

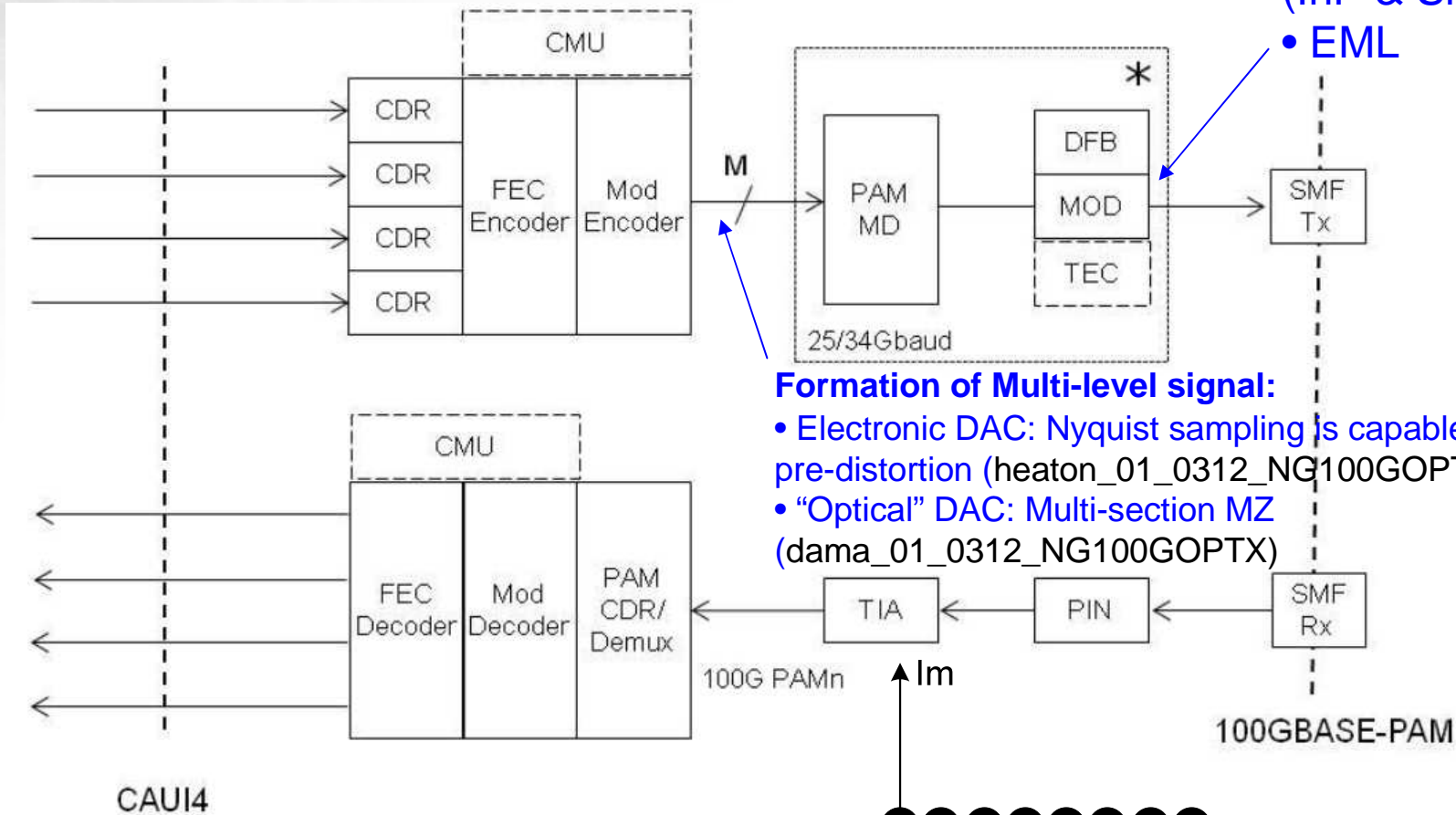
Optical Modulation Format and Direct Detection Schemes for the Single-Carrier PMD

