Probabilistic Shaping of High-Order QAM for Optical Fiber Systems

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Motivation

- Higher spectral efficiencies for increased data rates
- Practical limitations:
  - transmit power
  - transceiver SNR
  - modulation order
- Potential solution: probabilistic constellation shaping
- Shaping gives sensitivity gain of up to 1.53 dB
- Shaping has low complexity

Outline

Probabilistic Shaping Method[1]

Communication system with uniform QAM

[1] Böcherer *et al.*, IEEE Trans. Comm., 2015

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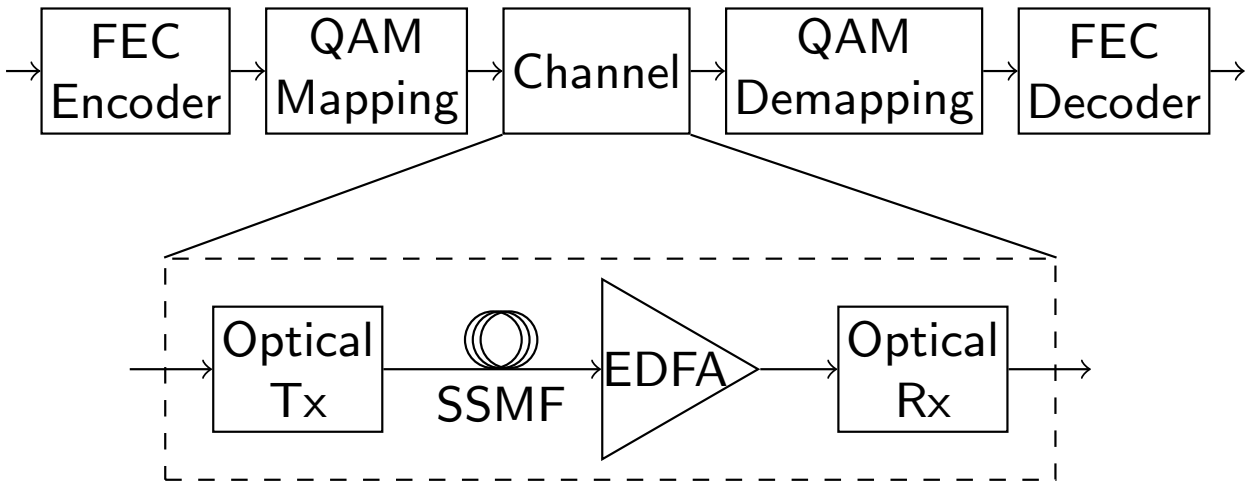
Communication system with uniform QAM



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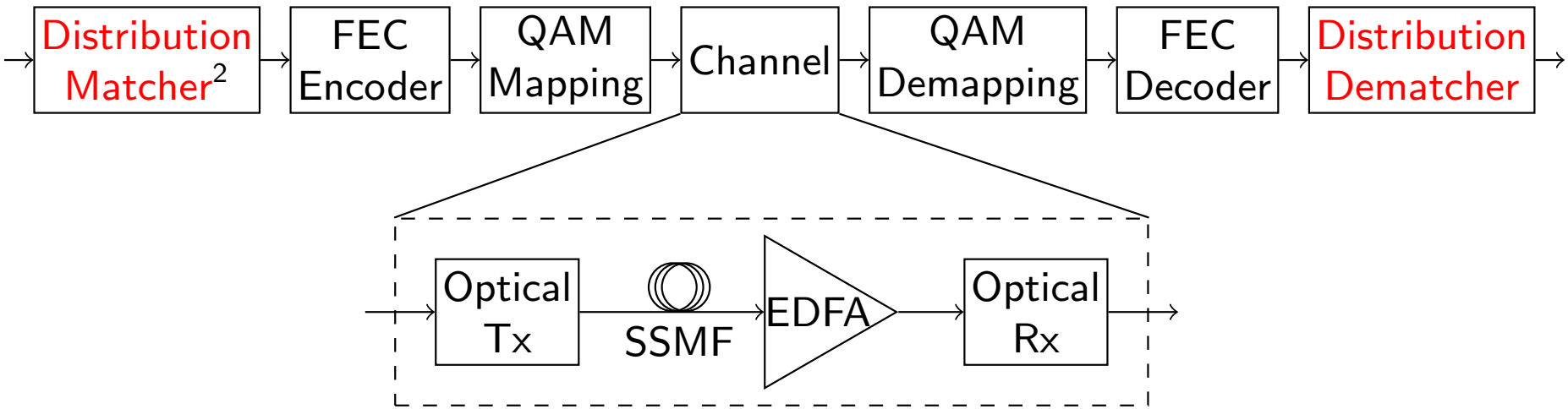
Probabilistic Shaping Method[1]

Communication system with shaped QAM



- Low-complexity distribution matcher[2] added "outside" FEC
- Very minor modifications to FEC encoder/decoder required

[1] Böcherer *et al.*, IEEE Trans. Comm., 2015
[2] Schulte and Böcherer, IEEE Trans. Inf. Theory, 2015

Probabilistic Shaping Method (cont'd)

- Probability mass function (PMF) of channel input X:

$$P_{\Delta X}(x_i) \sim e^{-\nu |x_i|^2},$$

  where Δ and ν are scalars.
- Optimization problem for each SNR: choose Δ and ν so that mutual information is maximized

$\Rightarrow$ One PMF per SNR

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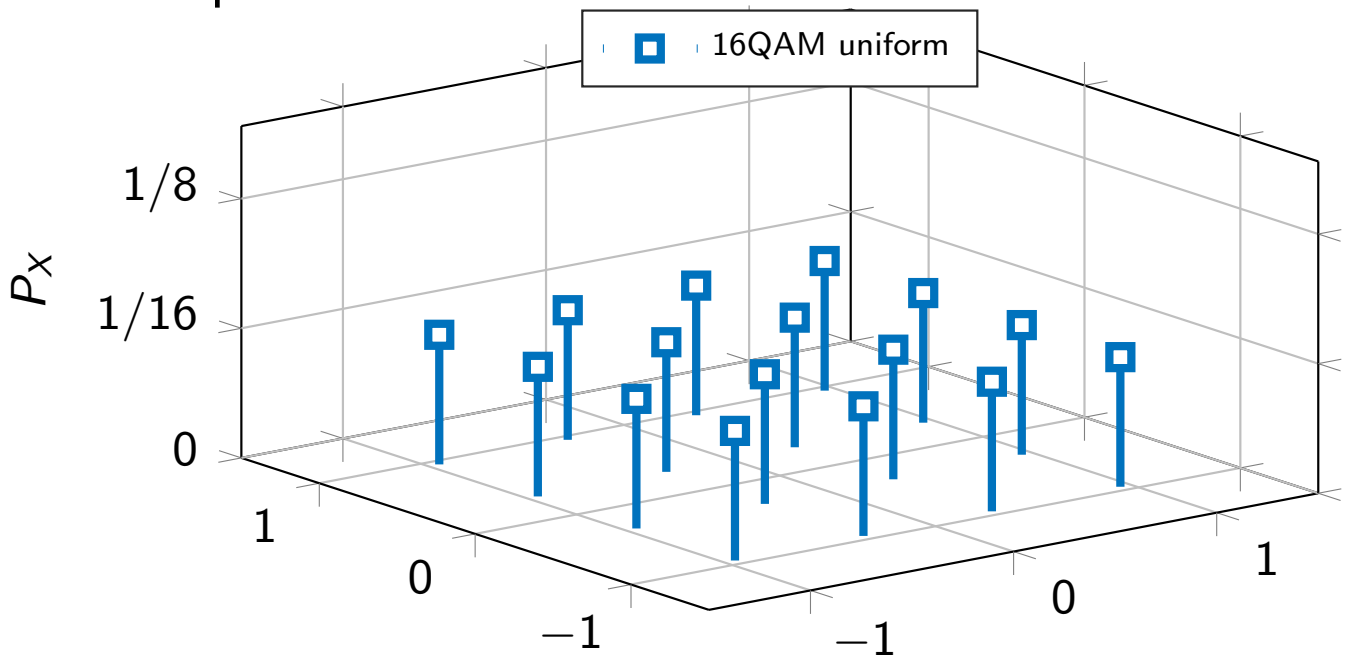

