



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

Xtera Communications, Inc.

Raman Amplification for Terabit Optical Networking Today and Tomorrow

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Raman amplification offers straightforward and efficient solution to go beyond 10 Tb/s per fiber pair. Today.

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- Original Motivations to Develop Raman WDM Transport Systems
- 100G + Raman by Xtera
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Conventional Technology and Strategy

Conventional Technology for EDFA-Based Systems



- Most of the optical transmission systems are based on Erbium-Doped Amplifiers (EDFAs):
 - 88 channels maximum due to EDFA spectral limitation/bottleneck
 - 8.8 Tb/s today with 100G PM-QPSK technology
- Strategies to go beyond 8.8 Tb/s:
 - As the EDFA-based line equipment imposes an upper limit on the number of wavelengths, the next steps for capacity increases must be achieved at the terminal/interface levels.
 - Needs to develop more sophisticated, more complex modulation/detection schemes
 - PM-16-QAM, PM-32-QAM, PM-64-QAM...
 - Super-channel, multi-carrier FlexChannel...

Limitations from EDFA-Based Systems



- PM-16-QAM, PM-32-QAM, PM-64-QAM...
 - Tripling the current capacity of 8.8 Tb/s would impose the development of 64-QAM modulation scheme (high complexity with significant limitations in reach).
 - Super-channel, multi-carrier FlexChannel...
 - This approach is said to offer a 25% increase in useable amplifier spectrum (corresponding to an equivalent channel count of 110).
 - Both strategies are on a per channel basis, making them expensive when many channels are lit.
- ➔ The limited EDFA bandwidth imposes the development of ever more sophisticated modulation schemes in order to go beyond 8.8 Tb/s.



Original Motivations to Develop Raman WDM Transport Systems

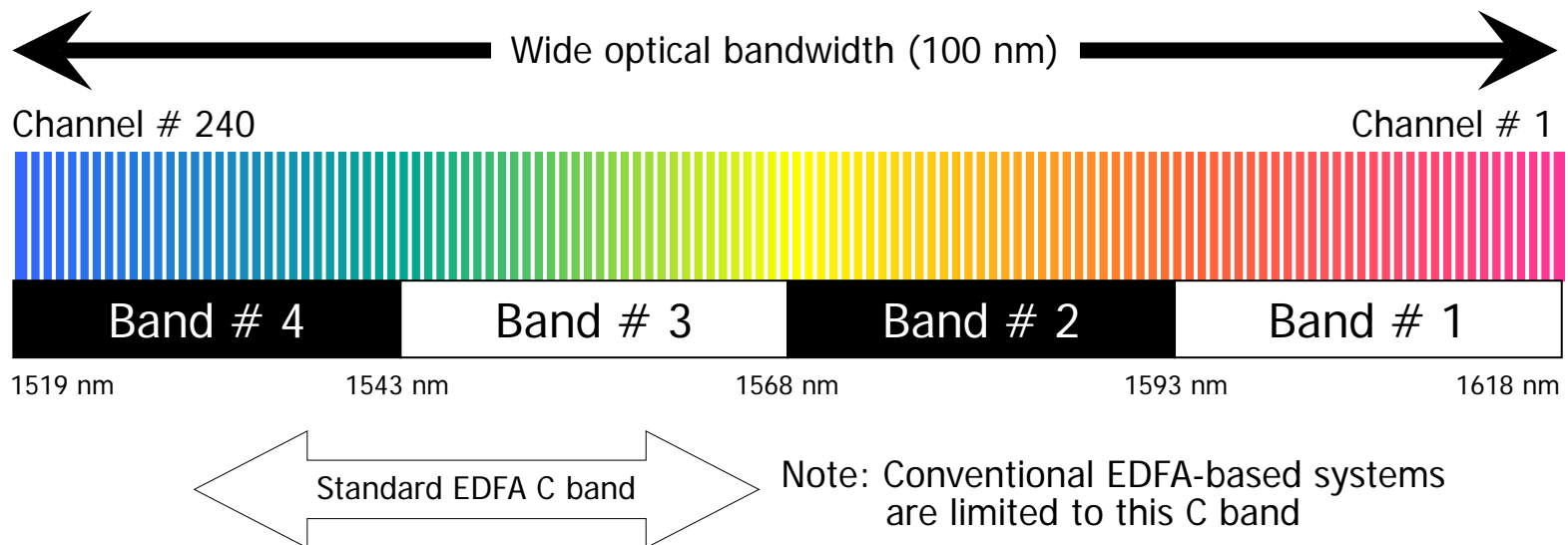
To make the best usage of optical amplification

