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Partial Response with Bounded Running Disparity and Optional Reed Solomon Forward Error Correction

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Introduction

- This a proposal for a 100BASE-T1L PHY architecture using PAM-3 8b6T coding with partial response (PR) and bounded running disparity with two modes; a low latency mode and a burst error protection mode using RS FEC
- A low latency mode using a 16B/17B block code with PAM-3 and 8b6T at 80 MSym/s
- A burst error protection mode using a 64B/65B block code and a RS (128, 122) FEC code with PAM-3 and 8b6T at 80 MSym/s

Partial Response with Bounded Running Disparity

- curran_3dg_01_05132024 described the details of the PAM-3 8b6T code, its construction and properties
  - There is one-to-one mapping from the PR sequences to the 6T code group which eliminates error propagation
  - There is a $\sqrt{2}$ minimum distance between any two PR sequences to allow an effective SNR gain of up to 3 dB
  - The code has balanced running disparity using 6T symbols with zero disparity and pairs of 6T symbols with positive & negative disparity
- The proposal curran_3dg_02_05132024 reserved 6T symbols for control codes and idle to achieve the lowest possible latency
- In this proposal an 8N/8N+1 block code is used to encode data and idle and thus only 256 6T symbols are required for the 8b data values
  - See Lo_3dg_01_012524 for more details on the 8N/8N+1 block code

Application to 8b6T at 80 MBaud

- We propose using the following list of NND 6-tuples
  - Total of 256 NND 6-tuples
  - 86 6-tuples with disparity 0
  - 81 6-tuples with disparity 1
  - 60 6-tuples with disparity 2
  - 29 6-tuples with disparity 3
  - Note we have removed the following two 6-tuples with disparity 0:

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(+1, +1, +1, -1, -1, -1)
(-1, -1, -1, +1, +1, +1)
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- In DATA we associate each of the 256 8-bit values from the encoder with a 6-tuple having disparity not exceeding 3

Control of Running Disparity

- We have constructed our list of NND N-tuples
  - Each N-tuple in this list with positive disparity has a complementary N-tuple with negative disparity that can be generated by negating it
  - Negating an N-tuple means negating each element
  - If RD is positive, and the m-bit value from the encoder is associated with an N-tuple with positive disparity, then the N-tuple should be negated before transmission
  - If RD is zero, and the m-bit value from the encoder is associated with an N-tuple with positive disparity, then a random Boolean value should determine whether to negate the N-tuple before transmission
  - RD is recomputed after transmission of each N-tuple