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**IEEE802.3 NG 100GE PMD Study Group
May 2012**

PAM (1)

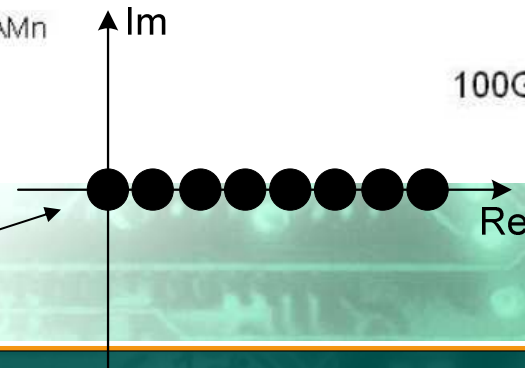
From nicoll__010312_NG100GOPTX



Formation of Multi-level signal:

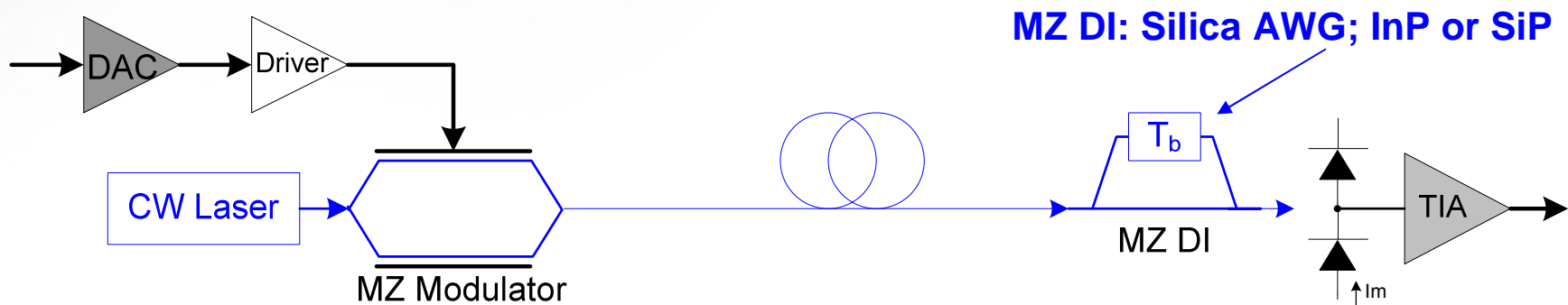
- Electronic DAC: Nyquist sampling is capable for pre-distortion (heaton_01_0312_NG100GOPTX)
- "Optical" DAC: Multi-section MZ (dama_01_0312_NG100GOPTX)

Unipolar PAM Constellation



PAM (2) Unipolar PAM vs. Polar PAM

- ❑ Unipolar PAM suffers ~3dB SNR degradation comparing to the un-utilized polar PAM
- ❑ The ~3dB degradation can be recovered in a polar PAM system if a balance receiver is used
- ❑ This scheme is also called DPSK since MZ modulator provides the “digital” phase modulation if it is biased at null instead of quadrature. No coherent detection is needed if data is differentially pre-coded



Example of polar PAM implementation

Reference:

Monolithic Rx including MZ DI and PIN: C. Doerr et al, OFC post-deadline paper, PDP23 (2008)

Systems Analysis: A. Gnauck, JLT 23, p. 115 (2005)

