Technical and Economic Feasibility of DQPSK Serial PMDs

IEEE HSSG Meeting, Monterey, CA – January 17-19th, 2007

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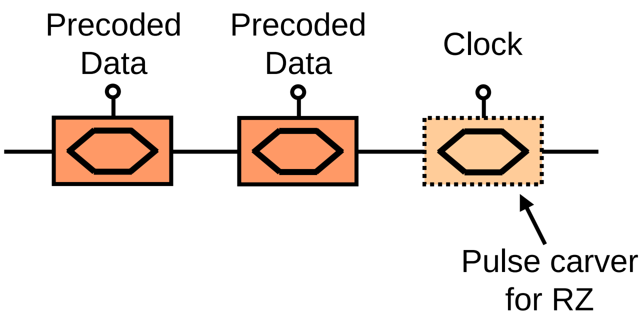
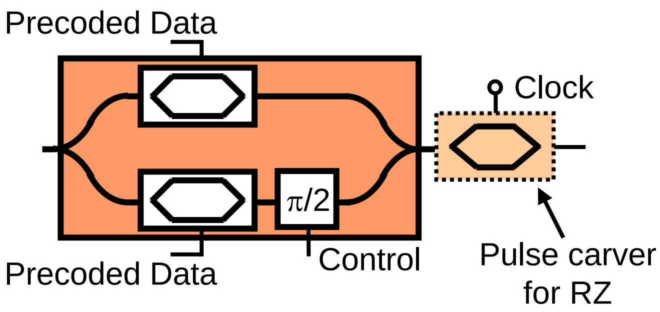
This presentation discusses ...

- Implementation of key optical DQPSK components (technical feasibility)
  – DQPSK modulator
  – DQPSK demodulator
- Integration of optical DQPSK components (technical/economic feasibility)
  – All high-speed (85-111 Gb/s) DQPSK transmission experiments have used $LiNbO_3$ data modulators that are common long-haul optical components but are not typically used in LAN or short-/medium-reach applications
  – Cost-effective implementations can be realized by integration, e.g. laser and DQPSK modulator (Tx), DQPSK demodulator and photodiodes (Rx)
- Need for stabilization or feedback loops (technical/economic feasibility)
  – Temperature stabilization vs phase stabilization
  – Feedback loops on Tx and Rx side
  – Required frequency/phase stability at Tx and Rx side
- For more general aspects of DQPSK for serial PHY implementation see
  – duelk_01_1106.pdf
  – duelk_01_0906.pdf

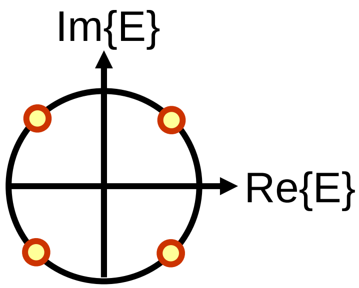
DQPSK Modulator Concepts





DQPSK is a 4-level phase modulation scheme, typically realized by two (digital) modulators – either serial or parallel – that each provide a 2-level phase encoding

Other schemes to generate DQPSK may exist that are not shown here !



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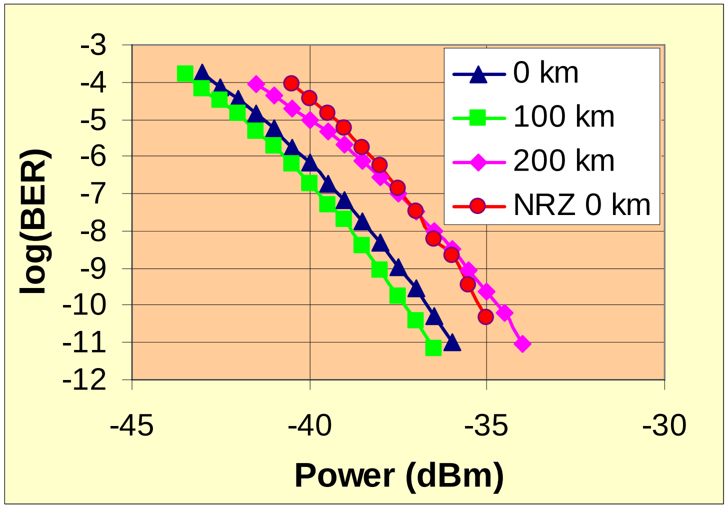
DQPSK Feasibility Demonstration

