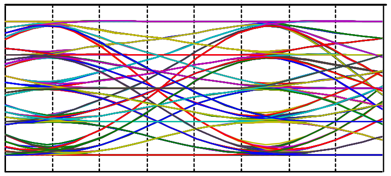
Multilevel Serial PMD Update

What is MAS?

- Multilevel Analog Signaling: Generic term used to describe various Multilevel Modulation methods
  - Applicable to most media: Copper, Wireless, Fiber, etc.
  - Common methods include PAM, FSK, DPSK, QAM, etc.
- Why? Reduce the Line Rate for a given Data Rate
- How Much? **½** the data rate first, **¼** is possible
- MAS transceivers bring CMOS to the PMD to:

- Reduce OptoElectronics *f*/cost
- Optimize System Interconnect
- Optimize Tx-Rx Link Operation
- Increase Link Distance
- Support Installed Fiber ≥200 m
- Simplify Emissions Compliance

MAS PMD Technology

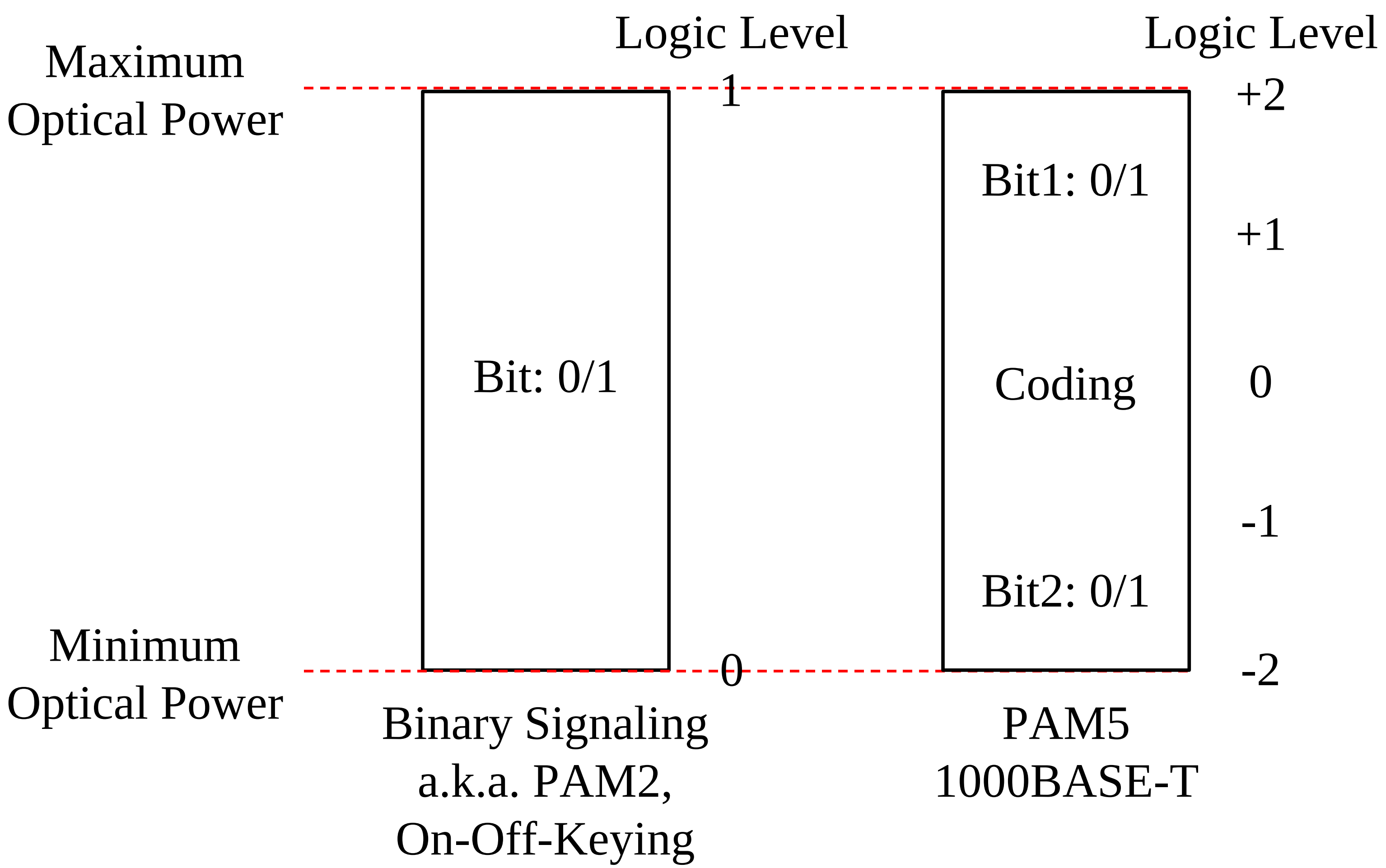


- NRZ, Quinary Amplitude Shift Keying of Optical Intensity
  - A.k.a. 5-level PAM of Optical Intensity
- 5 Gbaud (2.5 GHz) line rate for 10 Gbps
- Simple Single-Channel (Serial) PMD type
- Adaptation of 1000BASE-T Ethernet modulation, but simpler
  - No crosstalk, echo, DSP FEC compensation required
- PMD independent: Optical LW/SW, MMF/SMF, CX Copper
- Hari/MAS/laser driver implementable in, ≤0.18μm CMOS
  - Single CMOS chip includes Laser Driver for most PMDs
  - Only Laser, PIN, and TIA required for full PMD
  - Small, Low Power, accommodates Small Form Factor package
  - 10G PMD BOM should be not much higher than for 1G at maturity

