Learning to Exploit z-Spatial Diversity for Coherent Nonlinear Optical Fiber Communication

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University of Stuttgart
Institute of Telecommunications
Prof. Dr. Ing. Stephan ten Brink

Outline

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Agenda

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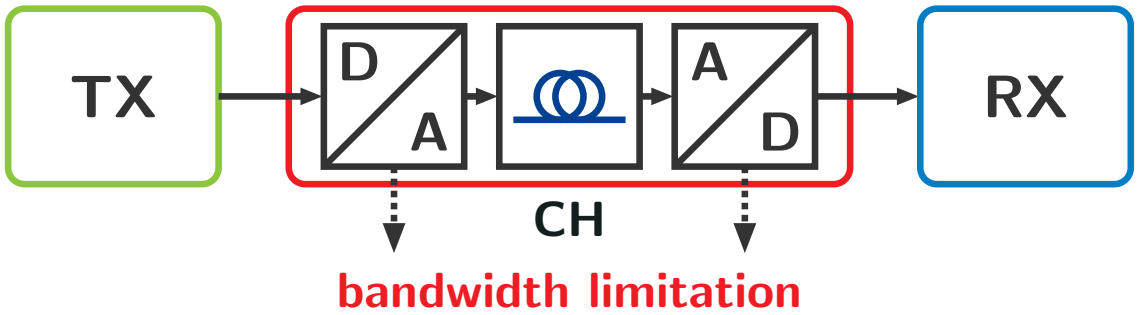
Problems

- Kerr-effect causes spectral broadening
- Part of the information gets lost due to bandwidth limitation of D/A- and A/D-converters
- WDM requires hard bandwidth limits per channel



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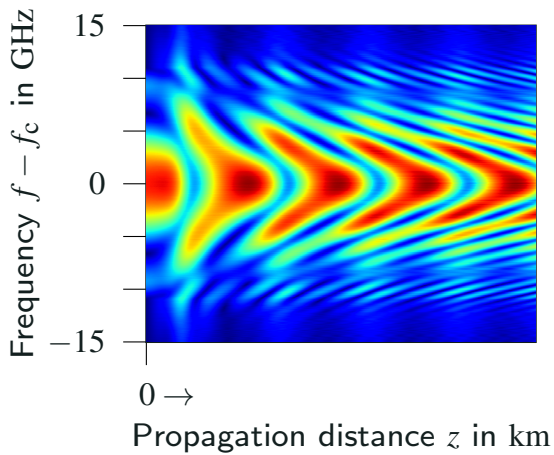
Solitonic propagation

- Nonlinear regime allows propagation of solitons
- Higher-order solitons posses spatial periodicity
- Spectrally inefficient for communications
- Given enough distance all impulses have solitonic behavior

➡ Can we exploit this?



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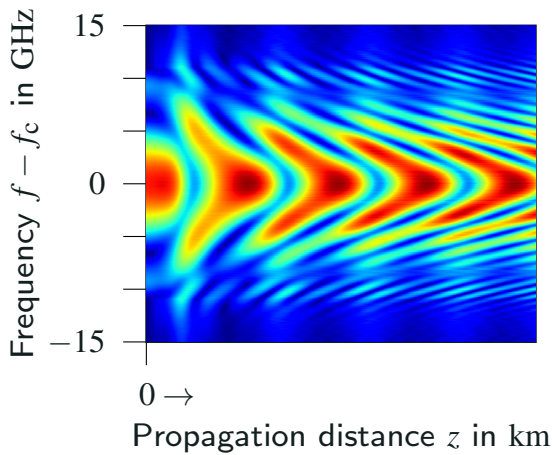

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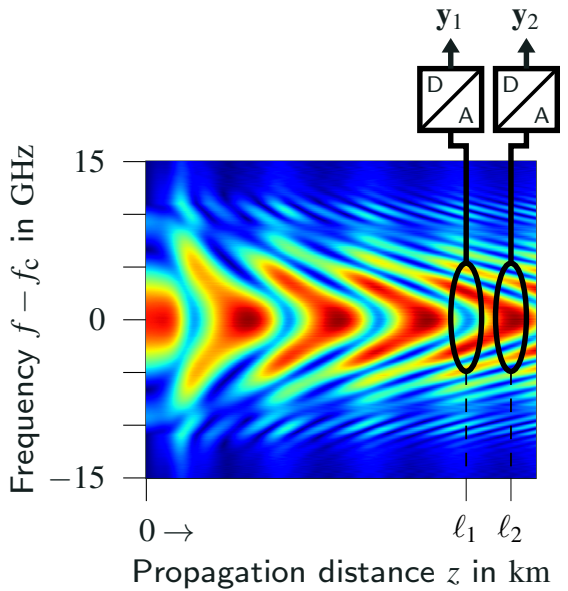
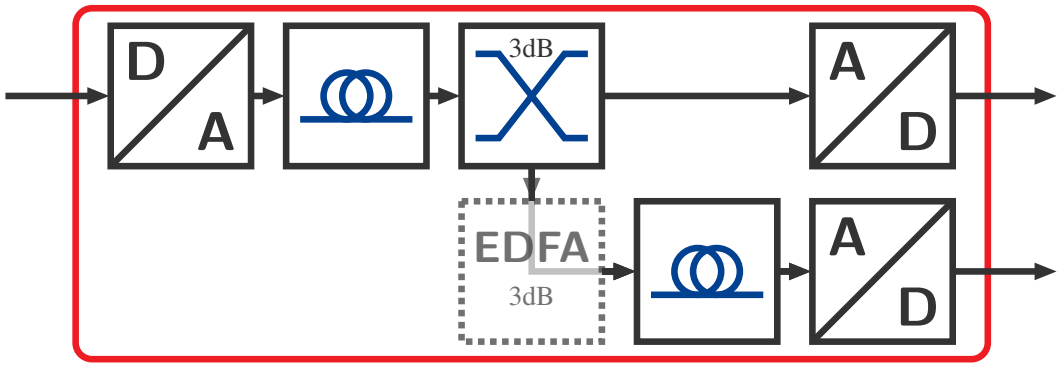


Spatial Diversity

- Ideal distributed Raman amplification
- Concatenate a second fiber
- Length of first fiber $\approx 1000\,\mathrm{km}$
- Split signal using a $3\,\mathrm{dB}$-coupler

Length second fiber?

Amplifier? ? RX design?