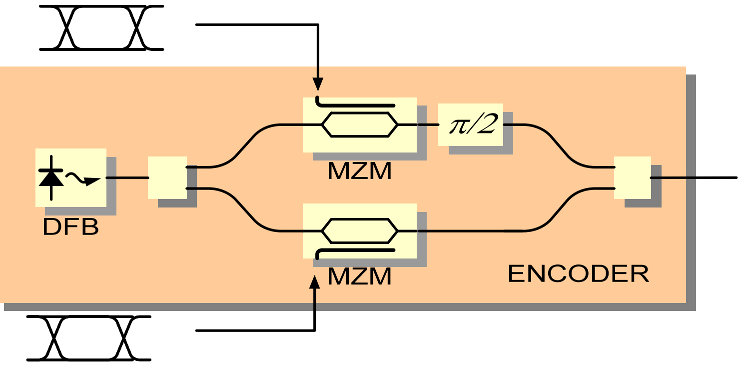
Initial experiments conducted using GaAs encoding chip copackaged with DFB laser (Griffin et al., OFC PD paper FD6, 2002)

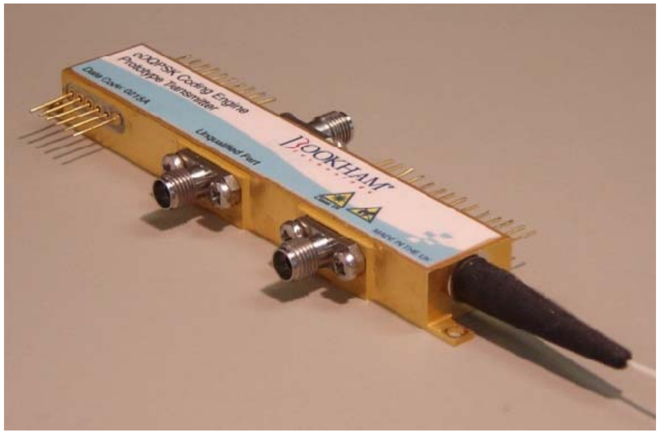
Operation with two 10 Gbit/s bit streams (20 Gbit/s at 10 Gbaud)

Technology scalable to 100G

Preferred implementation in InP integrated optics – chip size reduced x10, compatible with monolithic laser integration



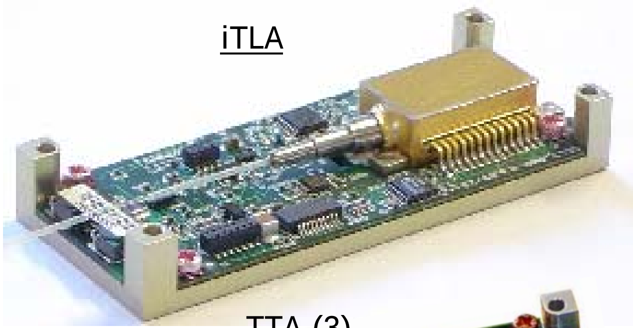




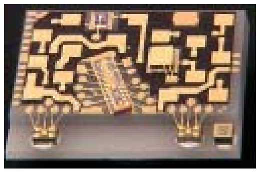
InP Integration

Packaged Laser

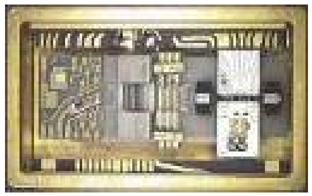
iTLA



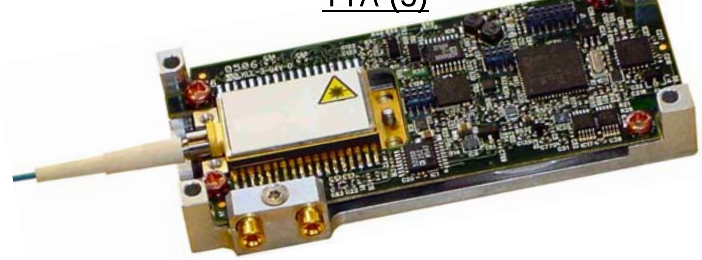
Tunable Laser



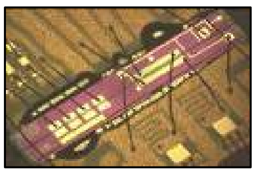
Tunable Modulator (1,2)