MAS Attributes

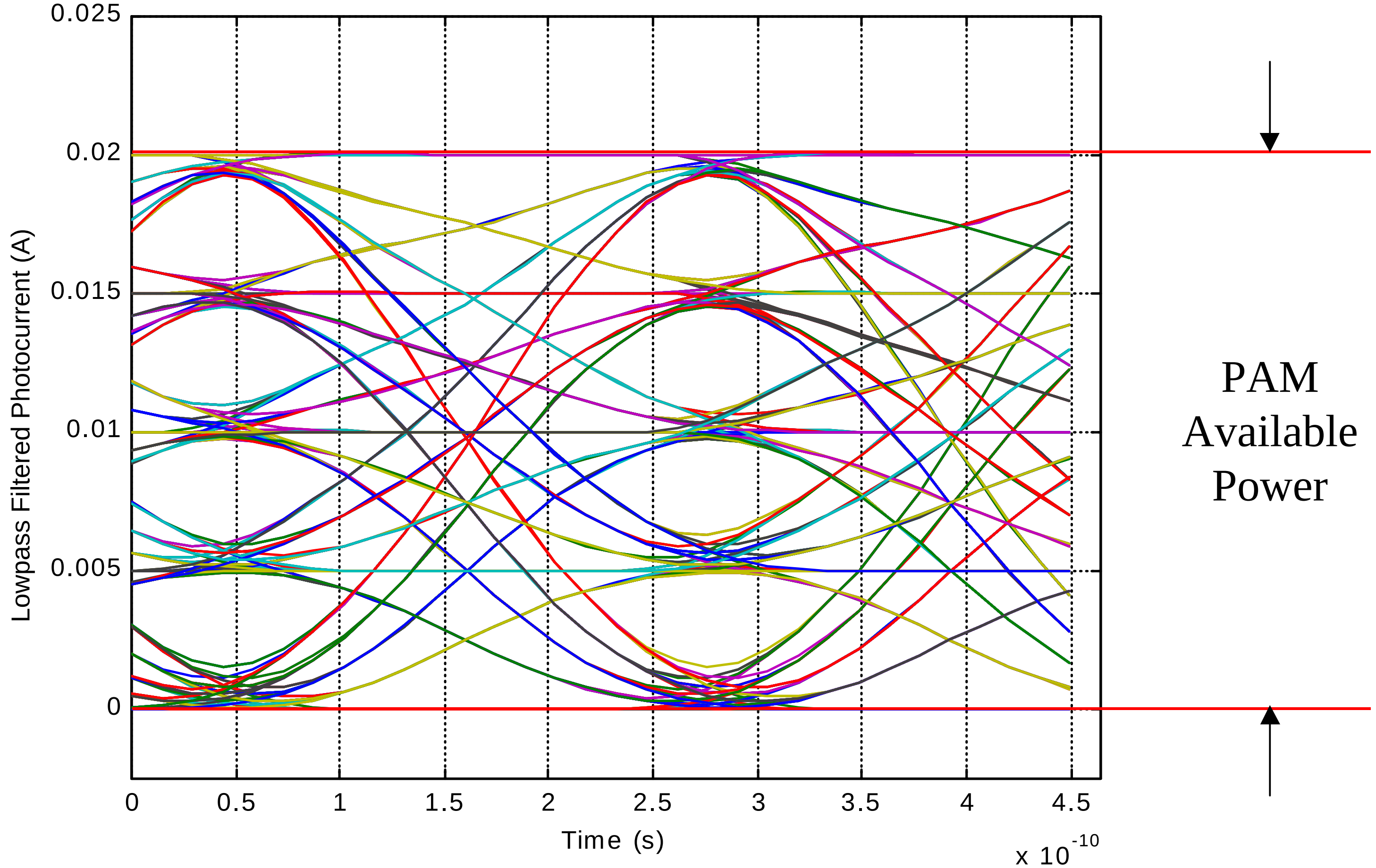
- Meets or exceeds ALL HSSG distance objectives
  - 2.5 GHz line rate yields ~200 m over installed MMF @ 1300 nm
  - ~800 m over enhanced MMF
  - 2/10/40 km SMF OK. Need HD Laser Driver for >10 km
- ↓ rate = ↓$ O/E, ↑ distance, ↑ reliability, ↓ emissions
- ↓ costs with CMOS, smart closed-loop optical feedback
- Only technology capable of supporting 1/10G operation
- Open technology, no basic IP, no barriers to entry
- Higher rates with more sophisticated modulation (e.g. PAM9, QAM, FDM), combination with WWDM, Parallel Optics
- Risks: New technology for optics, Need Linear TIA

PMA - Binary vs. PAM5 Signaling



PAM Signaling

PAM5 Example



Received pattern from simulation - Courtesy Transcendata, Inc.

PAM5×4 Code Mapping

- Simple, Direct Mapping
- Parallel 10GMII: 32 bit data path divided into four 8 bit lanes + 1 control bit per lane
  - Character set includes: DATA, IDLE, SOP, EOP, ERROR
- Serial 10GMII: 4 lane serial data path
  - One 8B/10B code-group corresponds to one Parallel 10GMII character
- PAM5×4: Serial link
  - One PAM5×4 symbol corresponds to one Serial GMII 8B/10B (Hari) code-group

PAM5×4 Code Mapping Example

Parallel 10GMII

D<0:7>	I	I	S	d_p	d	d	---	d	d	d	d_f	I	I	I	I	I
D<8:15>	I	I	d_p	d_p	d	d	---	d	d	d_f	T	I	I	I	I	I
D<16:23>	I	I	d_p	d_p	d	d	---	d	d	d_f	I	I	I	I	I	I
D<24:31>	I	I	d_p	d_s	d	d	---	d	d	d_f	I	I	I	I	I	I

Serial 10GMII

Lane 0	K	R	S	d_p	d	d	---	d	d	d	d_f	K	R	K	R	K
Lane 1	K	R	d_p	d_p	d	d	---	d	d	d_f	T	K	R	K	R	K
Lane 2	K	R	d_p	d_p	d	d	---	d	d	d_f	R	K	R	K	R	K
Lane 3	K	R	d_p	d_s	d	d	---	d	d	d_f	R	K	R	K	R	K

PAM5×4

R	R	R	S	d_p	d_p	---	d	d	d	---	d_f	T	R	R	K	K	K	K

PAM Coding Objectives

- PAM systems have coding objectives similar to those of On-Off-Keying (e.g. 8B/10B) including:
  - Special Symbol support (SOP, EOP, Idle, etc.)
  - DC Balance for jitter containment, AC/DC coupling
  - High Transition Density/Low Run Length (CDR)
  - Good Error Containment, Hamming Distance
  - Fast symbol/frame synchronization
  - Low Emissions/Good Spectral properties
  - Low complexity
- PAM systems benefit from FEC coding gain
  - E.g. Reed-Solomon(255,239) code in 10^{-4} BER, out 10^{-14}

