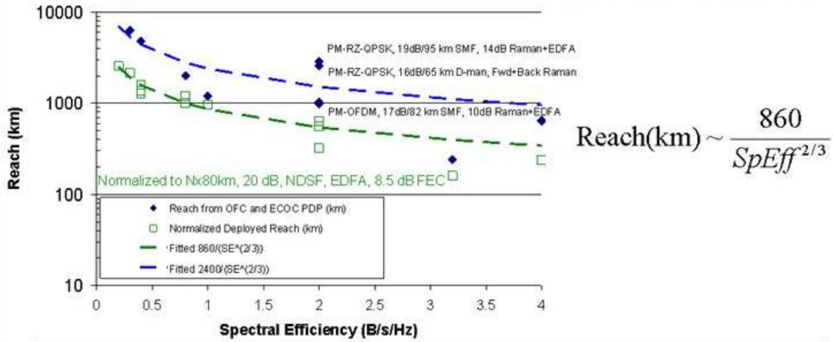
Raman Recognized in Industry as Technology of Choice for 40/100G

- Xtera field trial in 2005 (with Verizon Business) demonstrating 3,000-km unregenerated 40G transport
  - Unsurpassed since then

- 2008 Ciena/Nortel webinar
  - Benefits from Raman on optical network performance and economics

Scaling OFC/ECOC 'Hero' to 'Nominal Network'

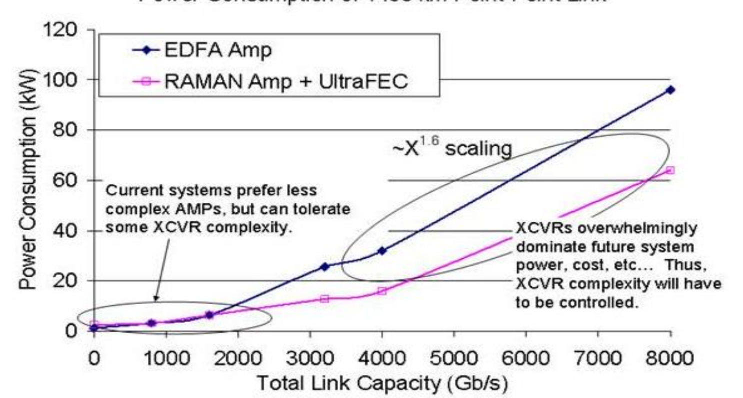


	Overlay EDFA only; 8.5 dB FEC; no 10G neighbors	New network build Raman gain; 9.5dB FEC; no 10G neighbors
40 Gb @ 50 GHz	1000 km	1850 km
100 Gb @ 100 GHz	860 km	1600 km
100 Gb @ 50 GHz	540 km	1000 km

ciena NORTEL LIGHT READING

WDM Layer Power Consumption

Power Consumption of 1400 km Point-Point Link



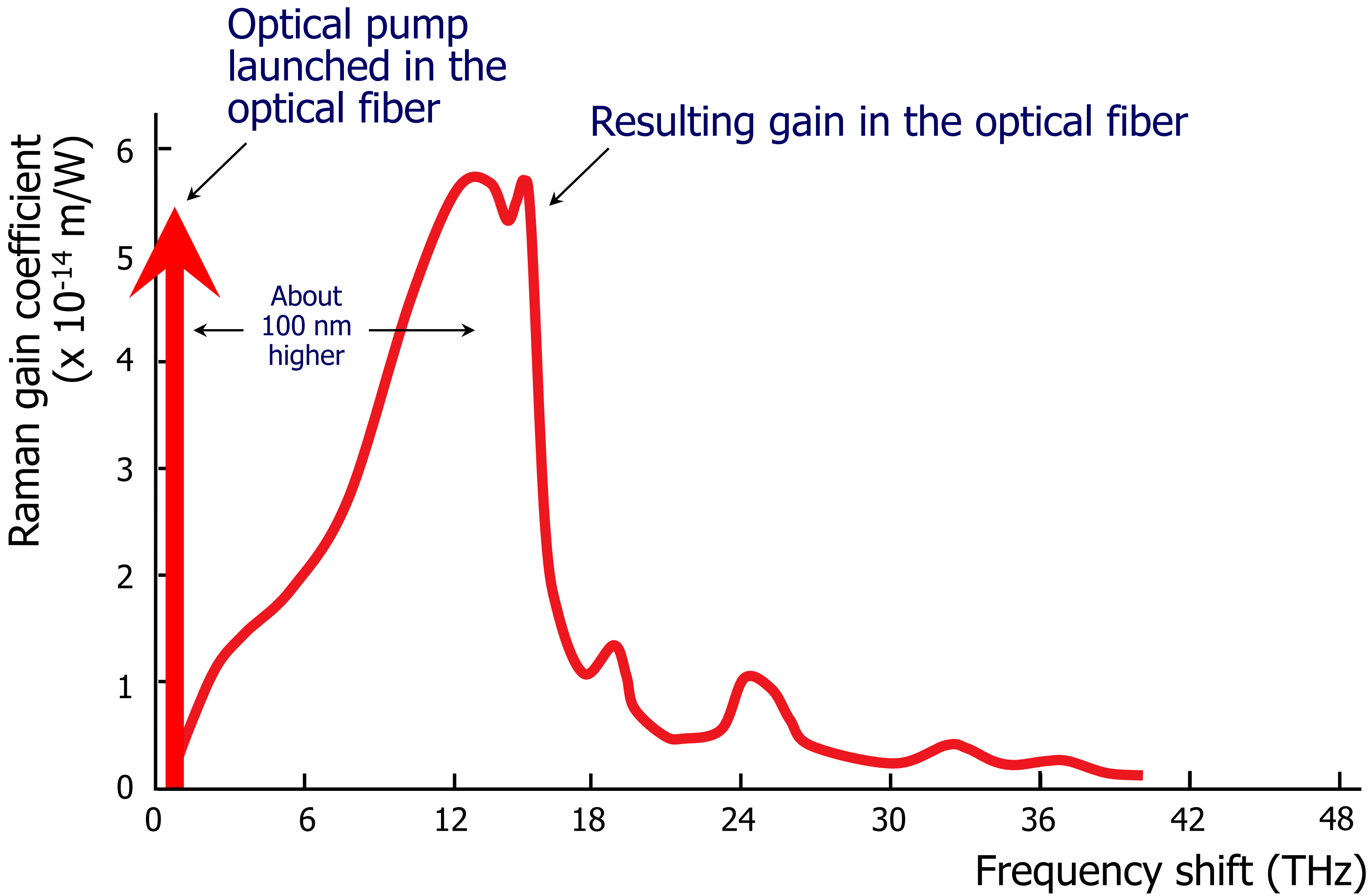
Network capacity demands pull in the direction opposite to XCVR performance

ciena NORTEL LIGHT READING

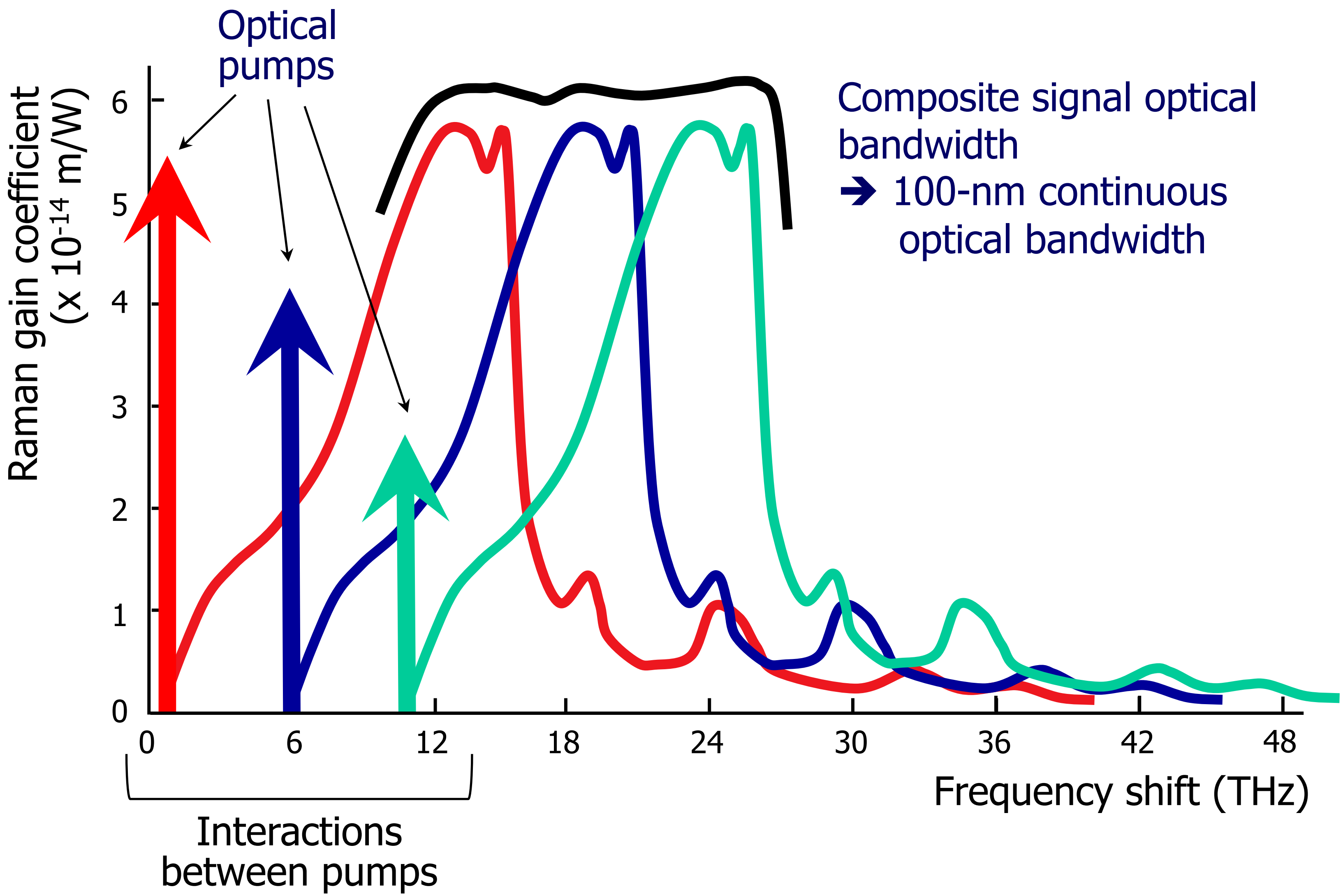
* Source: Light Reading webinar sponsored by Ciena and Nortel, October, 2008