- Optical subsystem able to simultaneously amplify multiple channels (for a cost shared by all the channels) instead of developing sophisticated per channel strategy (e.g. more complex modulation format), which results in extra cost for high channel count.
- This is one of the reasons why Xtera originally developed all-Raman optical amplification with ultra wide optical bandwidth.

Ultra-Wide Optical Bandwidth



- All-Raman amplification technology:
 - Up to 100-nm bandwidth (from 1519 to 1618 nm)
 - Contiguous spectrum (4 bands from multiplexing architecture)



Benefit from Raman Amplification Capacity

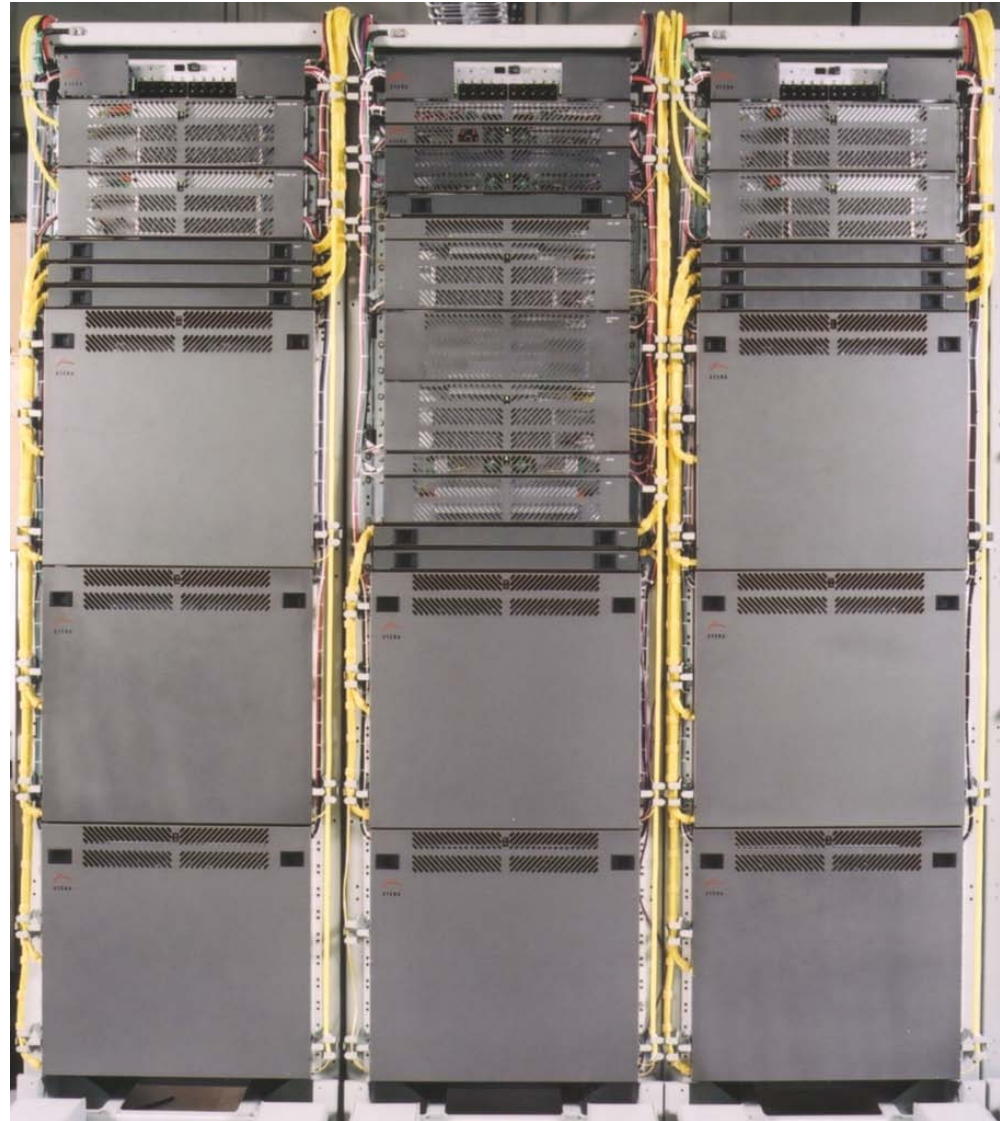


- Wide optical bandwidth:
 - 100 nm for our first-generation optical amplifiers
 - Up to 63 nm for last-generation optical amplifiers (offering a modular design for scalable optical bandwidth)
- Using standard 50-GHz channels spacing, these optical bandwidths turn into:
 - 240 optical channels for our first-generation optical amplifiers
 - 150 optical channels for our last-generation optical amplifiers
