Multilevel Analog Signaling
- a 10 Gigabit Technology -

IEEE 802.3 - Austin, TX
10 GbE Call for Interest

Rich Taborek
Principal Architect
Transcendata, Inc.
1029 Corporation Way
Palo Alto, CA 94303
Phone: +1 650 210 8800 x101
Fax: + 1 650 940 1898
Email: rtaborek@transcendata.com

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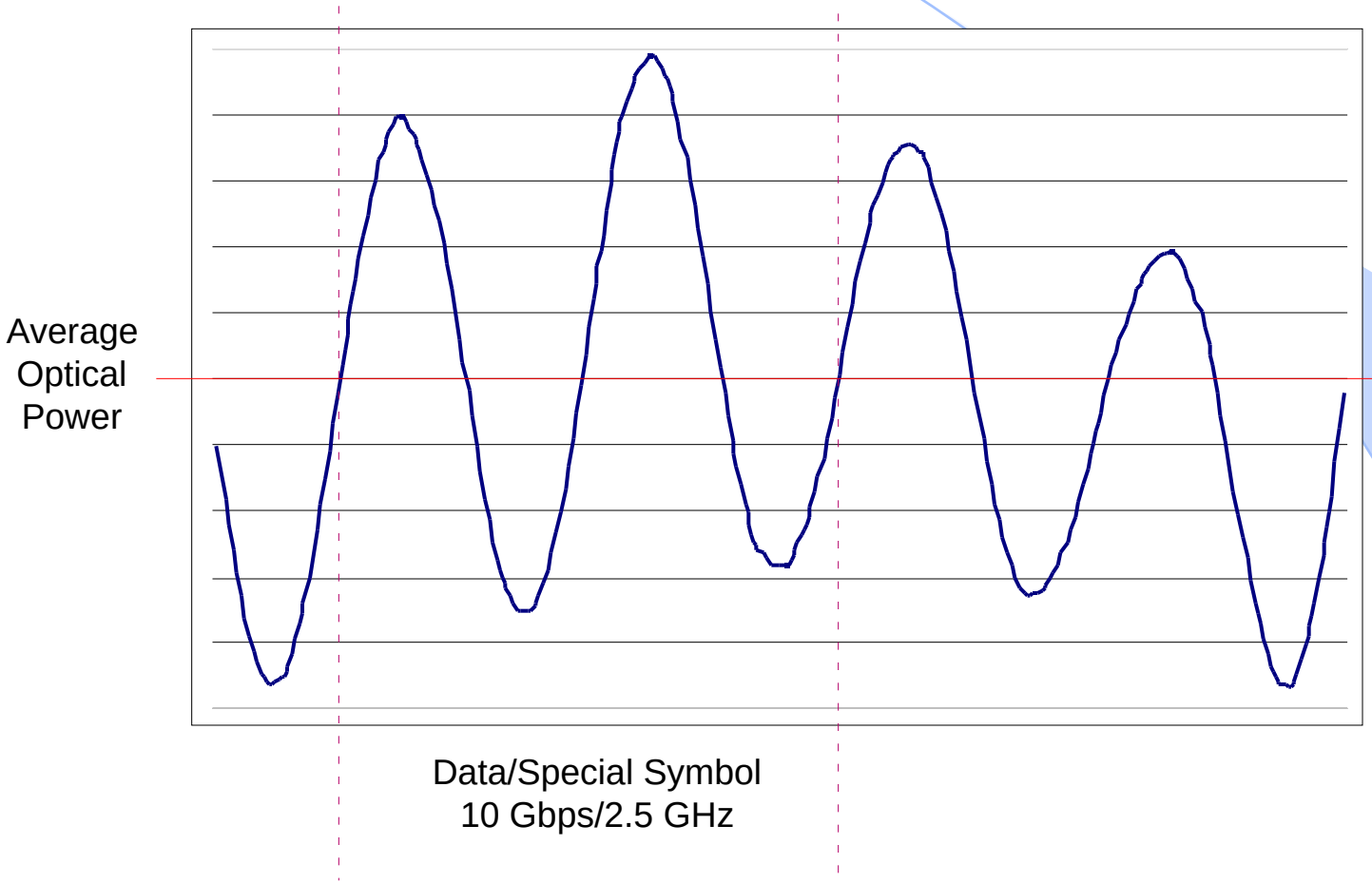
What's it look like?



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Technology Features

- Fundamental New Signaling Technology
- High-Speed Fiber-Optic Technology
- New Physical Layer
- Compatible with Existing Products/Technologies
- Telecom, Datacom WAN, LAN, SAN Applications
- Extends the life of the existing Cable Plant
- Technology applicable to Fiber, Copper, Wireless
- Coexistence with WDM
- Enables use of Gb optics at high multi-Gb rates

Signaling Qualities

- Synthesized, Multilevel, Intensity Modulation
  - Waveform synthesis/laser drive by high-speed D/A conversion
- Narrowband Frequency Spectrum
  - Approximately $f/2$ to $1.5f$
  - Significantly reduced spectrum compared to OOK (on-off keying)
- High Resistance to Dispersion and Nonlinearity
  - System is loss-limited, not dispersion-limited
- Data Transmission at 4X Baud is Feasible
- Minimal Emitter (Laser) Requirements
  - OC-48 optics yield OC-192 data rates
  - Usage of 1 GbE optics is feasible