Original Motivations to Develop Raman WDM Transport Systems

Raman Optical Amplification



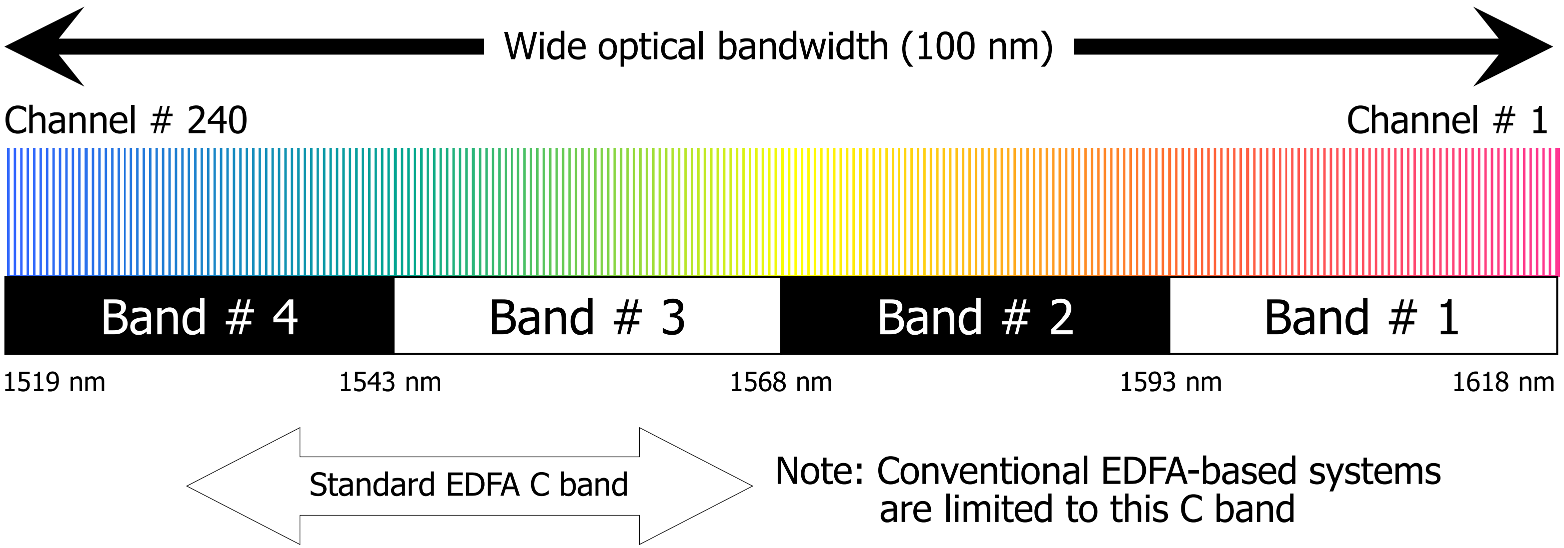
Raman Optical Amplification



Composite signal optical bandwidth
➔ 100-nm continuous optical bandwidth

Ultra-Wide Optical Bandwidth

- All-Raman amplification technology:
  - 100-nm bandwidth (from 1519 to 1618 nm)
  - Contiguous spectrum (4 bands from multiplexing architecture)
  - 240 x 10/40/100G optical channels (50-GHz channel spacing)
    - ➔ Enabling terabit capability as early as 2004 (240 x 10G = 2.4 Tb/s)
  - Flexibility for wavelength channel allocation
    - Non WDM-optimized fiber, old ROPAs...
  - Implemented 1 band at a time or in a modular way



Note: Conventional EDFA-based systems are limited to this C band

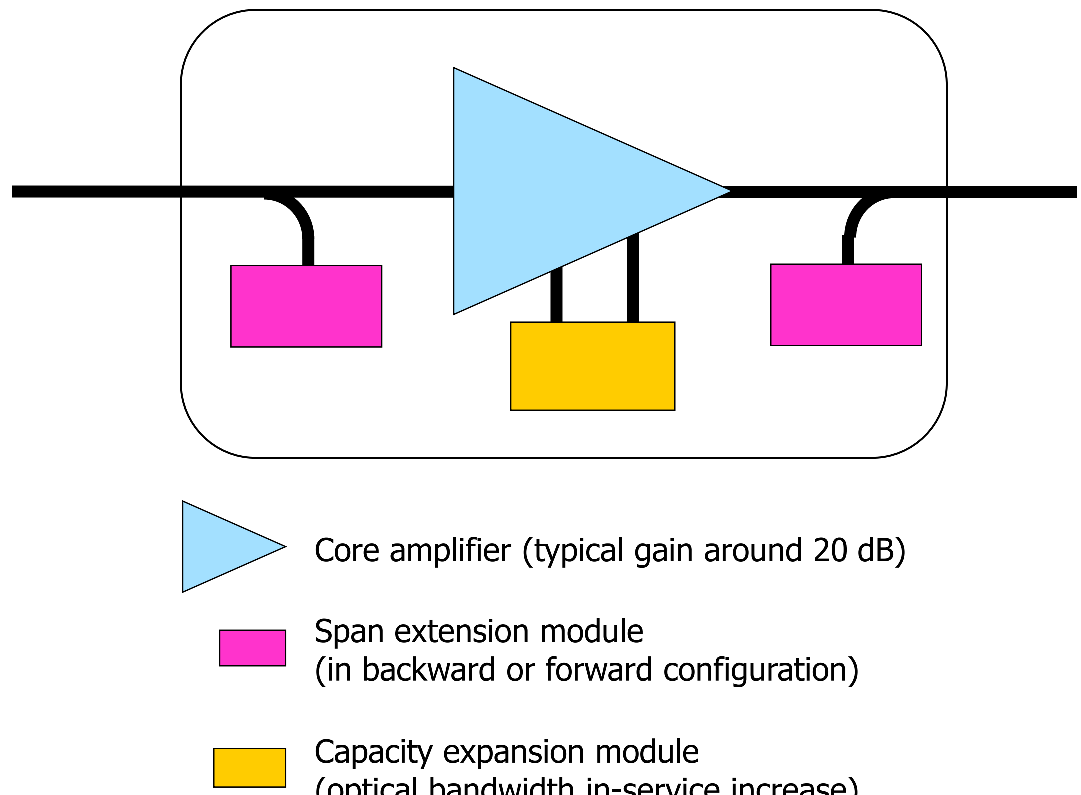
Why Raman Amplification Technology?

- Capacity
  - Up to 100-nm contiguous optical bandwidth
- Performance of line system allows for
  - Simple, low-cost N x 10G terminal technology
  - Upgrade to higher channel rates at terminal level
- Reach
  - Superior noise performance
  - Minimization of nonlinear effects
  - ➔ Multi-reach capabilities on all fiber types
- Intelligence and automation
  - Provisioning
  - Quiescent transmission
  - Transient control
- Robust and reliable via built-in redundancy

Raman by Xtera

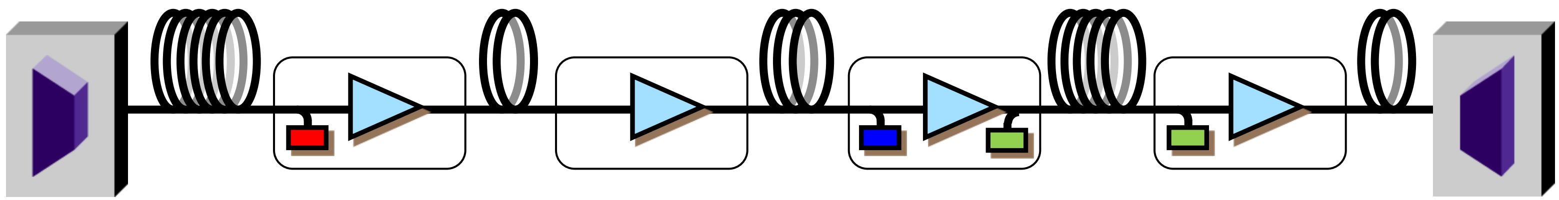
Modular All-Raman Implementation

- Core amplifier
- Span extension module (6, 12 or 24 dB of extra gain)
- Capacity expansion module
  - From 25- to 63-nm optical bandwidth in service
  - From 60 to 150 channels