Constellation of polar PAM-8

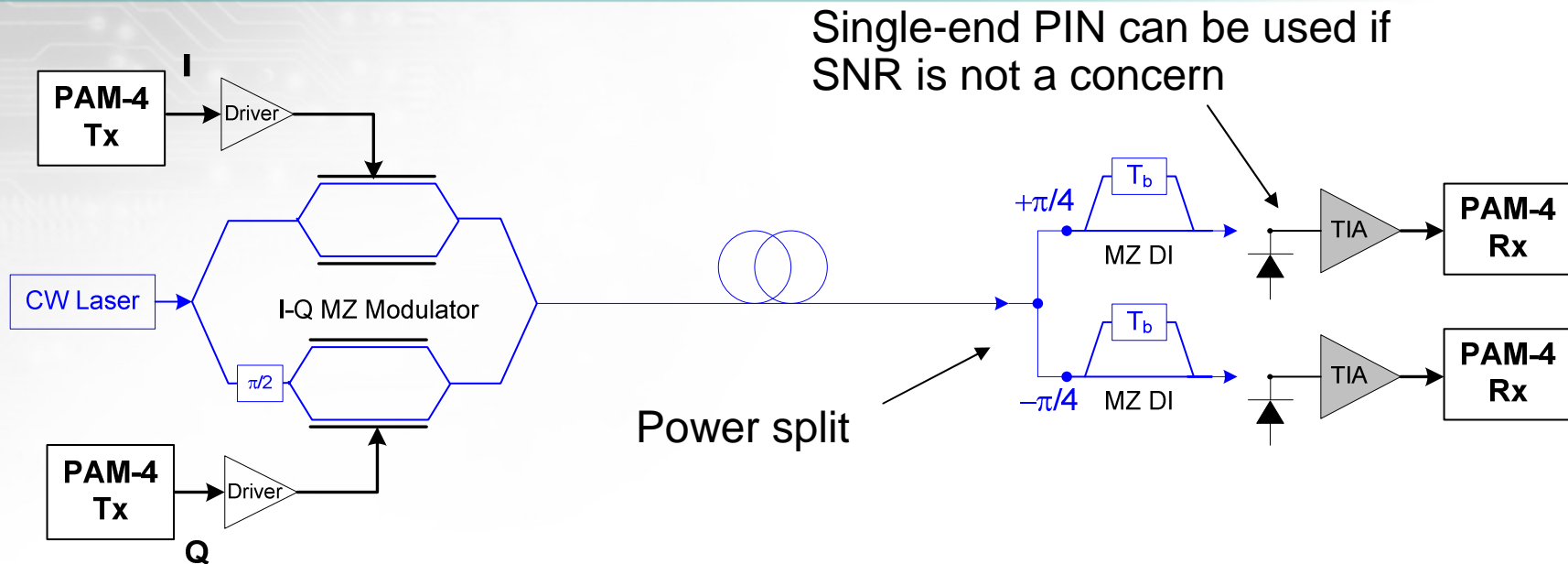


PAM (3)

- ❑ PAM can be implemented by simple Tx (single MZ modulator, EML or DML)
- ❑ **The Required SNR increases as multiplicity increases; to keep the low-noise implementation scaled up to high multiplicity is also challenge**
- ❑ For low cost, practical implementation, an electric data at symbol rate ≤ 25.78 GBaud with multiplicity $m \leq 4$, e.g. PAM-4 is desirable
- What other modulation formats?
 - QAM-16
 - CAP-16
 - PM-QAM-16
- What are the required detection schemes associated with the modulation formats?
 - Direct detection
 - Coherent

Format	PAM-8	PAM-16	QAM-16	CAP-16	PM-QAM-16
Symbol Rate (Gbaud)	34.38	25.78	25.78	25.78	12.89
Number of data lanes	1	1	2	2	4

QAM-16 (1)



❑ MZ DI: passive optics; Specs can be relaxed for single-ended Rx

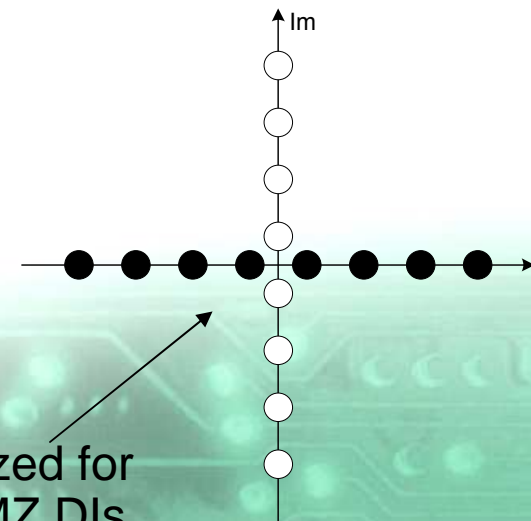
MZ DI by SiP: K. Voigt *et al*, IEEE PTL 20, p 614 (2008)

❑ PIN cost is relatively low comparing to Tx; can be made of InP or SiP

❑ Most challenging task is to form I-Q modulator in SiP

However...

