Hardware requirements for coherent systems beyond 100G

DSP & FEC: Towards the Shannon Limit

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Agenda

1. From 40G/100G to 400G
2. Implementation possibilities for 400G systems
3. Requirements for QAM with square constellations
4. Summary

Transition from 10G through 40G/100G to 400G

Fundamental limits

40G/100G systems have roughly the same robustness against distortions as 10G systems.

Enabling technologies:

- PSK/QPSK instead of OOK ← Highest SNR tolerance
- Polarization-multiplex ← No improvement possible
- Coherent detection & DSP ← Space for improvements
- More efficient FECs ← Space for improvements

400G systems will most likely have a lower tolerance against distortions (SNR, nonlinear effects) than 40G/100G systems.

Implementation of 400G transmission systems

The agony of choice

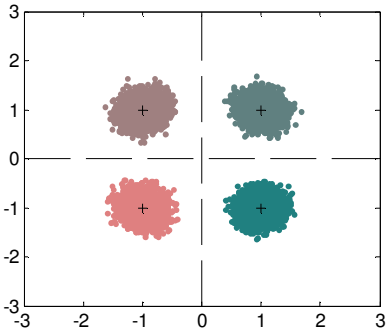
Single carrier transmission	⟷	OFDM
High-level constellations ▪ High spectral efficiency ▪ Low symbol rate	⟷	Low-level constellations ▪ High noise tolerance ▪ Long transmission range
Star constellations ▪ Good phase noise tolerance ▪ # of diff. encoded bits depends on # of beams	⟷	Square constellations ▪ Good ASE noise tolerance ▪ Max. number of diff. encoded bits is 2.
Blind equalization ▪ Non-data-aided ▪ Decision-directed	⟷	Pilot-assisted equalization ▪ At start-up ▪ Continuously
…	⟷	…

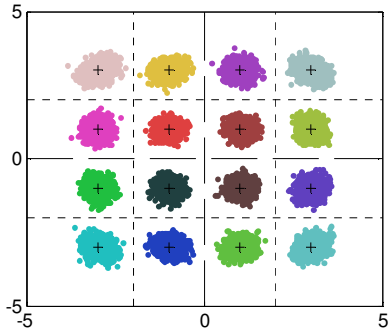
400G transmission systems using square QAM constellations

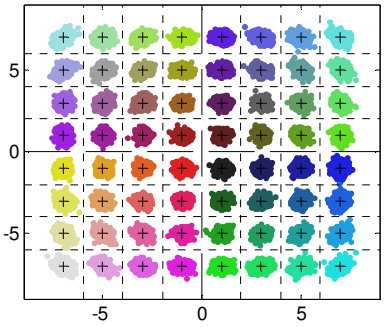
OSNR requirements

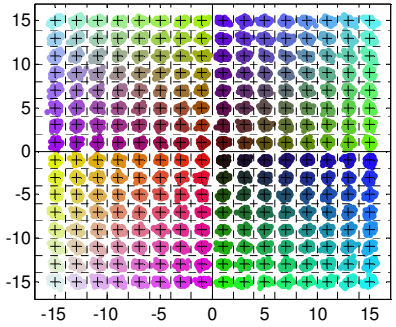
448 Gb/s polarization-multiplexed square QAM transmission system

	4-QAM (QPSK)	16-QAM	64-QAM	256-QAM
Spectral efficiency	4 b/s/Hz	8 b/s/Hz	12 b/s/Hz	16 b/s/Hz
Bandwidth	112 GHz	56 GHz	37 GHz	28 GHz
OSNR for BER=10^{-3}	16.3 dB	20.1 dB	24.3 dB	28.9 dB









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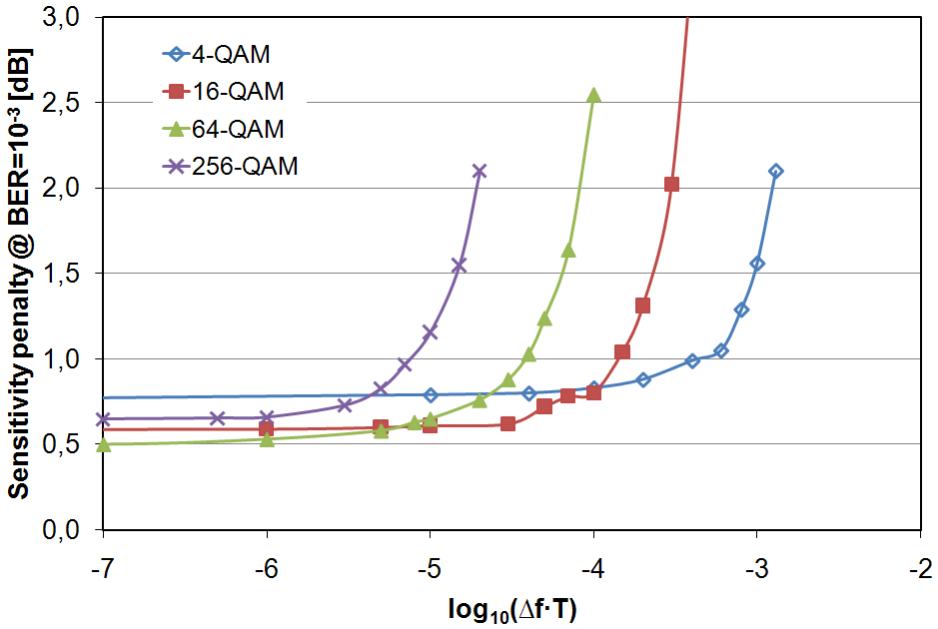
400G transmission systems using square QAM constellations