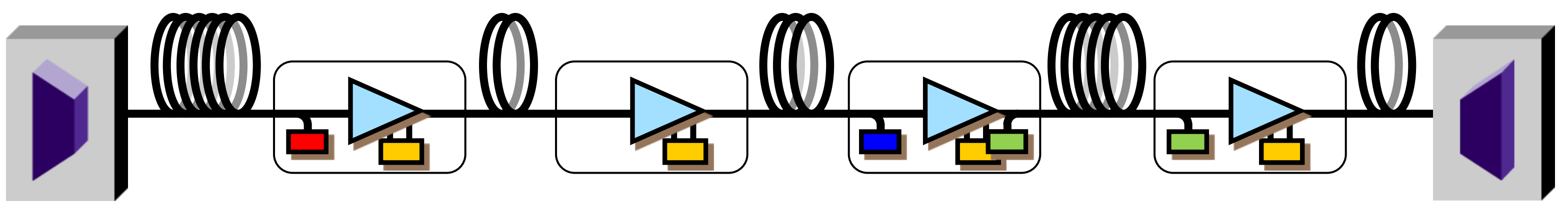


Two-Axis Scalability from Modular Raman Implementation

- Day one:
  - 60-channel capacity
  - Various span extension modules to accommodate for various span losses



- Long term:
  - 150-channel capacity
  - In-service upgrade



Core Amplifier | +90ch Amplifier Expansion | +6dB Span Extension | +12dB Span Extension | +24dB Span Extension

100G by Xtera

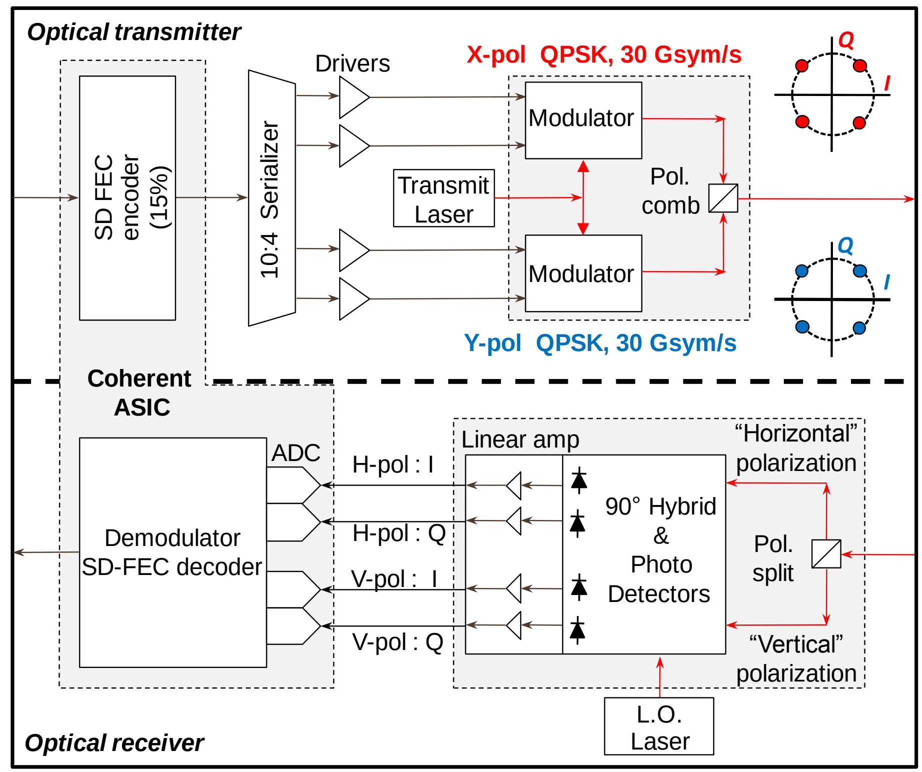
Drivers and Road to 100G

- Drivers to 100G:
  - Maximization of line capacity
  - Minimization of the transport cost per bit
  - Support of native 100G client signals
  - More power/space-efficient equipment
- Transmission challenges increase with the higher bit rate
  - 40G and 100G now require advanced modulation and coherent detection techniques to meet carriers’ requirements
- Rallying around PM (or DP)-QPSK with coherent detection
  - PM = Polarization Multiplexing | DP = Dual Polarization
  - QPSK: Quadrature Phase Shift Keying
  - Standardization of DWDM interface led by IOF, but also by
    - ITU-T Study Group 15, next-generation optical and transport
    - ITU-T G.709 OTN standard
    - IEEE 802.3 High Speed Study Group (HSSG): focus on the client interface
  - Build ecosystem of components and sub-systems
  - Avoid multiple modulation formats “mistake” of 40G

100G LH MSA Module

Form factor (5"x7") and management interface (Management Data Input/Output – MDIO) specified by OIF