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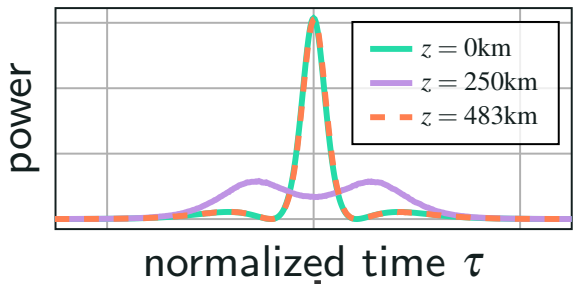
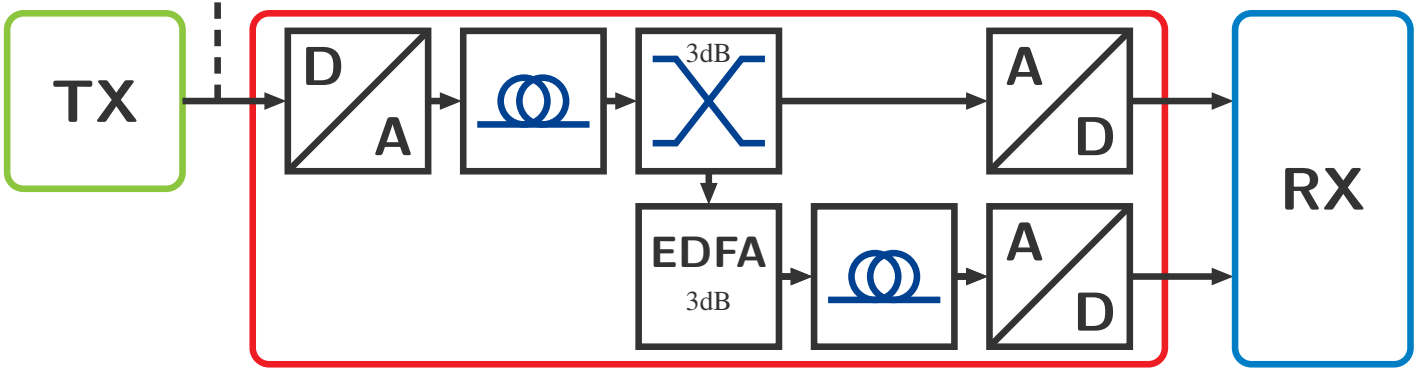
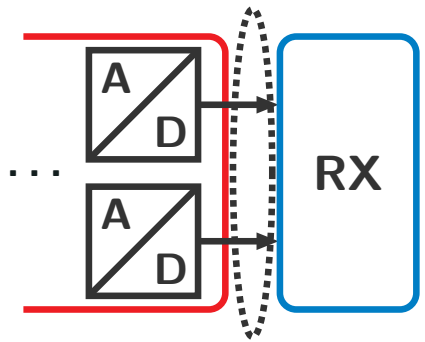
Sending solitons

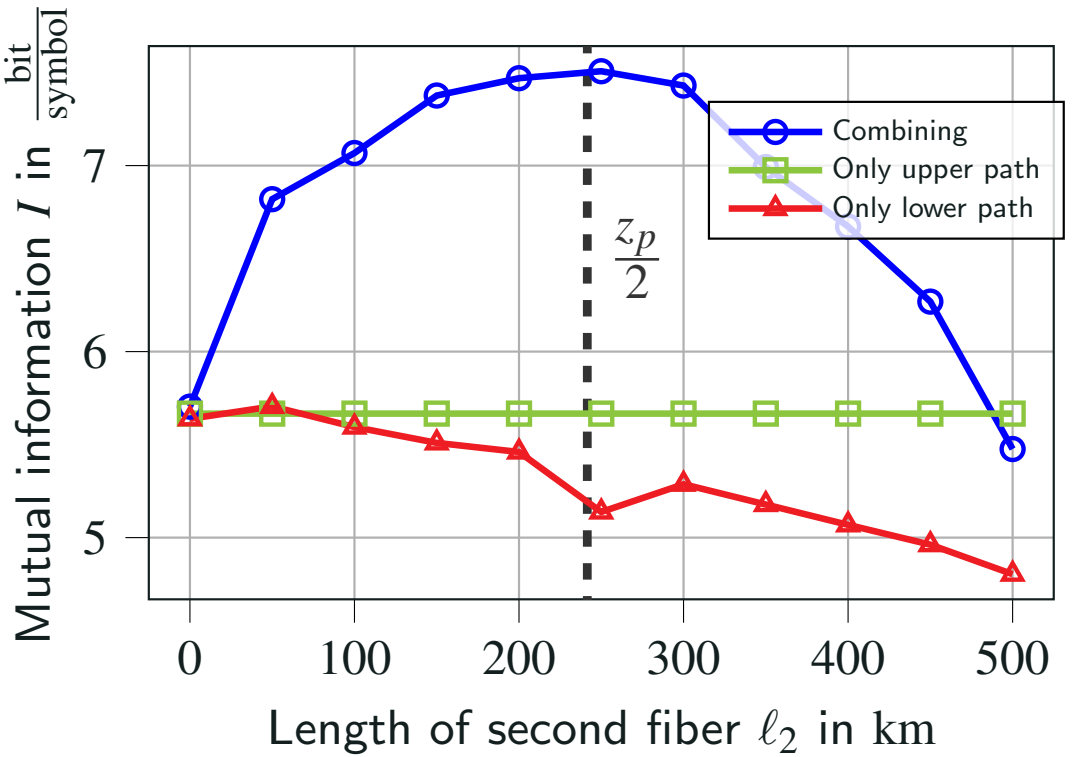


- 2nd order solitons
- average launch power $P_{\text{avg}} = 5\,\text{dBm}$
- periodic length $z_{\text{p}} = 483\,\text{km}$
- EDFA needed to compensate coupler loss



Results

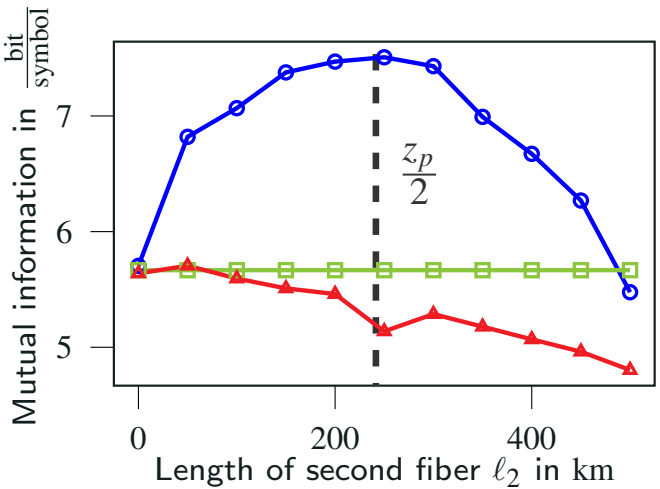

A
D
A
D
RX


Mutual information I in $\frac{\text{bit}}{\text{symbol}}$
7
6
5
0
100
200
300
400
500
Length of second fiber ℓ_2 in km
$\frac{z_p}{2}$
Combining
Only upper path
Only lower path