PAM5×4 Coding Detail

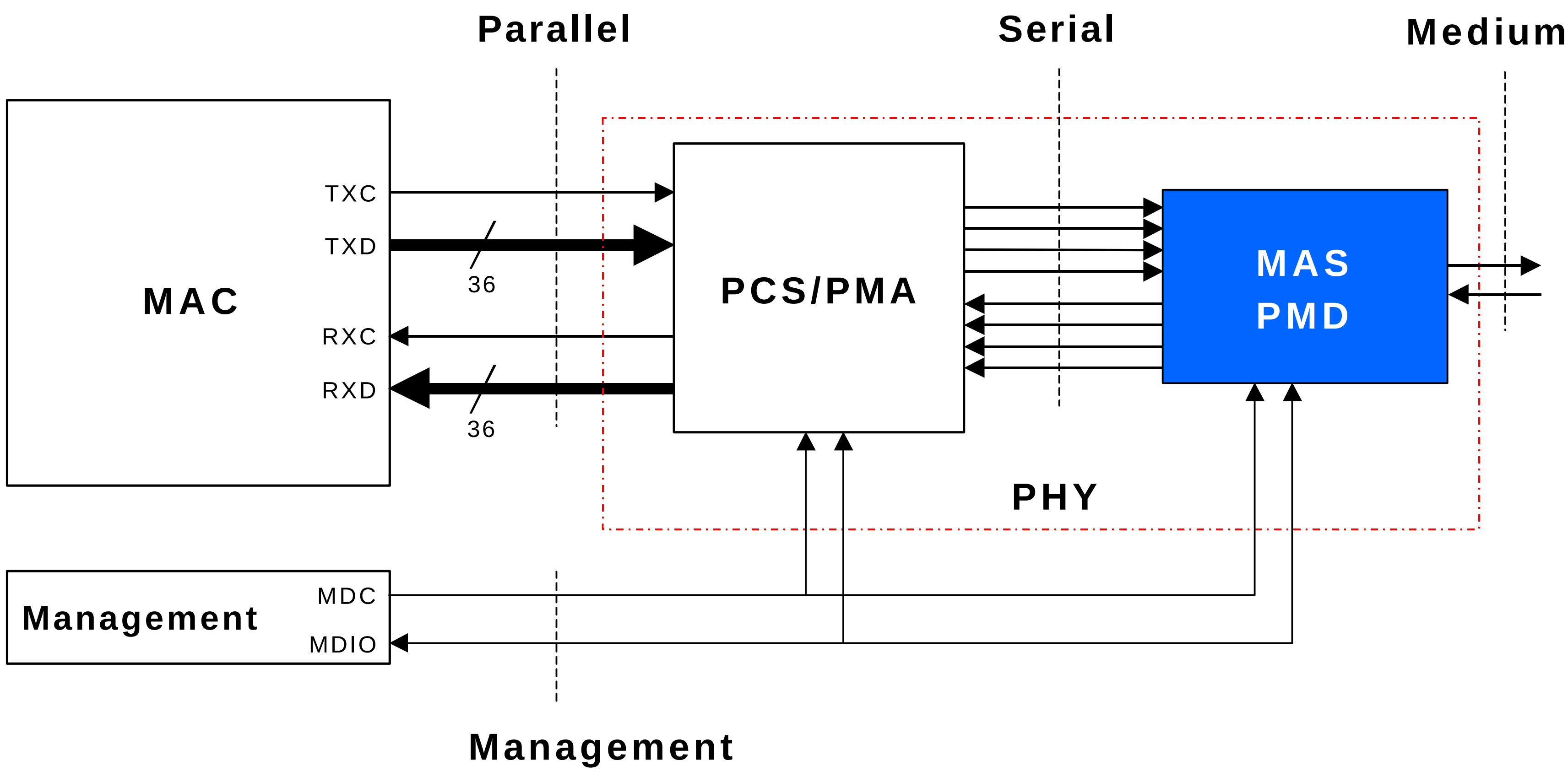
- 1 PAM5 symbol = 1 baud = 200 ps @ 5 Gbaud
  - Each PAM5 symbol supports 2+ bits
- 4 PAM5 symbols = 5^4 = 625 codes = ~9.22 bits
- 8B/10B supports 256 data codes, 12 special codes
  - 268 codes map to ~ 400/1024 total codes
- PAM5×4 coding structure

Avoid 5 "flat-line" symbols (e.g. all +2, +1, etc.)	5
Reserve ternary codes (+2, 0, -2) for special codes	81
Encode 9 bits per symbol: 8 Data, 1 FEC	512
Treat remaining 27 symbols as invalid	27
Scramble PAM5×4 symbols for DC Balance Total:	625