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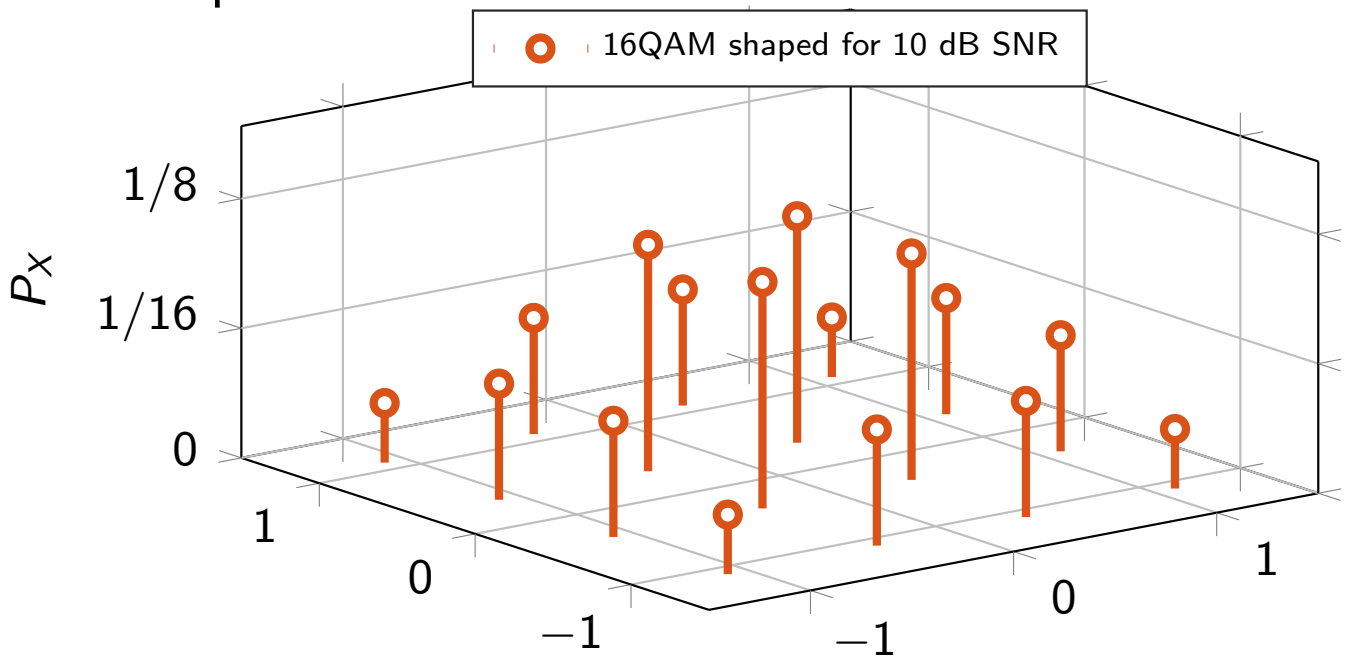

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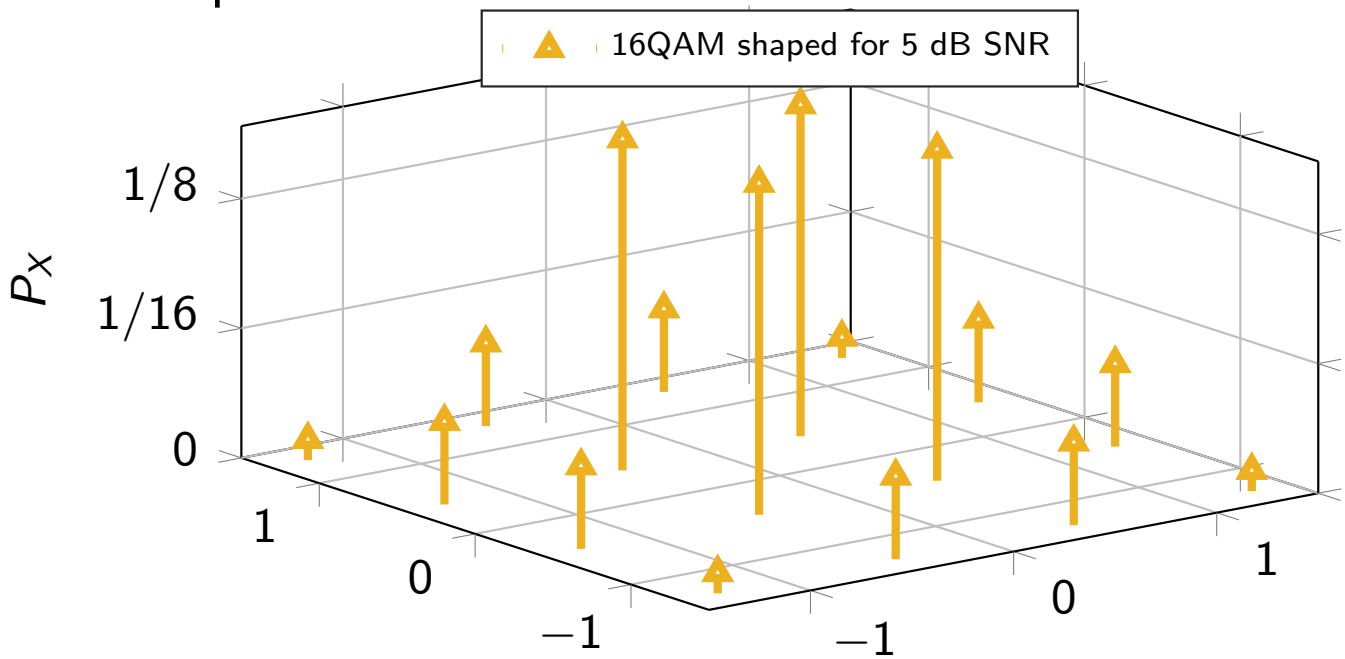

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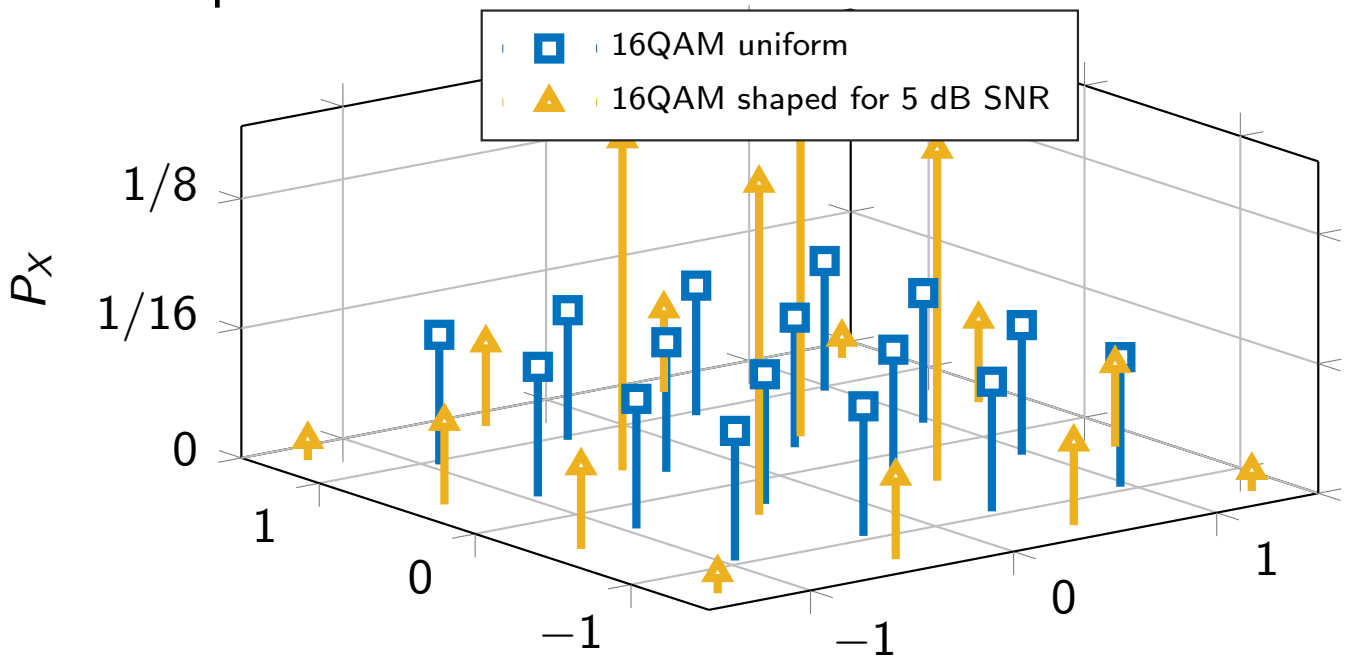
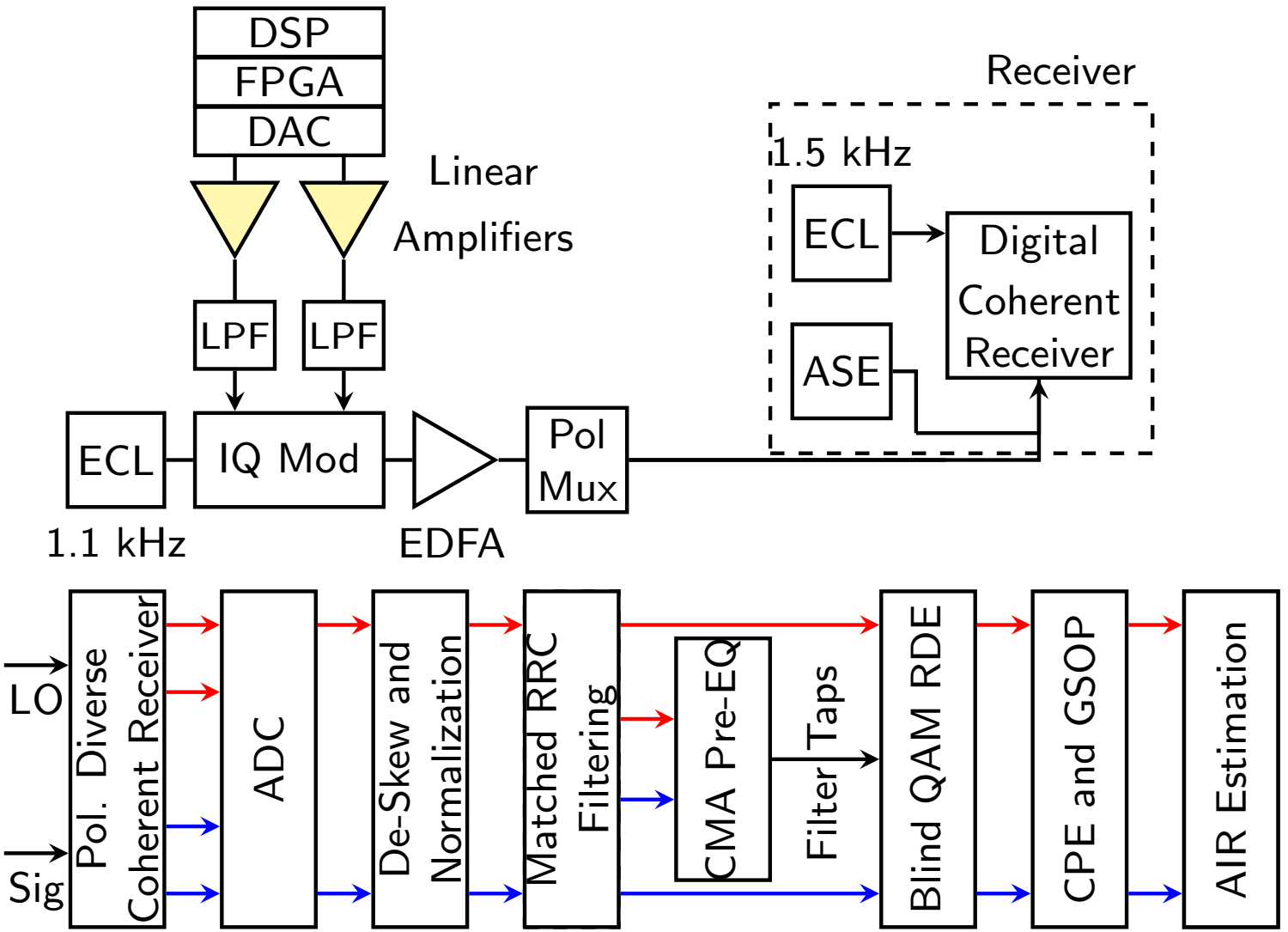