Results

- Combining both paths achieves gains
- Maximum achieved at $\frac{z_p}{2}$

$\Rightarrow$ Spatial diversity provides gains in solitonic communication



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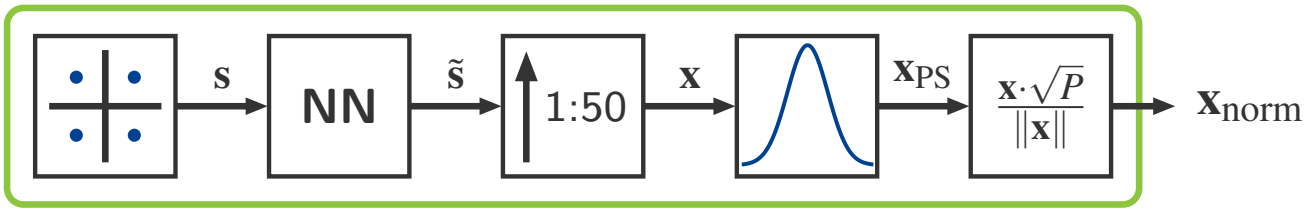
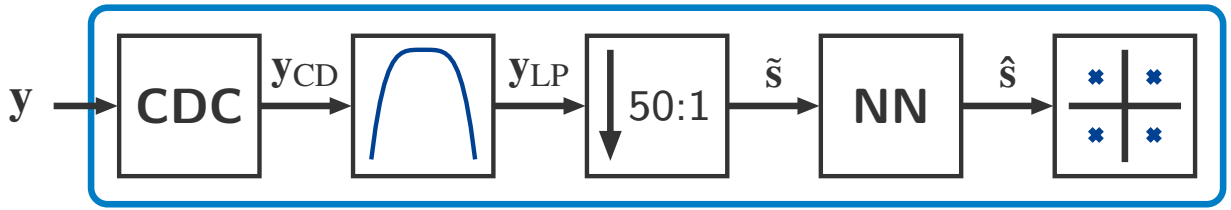
Transmitter



Receiver



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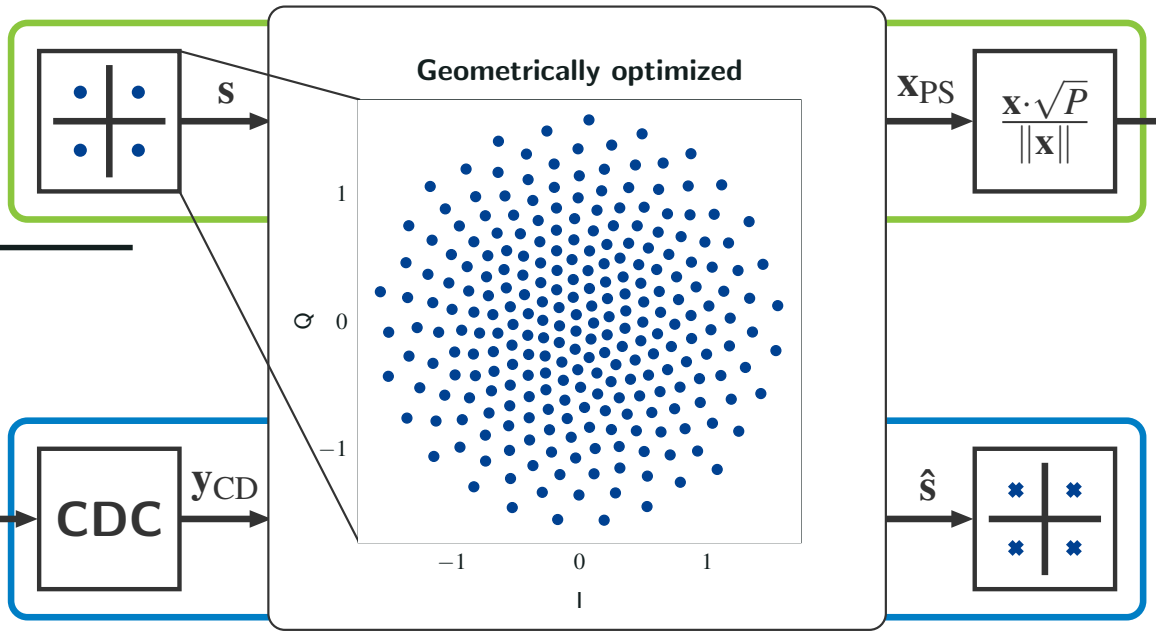

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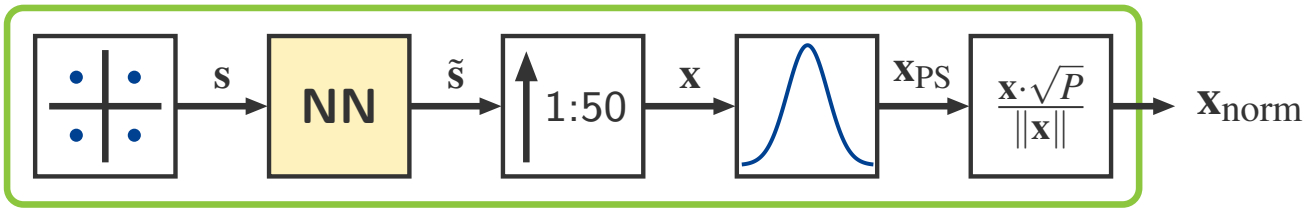
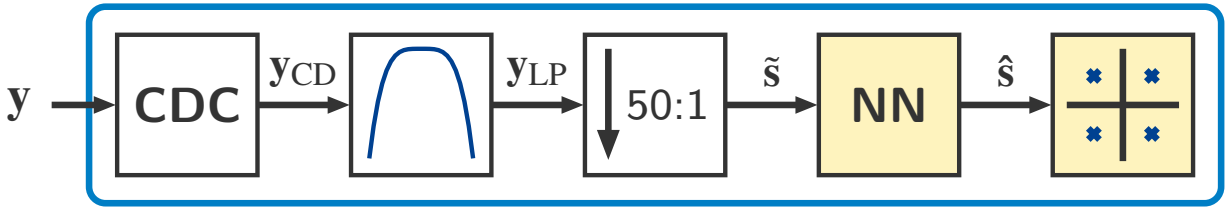