Constellation optimized for direct detection by MZ DIs



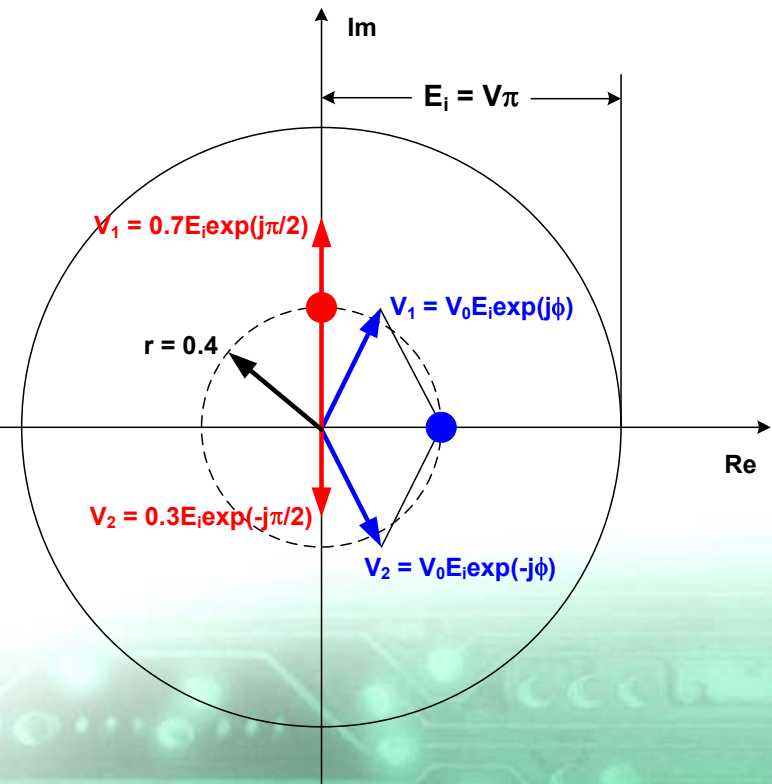
QAM-16 (2)

- ❑ I-Q modulator is also known as single side band (SSB) modulator
- ❑ The SSB can be generated by Hilbert transformed data by a dual-drive single MZ modulator:
 1. M. Siebend *et al*, JLT 17, p. 1742 (1999)
 2. P. Watts *et al*, Elec. Lett. 40 p. 958 (2004)

For a single MZ with dual drives, each arms generate phase modulations:

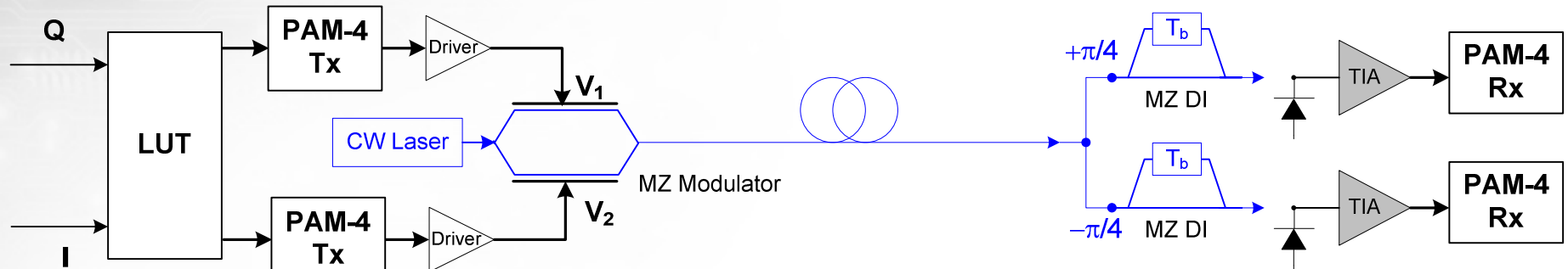
$$E_{out} = E_{in}/2 [\exp(jV_1) + \exp(jV_2)]$$