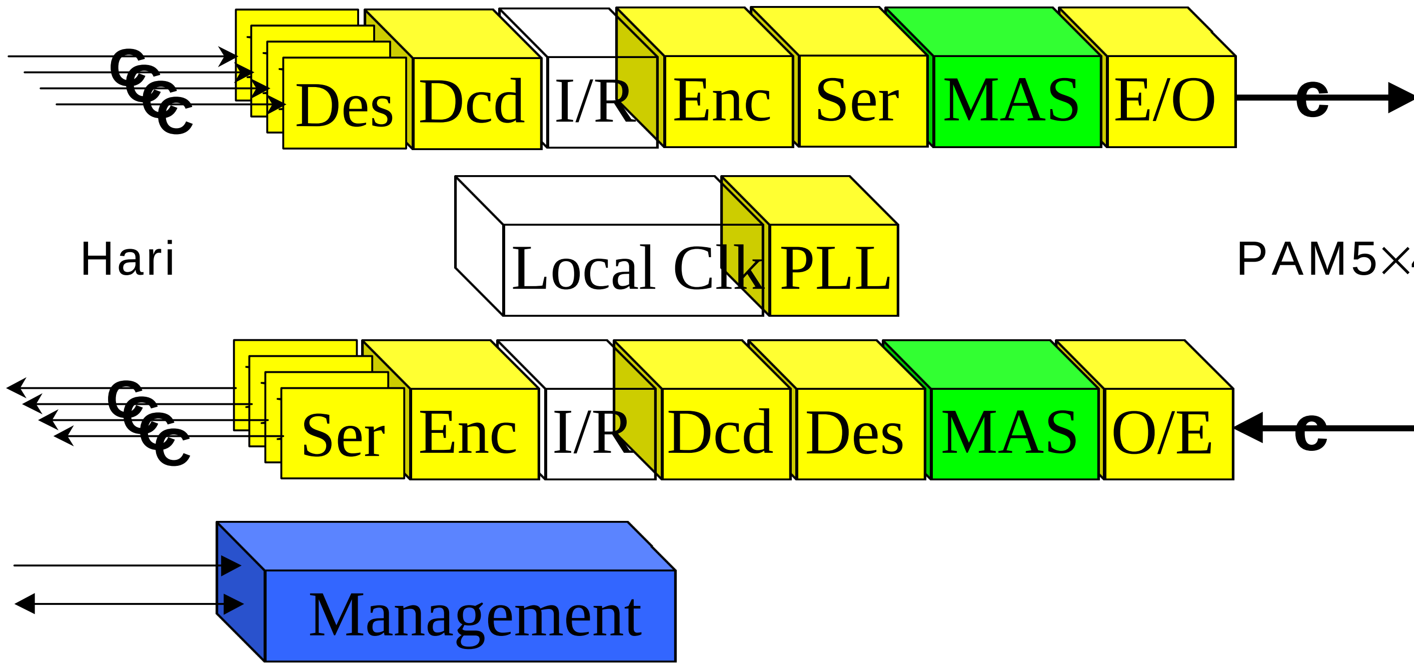
Circuit Design Challenges

- Waveform Synthesis and Capture
  - 5 GigaSymbols per second (Gsps)
  - but process amenable to parallel processing
- Clock and Data Recovery (CDR) for Hari & PAM5
  - Low Jitter PLL with/without Reference Clock
  - PAM5 no worse than Hari
- Forward Error Correction (FEC)
  - Focusing on Reed-Solomon codes
  - Issues:
    - Mapping efficiency, coding gain, gate count, low latency