Receiver

NN architecture: [Freire et al., 2021]



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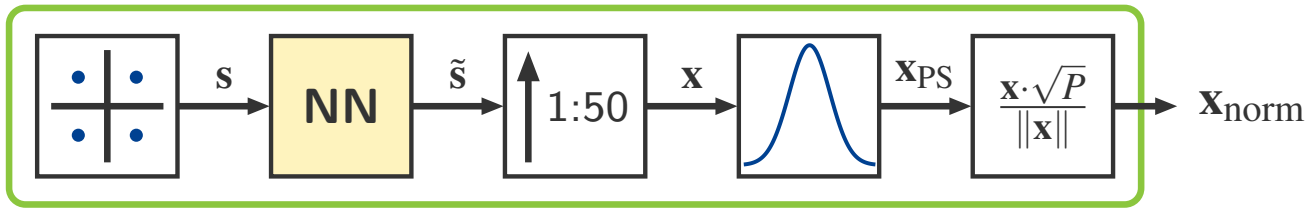

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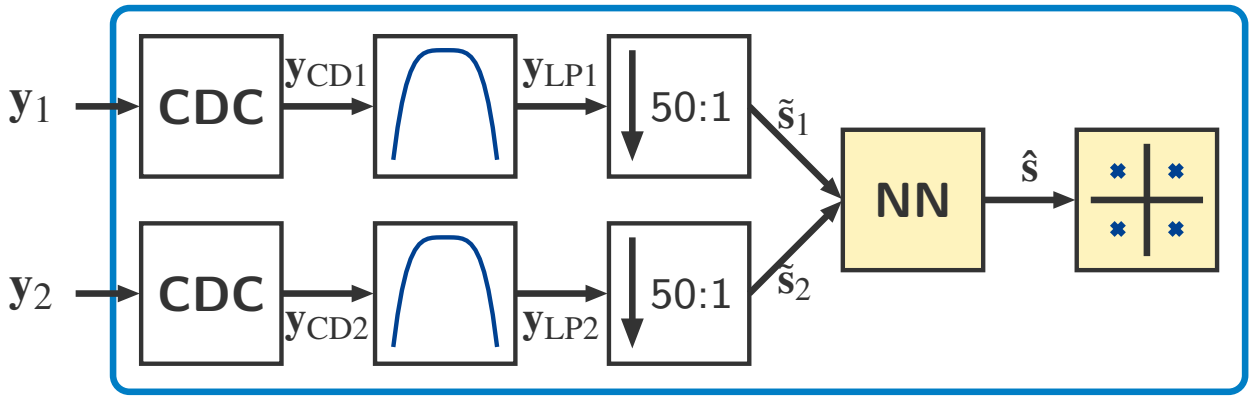

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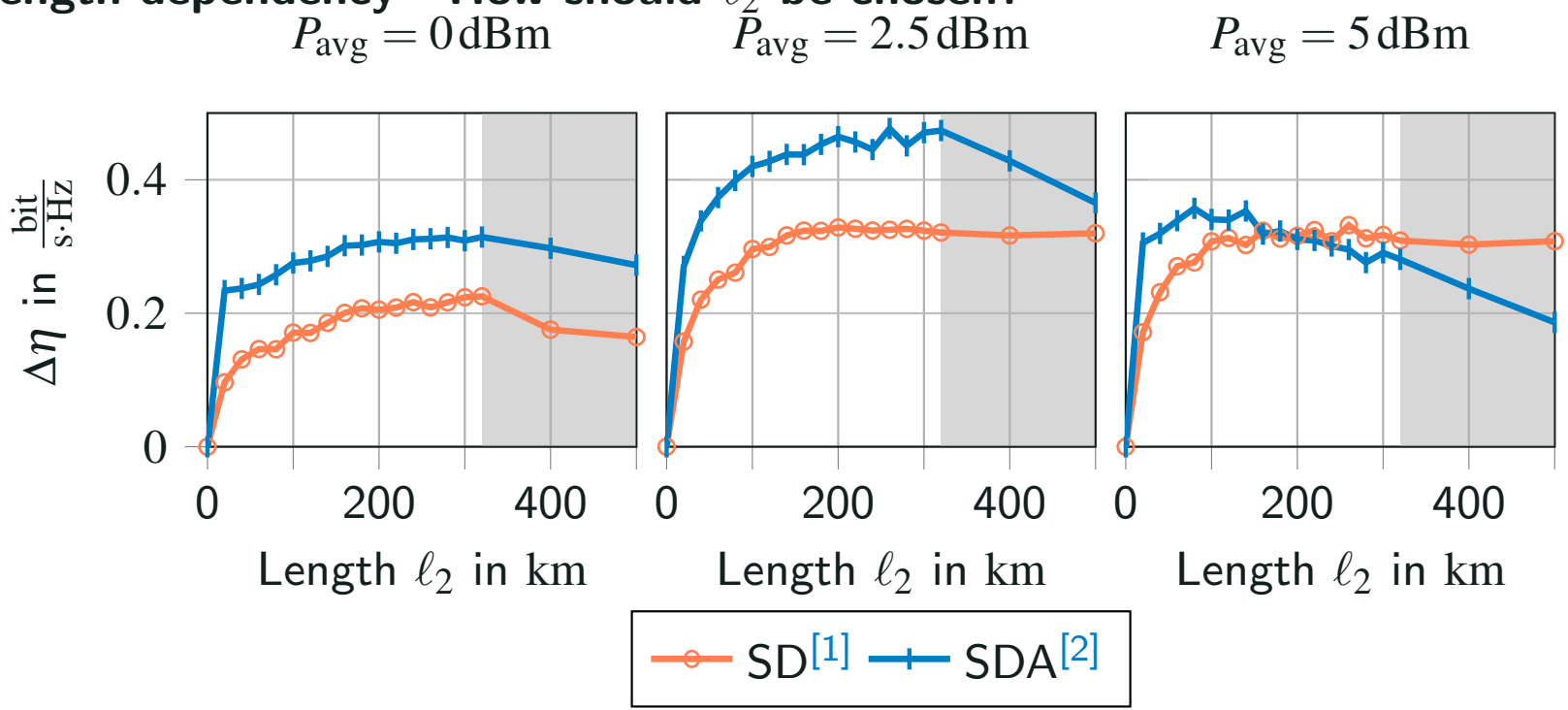
Length dependency - How should ℓ_2 be chosen?