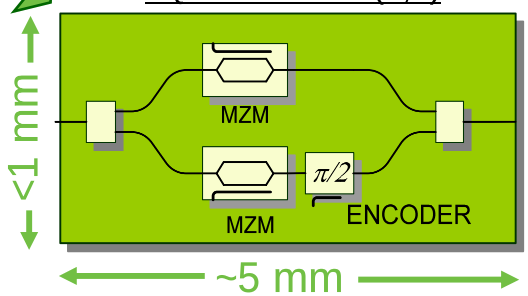
TTA (3)



Modulator



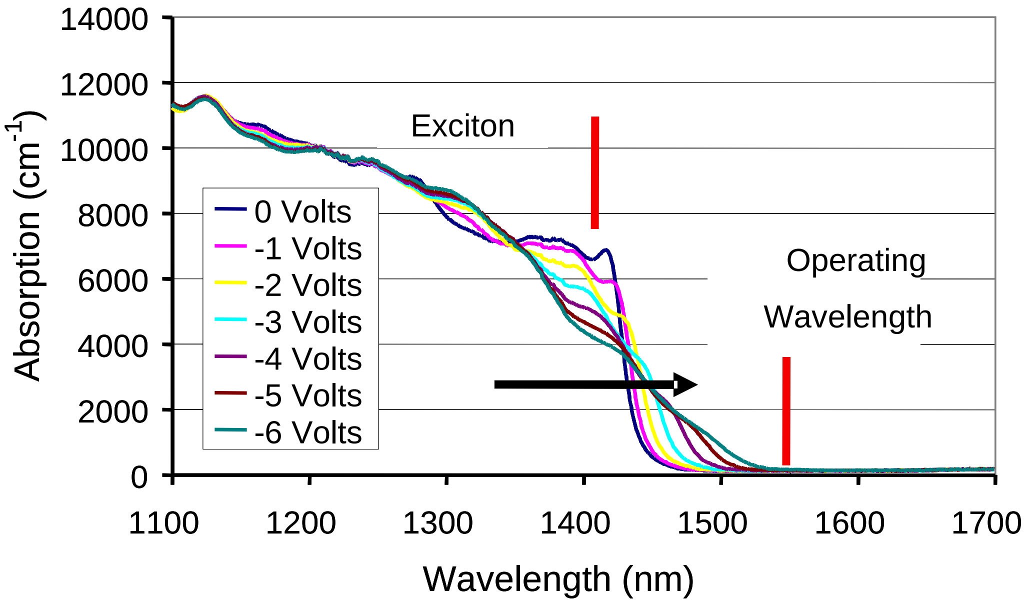
DQPSK Encoder (4,5)