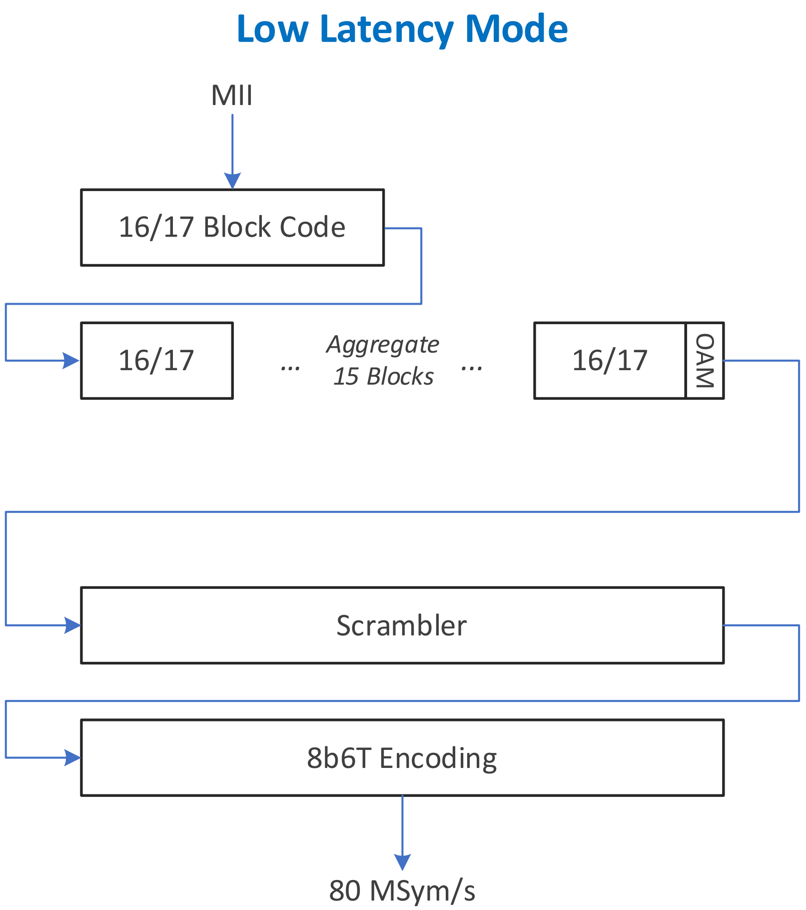
Low Latency Mode 100BASE-T1L PHY

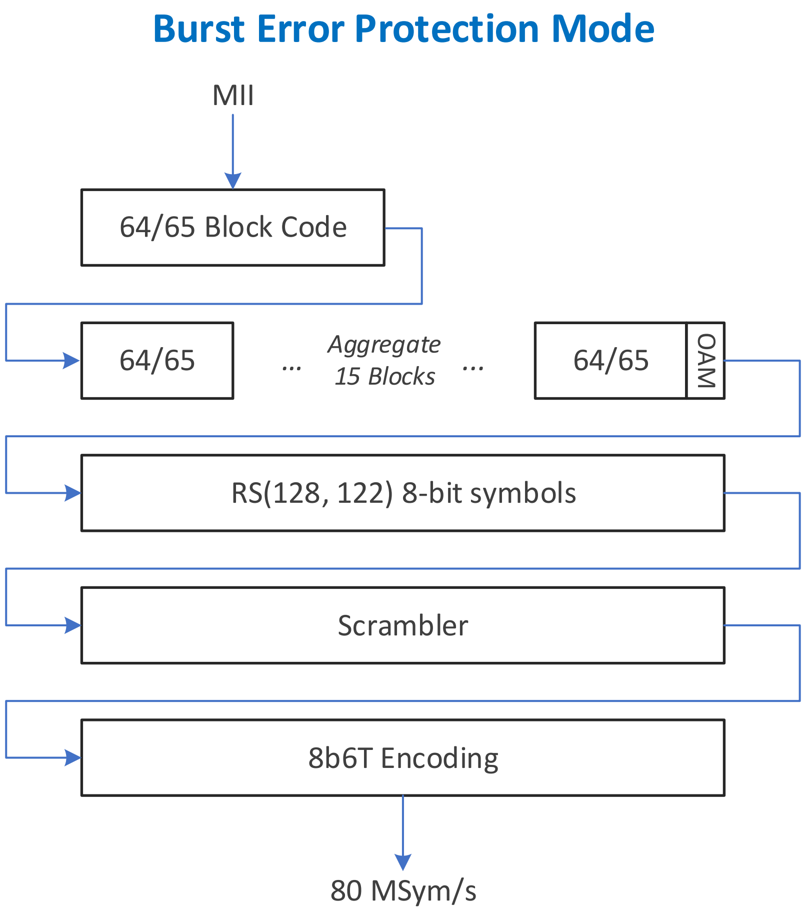
- Use PAM-3 modulation with an 8b6T code at 80 MSym/s
  - Use an 8N/8N+1 block code with N = 2: hence a 16B/17B block code
  - With L = 15 and a data block size of 15 x 16 = 240 bits
  - With L = 15 and 1 x OAM bit we have 15 x 17 + 1 = 256 bits after the block code
  - Transmitted as 16 x 8b6T symbols
  - The symbol rate is (256/240) x (6/8) x 100 = 80 MSym/s
- Tx + Rx latency of < 1 μs in this mode, implementation dependent

Burst Error Protection Mode 100BASE-T1L PHY

- Use an RS(128,122) code with a block size of 9.6 μs and 225 ns of burst error protection
  - This is the same RS FEC proposed in Tingting_3dg_14_05_2024
- Use PAM-3 modulation with an 8b6T code at 80 MSym/s
  - Use an 8N/8N+1 block code with N = 8: hence a 64B/65B block code
  - Use a Reed Solomon FEC code with a Galois Field of 8 and RS(128, 122)
  - With 3 correctable symbols for 225 ns of burst error protection
  - With L = 15 and a data block size of 15 x 64 = 960 bits and thus a block length of 9.6 μs
  - With L = 15 and 1 x OAM bit we have 15 x 65 + 1 = 122 x 8 = 976 bits after the block code
  - And a total RS block size of 128 x 8 = 1024 bits
  - Transmitted as 128 x 8b6T symbols
  - The symbol rate is (1024/960) x (6/8) x 100 = 80 MSym/s
- Tx + Rx latency of ~12 to 15 μs in this mode, implementation dependent

Block Diagram of Transmit Path for each Mode





100BASE-T1L SNR vs Ext Noise at 80 MSym/s

- Plot SNR versus external Gaussian noise
  - For values of 3, 5, 7 and 9 mV rms
  - For Insertion Loss model proposed for 802.3dg
    - For cable lengths 300, 350, 400, 450, 475 and 500 m derived from a scaled IL model
    - Scaling relative to the Insertion Loss model will be worse than a typical cable model
  - At 2.4V transmit level
  - After 1536K symbols of start-up, idle and data (~ 20000 µs)
    - Enter data after 300K symbols