[1] SD: Spatial diversity w.o. EDFA
[2] SDA: Spatial diversity w. EDFA

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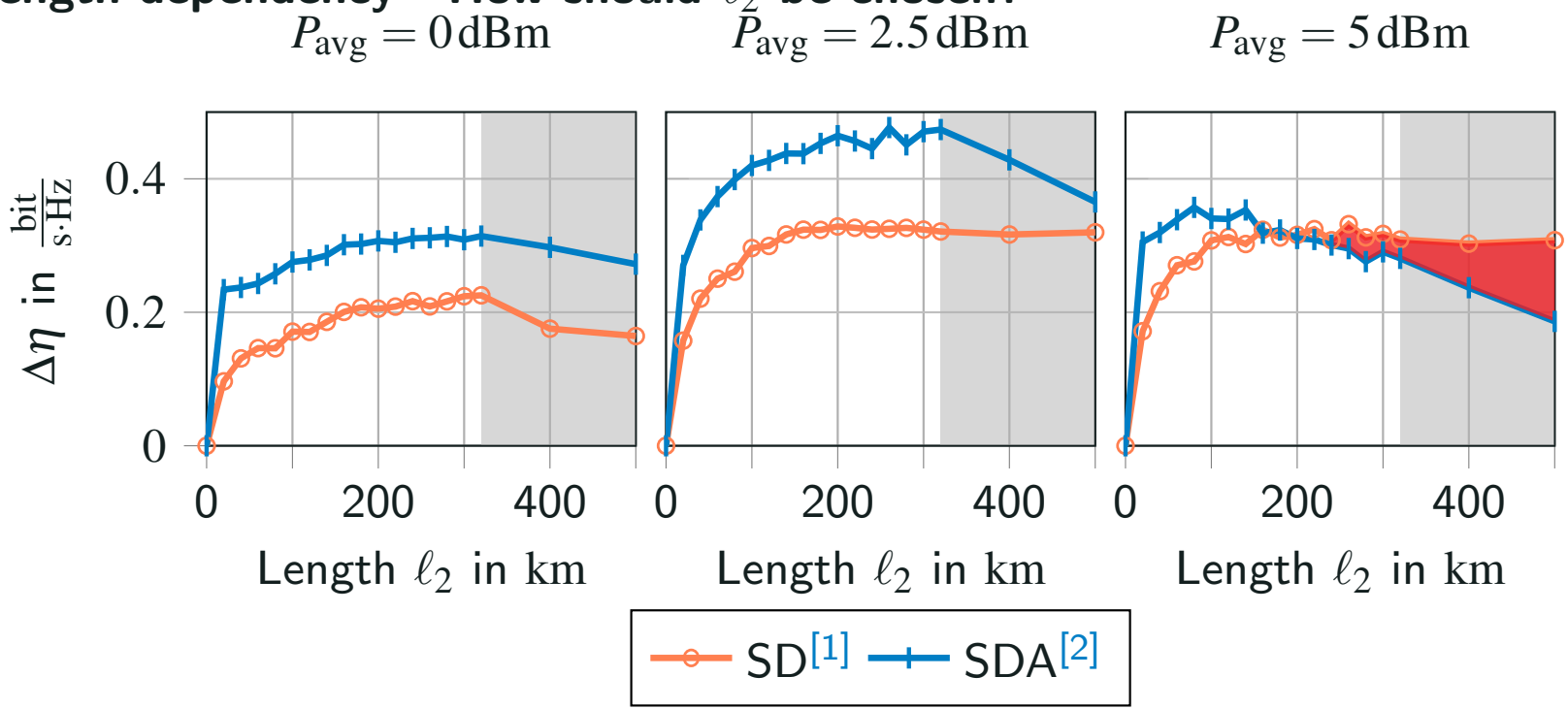

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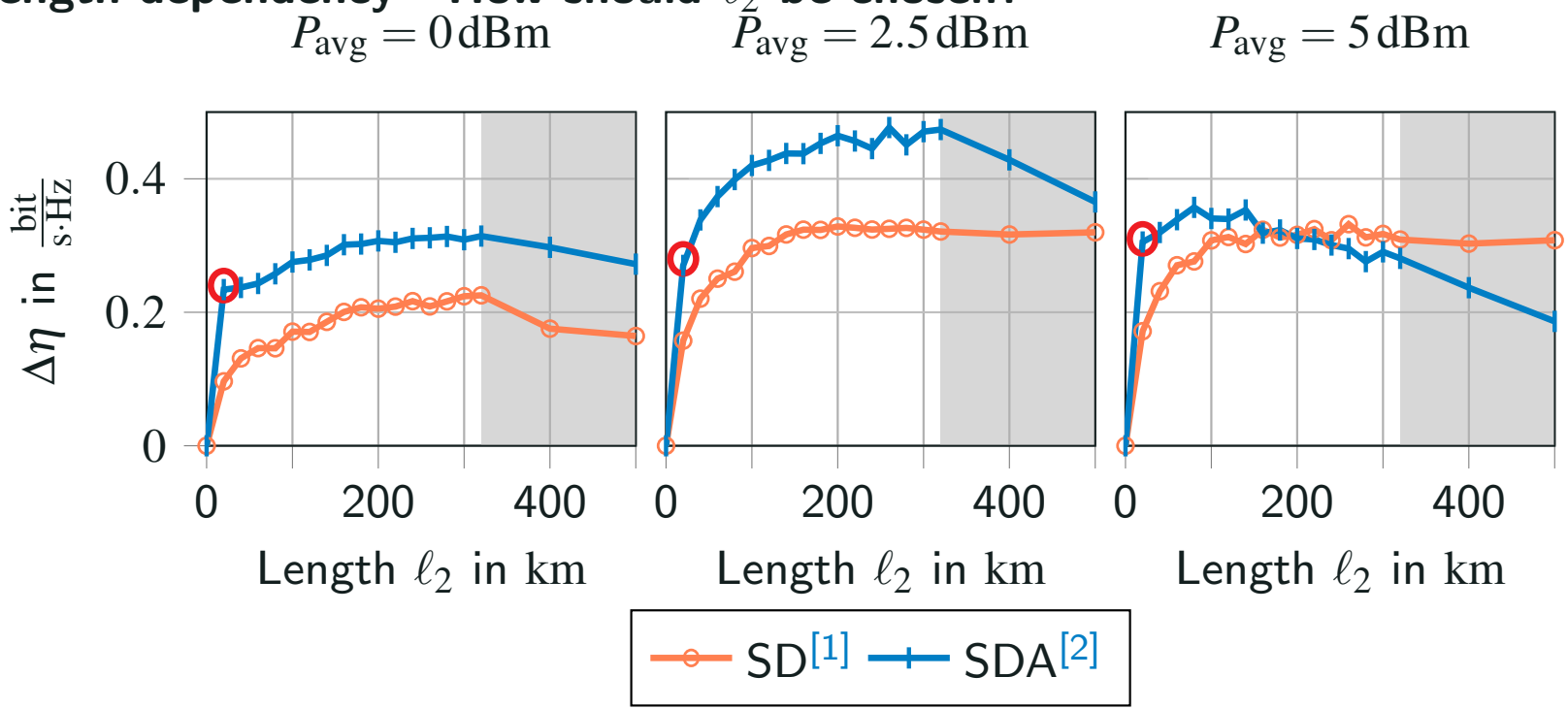