Block diagram

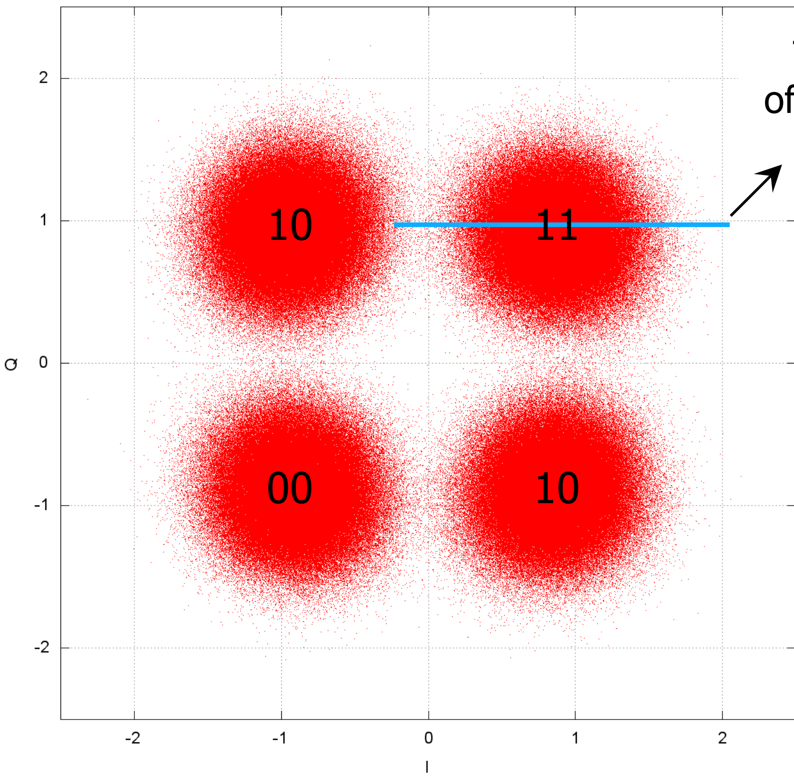


Framer interface 112G

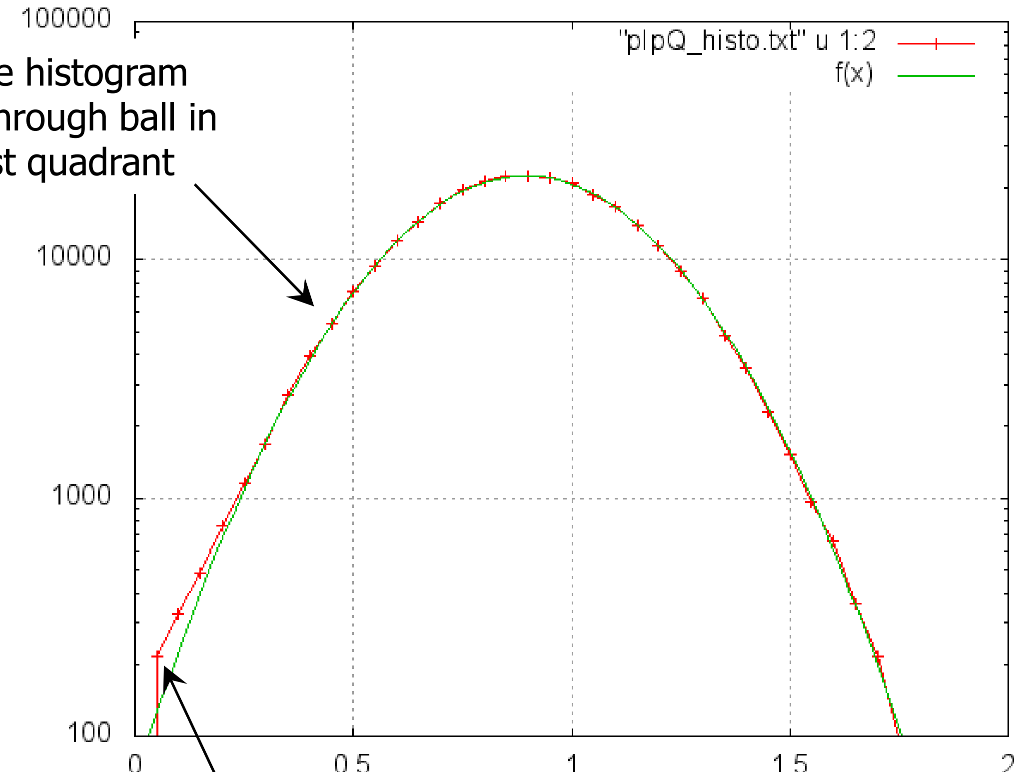
LH interface 120G

Quadrature Phase Shift Keying

- Moving from conventional eye diagrams to constellation plots



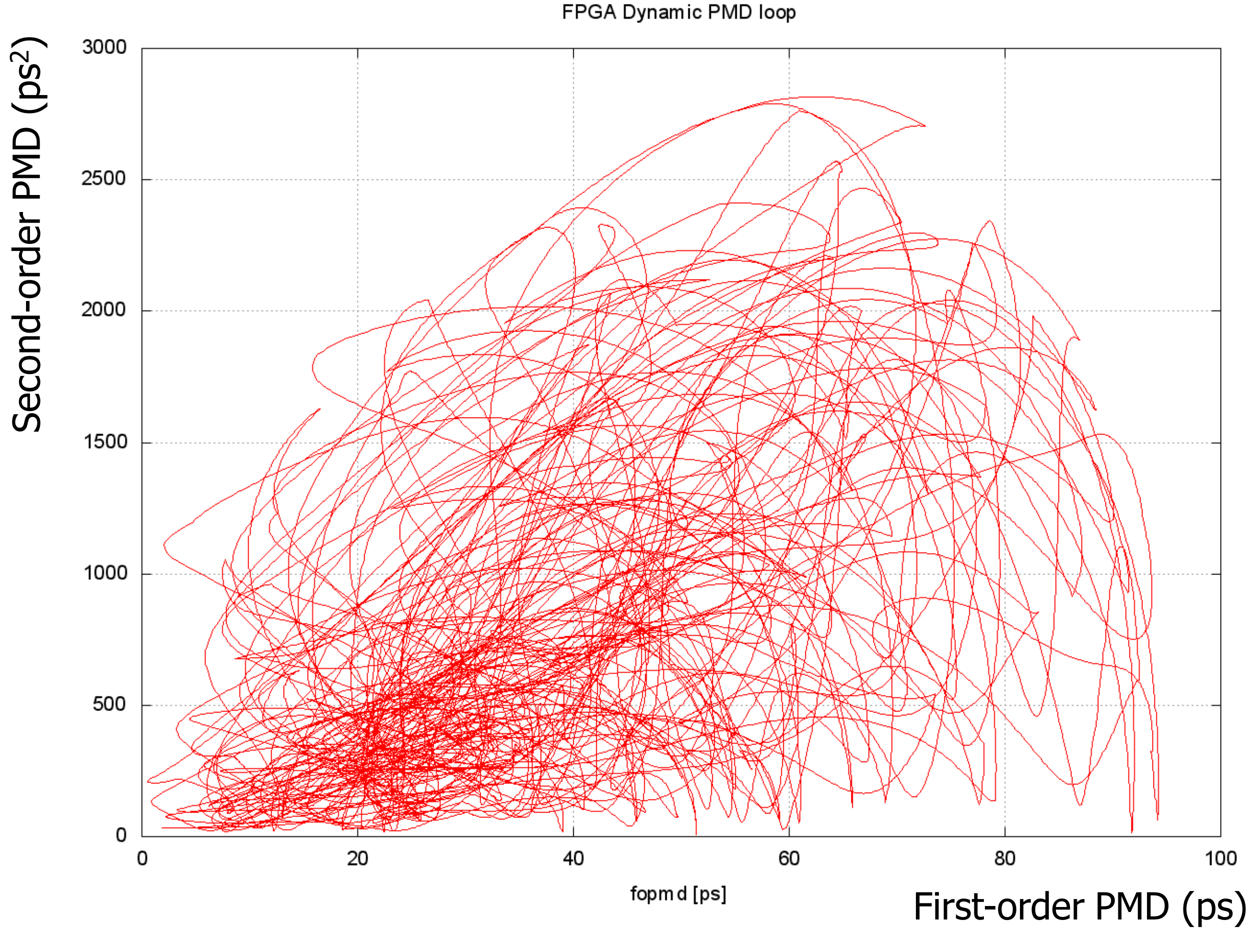
Take histogram of I through ball in first quadrant



Measured tail slightly higher than fit this side (origin), due to ball in 2nd quadrant spilling over into this quadrant (see constellation slide)

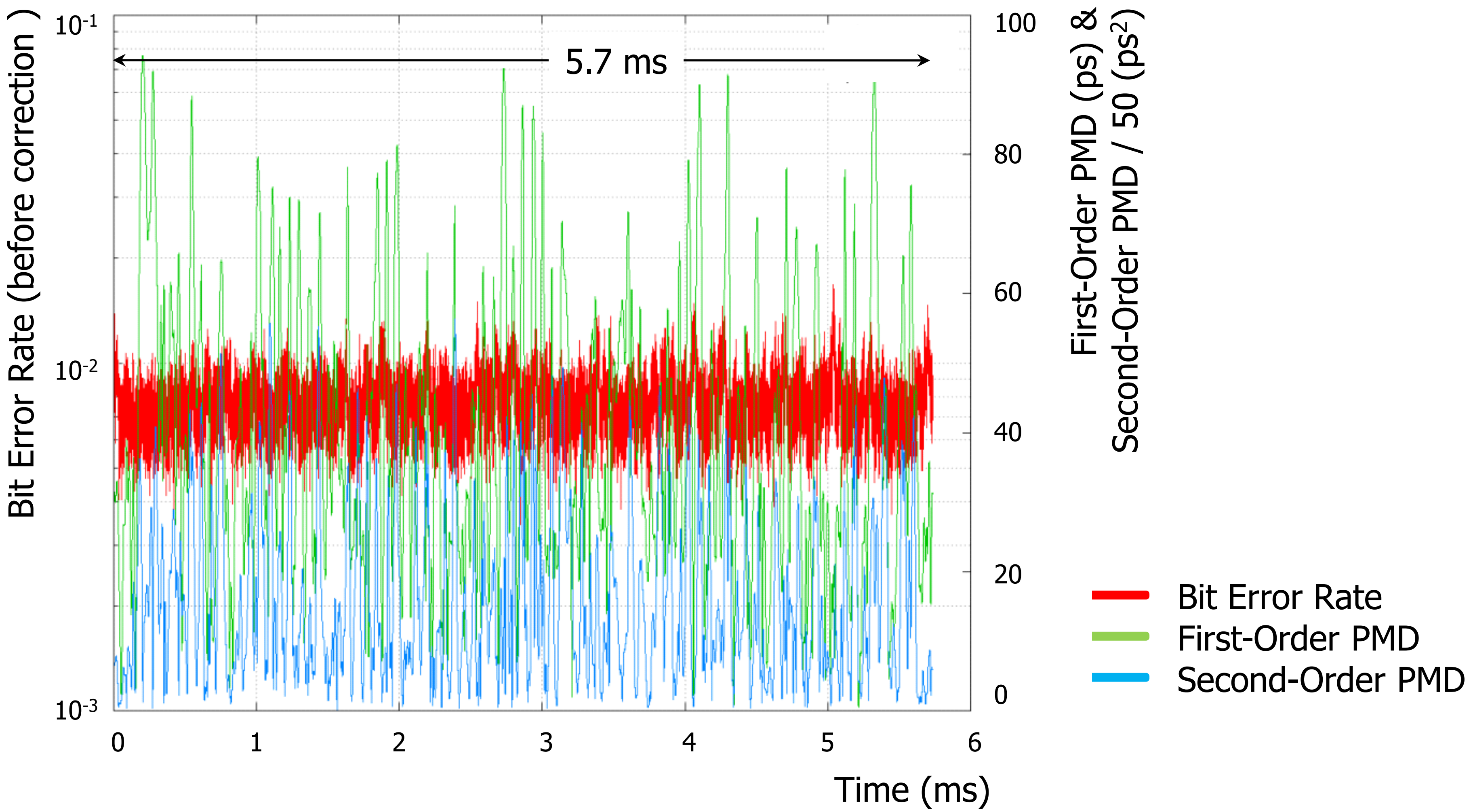
Verification of Dynamic PMD Compensation By FPGA Platform

- PMD equalizer test:
  - PMD path round trip in 5.7 ms, with DGD up to 90 ps (see below)
  - PMD pattern can be reproduced and rerun to test different transmission conditions



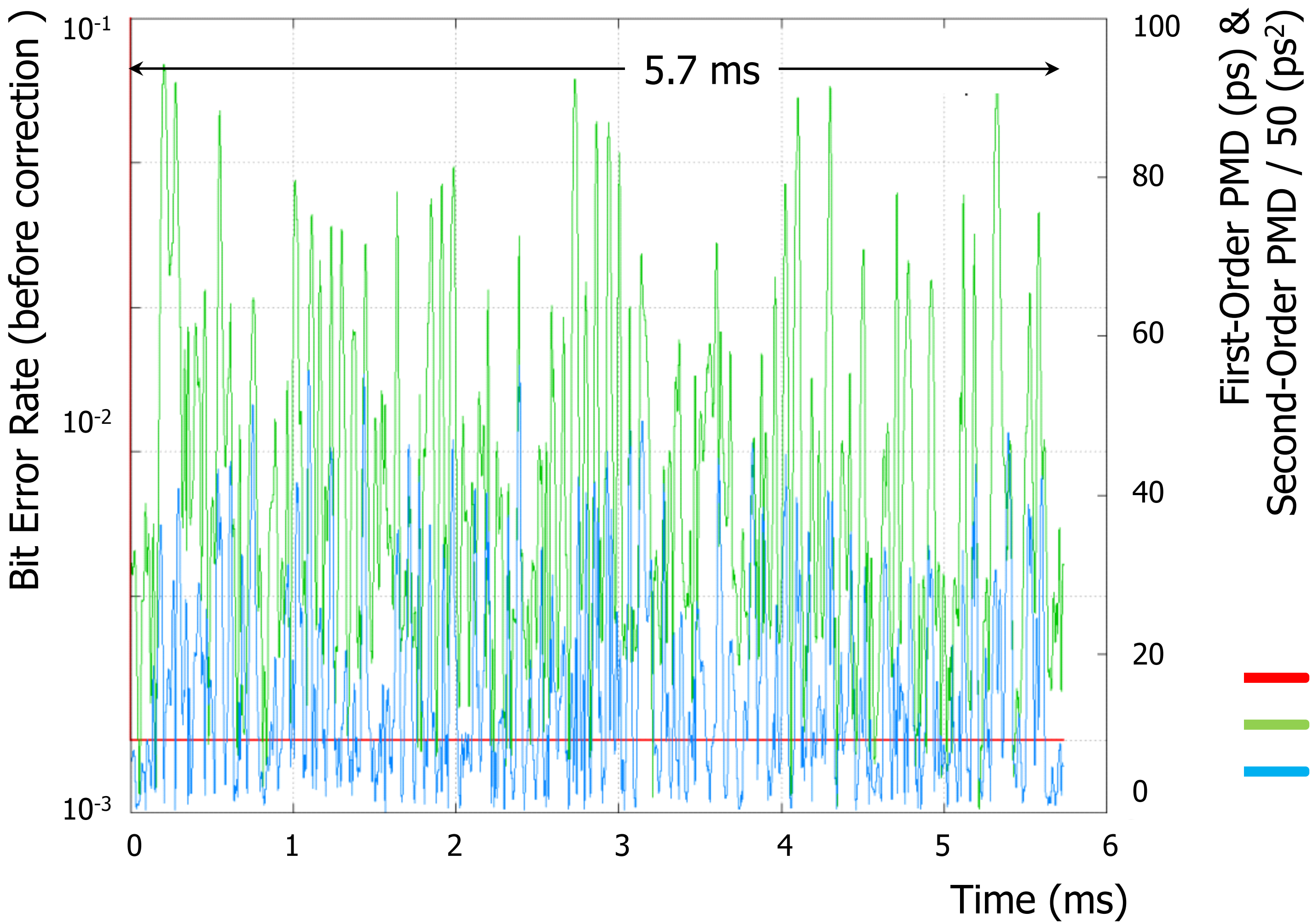
Verification of Dynamic PMD Compensation By FPGA Platform