Example on right shows how to generate the sub-set of a constellation along the Re and Im axis with a circle $r = 0.4E_i$, and thus a M-ary quadrature amplitude modulation can be realized by the different dual-drive voltages V_1 and V_2 with a single MZ modulator.

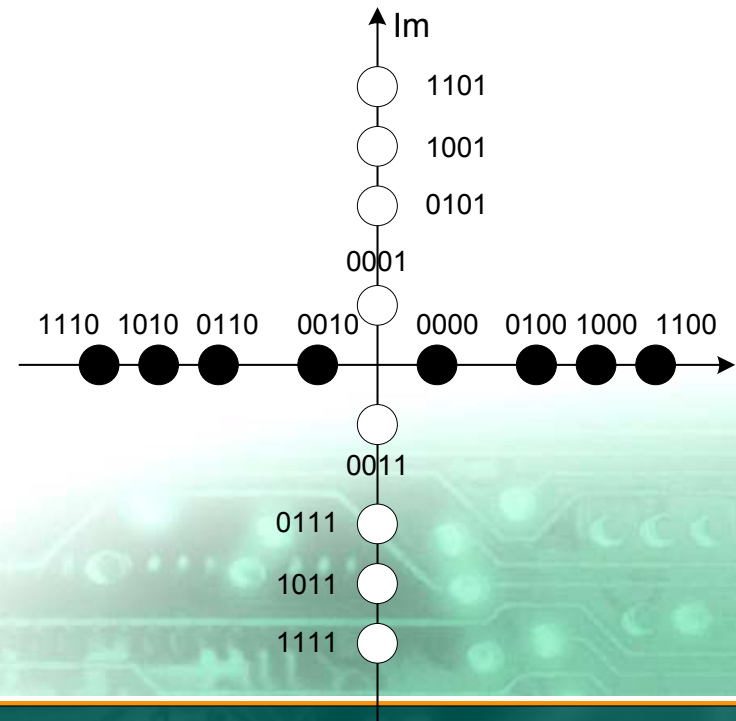


The combination of MSBs and LSBs can be used to determine amplitude and phase-domain respectively.

QAM-16 (3)



Predistortion from Nyquist DAC (digital Tx) or FFE (analog Tx) can be used to optimize the distance between eyes' spacing

