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PCS Running Disparity
Comment No. 231

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Introduction

- 100BASE-T1L uses PAM-2 during training
  - PAM-2 has a greater SNR than PAM-3 and thus an advantage during start-up and blind acquisition as it is easier to open the eye and lock the descrambler
  - A table of 16 possible non-negative disparity (NND) 4b6B PAM-2 6-tuples are used with a scheme to ensure control of running disparity and randomization of the transmitted signal
    - The PCS Transmit function uses bits $Sd_n[3:0]$ to select the NND code-group; a balanced code-group is generated by transmitting either the NND code-group or the inverse of the NND code-group, based on the current running disparity
    - This scheme is described in section **190.3.4.3 4B6B encoding** of the draft standard
- The number of PAM-2 NND 6-tuples used during training is 16, and is much less than the 256 PAM-3 NND 6-tuples used during normal operation
  - This results in some spurs in the spectrum of the transmitted signal during training
  - And in turn a different set of DFE and echo canceller coefficient in training compared to data
    - The PHY Control state diagram (Figure 190–18) includes a PAM3_TUNING state to allow for the adjustment of the coefficients after we transition from PAM-2 to PAM-3
  - The results presented to date appear to show that neither of the above is a significant problem
- However, there is a difference between the running disparity bound during PAM-2 training (± 7) and normal operation (± 5)

PAM-2 4b6B NND Code-Groups

- Table 190–8 lists the 4b6B NND code-groups used in PAM-2 training

Table 190–8—4B6B NND code-groups

Sdn[3:0]	$\{TA_n, TB_n, TC_n, TD_n, TE_n, TF_n\}$
0000	-1 1 -1 1 -1 1
0001	-1 -1 1 1 -1 1
0010	-1 1 1 1 1 1
0011	1 -1 1 -1 1 1
0100	-1 1 -1 1 1 -1
0101	1 1 1 -1 1 -1
0110	-1 1 1 -1 -1 1
0111	-1 1 -1 -1 1 1
1000	1 1 1 1 -1 -1
1001	-1 -1 -1 1 1 1
1010	-1 -1 1 -1 1 1
1011	-1 -1 1 1 1 -1
1100	1 1 -1 1 1 -1
1101	-1 1 1 -1 1 -1
1110	-1 1 1 1 -1 -1
1111	1 1 -1 -1 1 1

The entry [0010] = [-111111] has a disparity of 4

Bin Row	Sd_n [3:0]	$\{TA_n$	TB_n	TC_n	TD_n	TE_n	$TF_n\}$	Pattern	Disparity	Base_3 Index	In 8b6T
0	0000	-1	1	-1	1	-1	1	-+-+-+	0	182	**No**
1	0001	-1	-1	1	1	-1	1	--++-+	0	74	Yes
2	0010	-1	1	1	1	1	1	-+++++	4	242	**No**
3	0011	1	-1	1	-1	1	1	+-+-++	2	548	Yes
4	0100	-1	1	-1	1	1	-1	-+-++-	0	186	Yes
5	0101	1	1	1	-1	1	-1	+++-+-	2	708	Yes
6	0110	-1	1	1	-1	-1	1	-++--+	0	218	Yes
7	0111	-1	1	-1	-1	1	1	-+--++	0	170	Yes
8	1000	1	1	1	1	-1	-1	++++--	2	720	Yes
9	1001	-1	-1	-1	1	1	1	---+++	0	26	**No**
10	1010	-1	-1	1	-1	1	1	--+-++	0	62	Yes
11	1011	-1	-1	1	1	1	-1	--+++-	0	78	Yes
12	1100	1	1	-1	1	1	-1	++-++-	2	672	Yes
13	1101	-1	1	1	-1	1	-1	-++-+-	0	222	Yes
14	1110	-1	1	1	1	-1	-1	-+++--	0	234	Yes
15	1111	1	1	-1	-1	1	1	++--++	2	656	Yes

Table: showing the pattern, disparity and base_3 index for each row

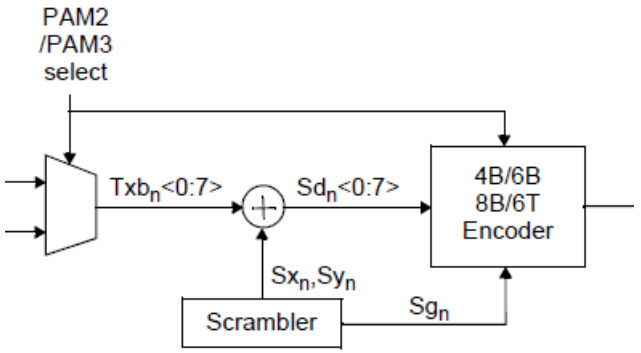
Range of Running Disparity in Training and in Data