- BER for Optical Signal-to-Noise Ratio (OSNR) = 13 dB / 0.1 nm



Verification of Dynamic PMD Compensation By FPGA Platform

- BER for Optical Signal-to-Noise Ratio (OSNR) = 22 dB / 0.1 nm



Verification of Dynamic PMD Compensation By FPGA Platform

- Soft-Decision Forward Error Correction (SD-FEC) can correct Bit Error Rate up to 10^{-1}.

  ➔ Error-free operation after correction for OSNR = 13 dB / 0.1 nm and PMD = 30 ps, even for fast-changing PMD conditions.

Features Specific to Xtera 100G

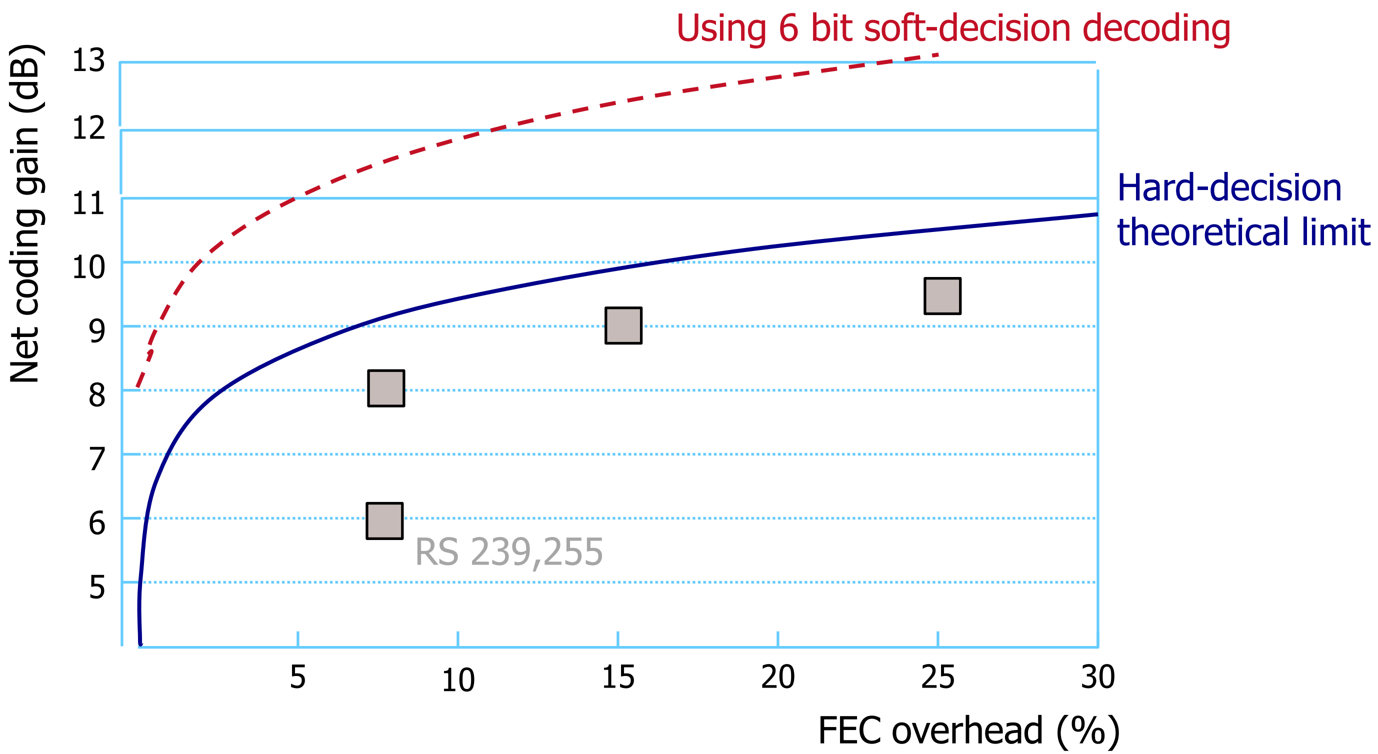
- Increase in equipment density:
  - 70% improvement (per 10G equivalent) compared to 10G interface card

- Lower power consumption/dissipation
  - Typical figure is close to 50% reduction (per 10G equivalent) compared to 10G interface card

- 40nm-CMOS technology allowing Soft Decision Forward Error Correction (SD-FEC)

Forward Error Correction

- So far all systems have used hard-decision FEC.



- Soft-Decision Forward Error Correction (SD-FEC) offers a gain around 2 dB and can correct BER up to 10^{-1}.

100G + Raman Combination

Benefits From 100G + Raman Combination

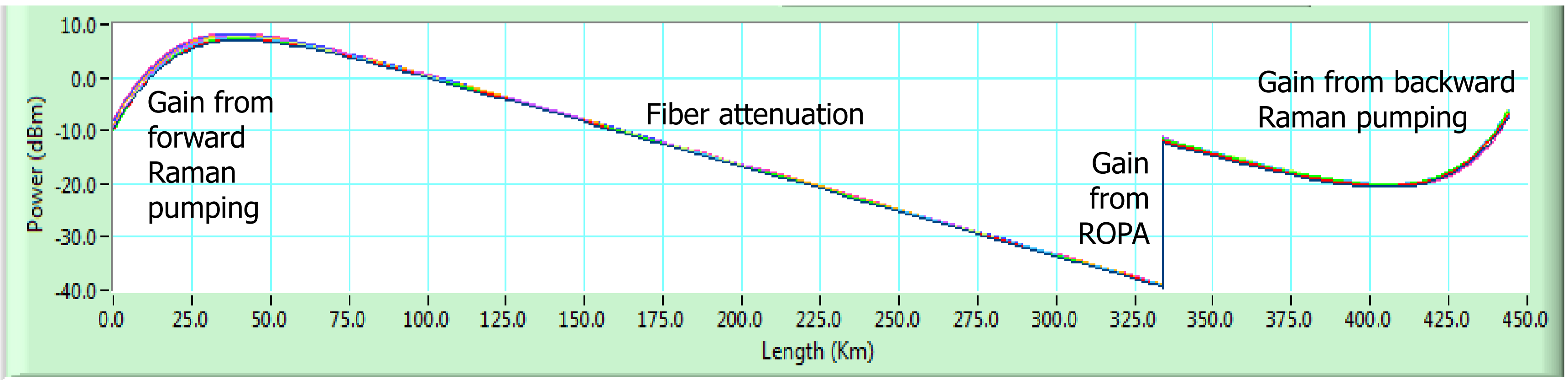
XTERA

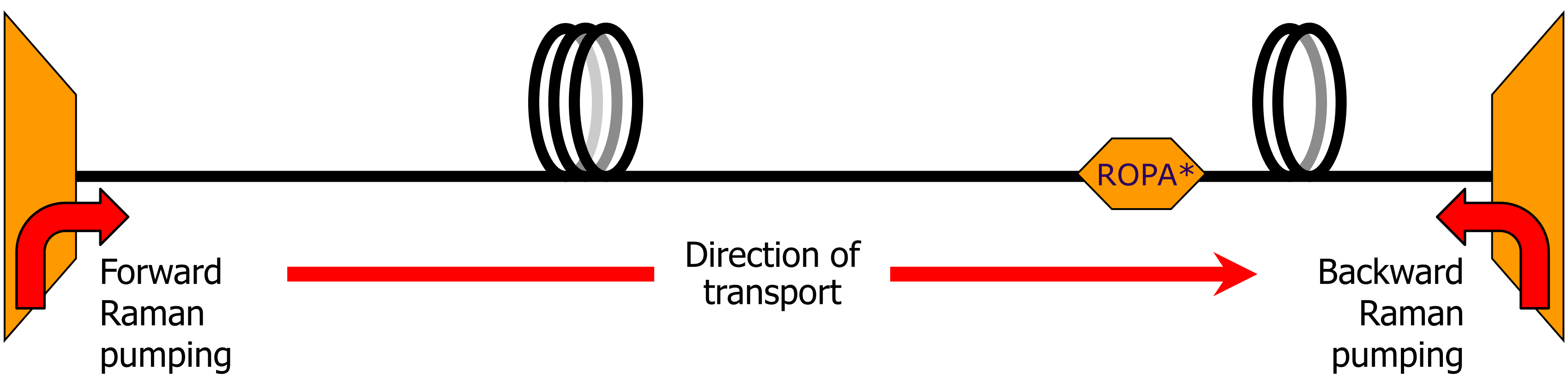
- Wide optical bandwidth enabled by modular Raman amplification implementation
  - 150 channels with 50-GHz channel spacing
  - Up to 15 Tb/s in the fiber today
  - Note: mixing of 10, 40 and 100G channels on the 50-GHz grid is possible.