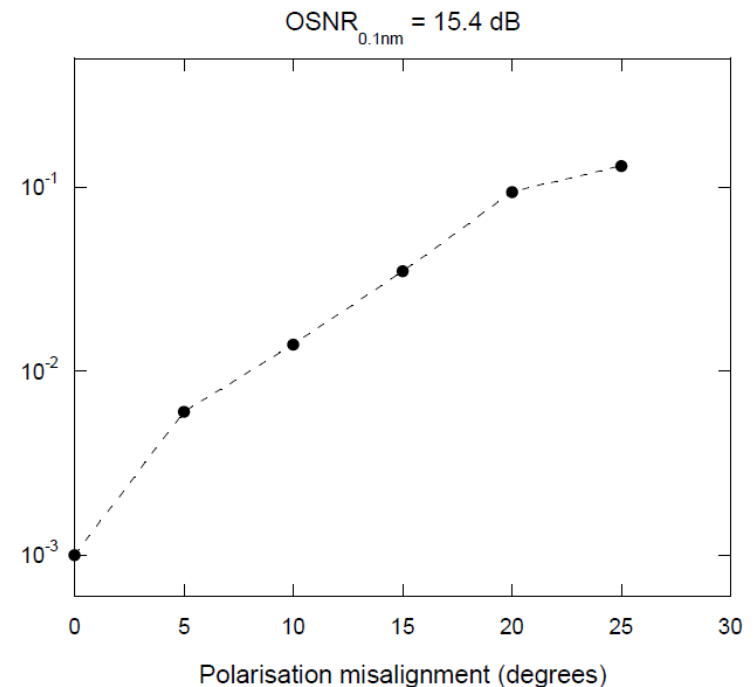
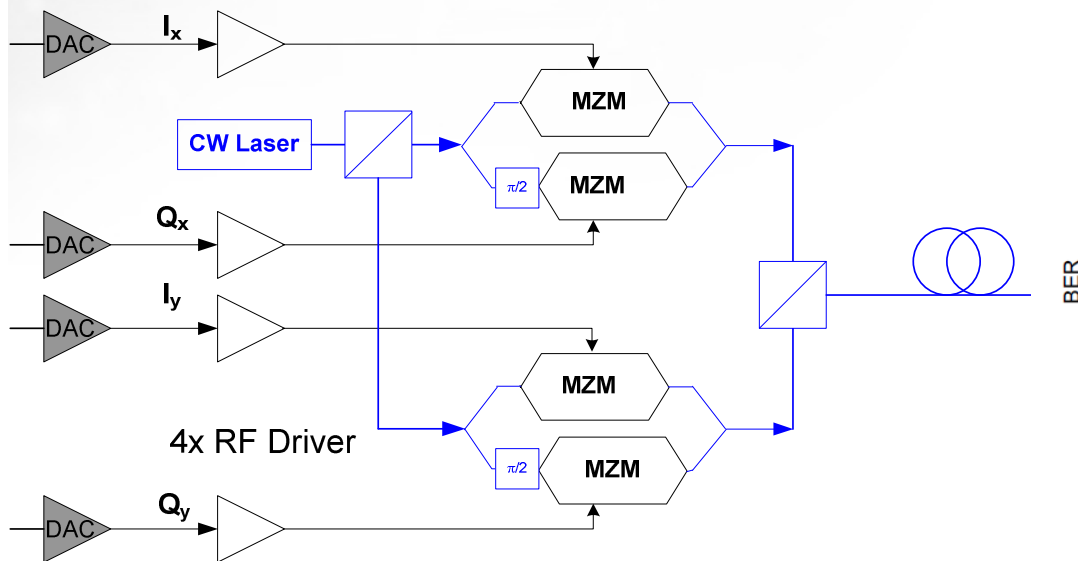


PM-QAM-n

❑ Polarization multiplexed system (e.g. QPSK) is the baseline for 100G long-haul transmission

❑ However the polarization mixture at Rx side is problematic for direct detection w/o the use of expensive polarization rotator

