10G-BASE-T

Jaime E. Kardontchik
Stefan Wurster
Carlos Laber

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email: kardontchik.jaime@microlinear.com

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Introduction

This proposal takes the best parts of several proposals that preceded it. It incorporates the 4-WDM approach, to reduce the clock rate. It is compatible with sound ideas of the MAS approach, which emphasized the benefits of adding waveshaping in order to reduce dispersion in the fiber and increase the achievable link length.

The 10G-BASE-T proposal is a complete architectural proposal, in the sense that it includes all the functions needed between the MAC layer and the optical fiber, including the PCS (Physical Coding Sublayer), that was taken from another Ethernet standard: the 802.3ab or 1000BASE-T. (The "T" suffix in its name emphasizes its conceptual origin).

In order to be able to make an apples-to-apples comparison with other proposals, the 10G-BASE-T proposal is compared with another powerful complete solution, not yet formally presented, but having two popular ingredients: 8b/10b encoder/decoder + 4-WDM using a 3.125 GHz clock.

In the original 1000BASE-T approach, the 802.3ab Task Force proposed a standard that allowed the vendor to select, through autonegotiation, whether to use simple symbol-by-symbol decoding (with a coding gain of 3 dB) or sequence decoding (with a coding gain of 6 dB). The 802 did not like the idea of having what appeared as a dual-approach in a Standard. In order to eliminate this obstacle towards the approval of the Standard, the 802.3ab Task Force decided to go for the "sequence decoding" approach (to keep the same SNR at the input of the slicer as in Fast Ethernet).

The sequence decoding approach (Viterbi decoding) is computational intensive, its implementation at GHz speeds would be difficult and its main reason of existence (SNR comparison with Fast Ethernet) does not exist anymore in 10 Gigabit Ethernet. The 10G-BASE-T proposal uses the simple version of symbol-by-symbol decoding (3 dB coding gain). By using symbol-by-symbol decoding, the complexity of its PCS is similar to the one found in the 8b/10b approach, both in computational intensity and number of gates, eliminating one obstacle in this apple-to-apple comparison.

10G-BASE-T

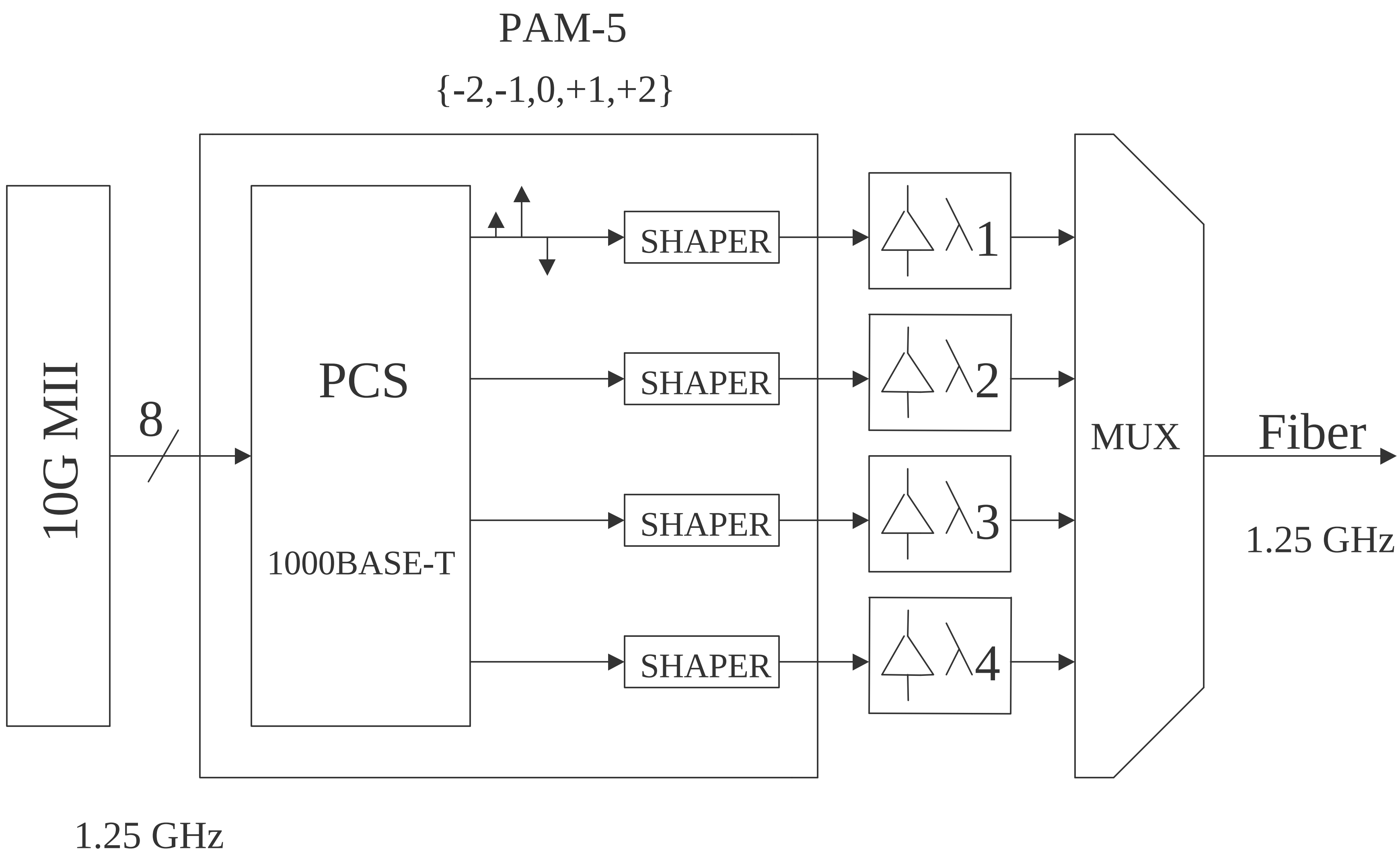
- Advantages:
  - Uses the lowest switching rate: 1.25 GHz. This simplifies the requirements on the electronics and optics.
  - Uses the PCS (Physical Coding Sublayer) from a finished Ethernet standard, 1000BASE-T, saving development time.
  - Uses the installed fiber for 1000BASE-X, characterized at 1.25 GHz.