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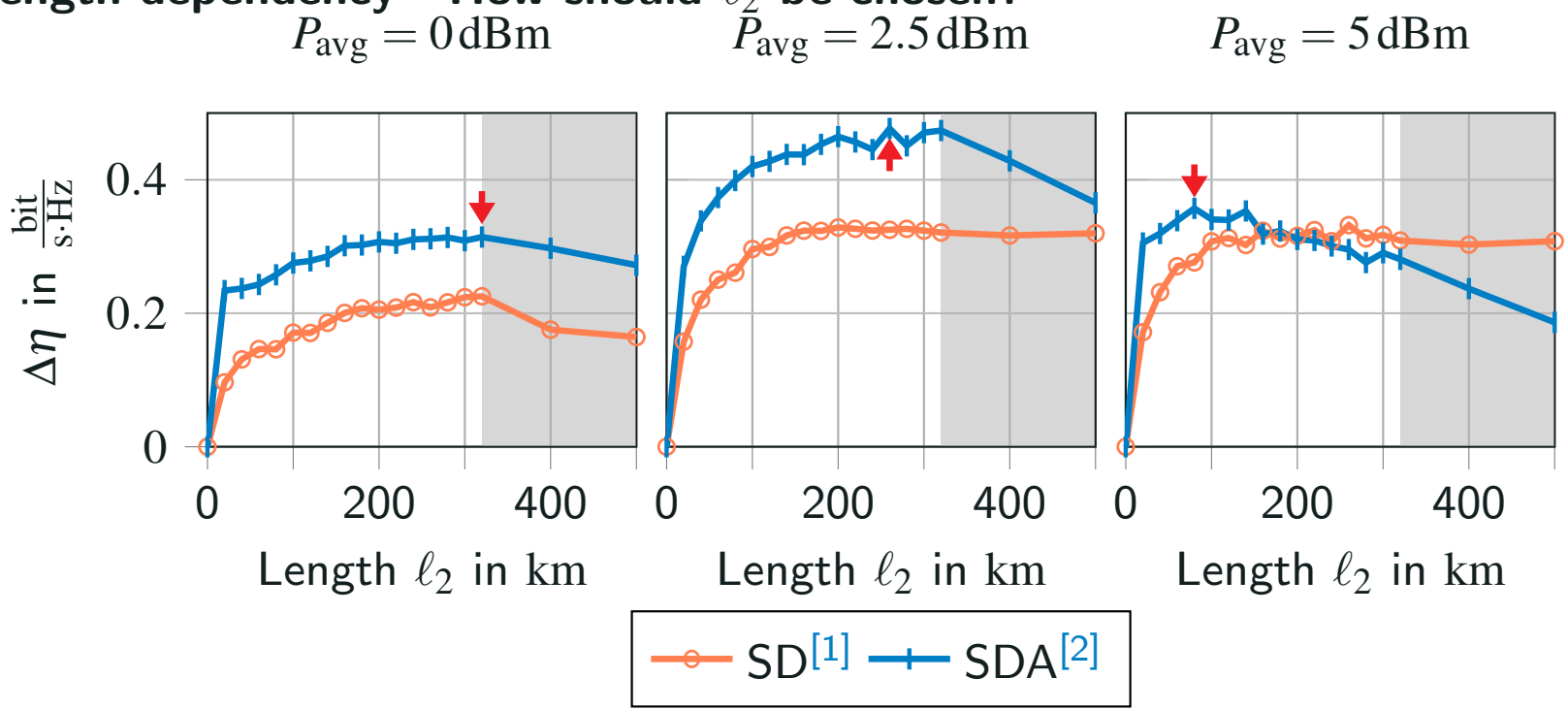