→ Coherent detection is required to find the inverse Jones' Matrix

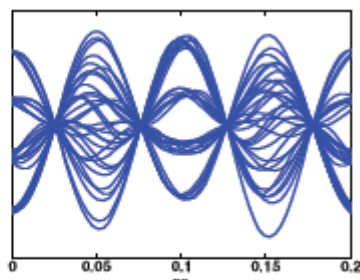
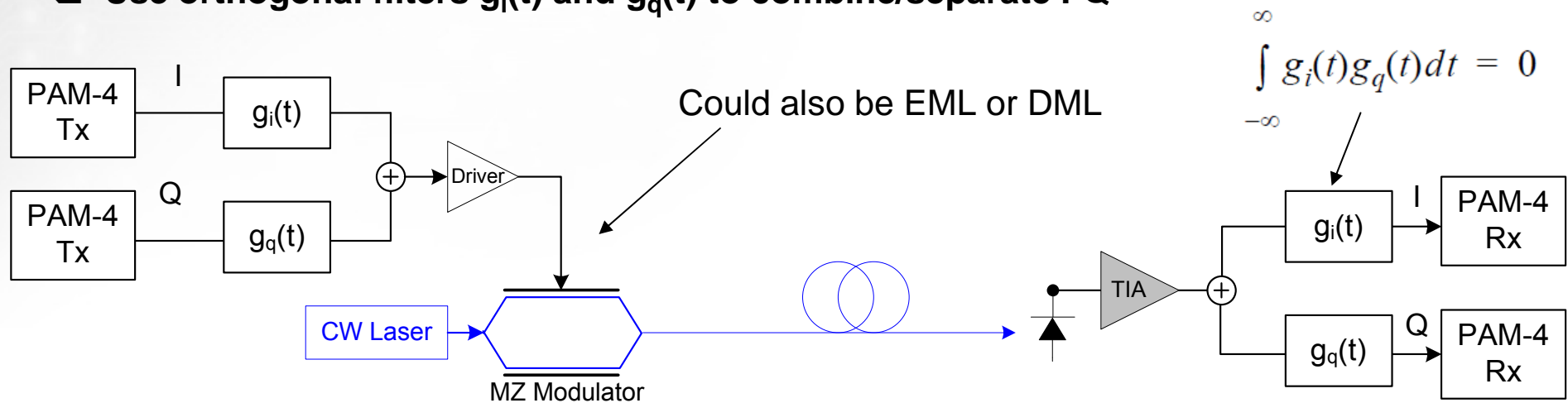


Simulated result with NRZ data at 28Gbaud

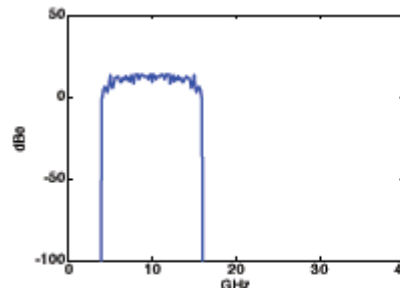
PM-QAM-n or PM-PAM-n are NOT cost effective for Client-Optics!

CAP-16

- ❑ CAP is a passband modulation of QAM (in contrary, QAM is baseband modulation to optical carrier)
- ❑ Electric performance of CAP-16 is similar to QAM-16
- ❑ Use orthogonal filters $g_i(t)$ and $g_q(t)$ to combine/separate I-Q



OThZ3.pdf



Observations:

- At 100G, the FIR filter implementation is more difficult
- System performance and relation to Tx/Rx parameters need further investigated

Fig. 1. (a) Eye diagram of a CAP16 waveform corresponding to 40 Gb/s aggregate transmission; (b) RF spectrum of the CAP16 waveform shown in (a), indicating a channel bandwidth of 10 GHz.

40G Result: J. Ingham *et al*, OCF Proc. OThZ3 (2011)

Summary

- ❑ Possible modulation format and the associated detection scheme under single optical carrier, and their potential application for the future 100G Ethernet SFM PMD are investigated:
 1. Extension of unipolar PAM to polar PAM can be realized by detection by a balanced Rx, which could results in ~3dB SNR improvement (high cost)
 2. QAM can be implemented either by an I-Q modulator or a dual-drive single MZ modulator
 - a) Dual-drive MZ modulator has been demonstrated at symbol rate = 25Gbaud with both SiP and InP, which is capable for QAM-16 implementation
 - b) QAM-16 with single-ended Rx has a SNR performance better than PAM-8
 - c) MZ delay interferometer (MZ DI) specs for single-ended Rx can be relaxed. SiP based PIN Rx and passive MZ DI have been demonstrated. which can provide further cost reduction
 3. PM-PAM or PM-QAM are not suitable due to polarization mixing at Rx, which requires coherent Rx to remove the polarization related degradation
 4. Detailed study for CAP-16 at both system level and component level are needed
- ❑ Further Link budget simulation and experiment to compare QAM-16 vs. CAP-16 is a good starting point to differentiate the cost and feasibility between the two