Phase noise tolerance

448 Gb/s polarization-multiplexed square QAM transmission system

	4-QAM (QPSK)	16-QAM	64-QAM	256-QAM
Laser linewidth [1]	22.5 MHz	3.9 MHz	750 kHz	110 kHz



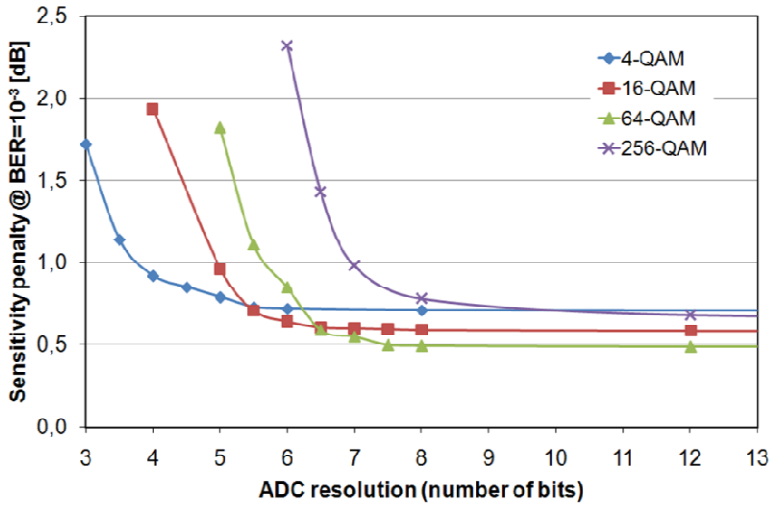
QPSK and 16-QAM can be realized with DFB lasers.

64-QAM and 256-QAM require ECLs.

[1] T. Pfau et al., IEEE J. Lightwave Technology, Vol. 27, No. 8, April 2009, pp. 989-999

448 Gb/s polarization-multiplexed square QAM transmission system

	4-QAM (QPSK)	16-QAM	64-QAM	256-QAM
Sampling rate (T/2-spaced sampling)	224 GSa/s	112 GSa/s	74 GSa/s	56 GSa/s
Effective # of bits (ENOB) [1]	3.8	4.9	5.7	7.0



56 GSa/s 8-bit analog-to-digital converter is available today (ENOB > 6-bit).

Source: http://www.fujitsu.com/emea/services/microelectronics/dataconverters/chais/index.html

30 GSa/s 6-bit digital-to-analog converter is available today (ENOB > 5-bit).

Source: http://www.micram.de/index.php/products/vega

[1] T. Pfau et al., IEEE J. Lightwave Technology, Vol. 27, No. 8, April 2009, pp. 989-999

400G transmission systems using square QAM constellations

Summary of system properties

448 Gb/s polarization-multiplexed square QAM transmission system

	4-QAM (QPSK)	16-QAM	64-QAM	256-QAM
Spectral efficiency	4 b/s/Hz	8 b/s/Hz	12 b/s/Hz	16 b/s/Hz
Bandwidth	112 GHz	56 GHz	37 GHz	28 GHz
OSNR for BER=10^{-3}	16.3 dB	20.1 dB	24.3 dB	28.9 dB
Diff. coding penalty	2	1.67	1.43	1.27
Laser linewidth	22.5 MHz	3.9 MHz	750 kHz	110 kHz
Sampling rate (T/2-spaced sampling)	224 GSa/s	112 GSa/s	74 GSa/s	56 GSa/s
Effective # of bits (ENOB)	3.8	4.9	5.7	7.0

Summary

- 400G systems will place higher requirements on the network infrastructure.
- There is a huge variety of implementation possibilities.
- Real-time implementation of 400G systems will be possible in the near future.

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