- Using today's 100G coherent technology, these optical bandwidths turn into:
 - 24 Tb/s per fiber pair for our first-generation optical amplifiers
 - 15 Tb/s per fiber pair for our last-generation optical amplifiers

Benefit from Raman Amplification Equipment Density



- Performance (optical bandwidth and OSNR) of the common equipment based on Raman optical amplification relaxes the requirements and specifications of the interface cards.
- 2.4 Tb/s in 3 racks by 2004 with 10G NRZ technology
 - PIC technology did not bring any density advantage.
- Today: 2.5 Tb/s per rack with 100G coherent technology

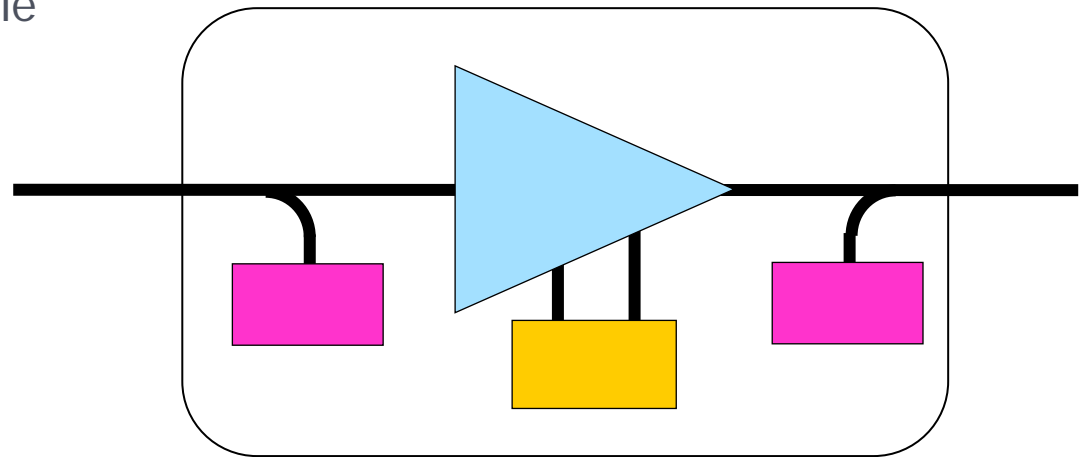


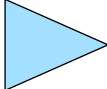




100G + Raman by Xtera

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 in service
 - From 60 to 150 channels



-  Core amplifier (typical gain around 20 dB)
-  Span extension module (in backward or forward configuration)
-  Capacity expansion module (optical bandwidth in-service increase)