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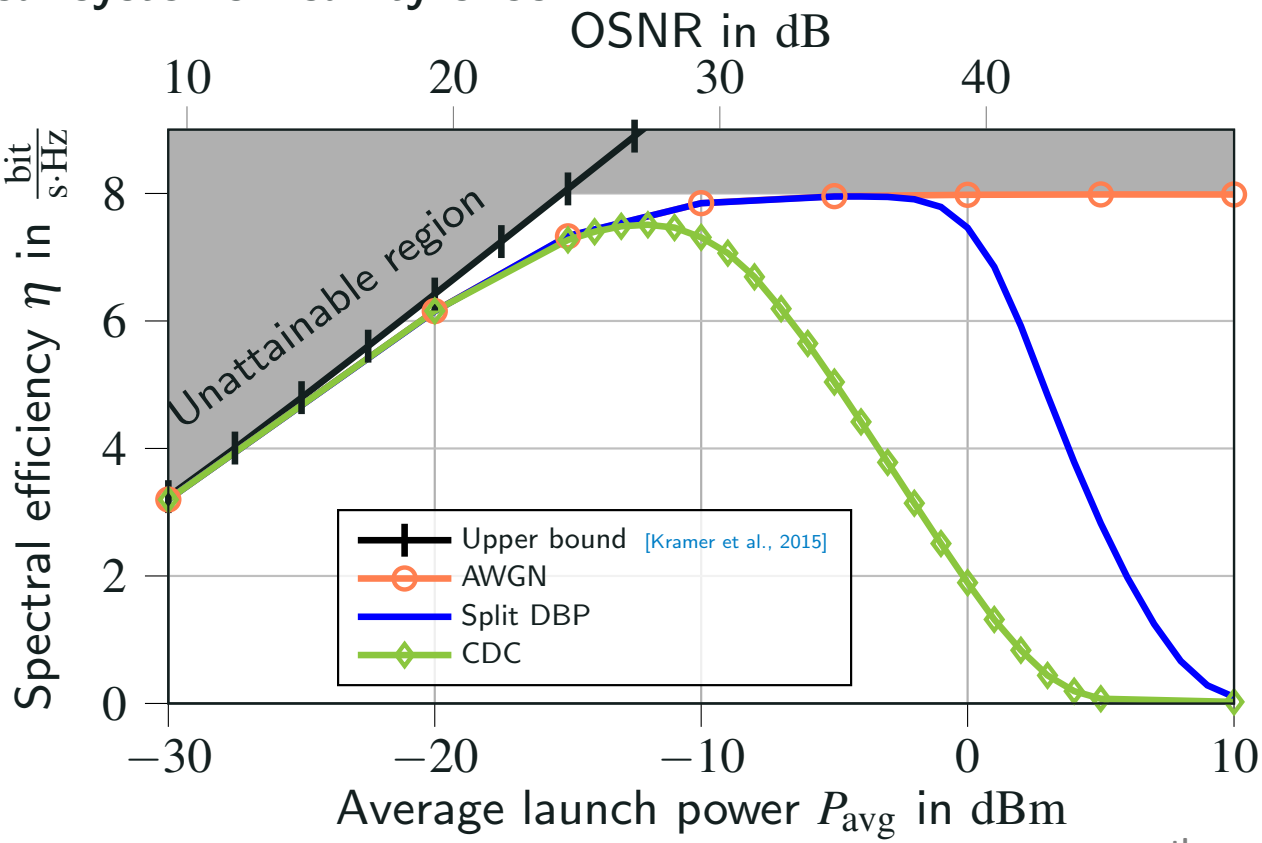
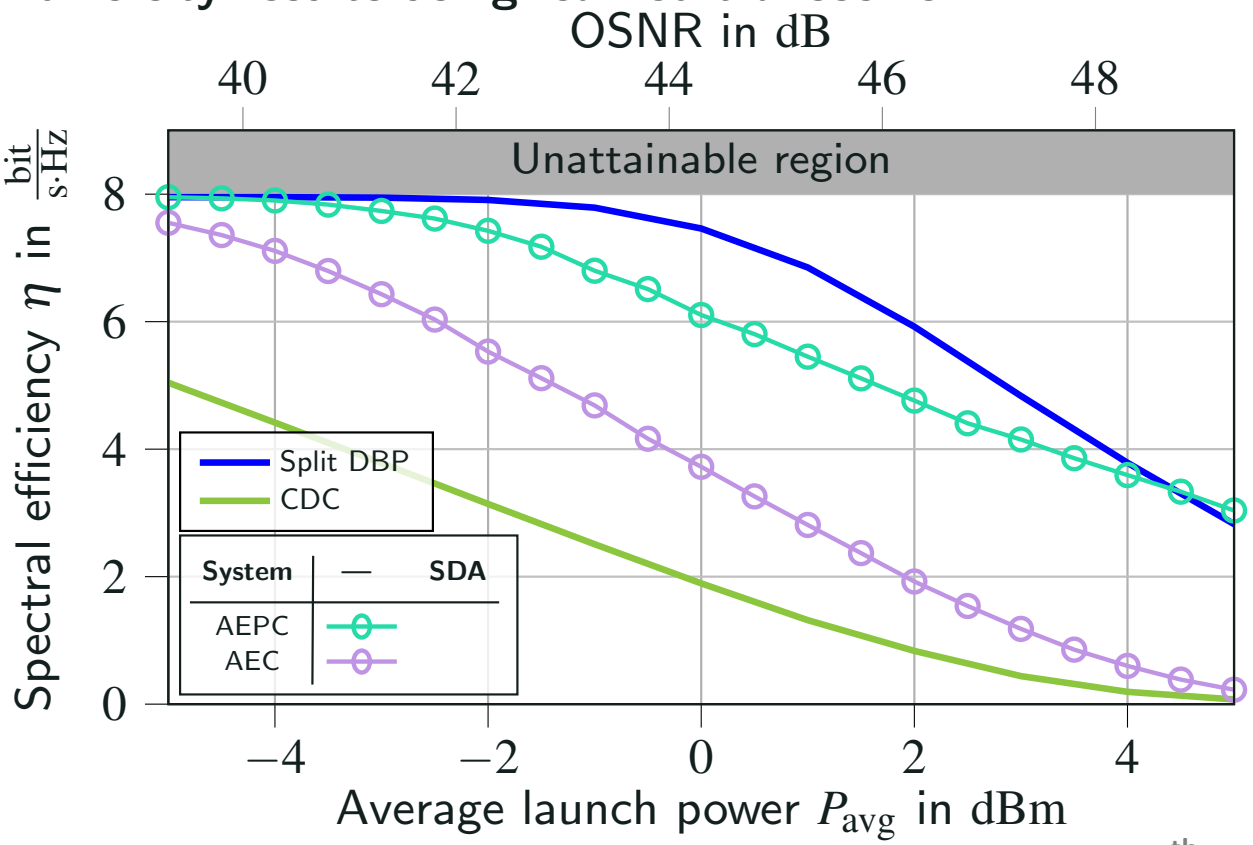
Classical systems - sanity check



