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OPTICAL DESIGNS FOR GREATER POWER EFFICIENCY

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Emerging Subsea Networks

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Celebrating 30 years of SubOptic

Presenter Profile

Alexei Pilipetskii is the Senior Director of System Research at TE SubCom. Alexei joined TE SubCom in 1997. Alexei has been involved in transmission research with a focus on next generation transmission technologies.

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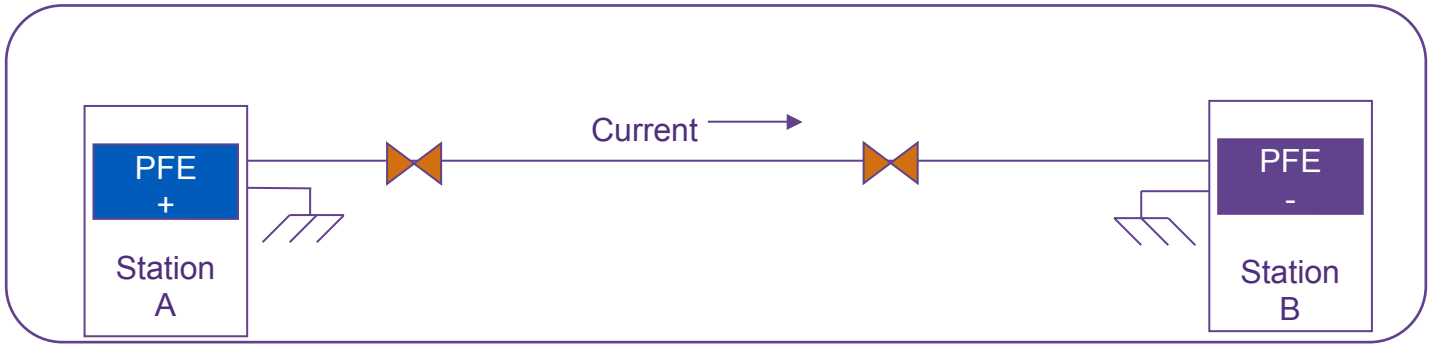
1. Motivation
2. Capacity demonstrations in a single mode fiber
3. System design and optical power optimization
4. SDM and power efficiency
5. Conclusions

Powering

- Undersea system powering
  - Power is supplied from the shore ends
  - Constant current power supply
  - Power available to the optical amplifiers is limited by maximum voltage drop on a cable

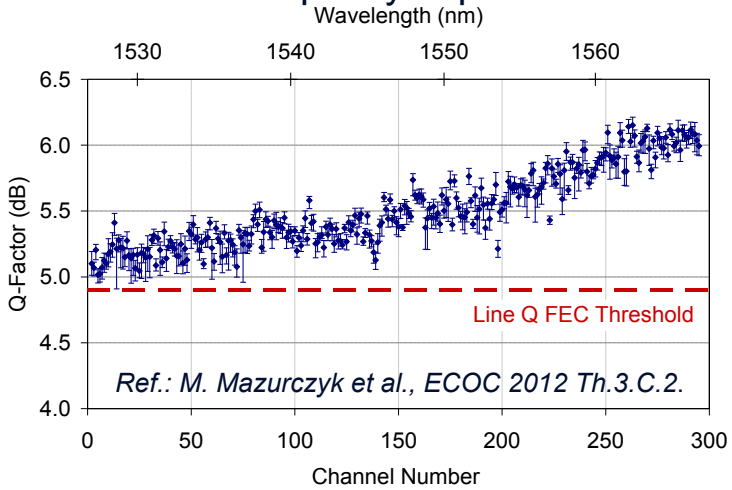


Typical Example

- Full C-Band EDFA system
  - Single-end feed ~ 15 kV
  - Output optical amplifier power up to 19dBm
  - Up to ~10 amplifier pairs (fiber pairs)
  - ~60 km repeater spacing
  - ~10 Mm transmission distances
    - More efficient power supplies help to alleviate powering problem
- What can be done from the optical standpoint?