1000BASE-T vs 10G-BASE-T

- 1000BASE-T
  - 125 MHz clock
  - GMII: 8 bit wide
  - PCS: 4 transmitters using PAM-5, with 3 dB coding gain
  - PMA: waveshaping to reduce EM emissions
  - PMD: 4 wires using cat-5 UTP

- 10G-BASE-T
  - 1.25 GHz clock
  - 10GMII: same
  - PCS: same, except no need to have Master and Slave
  - PMA: waveshaping to reduce dispersion
  - PMD: 4-WDM on 1000BASE-X optical fiber

10G-BASE-T ARCHITECTURE



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1.25 GHz vs 3.125 GHz (*)

- SNR at the input of the slicer
  - (back of the envelope comparison)

(*) 8b/10b encoder + 4-WDM

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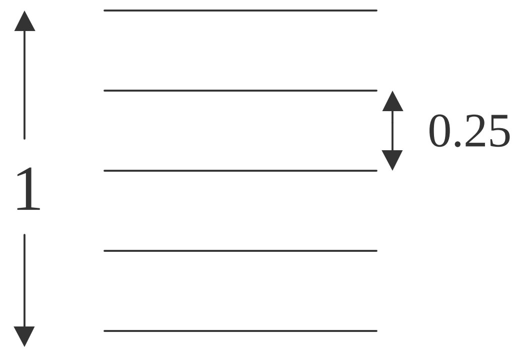
1.25 GHz vs 3.125 GHz