B2B Experiments: Setup



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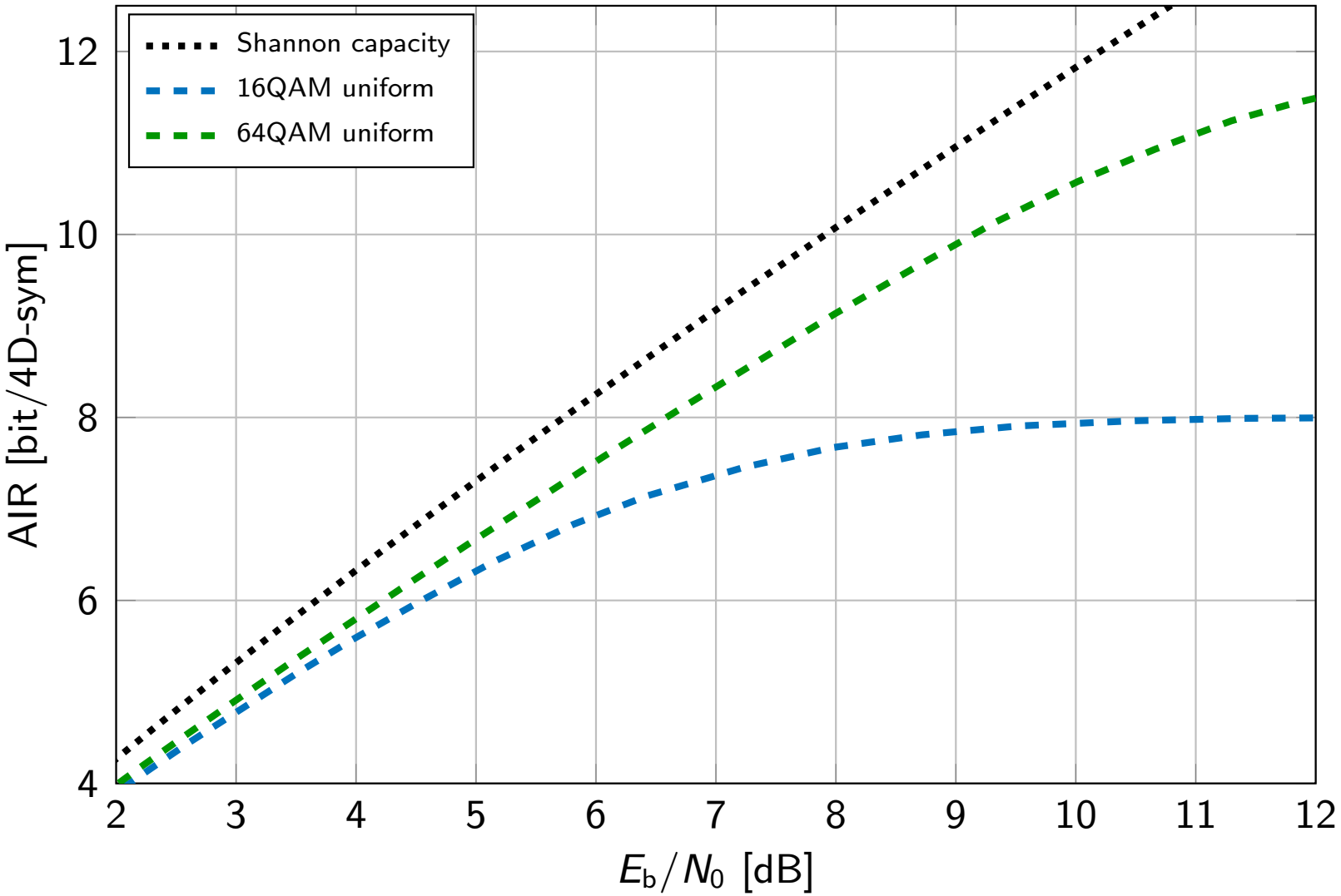

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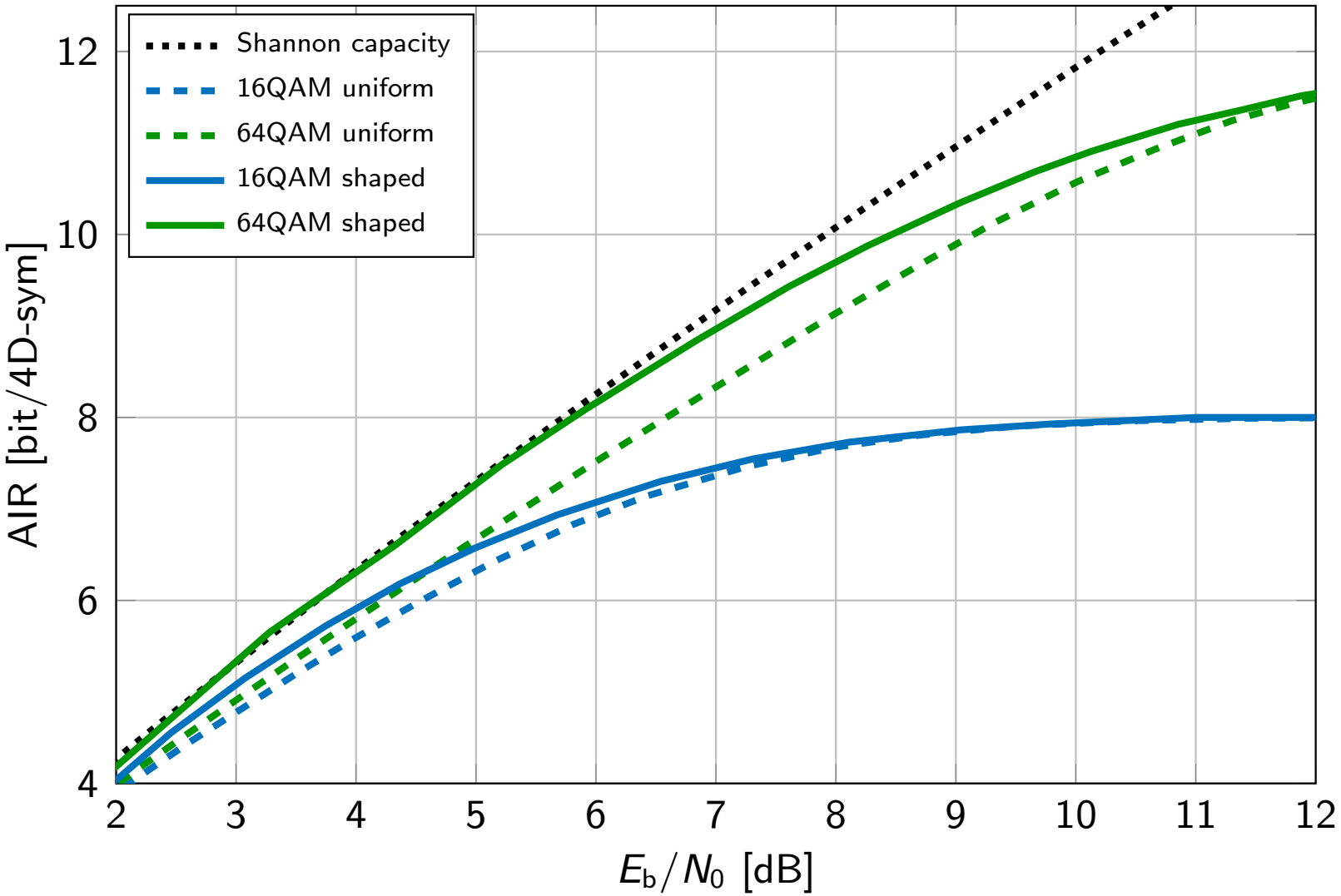