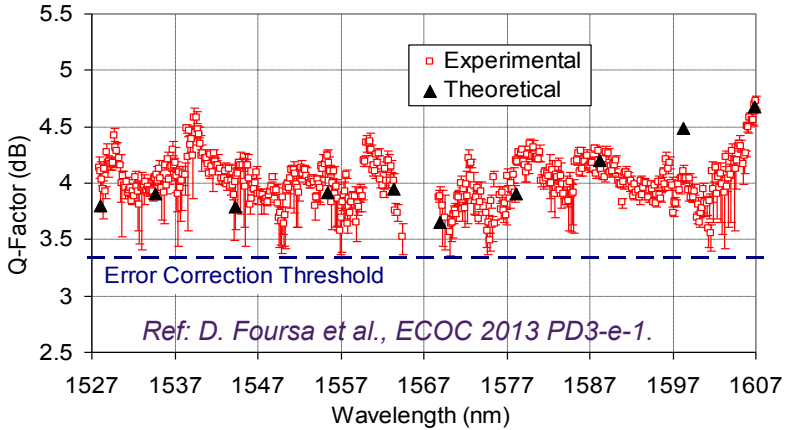
Capacity Demonstrations and Optical Power

Full C-band capacity experiment



- 40 nm full C band EDFA
- **19.5 dBm** EDFA output power
- 152 μm^2 effective area fiber
- 55 km amplifier spacing
- **30.58 Tb/s over 6,630 km**, 610% SE

C+L capacity experiment



- C+L band EDFA
- **20.0 dBm** EDFA output power
- 152 μm^2 effective area fiber
- 55 km amplifier spacing
- **44.1 Tb/s over 9,100 km**, 493% SE

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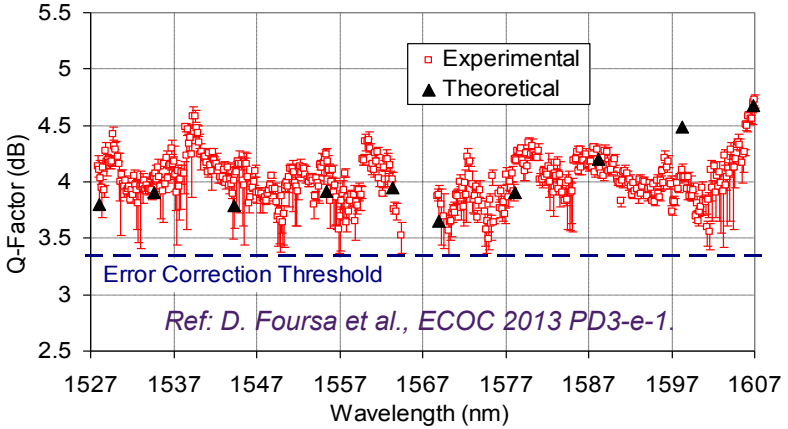
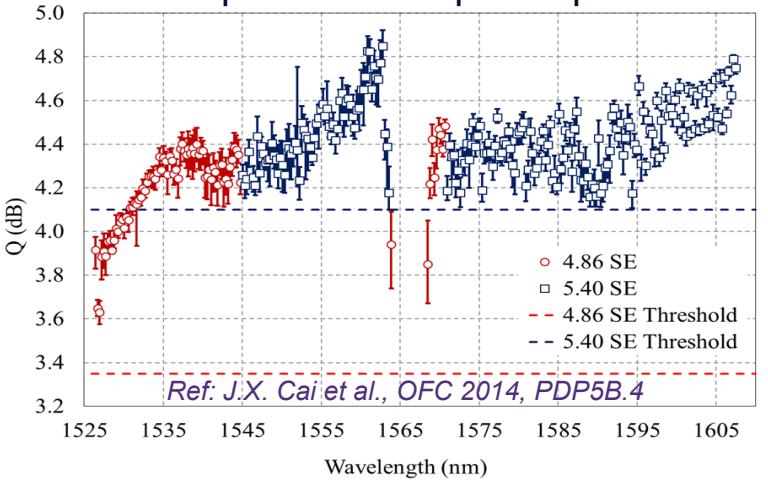
C+L Transmission Experiments at Low and Optimal Power Levels