- Better control of per channel optical profile along the link
  - Minimization of nonlinear effects
  - Longer reach and/or higher channel count

Example of Control of Per Channel Optical Profile

- Per channel optical power profile along a 444-km unrepeatered cable
- ROPA inserted about 110 km before the receive terminal

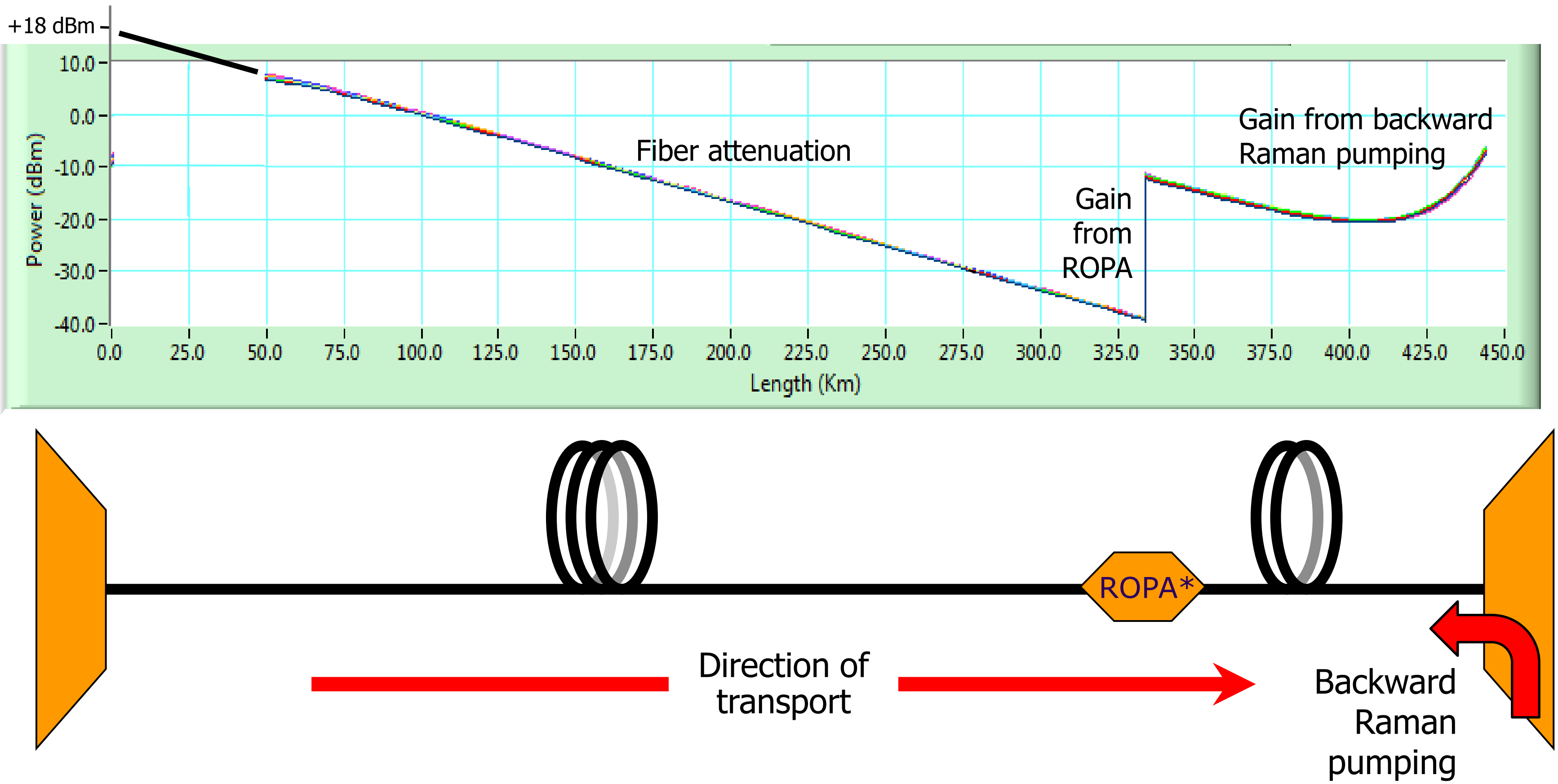




* ROPA: Remote Optically Pumped Amplifier

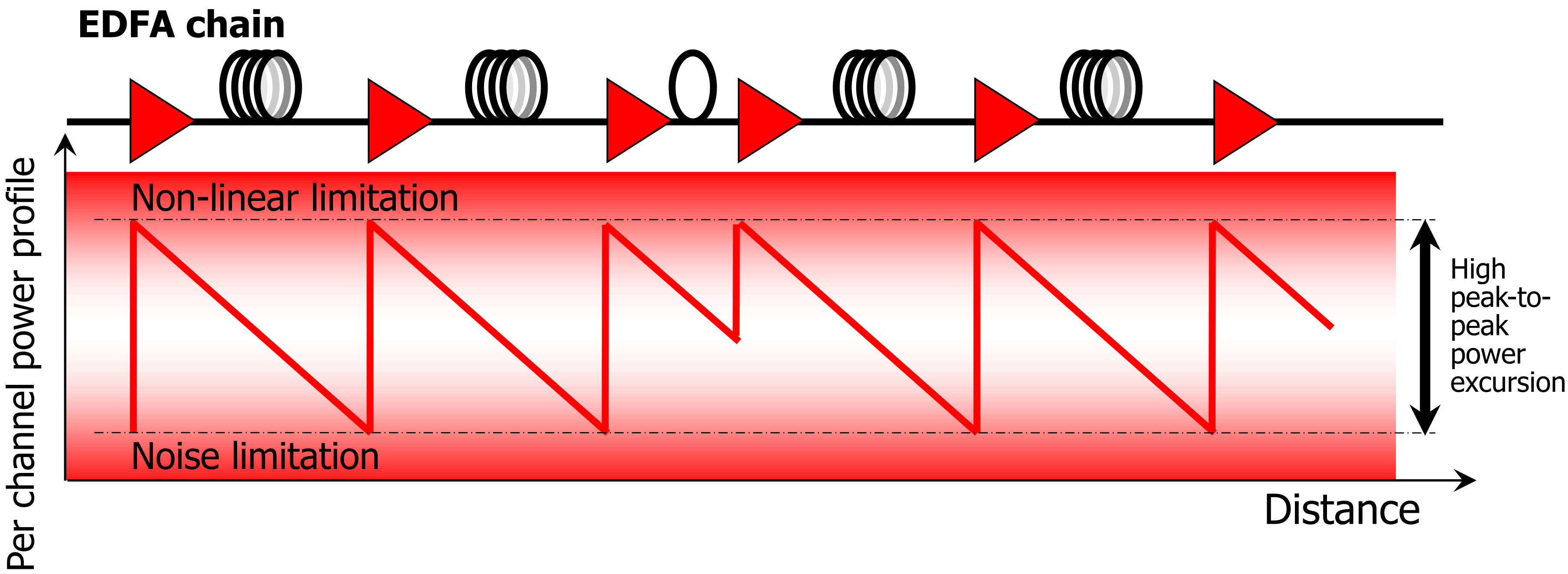
Example of Control of Per Channel Optical Profile

- With no forward Raman pumping, +18 dBm per channel launched power would be required to align on the Raman power profile
  - ➔ Too high nonlinear effects for 100G channels