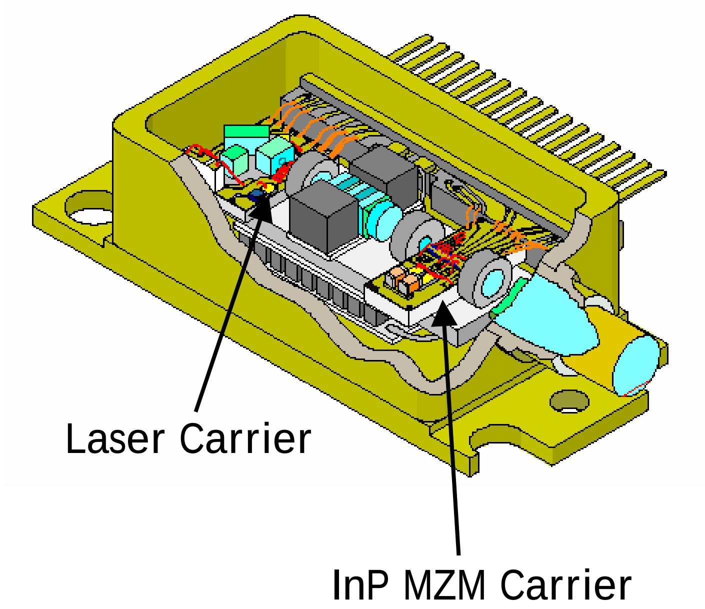


Notes

1) Fullband tunability is now being introduced in the same footprint as legacy fixed wavelength InP Mach-Zehnder's
2) Feasibility of monolithic integration of the laser & modulator has been demonstrated by two component vendors
3) A fullband Tunable Transmitter Assembly is being progressed through standards with the same outline as iTLA
4) Analysis of performance requirements predicts a chip of ~5mm length for a 100 Gb/s nested-MZ DQPSK encoder in InP
    - ~ 20% increment over current generation
5) DQPSK functionality is considered achievable within the current footprints
    - Applies to both the packaged component, and the module level incorporating control electronics

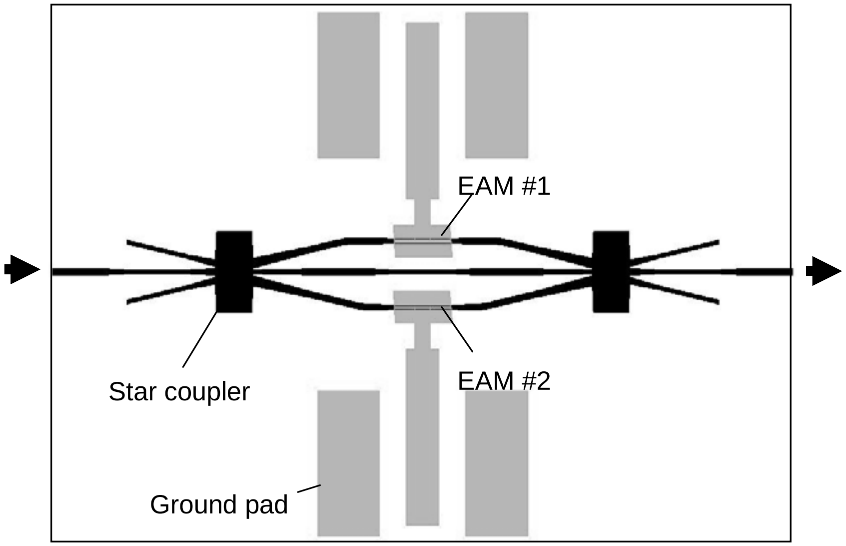
MQW InP Mach-Zehnder Modulator (MZM)





- An alternative to linear electro-optic modulators is to utilise QCSE in a semiconductor Multi-Quantum Well (MQW) MZM
- Absorption at short wavelength induces phase shift at operating wavelength through Kramers-Kronig relation
- Provides reduction in electrode length of more than 10x compared to lithium niobate MZM's
  - MZM co-packaged together with DFB in compact butterfly footprint

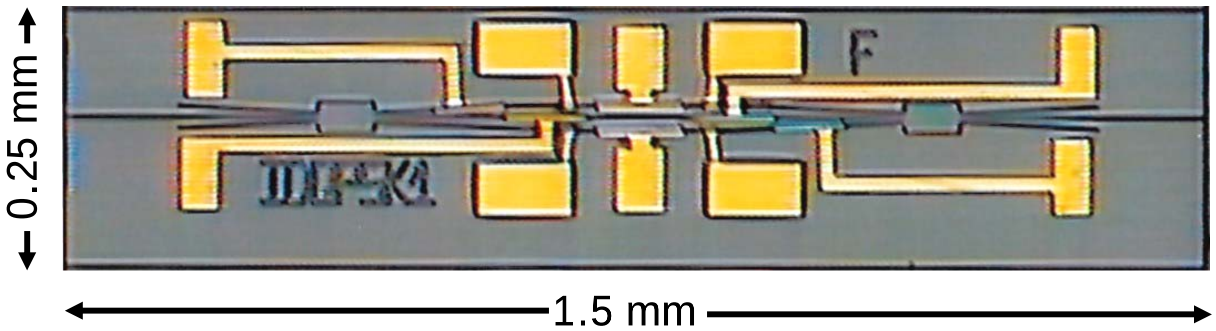
EAM-Based DQPSK Transmitter in InP



107 Gb/s DQPSK Optical Modulator realized in InP

- Small chip size (1.5 x 0.25 mm^2)
- Three-arm interferometer
- Electro-Absorption Modulators (EAMs)
- Single-ended drive @ 53.5 Gb/s