Bit energy = Power*time

Optical Power

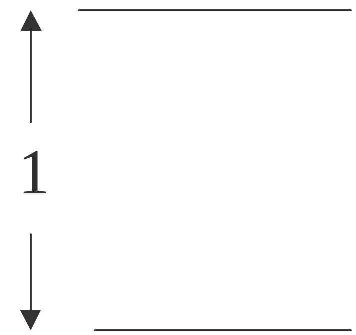


Symbol period = 0.8 nsec

Energy difference=0.25*0.8

- 7 dB

Optical Power



Symbol period = 0.32 nsec

Energy difference = 1*0.32

- 5 dB

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Receiver Front End

Assume PIN Photo Diode + Trans-Impedance Amplifier

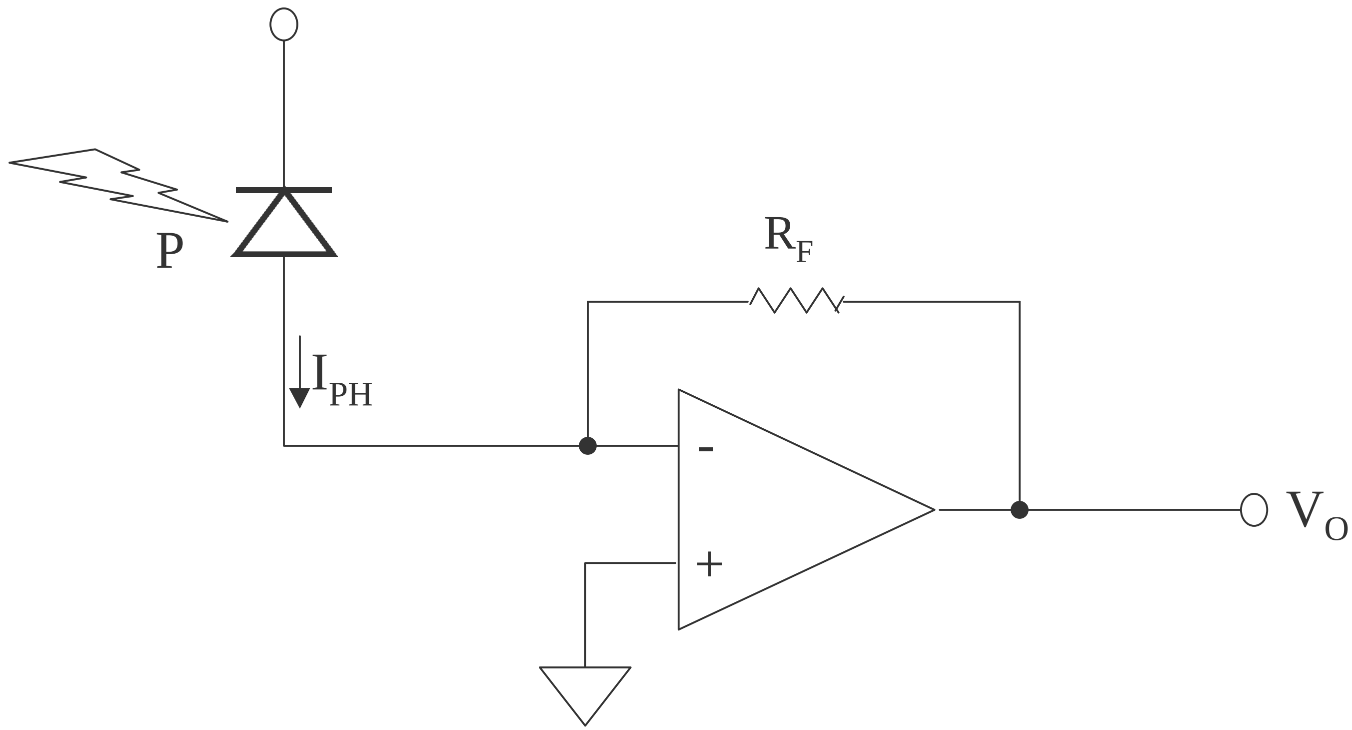

Photo Diode Current I_{PH} = Responsivity * Power

Output Voltage $V_O = I_{PH} * R_F$

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Optical SNR

- Thermal Noise Power = $(4kT/R_F) * B$
- Hence, Noise Power is proportional to the Bandwidth B

	10G-BASE-T 1000BASE-T PCS + 4-WDM	Other Approach 8B / 10B + 4-WDM
Signal Power	-7dB	-5dB
Noise Power	Same as in 1000Base-X	10log (3.125/1.25) = 4dB more

- 10G-BASE-T has a +2dB advantage in optical SNR

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Add coding gain

- Set parity bit in convolutional encoder to zero, i.e, use only the ‘EVEN’ subsets of 4D symbols. “Symbol-by-symbol” decoding is used to get a coding gain of 3 dB.
- Result: the 10G-BASE-T approach has a +5dB advantage in SNR