C+L Experiment at low power



- **20 dBm** EDFA output power
- 152 μm² effective area fiber
- 55 km amplifier spacing
- **44.1 Tb/s over 9,100 km**, 493% SE

C+L Experiment at optimal power



- 22.5 dBm EDFA output power
- 152 μm² effective area fiber
- 55 km amplifier spacing
- **49.3 Tb/s over 9,100 km**, 486 and 540 % SE

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Observations

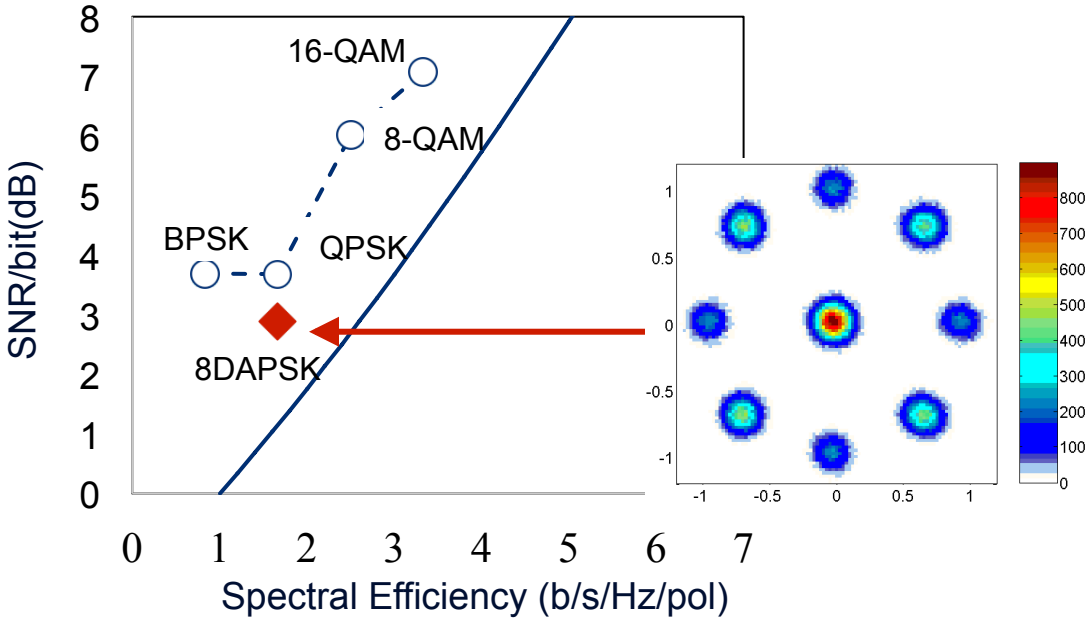
- Bandwidth increase results in a larger capacity per similar amplifier output power

- Increase power to optimal does not result in a proportional capacity increase

What else can be done?

- Modulation formats
- Amplifier bandwidth
- Repeater spacing
- Space division multiplexing