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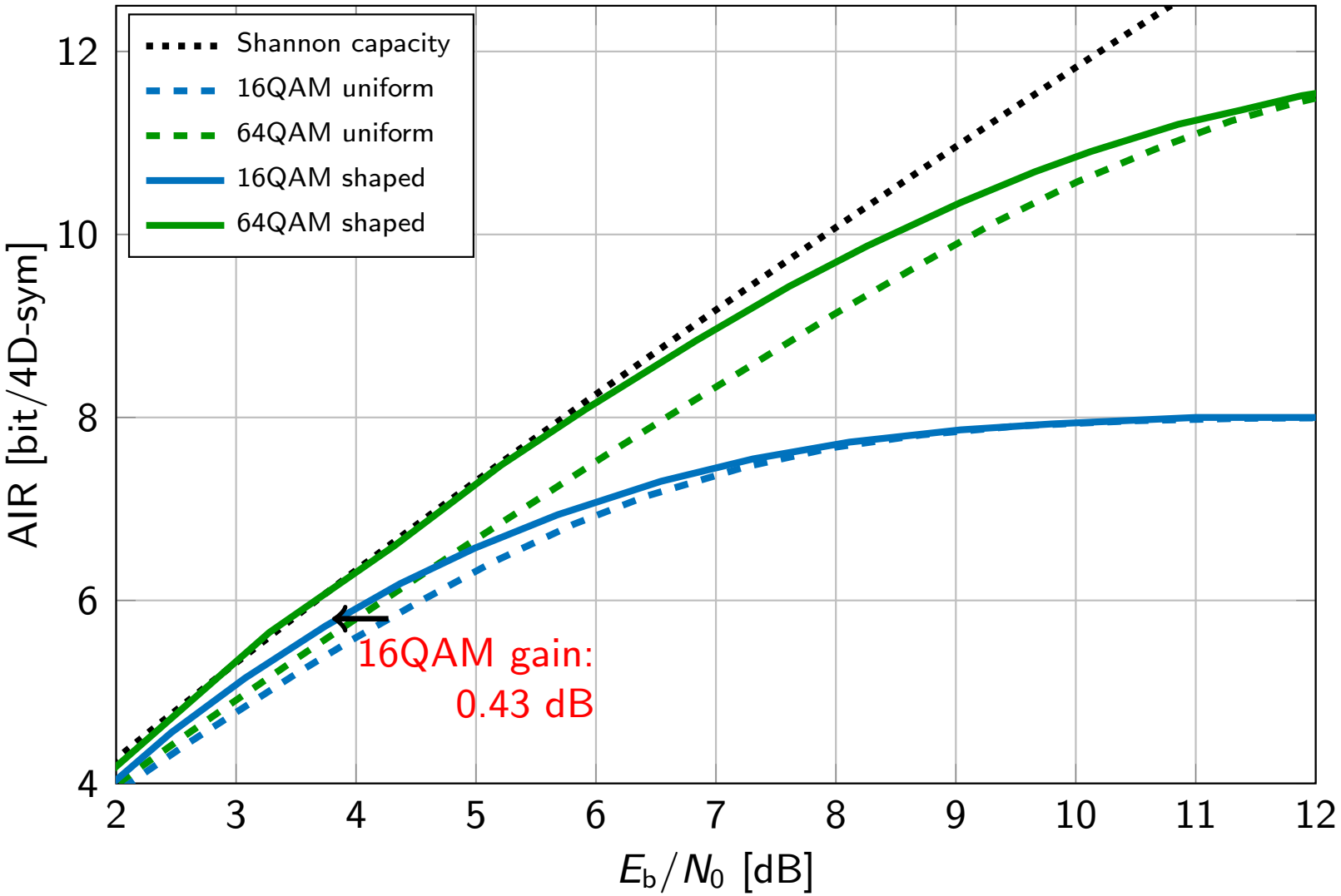

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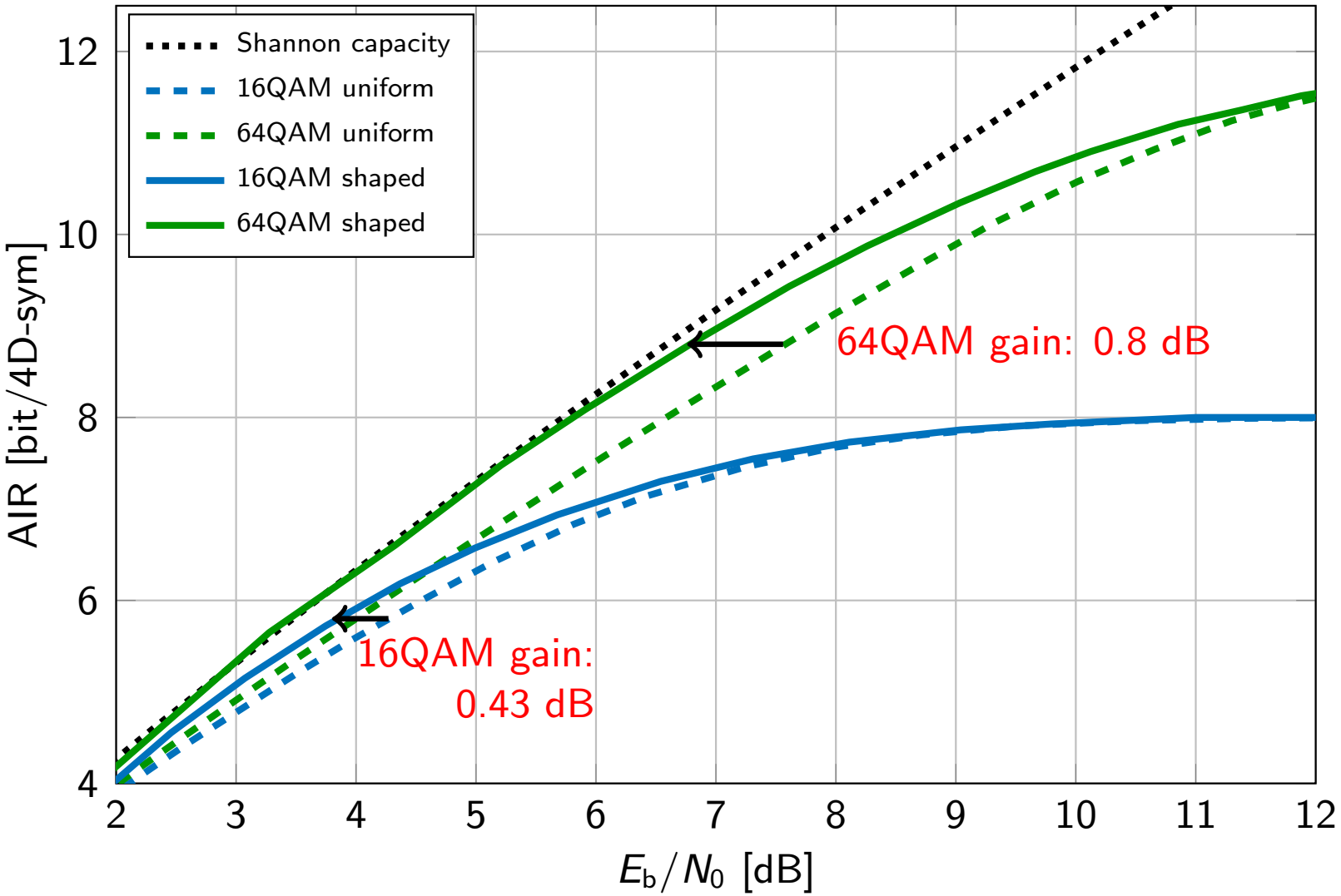