Spatial diversity results using learned transceiver



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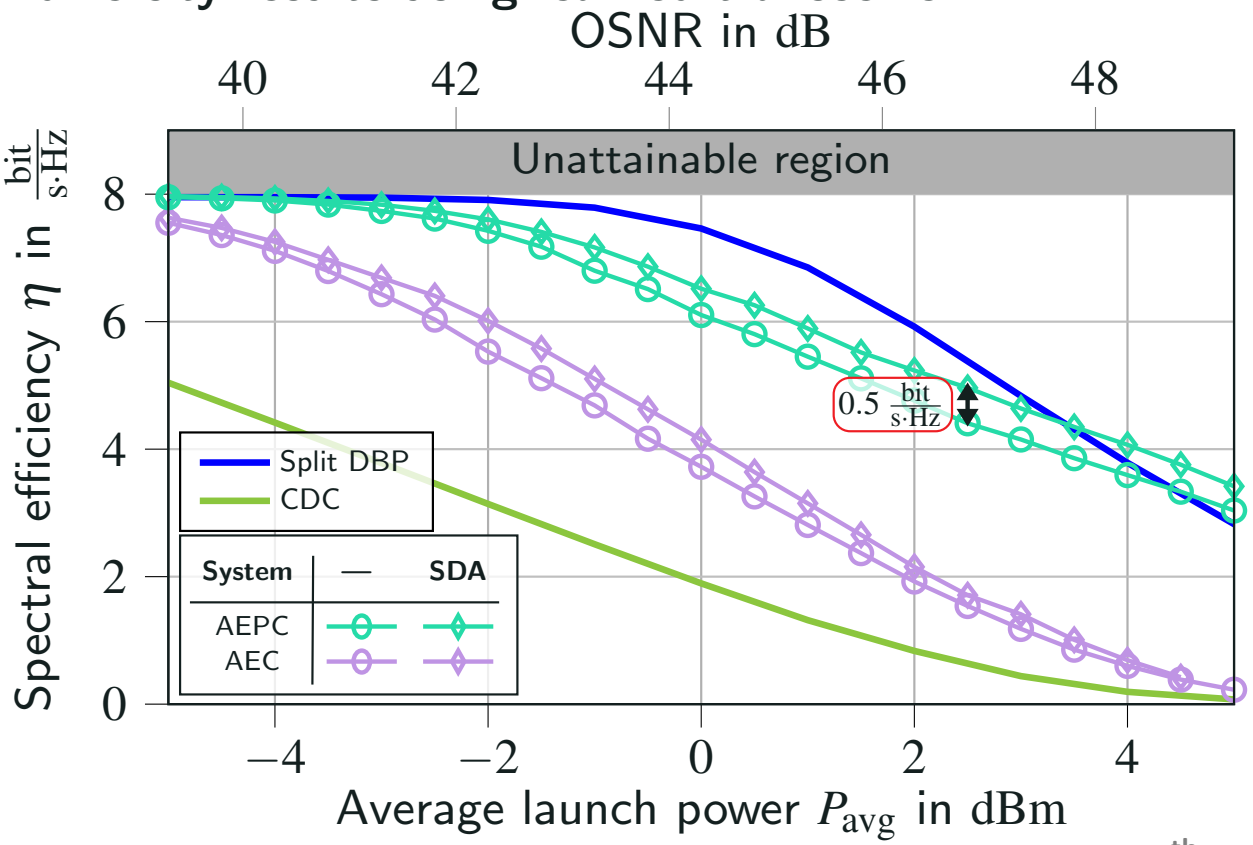

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Conclusions

- Spatial diversity provides significant gains around $0.5\,\frac{\text{bit}}{\text{s}\cdot\text{Hz}}$
- Input power influences optimal length ℓ_2
- Even non-ideal lengths of $\ell_2 \approx 20\,\text{km}$ provide gains

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+ Combine with WDM
+ Use different fiber

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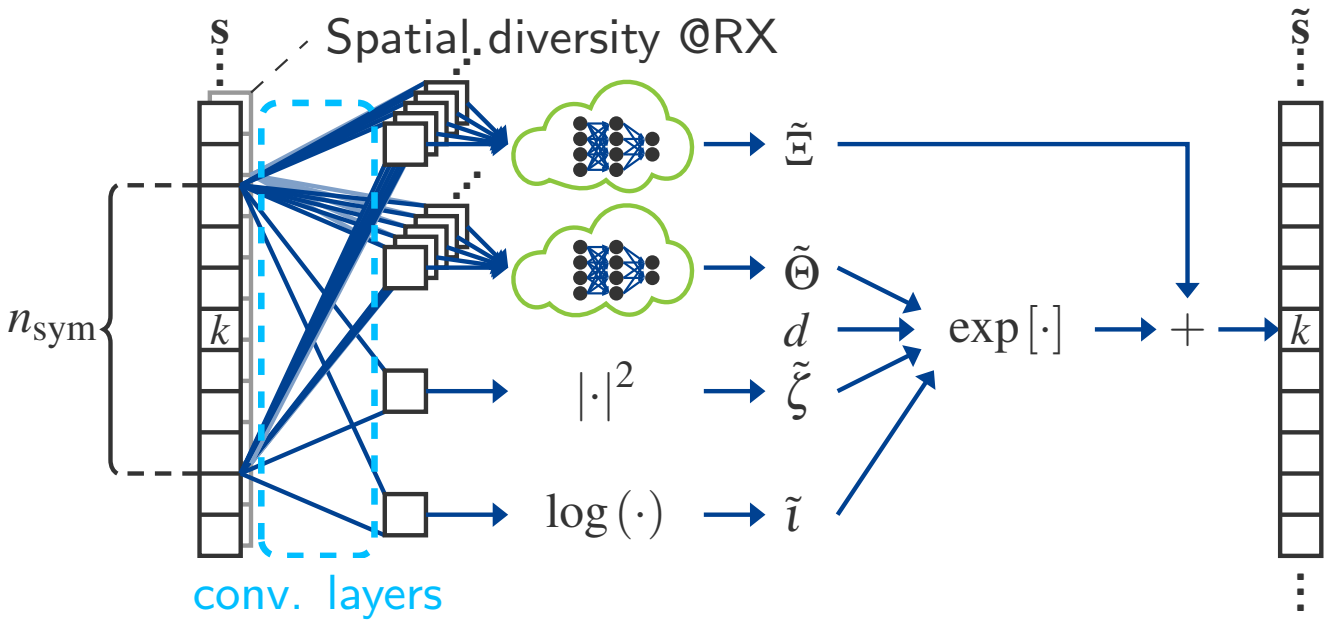
Thank you for your attention!

References

[Freire et al., 2021] Freire, P. J., Neskornuik, V., Napoli, A., Spinnler, B., Costa, N., Khanna, G., Riccardi, E., Prilepsky, J. E., and Turitsyn, S. K. (2021).
Complex-valued neural network design for mitigation of signal distortions in optical links.
Journal of Lightwave Technology, 39(6):1696–1705.

[Kramer et al., 2015] Kramer, G., Yousefi, M. I., and Kschischang, F. R. (2015).
Upper bound on the capacity of a cascade of nonlinear and noisy channels.
In *2015 IEEE Information Theory Workshop (ITW)*, page 1–4.

Compensation/Predistortion [Freire et al., 2021]



$$[\tilde{\mathbf{s}}]_k = \exp\left[\tilde{\imath} - d\tilde{\zeta} + \tilde{\Theta}\right] + \tilde{\Xi}$$