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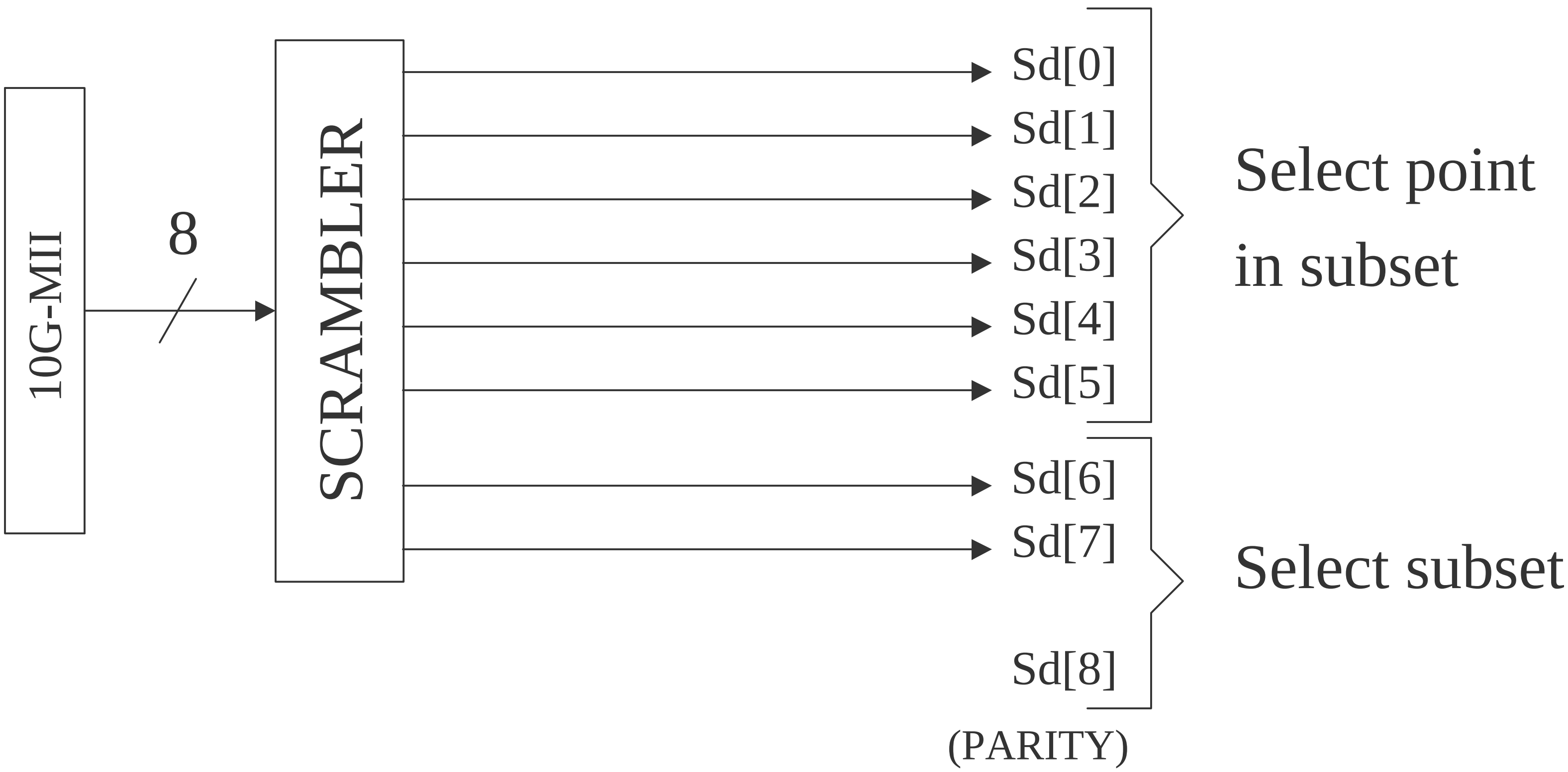
1000BASE-T PCS



Setting Sd[8]=0 selects the EVEN family of subsets (with +3 dB coding gain)

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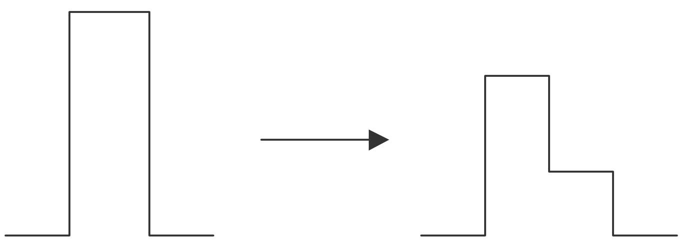
Shaper (wave-shaping)