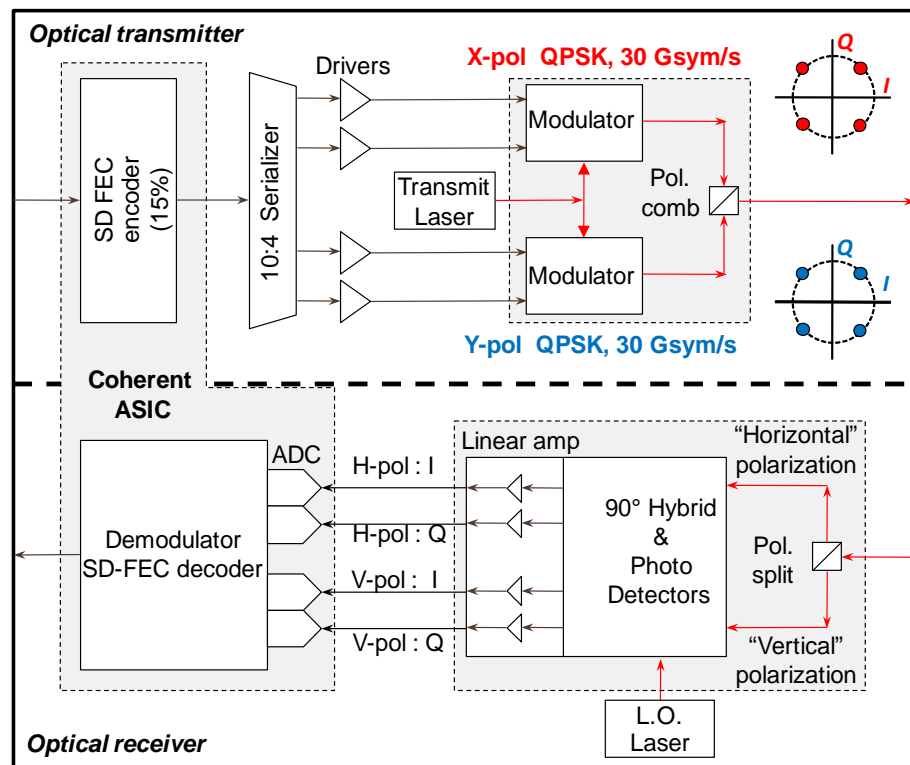
100G LH MSA Module



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



Block diagram



Under deployment today



Framer interface
112G

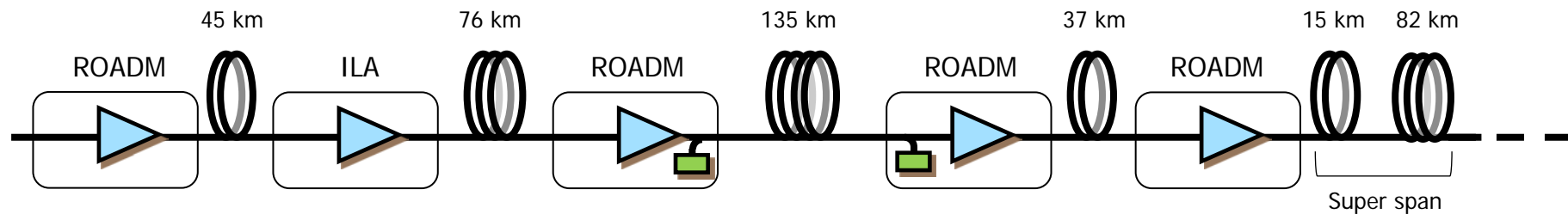


LH interface
120G

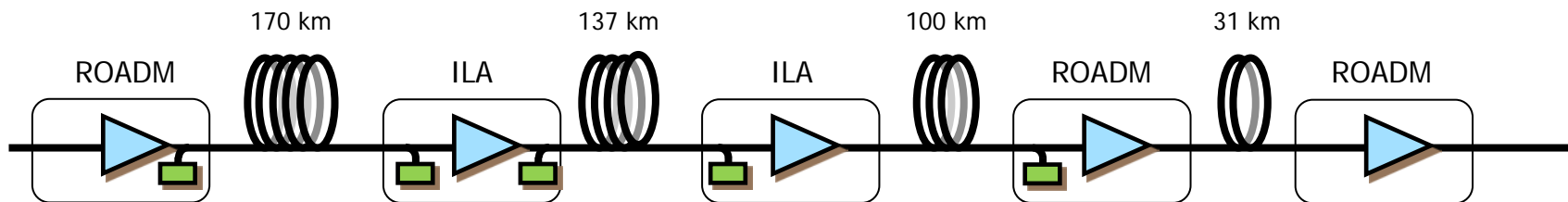
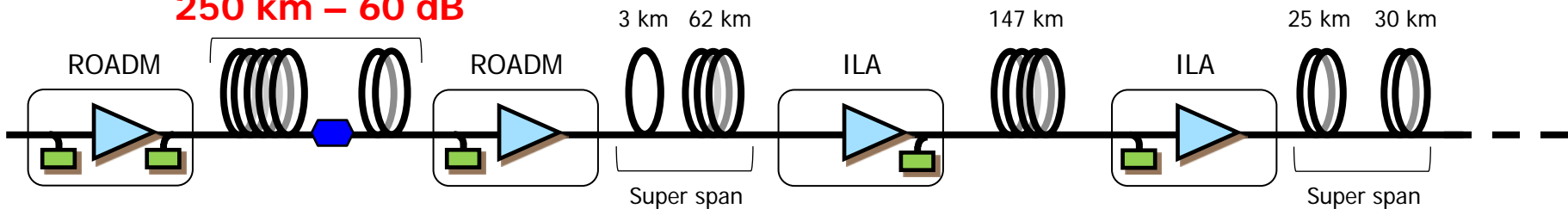