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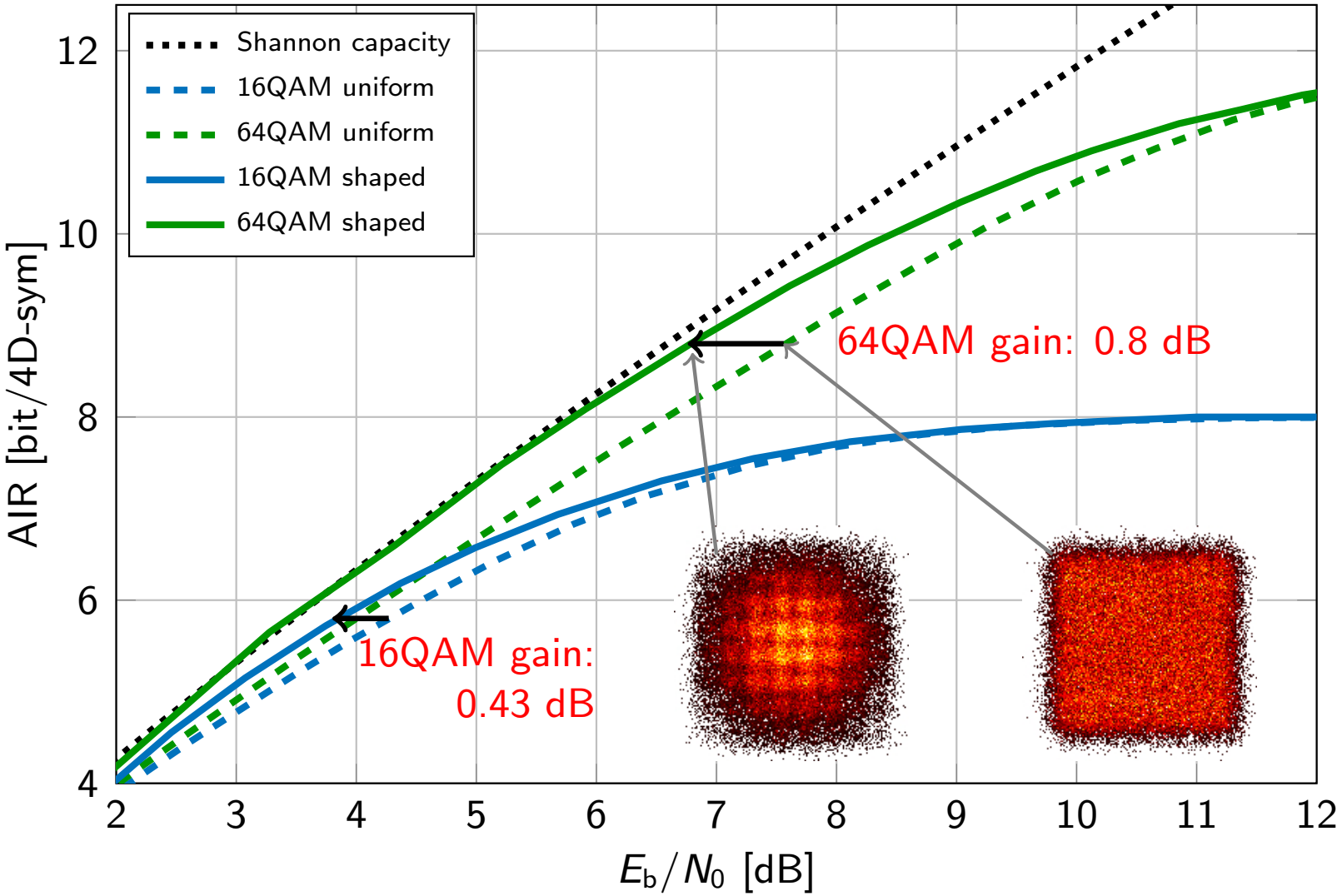
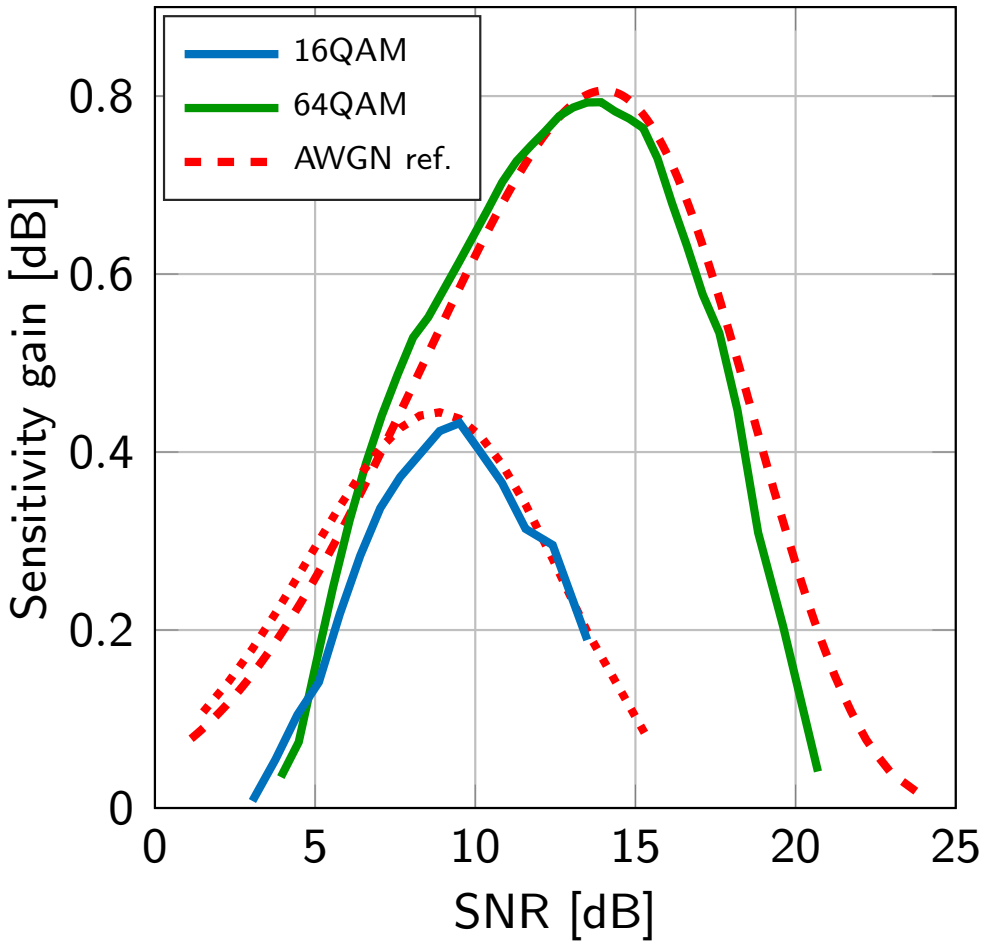
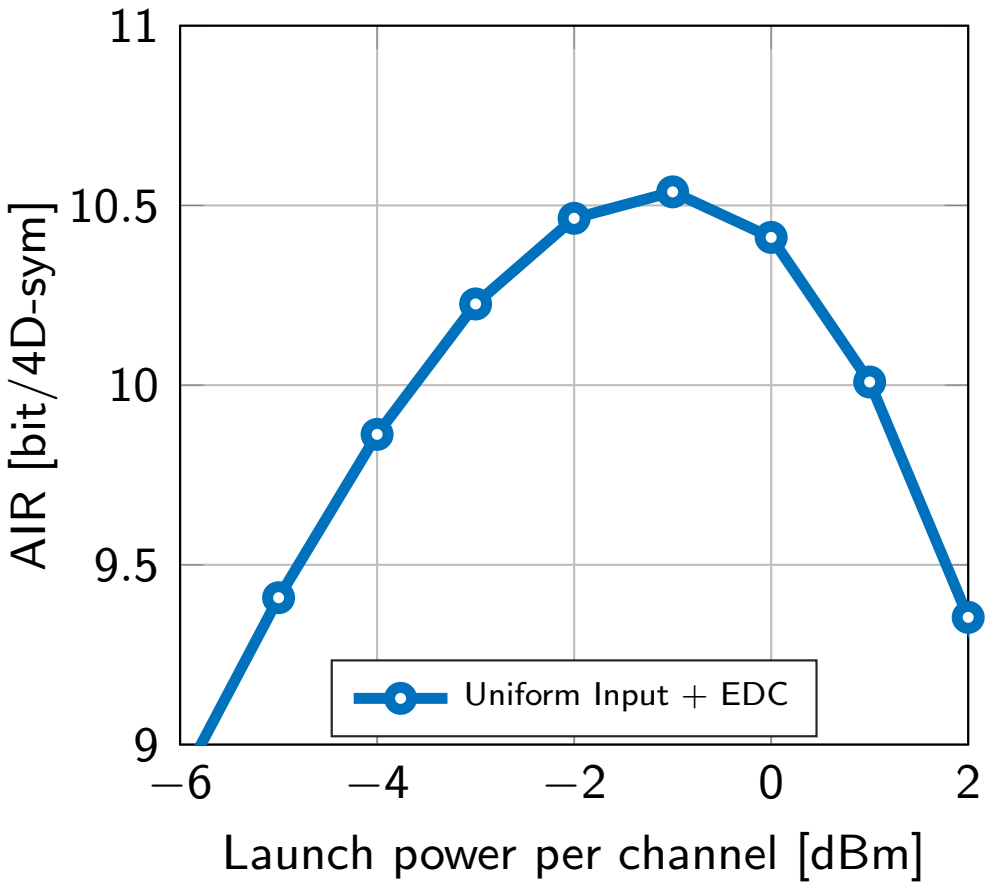