* ROPA: Remote Optically Pumped Amplifier

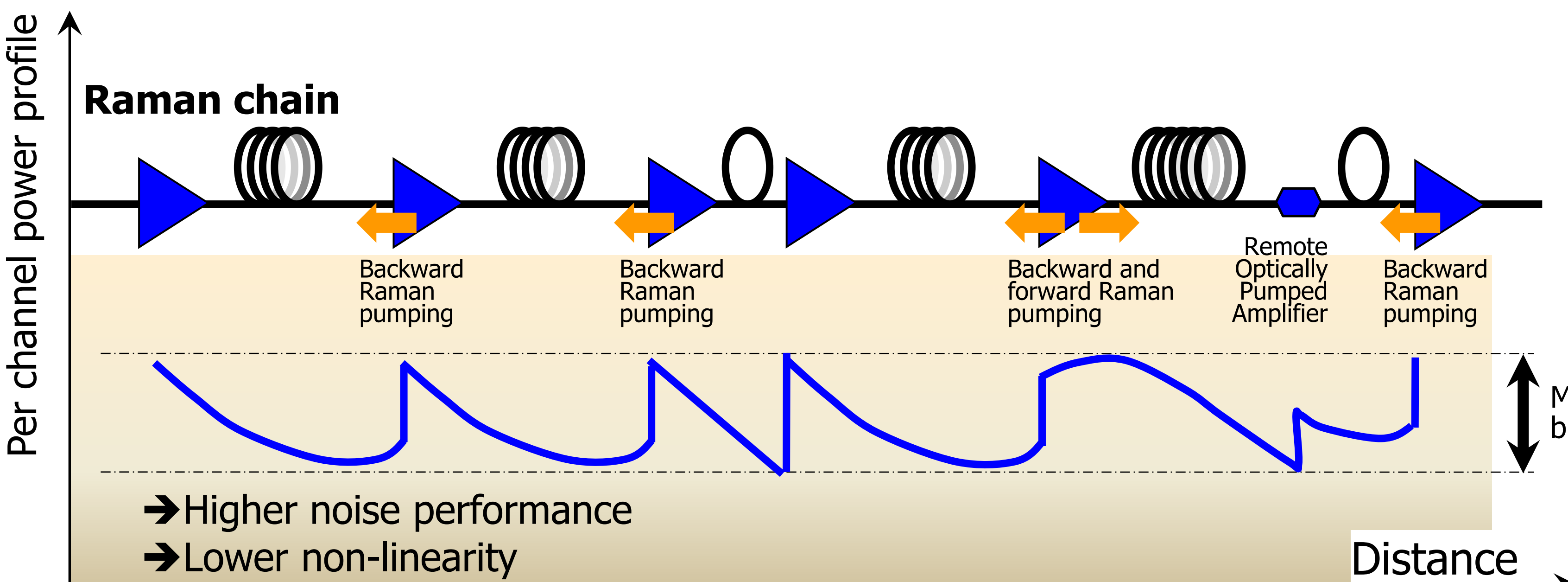
Example of Control of Per Channel Optical Profile EDFA-Based Long-Haul System



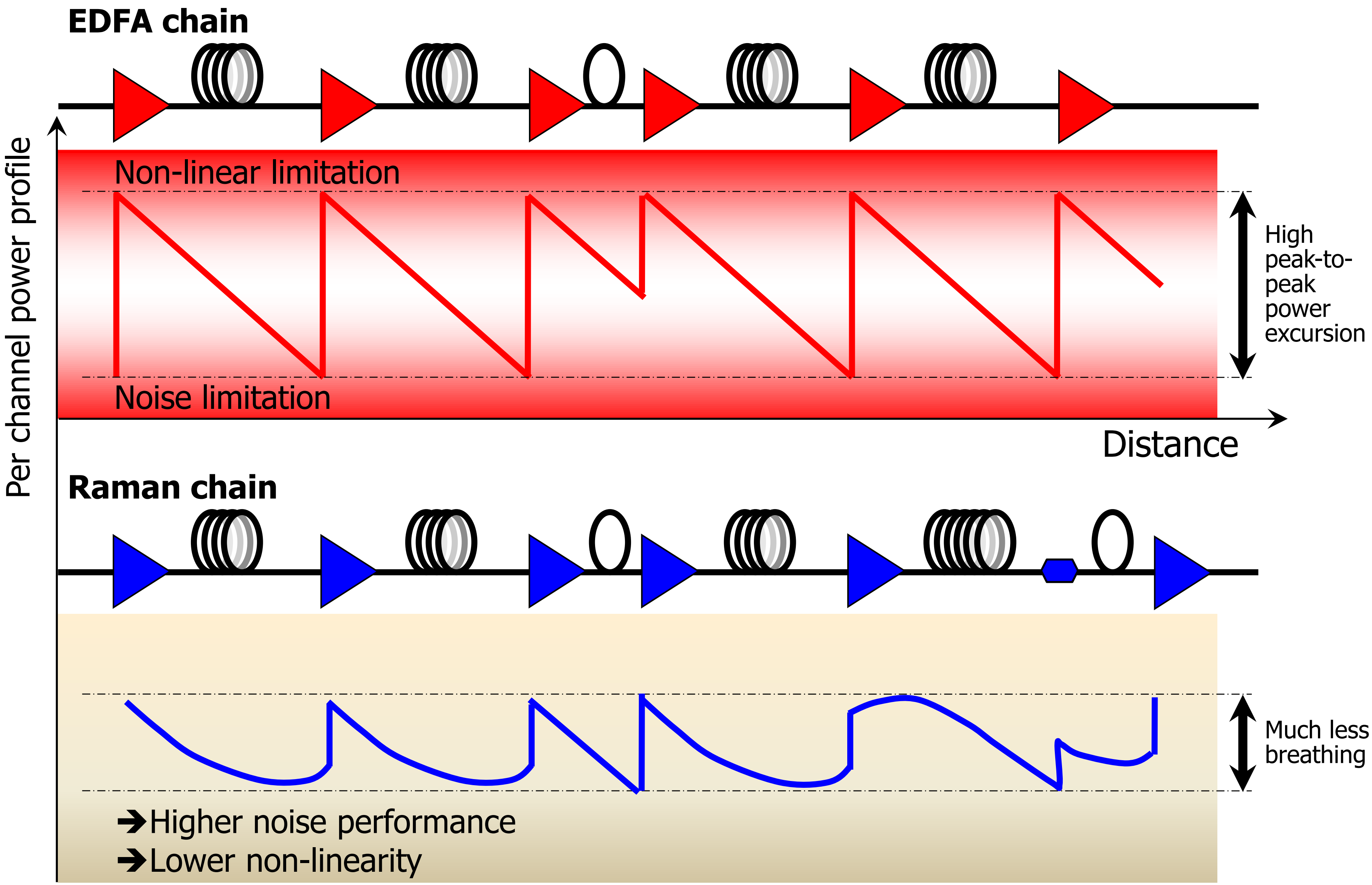
- Upper limit caused by signal degradation from too high nonlinear effects
- Lower limit caused by Optical Signal-to-Noise Ratio (OSNR) degradation
- Each EDFA represents a "hot point" along the optical path:
  - Significant per channel power breathing
    ➔ Channels periodically accumulate strong degradations
  - Maximum EDFA gain limited to below 40 dB
    ➔ Issue for long spans or high-loss fibers

Example of Control of Per Channel Optical Profile Raman-Based Long-Haul System

- For increasing span losses, use of
  - Backward Raman pumping
  - Backward Raman pumping + Forward Raman pumping
  - Backward Raman pumping + Forward Raman pumping + ROPA
- Amplification toolkit enables to
  - Efficiently accommodate for different span attenuations
  - Turn the line fiber into an amplification medium for more uniform per channel optical power all along the optical path



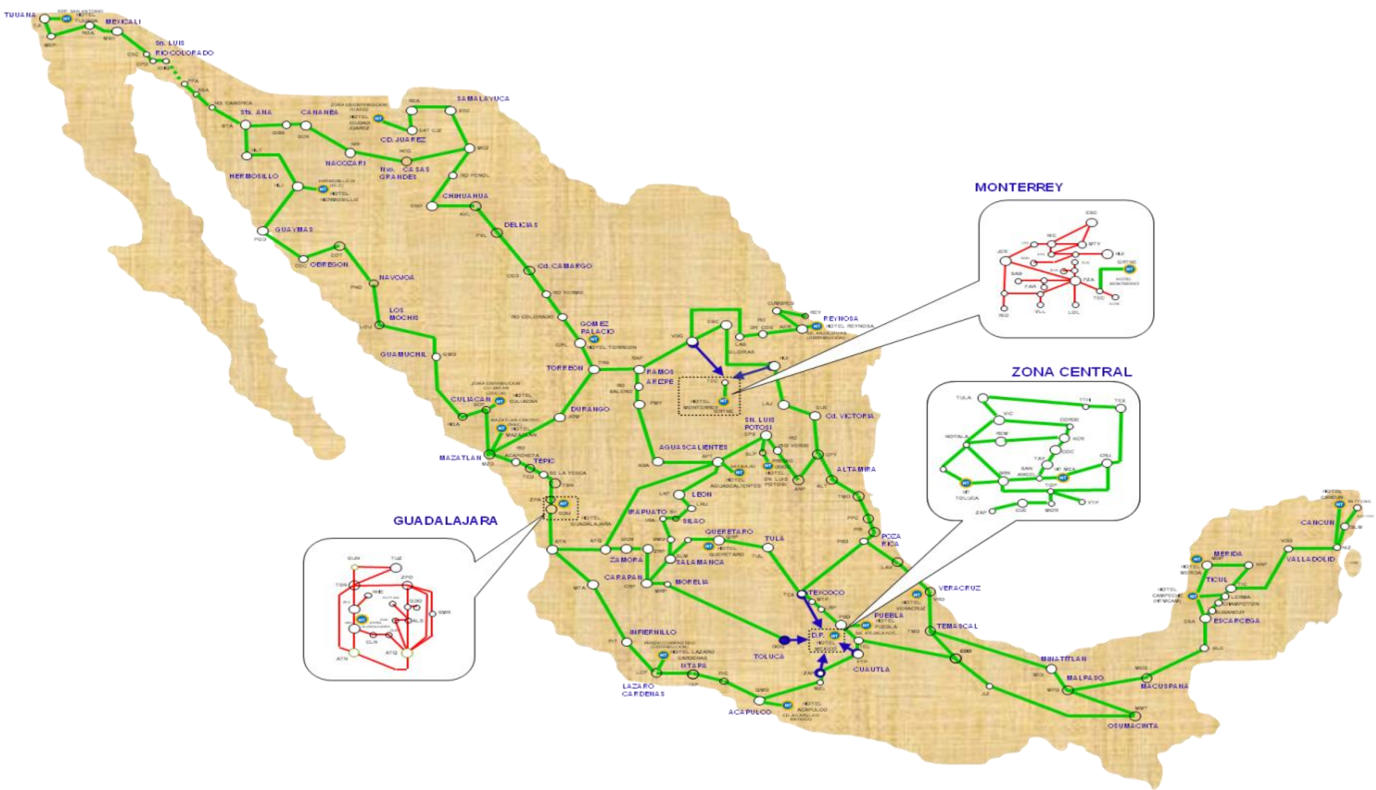
Example of Control of Per Channel Optical Profile EDFA/Raman Based Long-Haul Systems Comparison