MAS PMD Location in 10 GbE

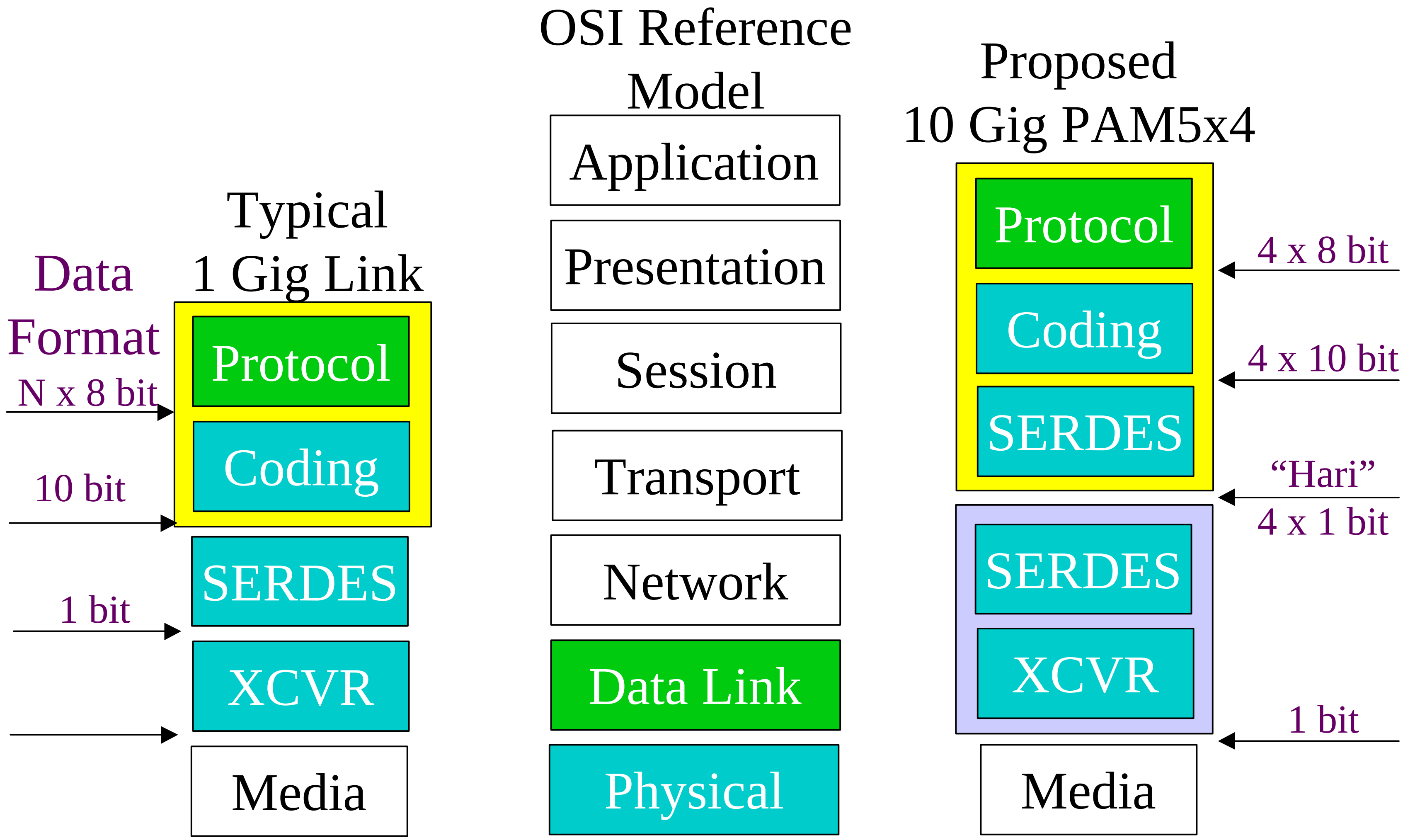


MAS PMD/Transceiver Data Flow

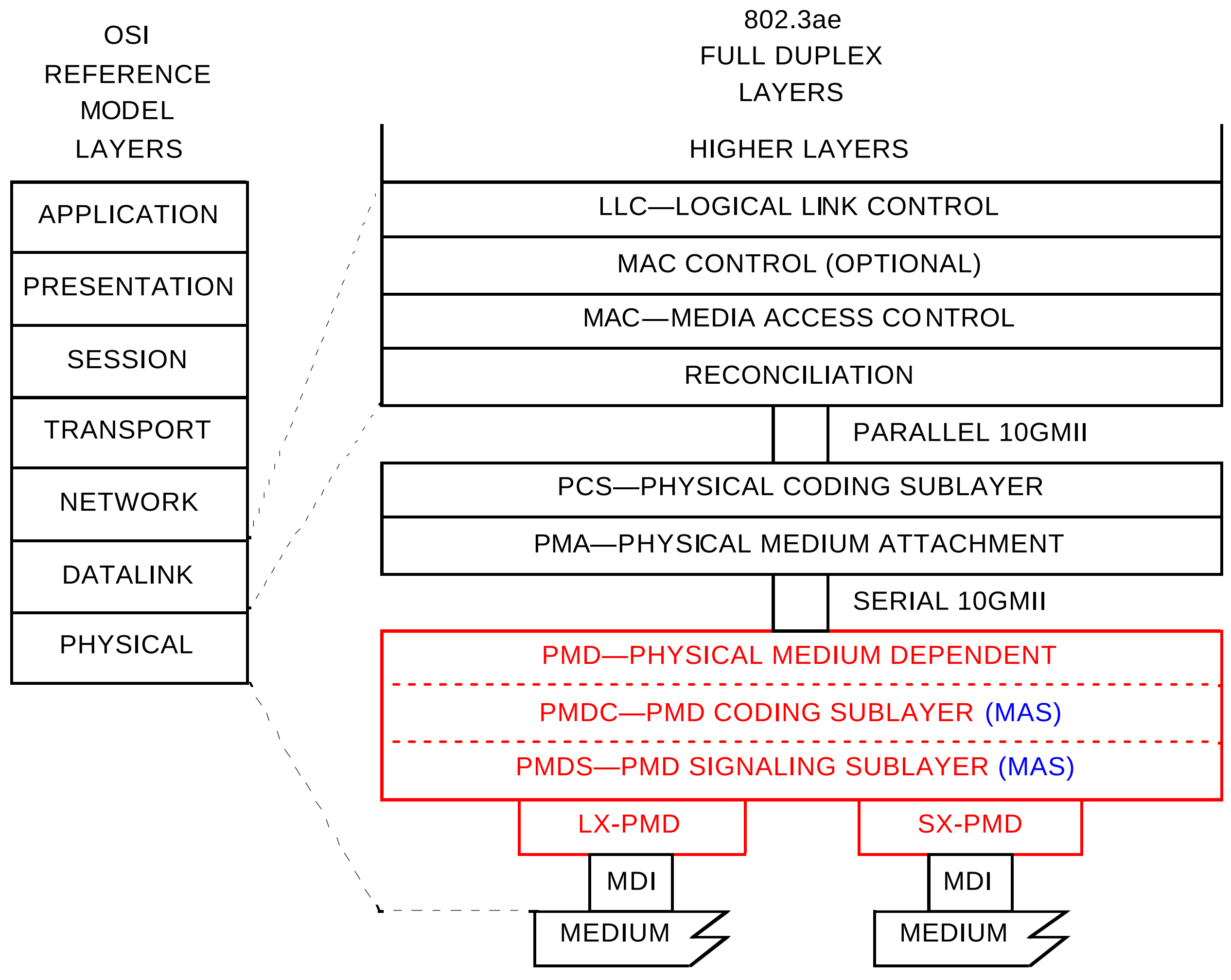


- PAM5×4 Link operates independently of Hari
- Local Clock not supported on Hari, Optional in Transceiver
  - Insert/Remove protocol not required if no Local Clock