Reach Benefits Offered by Raman Amplification

Mixing Spans and Amplification Technologies Along a Typical Route (1,340 km)

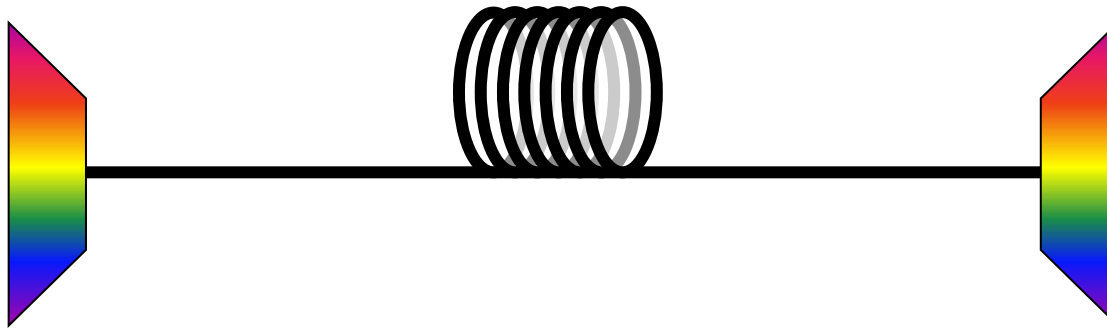


250 km – 60 dB

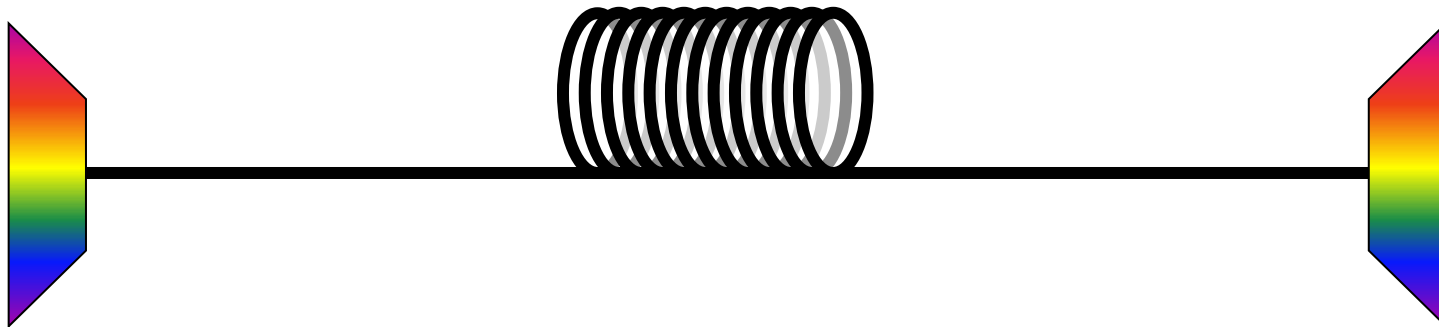


Unrepeated Reach

- On 360-km cable route: $70 \times 100\text{G} = 7 \text{ Tb/s}$ per fiber pair



- On 440-km cable route: $8 \times 100\text{G} = 800 \text{ Gb/s}$ per fiber pair



- Raman amplification in commercial services in backbone networks since 2004 with 100-nm optical bandwidth
- **CAPACITY** – Scalable optical bandwidth enabled by modular Raman amplification implementation
 - 150 or 240 channels with 50-GHz channel spacing
 - Up to 24 Tb/s in the fiber
 - Mixing of 10, 40 and 100G channels on the 50-GHz grid
 - Available today
- **REACH** – 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)



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