C. R. Doerr et al.,
to be submitted to IEEE Photonic Technology Letters



Temperature or Frequency Stabilization @ Tx

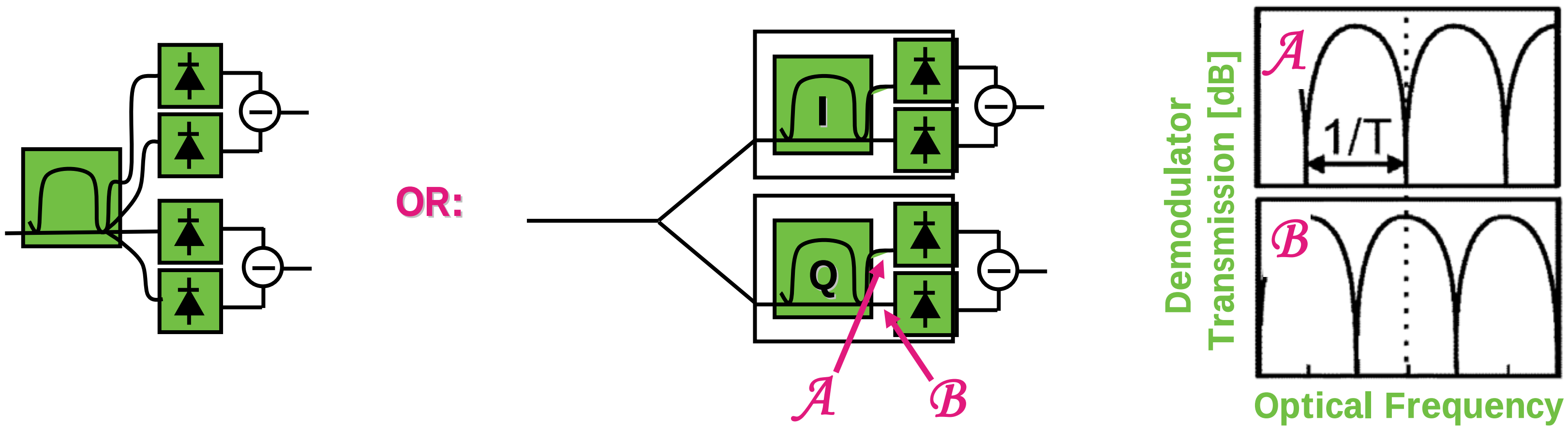
Stabilization of the Laser

- Temperature stabilization will stabilize output power and optical frequency
- Frequency stabilization needed for optical demodulator @ Rx (see slide 12)

Stabilization of the DQPSK Modulator

- Bias stabilization for the MZMs or the EAMs
- Bias stabilization for phase shifter(s)
- Bias stabilization typically realized with pilot tones and local feedback loops, already used in all externally modulated transmitters (e.g. OOK or DPSK), solutions for corresponding circuits for DQPSK exist

DQPSK Demodulator



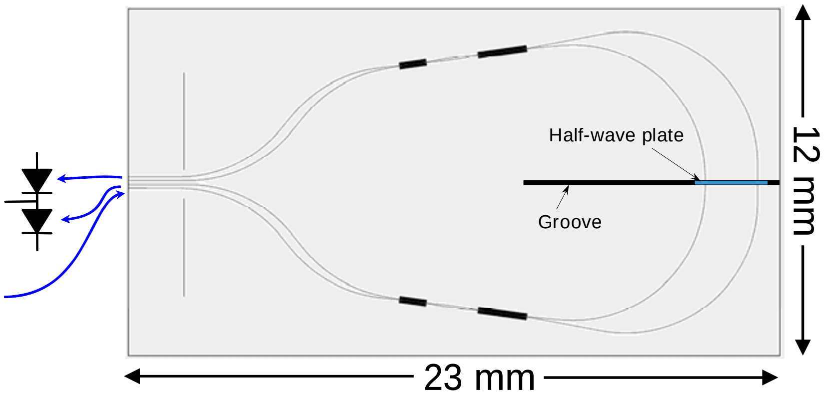
Direct-detection optical receivers detect *optical power* but not phase, therefore an optical demodulator is required to convert *phase differences* between adjacent bits into power changes