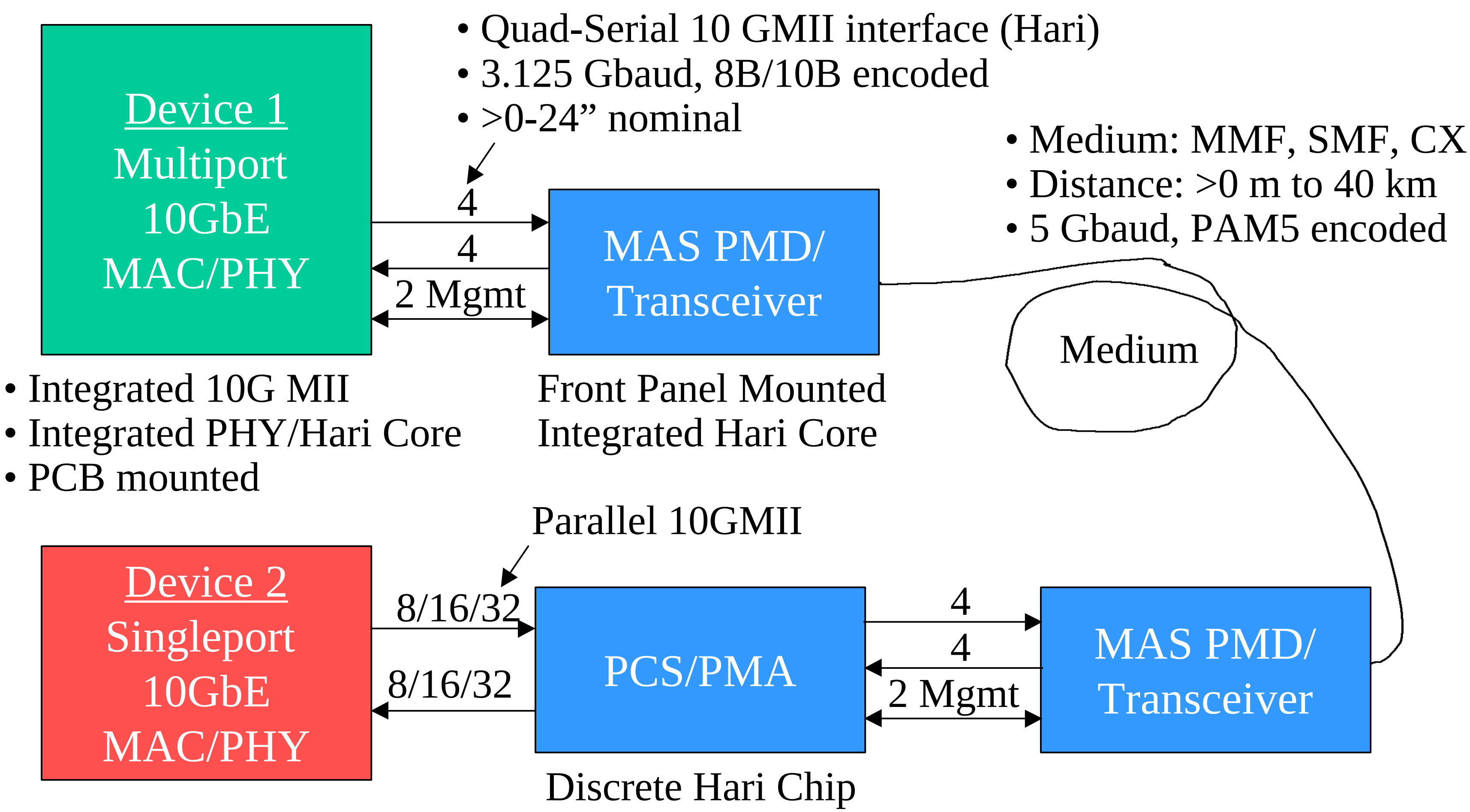
OSI/1 GbE/10 GbE MAS Models



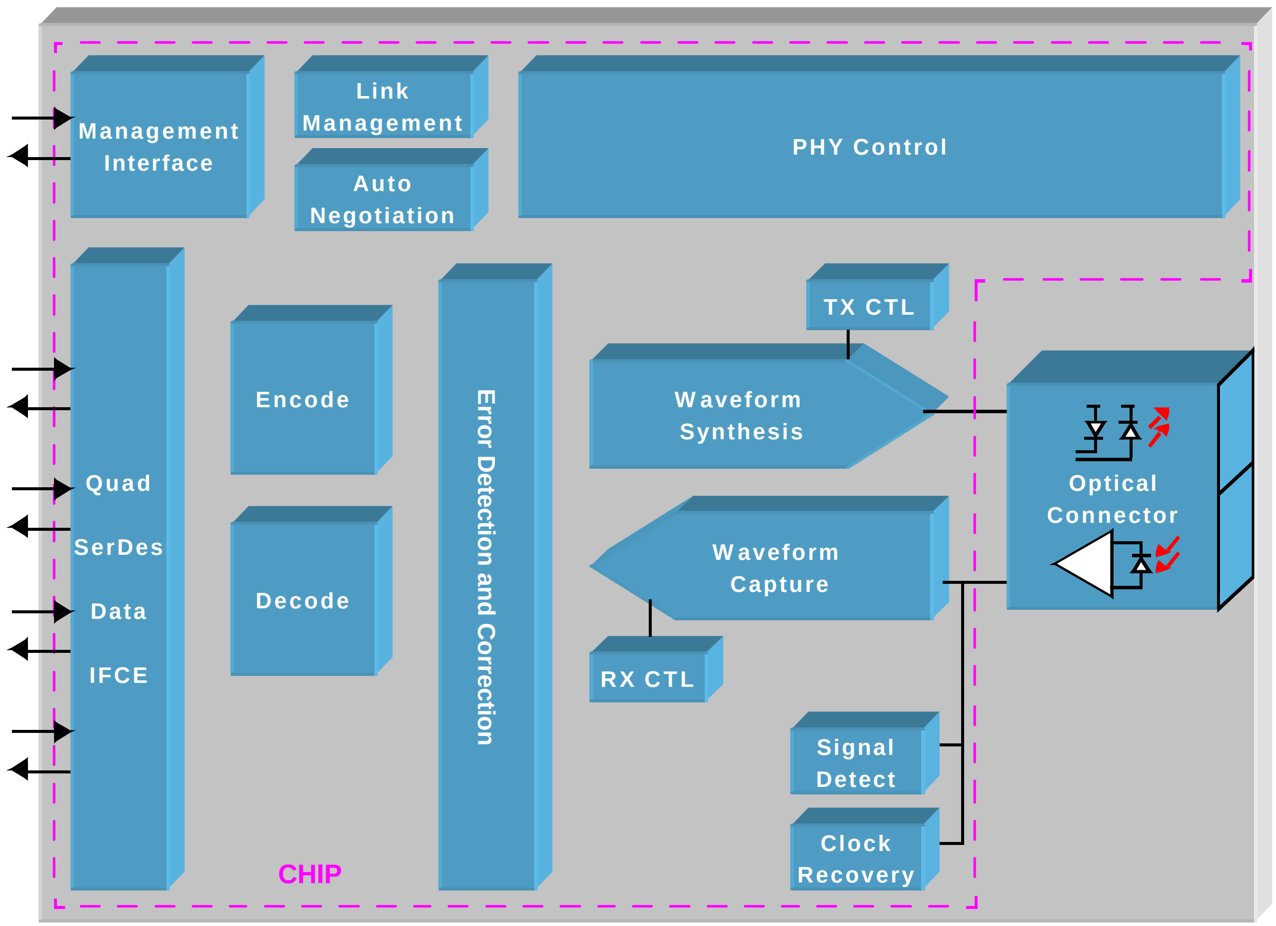
10 GbE MAS Specific Elements



MAS System Structure Example



MAS Transceiver Block Diagram



Optics Version shown, Alternatives: Short-haul Copper

PAM’s History in Ethernet

- 100BASE-TX uses multi-level coded symbols
- 100BASE-T4 uses multi-level coded symbols
- 100BASE-T2 uses PAM5
- 1000BASE-T uses PAM5