Broad Market Potential √

- Broad set(s) of applications
- Multiple vendors, multiple users
- Balance cost, LAN vs. attached stations

- The fast growth of CPU speed and demand fueled by the Internet and Corporate networks is forcing the development of higher bandwidth LANs.
- The following applications and environments will benefit from 10 Gbps Ethernet capability:
  - High-end Backbone, Server and Gateway connectivity;
  - Higher Bandwidth for internet, multimedia, distributed processing, imaging, medical, CAD/CAM, and pre-press apps;
  - Aggregation of GbE switches;
  - Upgrade for large installed base of 10/100/100 Ethernet.

Compatibility with IEEE 802.3 √

- Conformance with CSMA/CD MAC, PLS
- Conformance with 802.2
- Conformance with 802 FR

- MAC conformance, with 10 Gbps authorized extensions
  - CSMA/CD is another story (independent of Multilevel Analog Signaling)
- New Physical Layers (PHY) for 10 Gbps operation
- 802.2 LLC interface conformance
- 802 Functional Requirements Document conformance (with the possible exception of Hamming distance)
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Distinct Identity √

- Substantially different from other 802.3 specs/solutions
- Unique solution for problem (not two alternatives/problem)
- Easy for document reader to select relevant spec

- 10 Gbps upgrade for 802.3 users
- Established benefits of the 802.3 MAC include:
  - High efficiency in full-duplex operating mode
  - Well-characterized and understood operating behavior
  - Broad base of expertise in suppliers and customers
  - Straightforward bridging between networks at different data rates
- Consistency with the 802.3 MIB for 10/100/1000 Mbps
- One PHY per media (e.g. SFF, MMF, others)
- Supplement to the existing 802.3 standard as new clauses

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Technical Feasibility √

- Demonstrated feasibility; reports/working models
- Proven technology, reasonable testing
- Confidence in reliability

- Multiple technologies are proposed:
  - Multilevel Analog Signaling (this one)
  - Parallel Optics
  - Fast Optics (~OC-192 rate)
  - Coarse WDM
- Scaling the MAC to higher speeds has been proven
- Bridging equipment which performs rate adaptation between 802.3 networks operating at different lower speeds has been amply demonstrated.
- Still a bit of work to do to fill out this item

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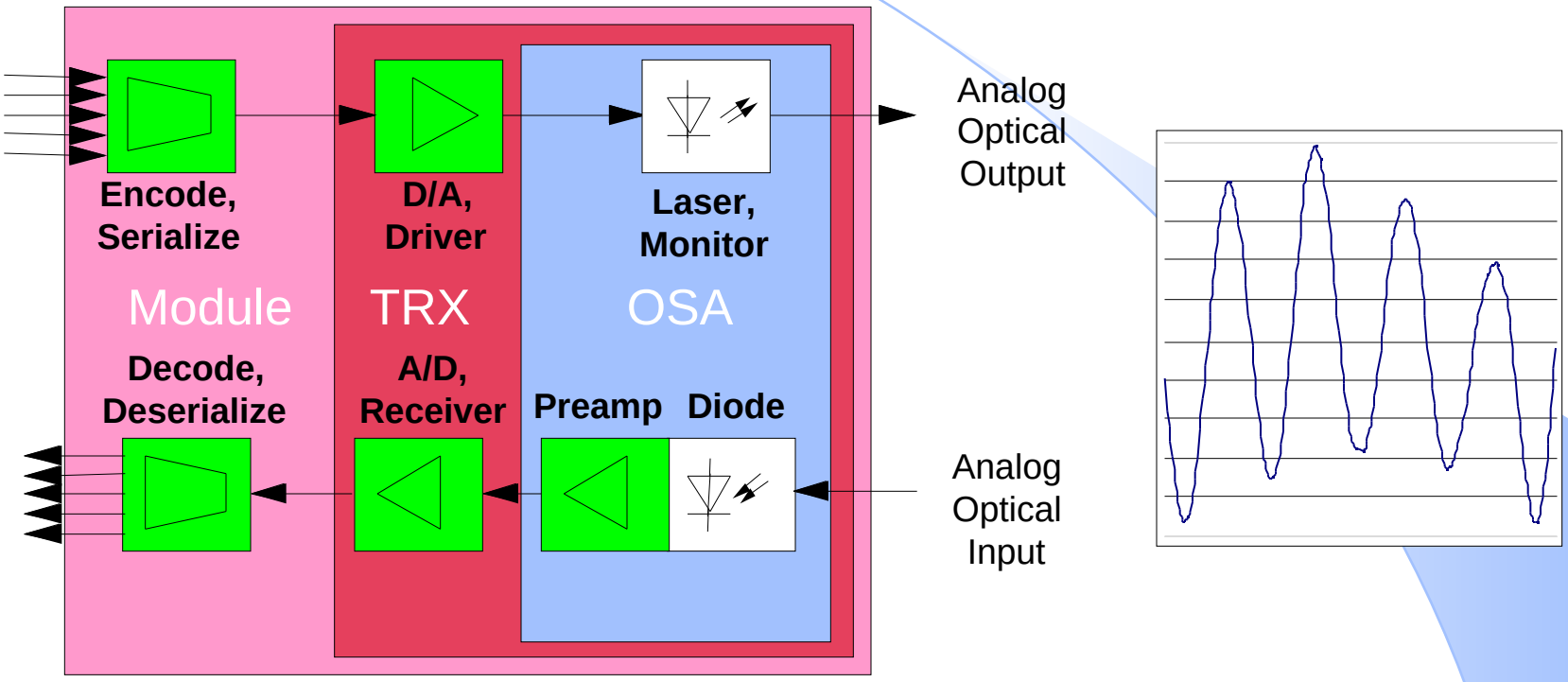
Economic Feasibility √