Power Efficient Modulation Schemes



Power efficiency ∝ 1/SNR per bit

Ref: H. Zhang et al., ECOC 2015, Th.2.2.1

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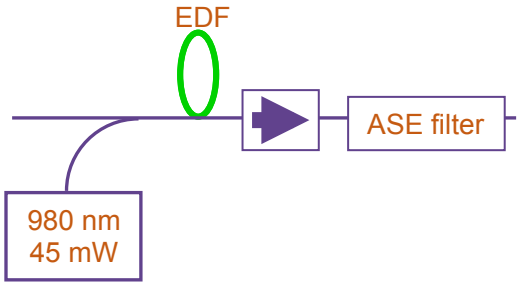
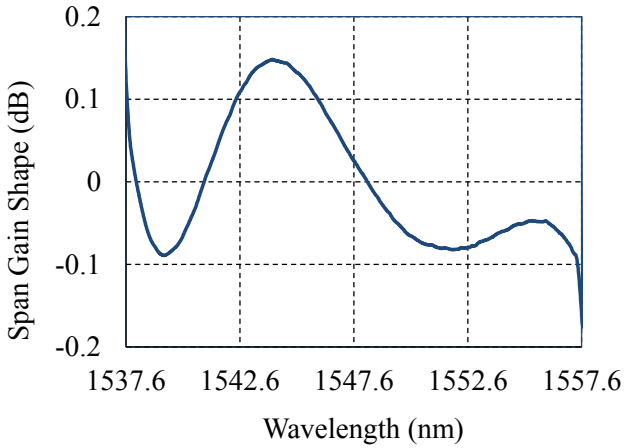
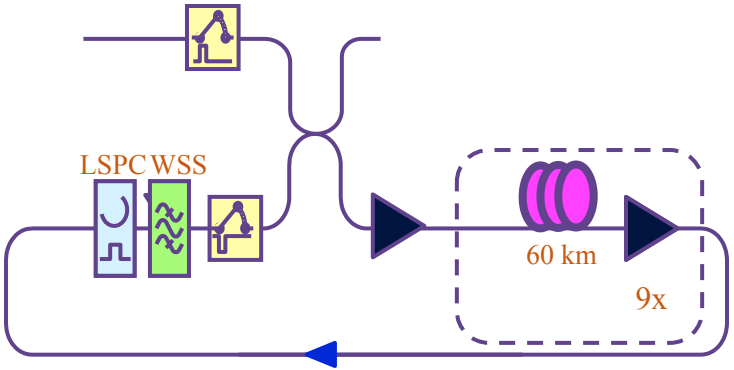
Power Efficient Transmission Experiment





- Narrow BW single-stage EDFAs
  - No gain equalization in EDFA
- 45 mW pump power
- 8.12 Tb/s capacity over 9,750 km



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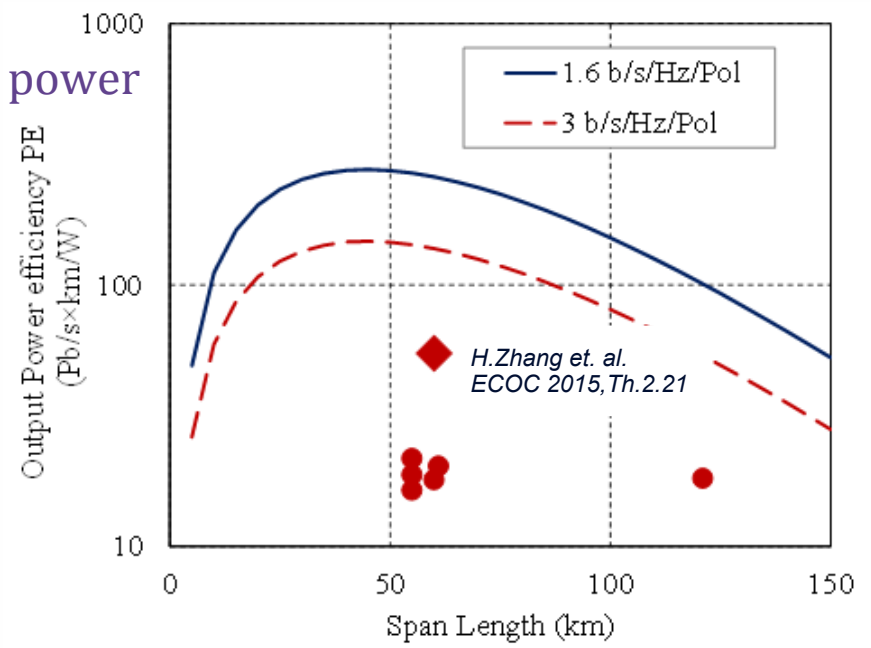
Power Efficiency and Repater Spacing