Experimental Results: B2B (cont'd)



- Significant gain over uniform
- Gains present over wide SNR range
- Good match with AWGN reference

Fiber Simulations

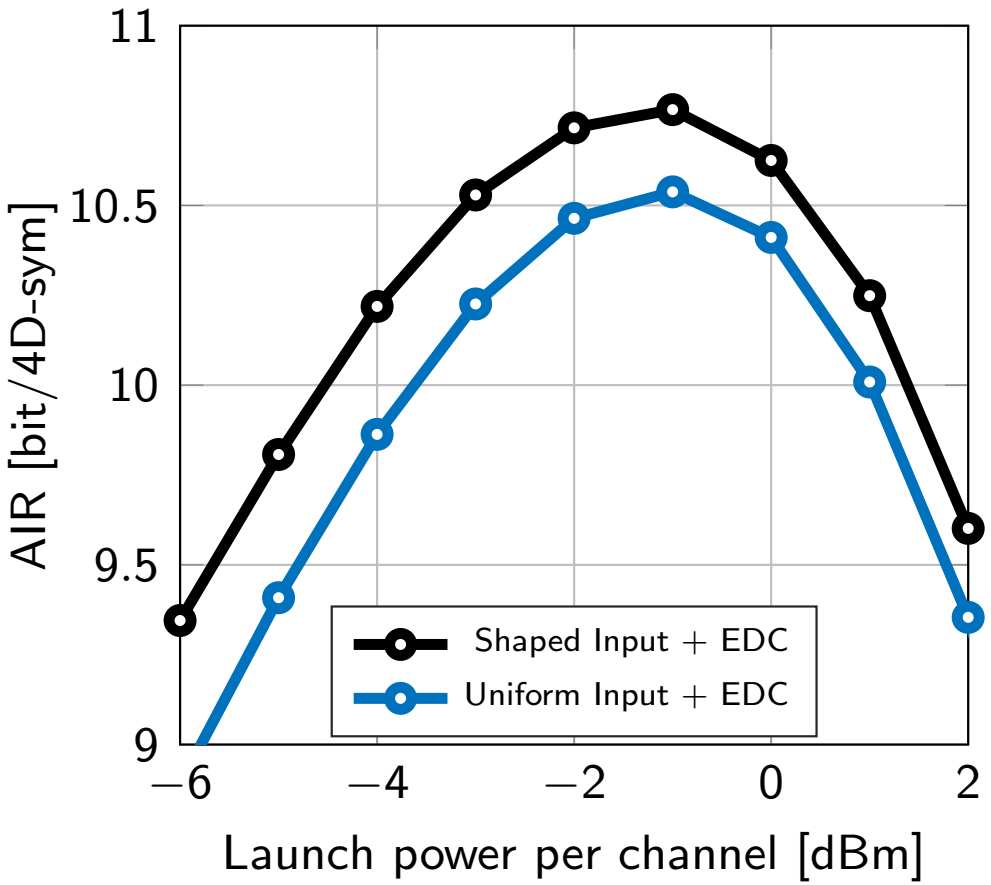


- DP-64QAM @ 28 GBaud
- RRC pulse shaping
- 9 WDM channels
- WDM spacing: 30 GHz
- 1000 km SMF w/ EDFAs
- EDC only
- Uniform input

AIR (at opt. power)

10.5 bit/4D-sym

Fiber Simulations



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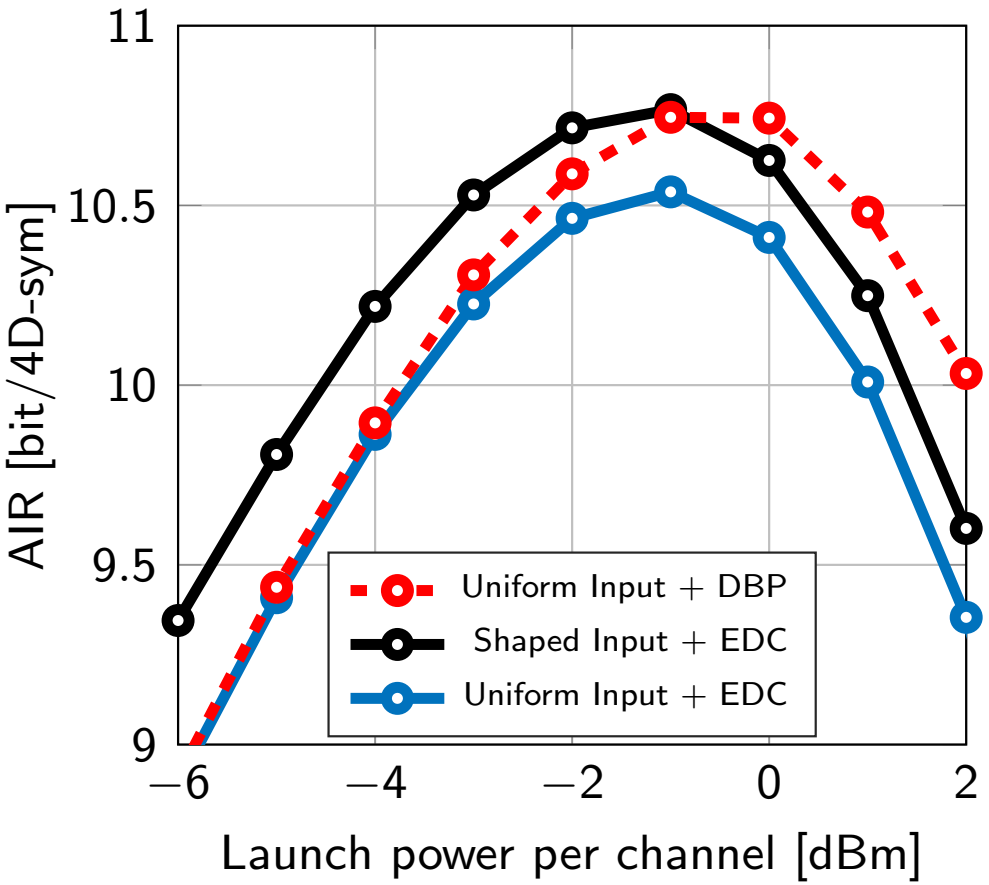
Shaping Gain