CFE Case Study

CFE – Comisión Federal de Electricidad (Mexico)

- Mexican state-owned monopoly for electricity generation and distribution
  - $20B revenues and 80,000+ employees
- Nationwide footprint including more than 22,000 kilometers of OPGW fiber
- CFE Telecom was formed in 2006 as a wholly owned subsidiary of parent
- Markets services to Mexican enterprises, carriers and government entities



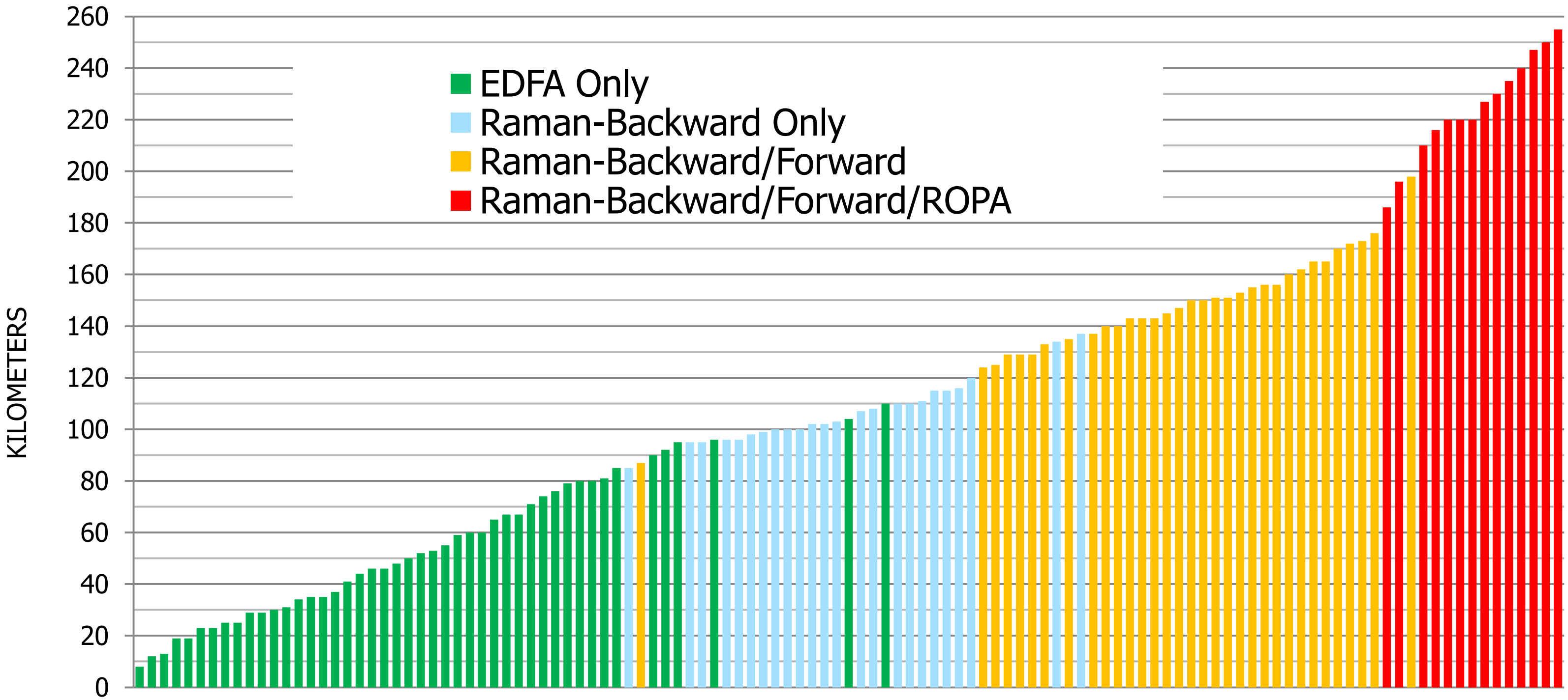
Raman Selected Best Network Solution

- Raman approach was selected as the best technical offer and was 30% lower cost than the technically-qualified alternative.

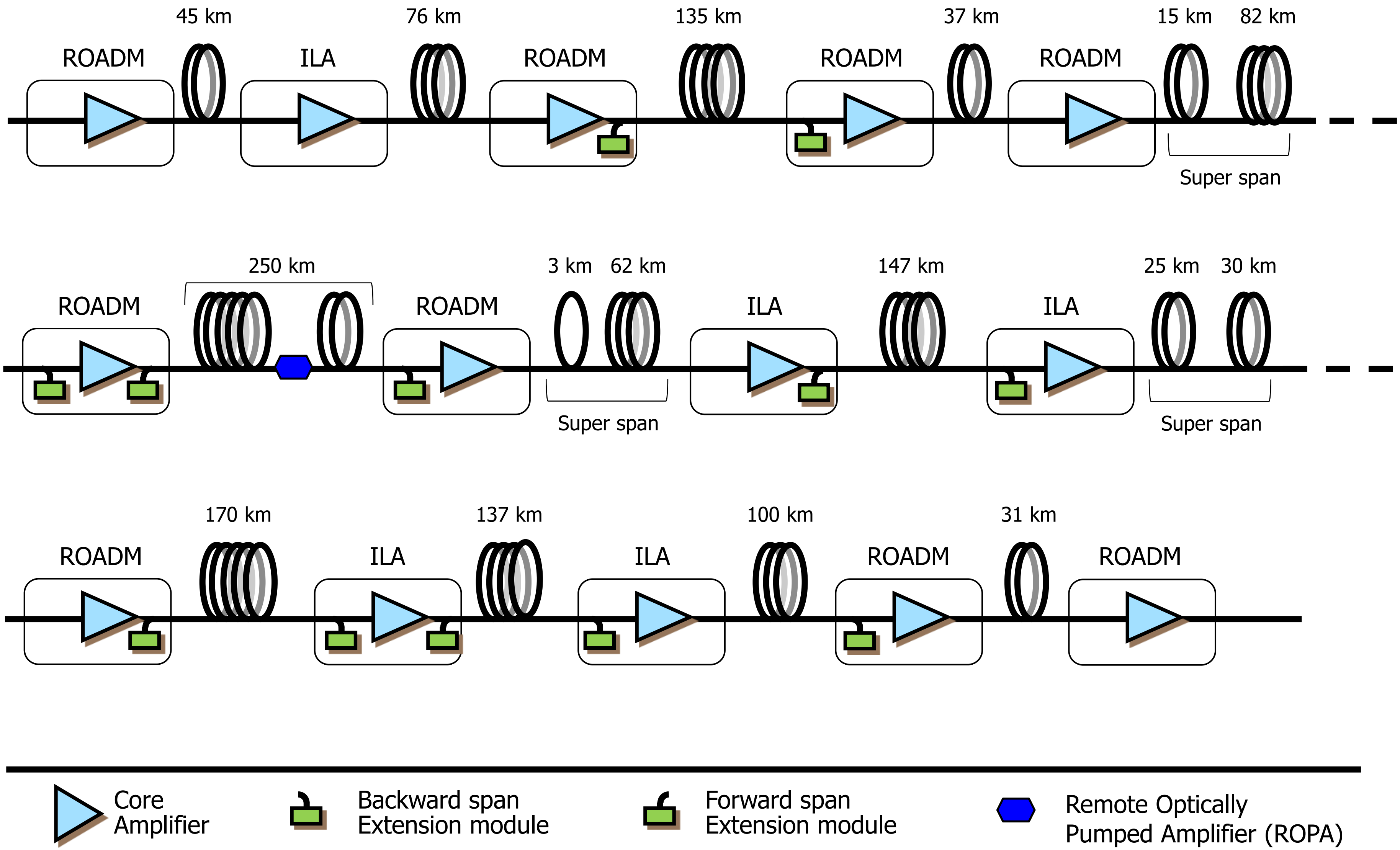
- Technical highlights of Xtera's Raman solution:
  - RFP asked for and was awarded on the basis of a 40G network; it was Xtera's choice to design the optical layer at 100G
  - Hybrid EDFA/Raman eliminated in-line amplifiers
    - Avoid installation of numerous repeaters and costly new huts
    - Best usage of existing outside plant
  - Hybrid EDFA/Raman supports 2,400-km non-regenerated routes
  - Multiple multi-degree ROADMs (up to 5 degrees) for compact junction sites and hotel complexes
  - Lowest CapEx of all technically-qualified offers

Mixing Spans Across the Network

- Technical solution performing on all the long spans
  - 20 of them longer than 170 km
  - 12 of them longer than 200 km



Mixing Spans and Amplification Technologies Along a Typical Route



Conclusion

Conclusion

- Raman amplification in commercial services in backbone networks since 2004 with 100-nm optical bandwidth

- Scalable optical bandwidth enabled by modular Raman amplification implementation
  - 150 channels with 50-GHz channel spacing
  - Up to 15 Tb/s in the fiber today
  - Note: mixing of 10, 40 and 100G channels on the 50-GHz grid is possible.

- Better control of per channel optical profile along the link
  - Minimization of nonlinear effects
  - Longer reach and/or higher channel count

  For:
  - Skipping of intermediate sites
  - Long regenerated sections in terrestrial networks (e.g. 150 x 100G on more than 2,000 km)

Maximizing Network Capacity, Reach and Value

Over land, under sea, worldwide