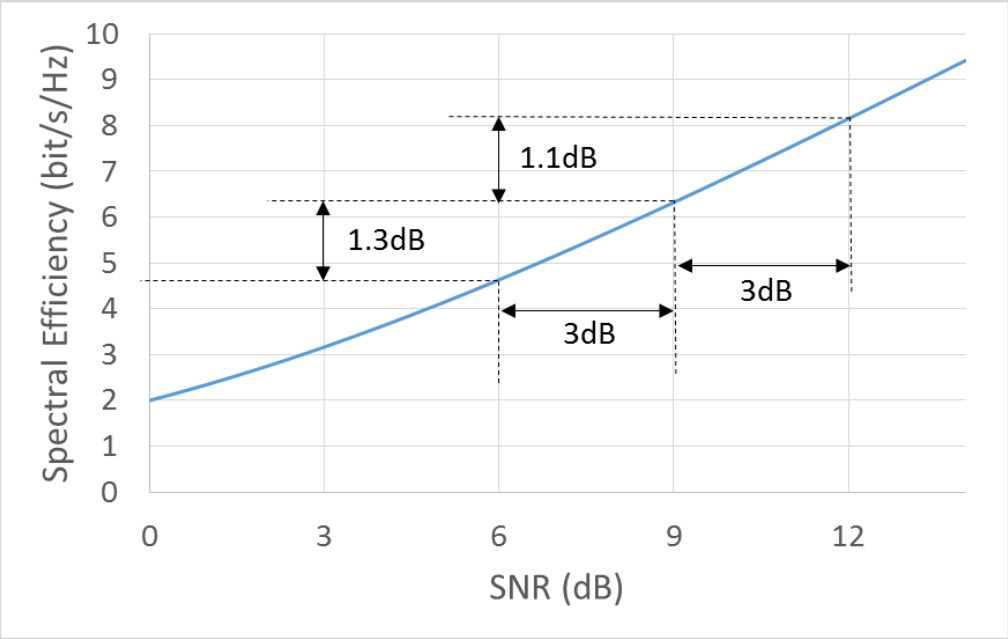
Power Efficiency Metric

$$PE = \text{Capacity} \times \text{Distance} \,/ \sum \text{EDFA output power}$$

- Shorter spans (~10 dB loss) are optimal
  - Theoretical assumtions:
    - Ideal 3 dB amplifier NF
    - Modulation formats are at Shannon capacity



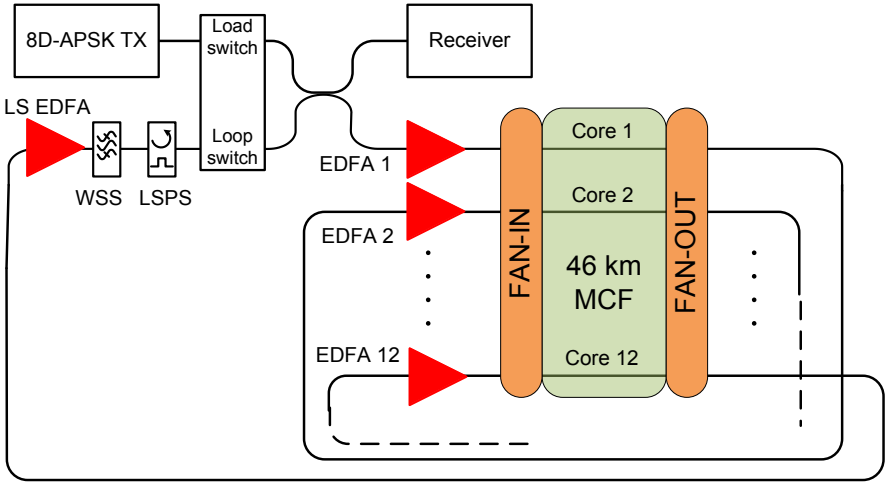
Space Divison Multplexing Can Help



$$SE = 2\log_2(1 + SNR)$$

- SDM can provide higher capacity for the same power
- Additional benefit can come from lower nonlinear penalties

Transmission Experiment in MCF



- 46km 12 core MCF spans
- 14,350km transmission
- 82X106.8 Gb/s per core
- 105.1 Tb/s capacity
- **Total Pump Power = 800mW**

Ref: A. Turukhin, et. al., OFC16 Th4C.1

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Conclusions

- Optimization of optical power efficiency can result in a significant capacity increase
- SDM might be a promising path towards increase in capacity in power efficient manner
- Optimization studies need to be done to come up with the future solutions

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