0.23 bit/4D-sym

Fiber Simulations



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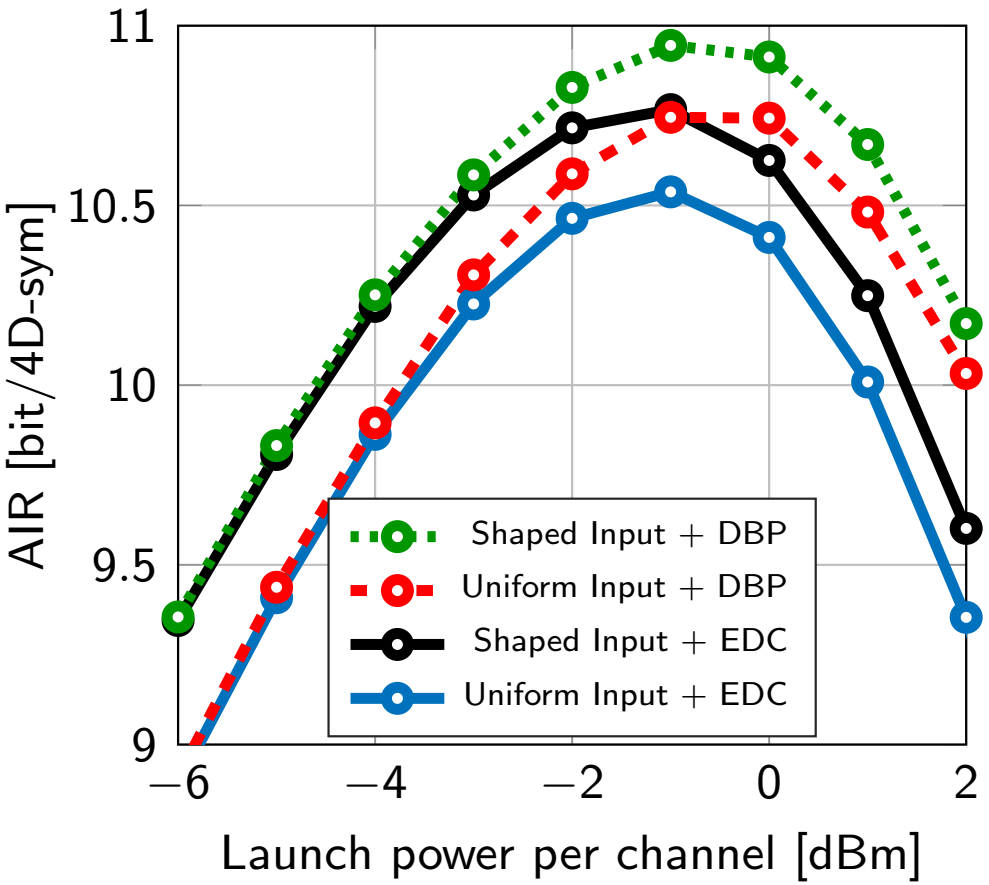
- 9 WDM channels
- WDM spacing: 30 GHz
- 1000 km SMF w/ EDFAs
- Ideal single-channel DBP
- Uniform input

DBP Gain

0.21 bit/4D-sym

Fiber Simulations



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- Ideal single-channel DBP
- Shaped Input

DBP + Shaping Gain

0.41 bit/4D-sym

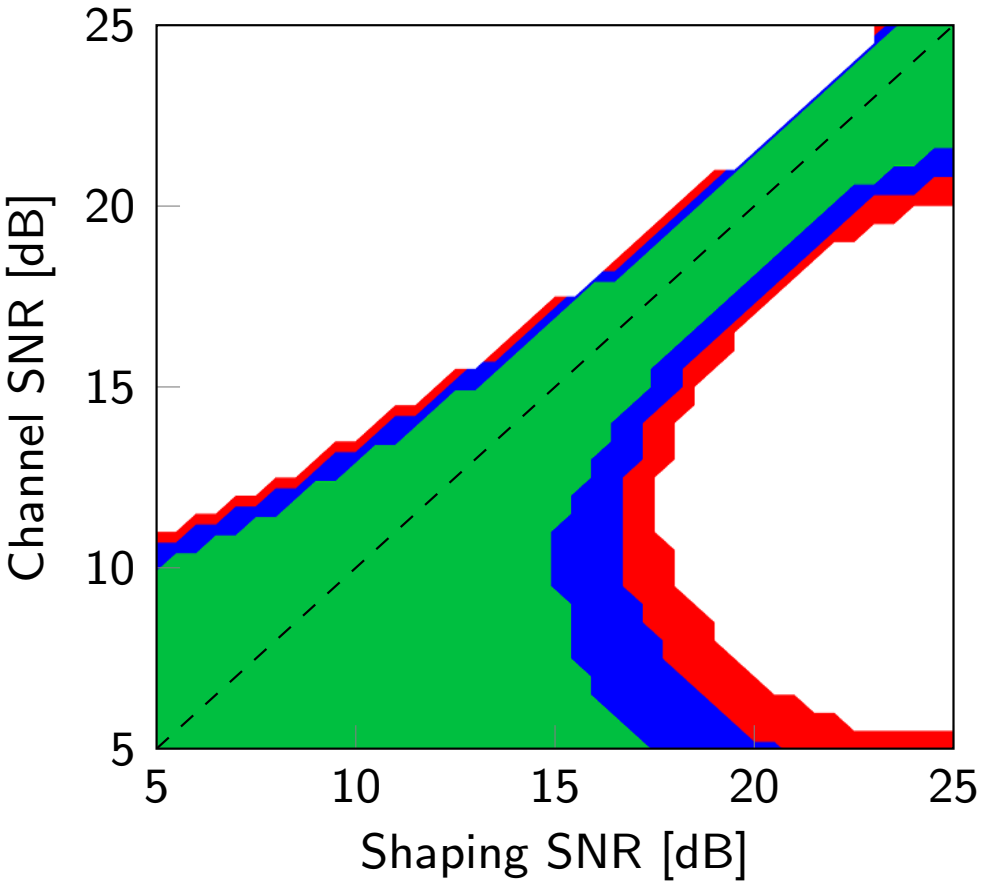
Mismatched Probabilistic Shaping

- Ideally: One shaped input PMF for every SNR
- In reality: fluctuations of *channel SNR* after DSP

$\Rightarrow$ Mismatch between *shaping SNR* at TX and channel SNR

- We observed a robustness against such a mismatch
- Figure of merit: penalty in sensitivity gain from using *mismatched* shaping instead of perfectly *matched* shaping

Mismatched Shaping: 64QAM over AWGN



- Green:
  penalty $\leq$ 0.1 dB
- Green+Blue:
  penalty $\leq$ 0.2 dB
- Green+Blue+Red:
  penalty $\leq$ 0.3 dB

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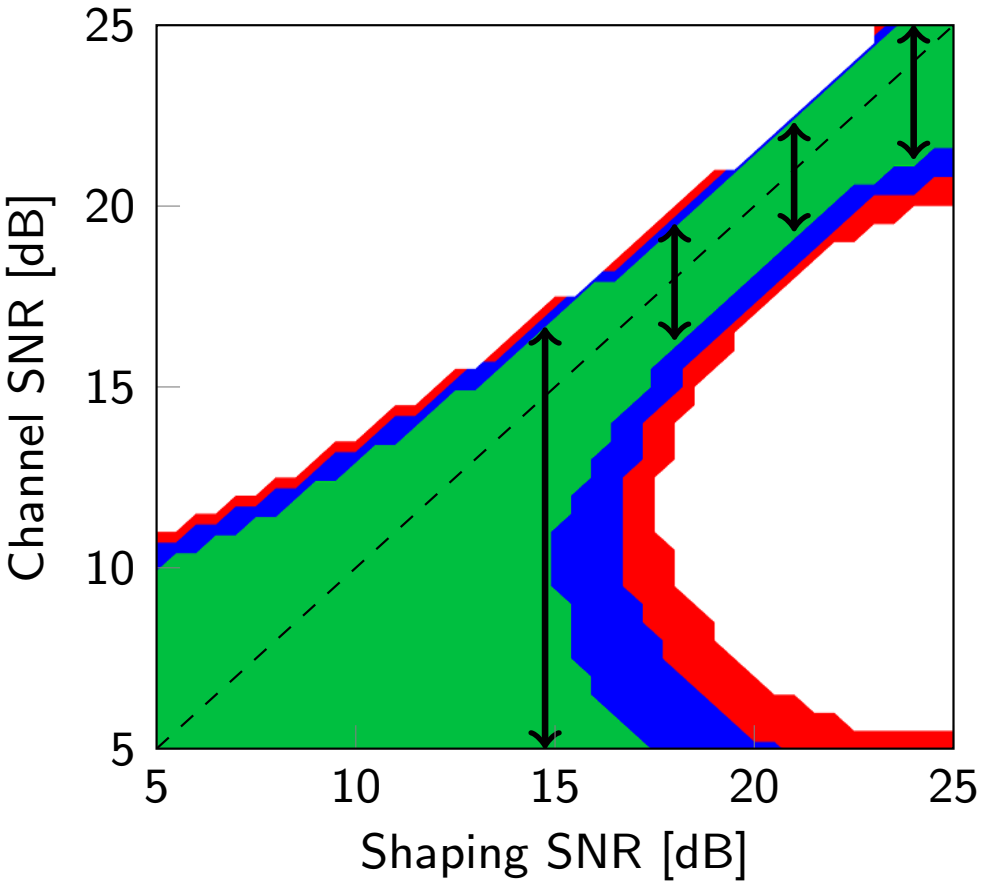