Wave-shaping in 1000BASE-T



$$H(z) = 0.75 + 0.25 * z^{-1}$$

(adds controlled ISI)

- Wave-shaping is used to control EM emissions above 30 MHz
- 1) use digital filter:
- 2) control rise/fall time of driver

Wave-Shaping in 10G-BASE-T

$$H(z) = \; ?$$

(area of future work)

- Wave-shaping is used to reduce dispersion in the optical fiber, in order to:
- a) increase the maximum distance between stations.
- b) use cheaper fiber (multimode).

Wave-Shaping in 8b/10b+4-WDM

- Digital filtering can not be used (we would loose the main advantage : 2-level signaling)
- Rise/fall times of driver are much shorter, increasing the frequency content of the signal and, hence, the dispersion in the optical fiber

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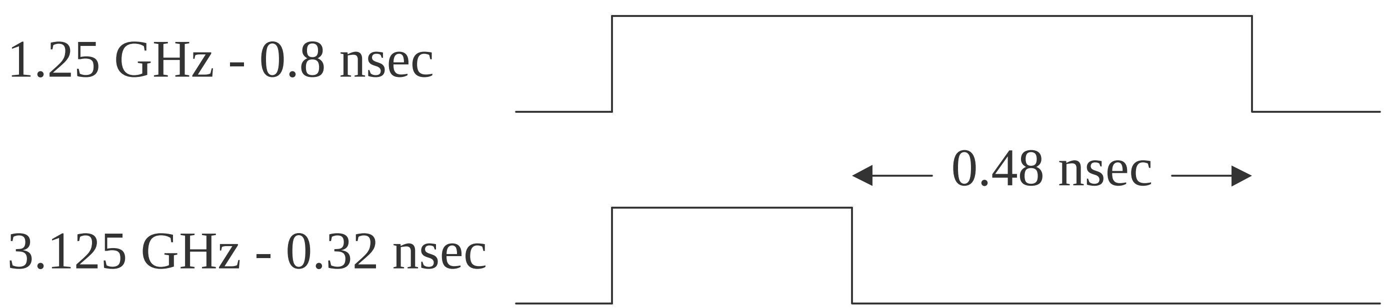
Differential Skew

- 4D symbol alignment at the receiver is needed to decode the symbols.
- Differential delay in 4-WDM is mainly due to chromatic dispersion
- It seems that small skews of a few nsec (say, less than 10 clock periods) over 1 km of fiber are achievable, at least around 1.3 um, where the group delay is flat. The 1000BASE-T PCS can deal with these differential skews.

Scrambling

- There is no baseline wandering in 10G-BASE-T (there are no wires and, hence, no need for transformers to isolate them electrically)
- Timing Recovery: Notice the large additional timing budget available for clock alignment:



Scrambling and Error Multiplication

- After the descrambler is synchronized (when the link is established) its state becomes independent of the incoming idles/data
- There is no error multiplication after synchronization: one decision error at time k*T does not propagate into another decision error at time (k+1)*T

1000BASE-T PCS+4-WDM vs 8b/10b+4-WDM

- Summarizing:
  - 10G-BASE-T @ 1.25 GHz has better SNR than 8b/10b+4-WDM @ 3.125 GHz, similar digital complexity while it runs at lower speed (lower cost technology), uses the installed fiber for Gigabit Ethernet, characterized at 1.25 GHz, and can possible be used at longer link lengths, due to its smaller dispersion in the optical fiber.

The Complete SNR Table

Architecture	SNR [1]
1000BASE-X	-1 dB [2]
8b / 10b + 4-WDM	-9 dB
10G-BASE-T - Even Coding	-4 dB
10G-BASE-T - Trellis Coding	-1 dB

[1] relative units

[2] 10log (1 * 0.8) ~ -1 dB

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Acknowledgment

- My thanks to Rich Taborek, from Transcendata, for helpful comments.

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References

- 1) IEEE Draft P802.3ab/D6.0 (in private web site of the 802.3ab (1000BASE-T))
- 2) tutorial on Trellis-Coding used in 1000BASE-T, by Jaime E. Kardontchik (can be found in private email site of the 802.3ab, titled: “rev B of 4D tutorial”, 21 August 1997)

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