- MAS, PAM5, is **NOT** new to Ethernet

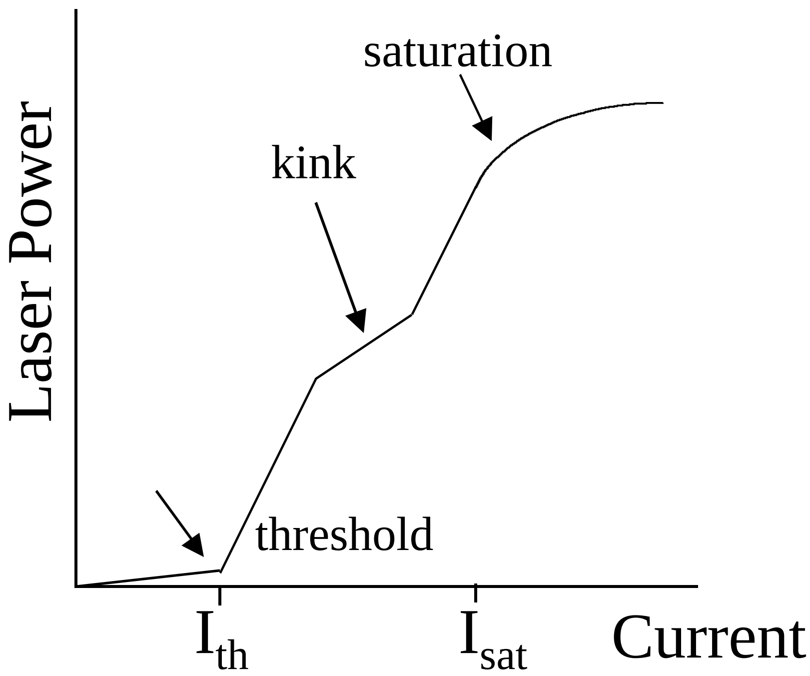
Optical Issues Non-Issues

- Laser BW ~1.1 Baud ~5.5 GHz
- Kink-free Lasers required
- Non-linearity Characterization
- Laser Noise Containment
- Rx BW ~0.75 Baud ~ 4 GHz
- Linear TIA Availability
- MAS Optical Power Penalty
  - 4.1 dB (optical) for PAM5

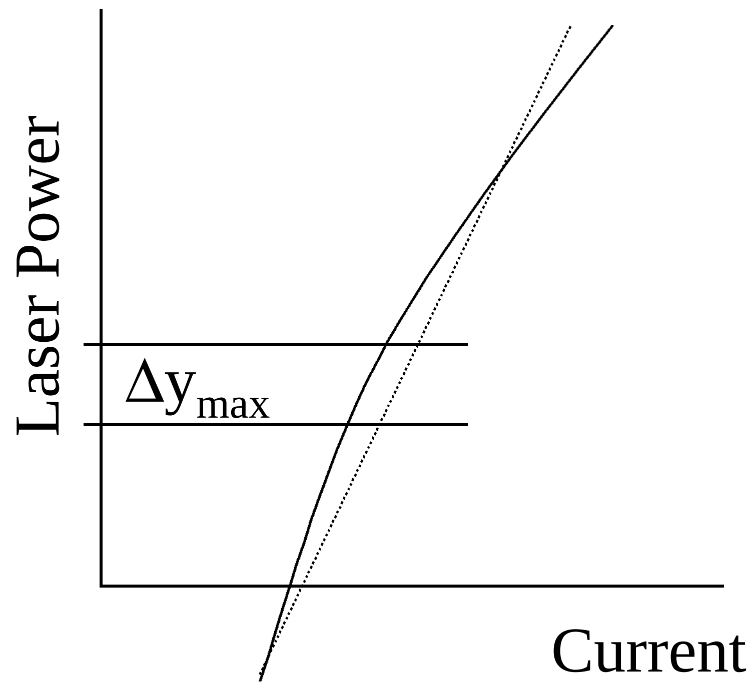
- Receiver Nonlinearity
- Large Signal Nonlinearity
- Sidemode Supression Ratio
- Laser Absolute Wavelength
- Laser Temperature Control
- Photodetector linearity
- Skew (lane, power)
- Crosstalk
- Packaging (independent)
- Protocol (independent)
- Media (independent)