100BASE-T1L SNR vs Ext Noise – PAM-3 dg IL Model

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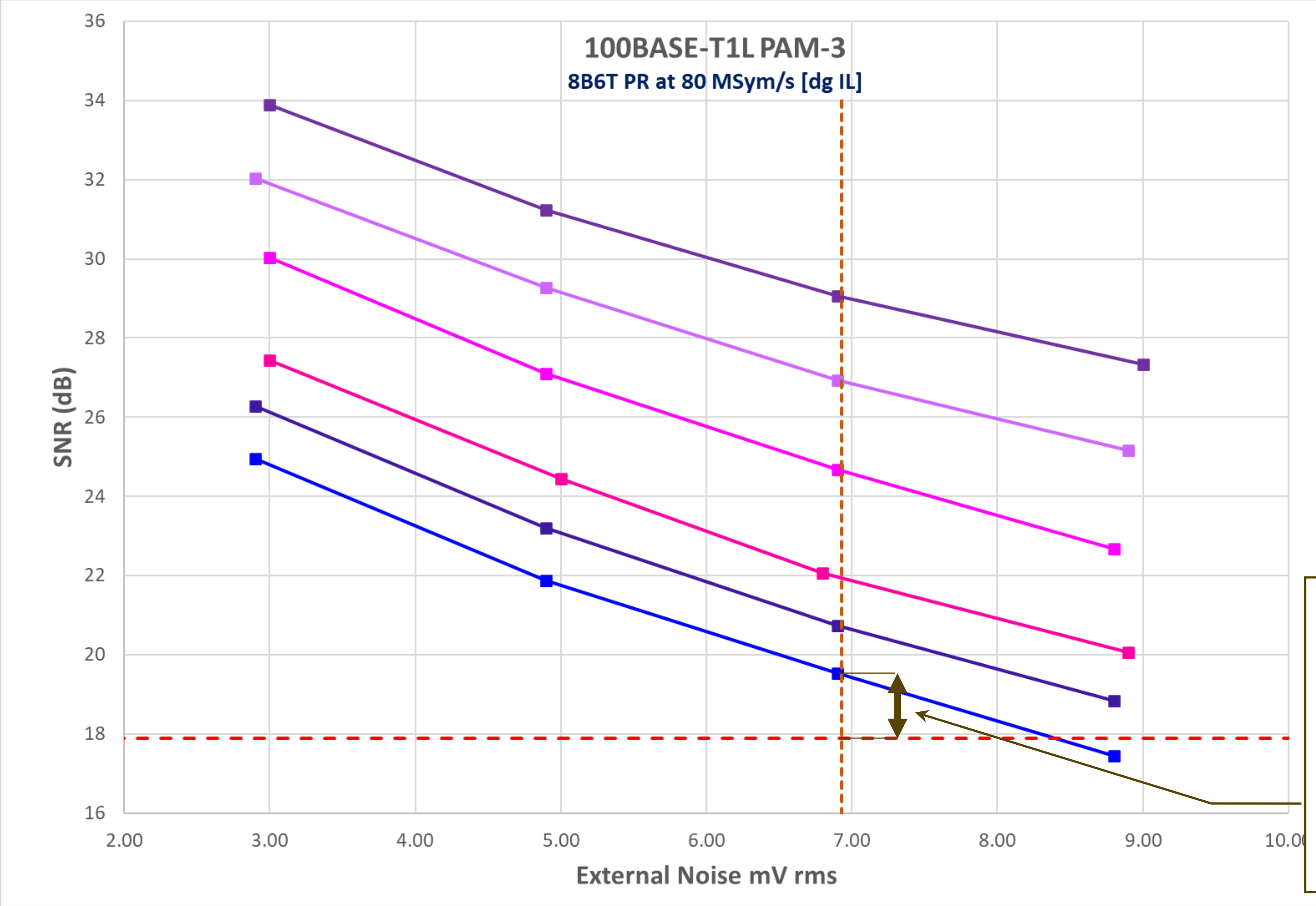
100BASE-T1L 80 MSym/s 8b6T PR: SNR versus External Noise – 2.4V Tx Amplitude



- 1.6 dB of SNR margin at 500m and 802.3dg IL model at 6.9 mV rms
- This includes the effective SNR gain using the 8b6T PR code
- It does not include additional effective SNR gain due to the RS-FEC which also improves margin for AWGN

Summary

- PAM-3 coding using 8b6T with partial response at 80 MSym/s meets the reach requirements of 500 m on the proposed link segment specifications with ~1.6 dB of SNR margin for low latency
- PAM-3 8b6T with partial response has balanced running disparity to support intrinsic safety and lowest component cost for single-pair power over Ethernet (SPoE)
- PAM-3 8b6T with partial response has the advantage of up to 3 dB of effective SNR gain due to the $\sqrt{2}$ minimum distance between any two partial response sequences
- PAM-3 has the advantage of wider spacing of decision thresholds which gives the greatest immunity to impulse noise
- Operating at 80 MSym/s allows a single PHY to support a low latency mode and a higher latency mode with RS FEC for burst error protection
- PAM-3 8b6T with partial response eliminates error propagation which is particularily important for a RS FEC to ensure a burst of errors does not propagate for longer than the number of correctable errors in the RS block

Questions ?