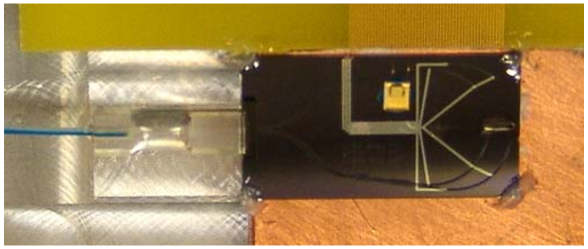
DQPSK demodulators are based on delay interferometers and can be realized using

- Optical fibers
  - Low insertion loss
- Free-space optics
  - Polarization-independence
- Integrated (silica) Planar Lightwave Circuits (PLCs)
  - Fast tuning (phase adjustments)
- Integrated (InP) Photonic Integrated Circuits (PICs)
  - Possible integration with photodiodes

Integrated DQPSK Demodulators

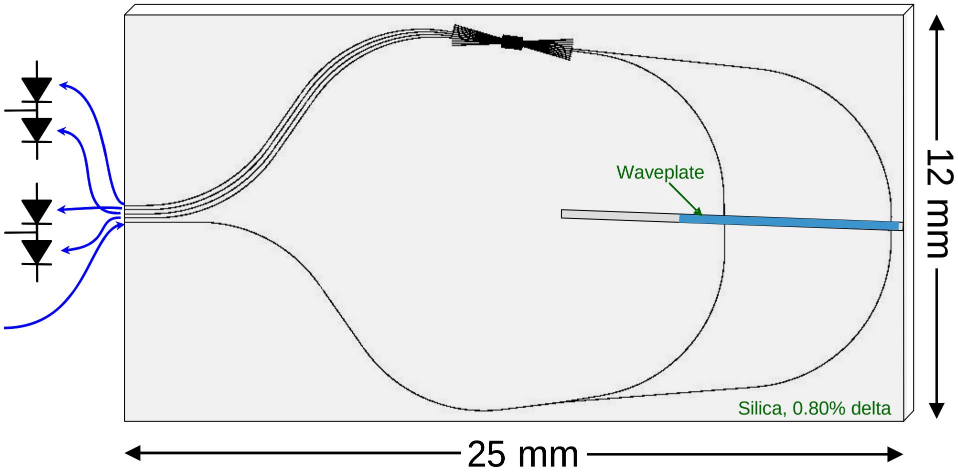
Single-quadrature demodulator
(need two of those)





PLC demodulator for 53.5 Gbaud

Dual-quadrature demodulator
(need only one)



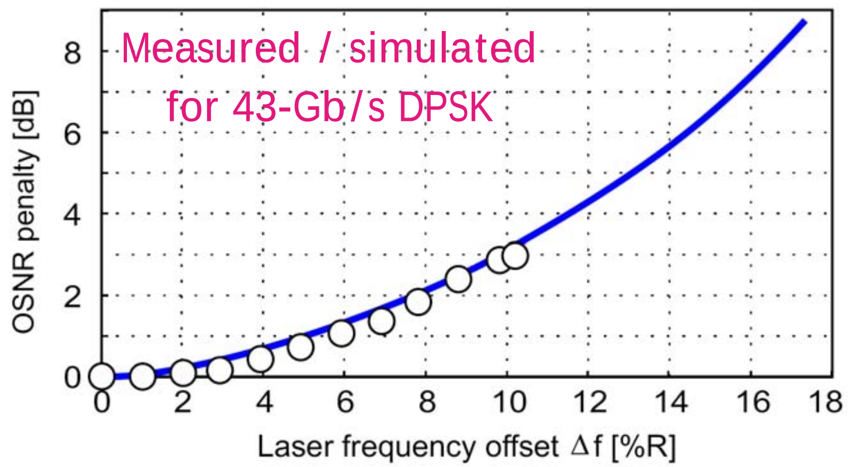
PLC DQPSK demodulator for 43 Gb/s, C.R. Doerr et al., Journal of Lightwave Technology, pp. 171-174, 2006