- Cost factors known, reliable data
- Reasonable cost for performance expected
- Total installation costs considered

- A reasonable cost increase (3X of 1000BASE-X) with a ten-fold increase in available bandwidth in the full duplex operating mode is desirable.
- Customers will in many cases be able to re-use their existing fiber that has been installed in accordance with ISO/IEC 11801. Installation costs for new fiber runs based on established standards are well known and reasonable.

Block Diagram



- Unencoded/Encoded data rate on fiber: 10 Gbps
- Fiber line rate: 2.5 GHz

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Physical Layer Evolution

- Evolutionary PHY, revolutionary signaling
  - High data rates, longer distances over existing cabling plant
- Maximize customer investment in the installed cable plant
  - MAS is Attenuation, not Dispersion limited
  - Potential to go significantly farther over MMF than 1000BASE-X
- Longer distances over existing fiber/optics
    - MMF, SMF, SW, LW, VCSEL, FP, DFB
- Higher data rates using existing optoelectronics
- Follow legacy market strategy
  - Ethernet over UTP-5, 10BASE-T, 100BASE-T, 1000BASE-T
  - Now 1000BASE-X, 10KBASE-X, (10BASE-F, 100BASE-FX ?)

MAS Physical Layer

- Multilevel Analog Signaling (MAS) PHY includes:
  - Frame Payload Interface (GMII-like)
  - Physical Coding Sublayer (PCS) (not 8B/10B)
  - Physical Media Attachment (PMA) (DAC/ADC)
  - Physical Media Dependent (PMD)
    - Includes multiple media specifications (SX, LX)
    - Optical connector independent (SC, any SFF)
  - Auto-Negotiation (optical, MAS, 1000BASE-X)

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PCS & PMA

- Physical Coding Sublayer (PCS)
  - Pre-encoded 8B/10B input (data + D/K bit)
  - Multiple bits/symbol (9), tradeoff Baud/#levels/BER
  - 4-7-7-4 code yields 784 codes for 256 data + 12 special codes
    - Ref: 8B/10B yields 1024 codes for ...
  - Error detection, special symbols, link init and synchronization
  - DC (average optical power) balanced per symbol (code-group)
- Physical Media Attachment (PMA)
  - Xmit: Conversion of code-groups to analog waveforms (DAC)
  - 4-7-7-4 code means 14 levels about average optical power
  - Zero-crossing derived clocking
  - Rcv: Conversion of analog waveforms to code-groups (ADC)

Auto-Negotiation (AN)

- New: Signal Detect-based Link Code Words
  - Not required for Multilevel Analog Signaling
  - Enables 1000/10k operation, may extend to 10 & 100 optical
  - May extend to other protocols (e.g. FC, P1394b, NGIO, FIO, etc.)
- New: MAS compensation optimizes PHY performance
  - Not strictly required, but suggested
- Old: 1000BASE-X-like AN for flow control, remote fault, etc.
- AN management compatible with existing Ethernet AN

Physical Medium Dependent

- 10kBASE-SX, LX, EX?
- Similar optical components as 1000BASE-X
  - Need to generate 2.5 GHz sinusoids
    - Could be slower with more complex coding
  - Laser linearity is important, good results with LW so far
- Same media as 1000BASE-X
- Increased distances over 1000BASE-X variants
  - 62.5 µm MMF 1300 nm > 1km
  - 50 µm MMF 1300 nm > 1km
  - 9 µm SMF 1300 nm >10 km
- NOT ignoring SW VCSELs!!! more work req'd

Related Technologies

- Cable TV optoelectronics
  - Currently use many more levels than 14
  - Very linear lasers
  - Very expensive
  - Multilevel Analog Signaling goal is the make the best tradeoffs to utilize existing components
- Analog Signaling
  - Currently in use in a few applications
    - Ethernet
    - Cell phones
    - AM Radio

Conclusion

- Multilevel Analog Signaling has the potential of exceeding the cost/performance goals of 10 GbE
- This **IS** the appropriate time to initiate a 10 Gigabit Ethernet standards activity
- Additional technology info available in a paper (didn't make the '99 OFC post-deadline cut) to be available on the IEEE 802.3 web site

➢ http://grouper.ieee.org/groups/802/3/10G_study/public/march99/taborek_2_0399.pdf

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