100BASE-T1L SNR vs Ext Noise – PAM-3 dg IL Model

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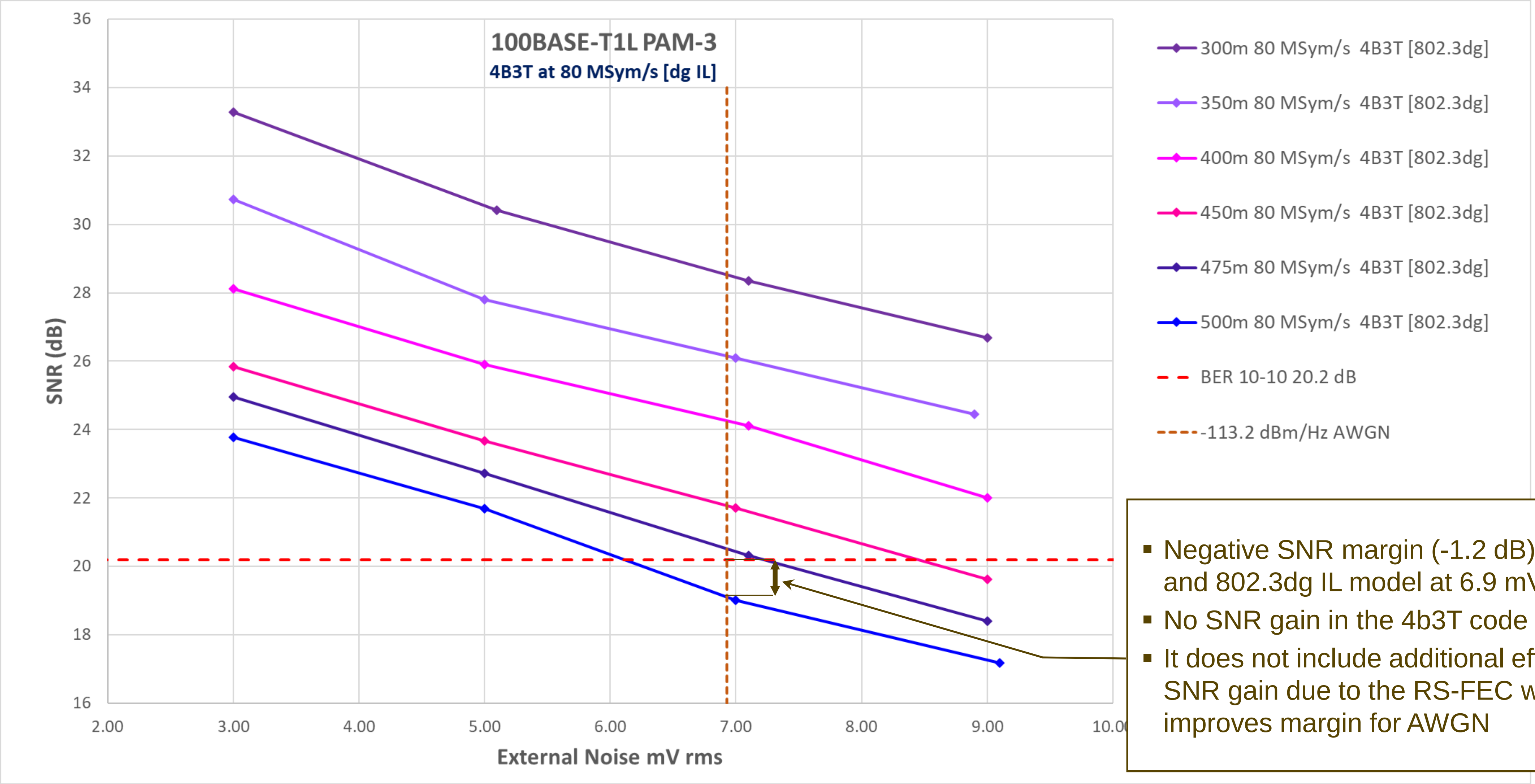
100BASE-T1L 80 MSym/s 4b3T: SNR versus External Noise – 2.4V Tx Amplitude



- Negative SNR margin (-1.2 dB) at 500m and 802.3dg IL model at 6.9 mV rms
- No SNR gain in the 4b3T code
- It does not include additional effective SNR gain due to the RS-FEC which also improves margin for AWGN