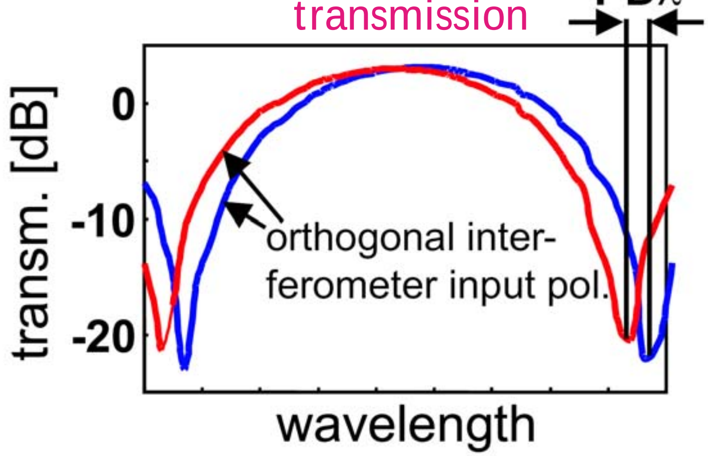
Above examples are realized in silica

Demodulators in InP could be 3-6 times smaller in each dimension (e.g. 2x4 mm^2)

All demodulators have tuning section to adjust the phase

Frequency Sensitivity and PDF of DPSK/DQPSK Demodulator





Ref.1: D. Stahl et al., Proc. 5. ITG-Fachtagung Photonische Netze, Leipzig, pp.211-218 (2004)
Ref.2: H. Kim et al., Journ. Lightwave Technology, vol.21, no.9, pp.1887-1891 (2003)

Both figures are for a commercial 43 Gb/s DPSK system[1]

DQPSK is 6-times more sensitive to frequency variations[2]

- DPSK: 1dB penalty @ Δf~5%R; 3dB penalty @ Δf~10%R (R=Bit Rate)
- DQPSK: 1dB penalty @ Δf~0.8%R; 3dB penalty @ Δf~1.6%R (R=Bit Rate)
- Exact numbers depend on component characteristics, e.g. modulator type, Rx/Tx bandwidth, …
- Estimates for 100 Gb/s DQPSK: 1dB penalty @ ±800MHz; 3dB penalty @ ±1600MHz

Laser frequency needs to be tracked (required accuracy depends on allocated system margin) and Polarization-Dependent Frequency/Wavelength Shifts (PDF/PDλ) in the demodulator need to be minimized (dependent on interferometer technology used)

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Temperature or Frequency Stabilization @ Rx

Stabilization of the DQPSK Demodulator

- Phase shifter inside demodulator has to track combined temperature variations of laser and demodulator (feedback loop)
  - Laser frequency varies with temperature
  - Demodulator transmission curve shift with temperature (demodulator is based on optical path length difference $\Delta n \times \Delta L$ where Δn may change with temperature, dependent on technology)
- Temperature stabilization of demodulator may be required

100G DQPSK demodulator has 50 GHz periodicity (see slide 9)

- "Reset problem" of phase shifter control voltage may occur if laser frequency exceeds certain frequency range, e.g. ±25 GHz for 2π phase shifters
- System outage during resetting and relocking period (can take several 10 ms or several 100 ms, depending on demodulator technology)
- Reset problem can be alleviated, for example with phase shifters having larger tuning ranges (e.g. 4π, 6π, etc.), depending on implementation details

DQPSK will (most likely) require temperature stabilization of both laser and demodulator, even for single-channel systems

Summary

- High-speed integrated small-size (and hence cost-effective) DQPSK modulators can be realized in InP
- InP will allow possible integration with laser or photodiodes
- Optical DQPSK demodulators can be realized on various technology platforms (fiber, free-space, silica, InP)
- Integrated demodulators in silica demonstrated, possible in InP
- 100G serial DQPSK can be realized with today's technology platforms