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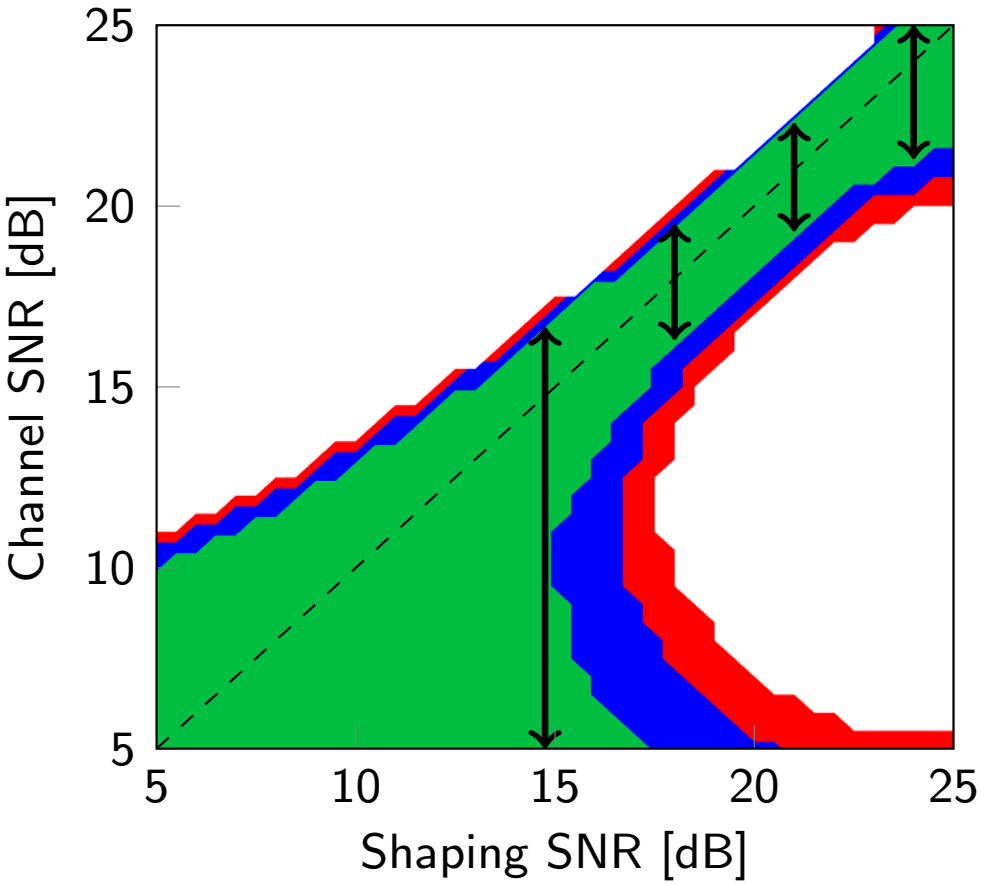

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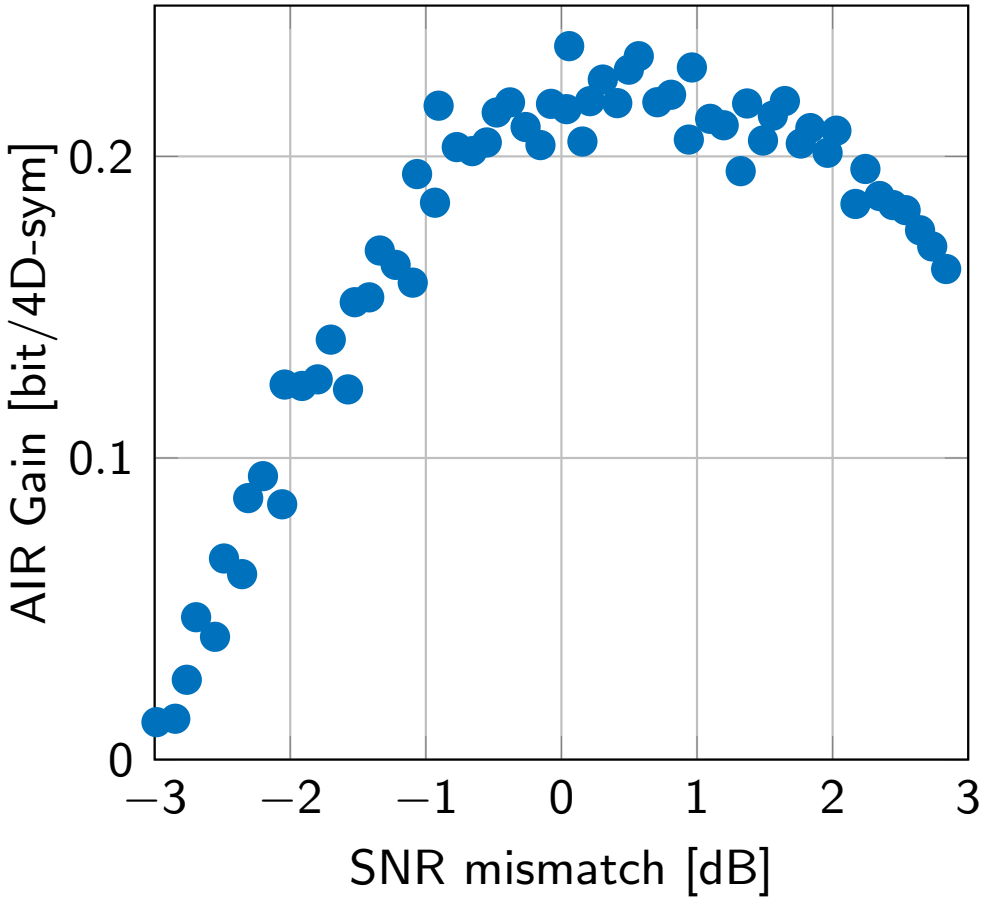
Takeaway

Shaping is robust for AWGN channel

Mismatched Shaping: Fiber Simulations



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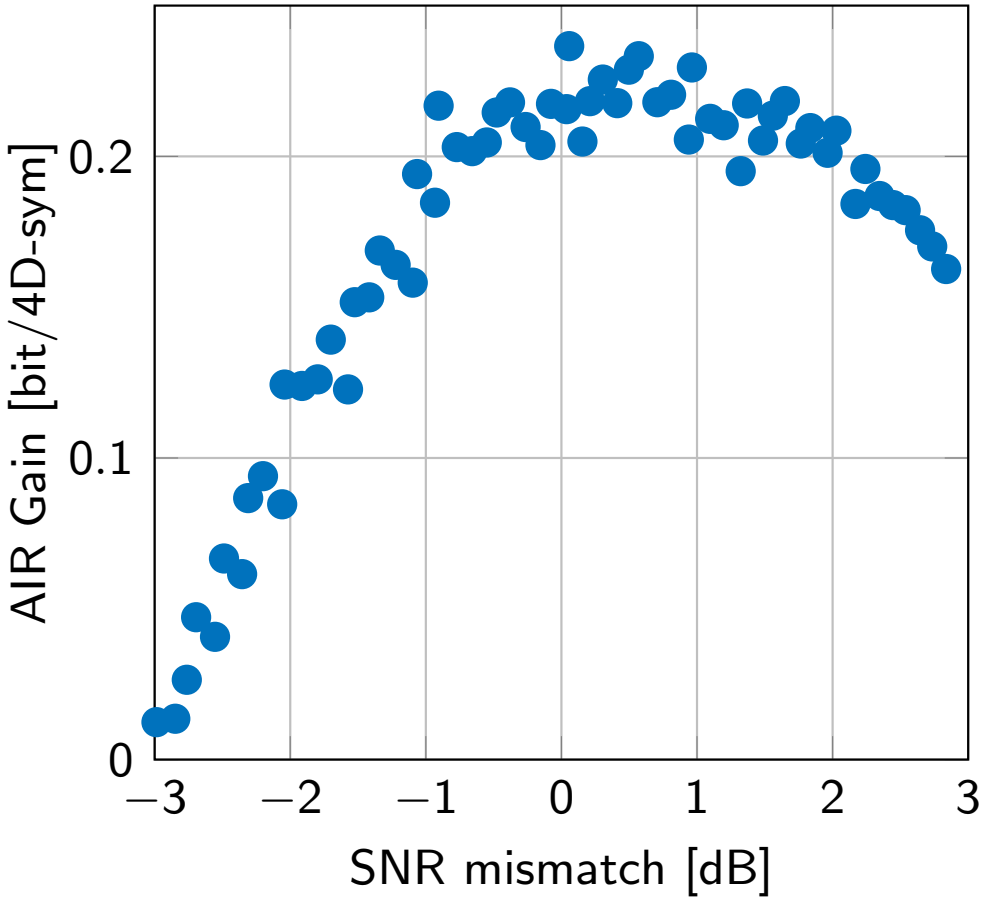

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Takeaway

Shaping is robust for nonlinear fiber channel

Conclusion

- Experimental demonstration of 0.8 dB sensitivity gain by probabilistic shaping
- Fiber simulations show gains of 0.23 bit/4D-sym by shaping (comparable to ideal single-channel DBP)
- Combine DBP and shaping
- Mismatched shaping: one or two input PMFs are sufficient

Thank you.

References

- T. Fehenberger, G. Böcherer, A. Alvarado, and N. Hanik, "LDPC coded modulation with probabilistic shaping for optical fiber systems," in *Proc. Optical Fiber Communication Conference (OFC)*, Paper Th.2.A.23, Mar. 2015.
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