Large and Small-Signal Nonlinearity

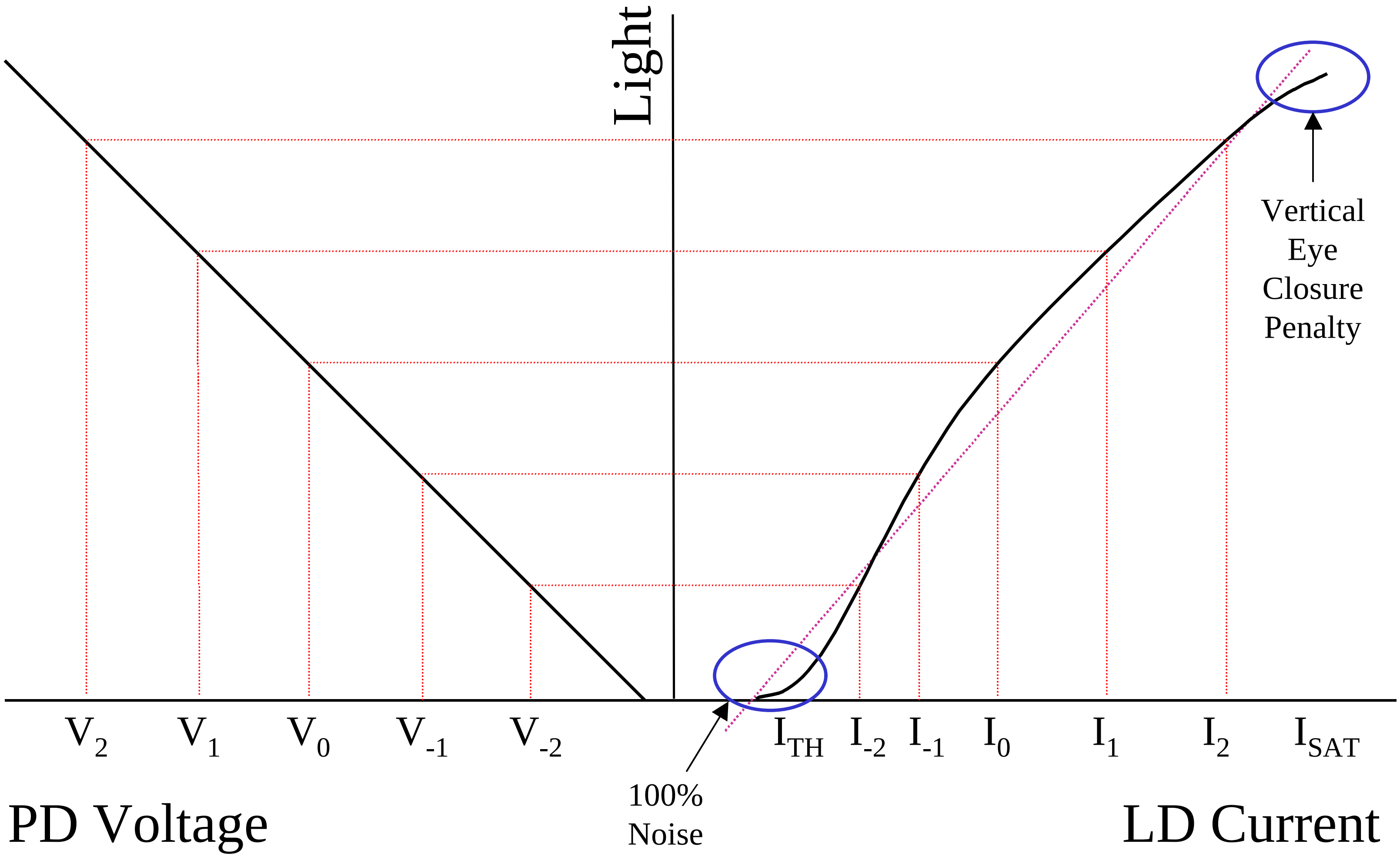
LD Gross Nonlinearity



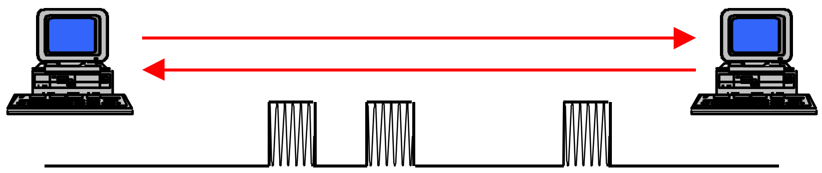
LD Small-Signal Nonlinearity



Linearity Compensation

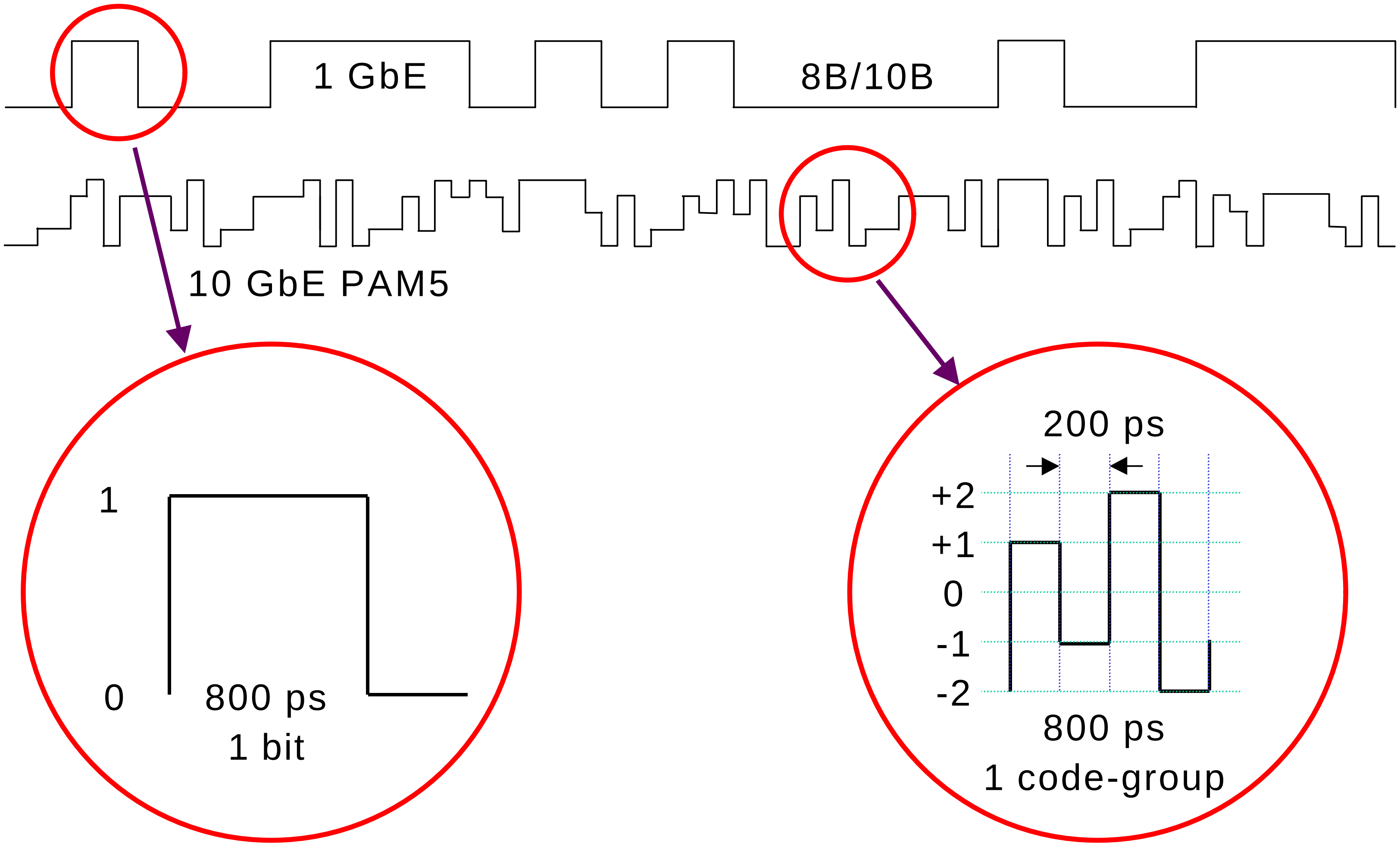


Auto-Negotiation



- Protocol uses Signal Detect-based “Tones”
  - New AN protocol for optical/copper serial links
  - Enables speed negotiation, simple 1/10 GbE integration
  - Tone frequency can easily span >10X line rates
  - Tone Pulses correspond to Fast Link Pulses (FLPs)
  - Tone Pulses are arranged 17-33 Pulses to a Burst
- Tone Pulses calibrate MAS Tx power and Rx levels
  - Increases optical link budget
  - Eliminates optical compression penalty
  - Compensates for laser non-linearity
  - Rx levels set to ensure same SNR/BER for all “eyes”

1/10 GbE MAS Signaling



New Optical Multilevel Technology

- Kestrel Solutions - Optical FDM
  - Uses Frequency Division Multiplexing combines individual 155 Mb/s channels into a single wavelength
  - http://www.kestrelsolutions.com/
- QPSK is the simplest form of QAM (QAM4)
  - Multiple-Subcarrier Modulation (MSM)
    - Multiple digital streams are modulated onto carriers at different frequencies, permits transmission with minimal ISI.
  - Work in Progress: Roy You and Joseph M. Kahn, “Average-Power Reduction Techniques for Multiple-Subcarrier Optical Intensity Modulation”, IEE Colloquium on Optical Wireless Communication, London, England, June 22, 1999.