- Range of Running Disparity
  - The range of running disparity for PAM-3 8b6T is ± 5
    - For 8b6T data the running disparity bound at the 6-tuple boundary is ±3
    - We do have some zero disparity codes starting with (+ + and (– –
      - E.g. (+ + – – – +) or (– – + – + +); 8b6T does not use the (+ + + – – –) or (– – – + + +) codes
    - Thus, the instantaneous disparity can be in the range ± 5
  - The range of running disparity for the PAM-2 training is ± 7
    - All but one of the NND 4b6B 6-tuples have a disparity of 0 or 2, these would result in running disparity bound at the 6-tuple boundary of ±2
    - However, the single NND 6-tuple with disparity 4 means running disparity bound at the 6-tuple boundary is ±4
    - And as there is a zero disparity code (+ + + – – –) the instantaneous disparity can be ± 7
    - So we can have sequences of 7 +'s or 7 –'s in a row, which is not good for timing
- We should have the same disparity bound during training and normal operation
  - This can easily be achieve by replacing the code with a disparity of 4 with a code of disparity 2
  - So replace the 6-tuple (– + + + + +) for entry [0010] in Table 190-8 with the 6-tuple (– + – + + +)

- **8b6T has 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

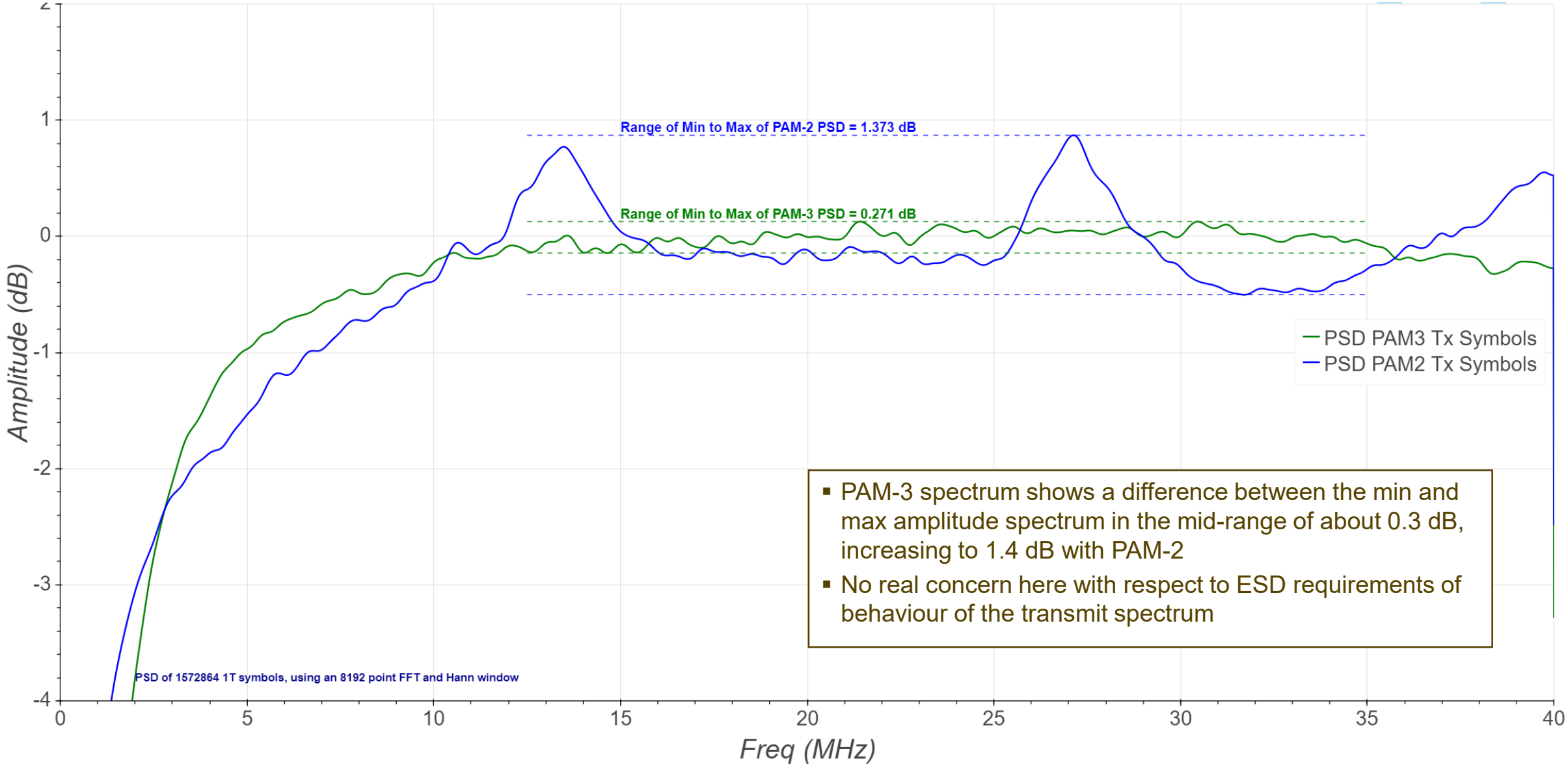
Calculation of the Amplitude Spectrum

- The amplitude spectrum of the PAM-3 8b6T and PAM-2 4b6B symbols are calculated using the Welsh method with overlapping segments
  - Using 262144 6-tuples
    - This is 1572864 1T symbols, ~20 ms time duration
  - Using an 8192 point FFT and Hann window
  - Identical data set used for PAM-3 and PAM-2
    - A test signal is generated in the same way as the refresh signal by setting all of the bits of each transmit octet $Txb_n<0:7>$, (shown in Figure 190–4), to zero
    - Each transmit octet is then scrambled and converted into a code-group consisting of 6 PAM-2 or 6 PAM-3 symbols



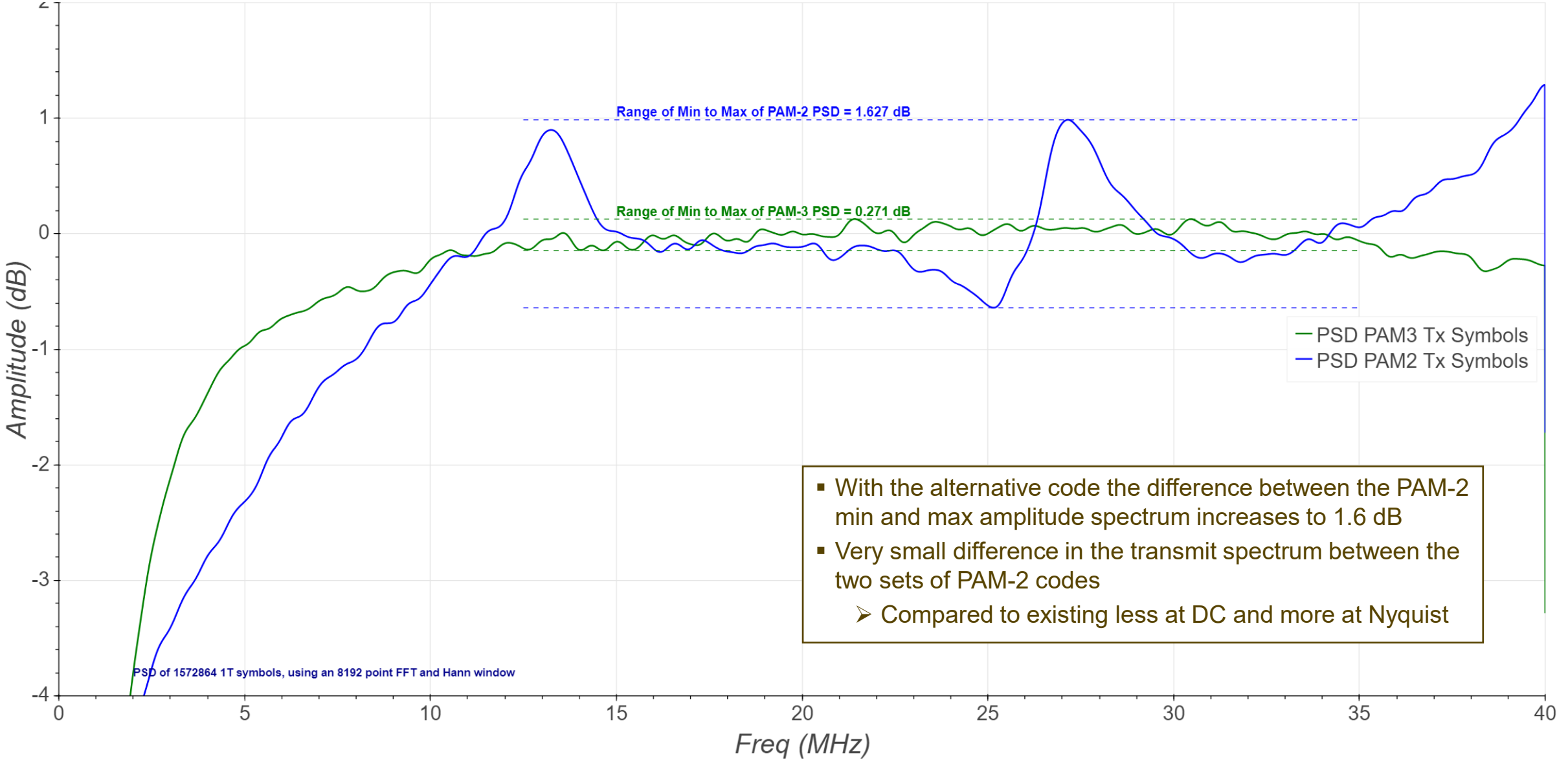
- Do not average multiple spectrum
  - Spectrum results are presented for this set of 262144 scrambled octets

Spectrum of Existing PAM-2 and PAM-3 Symbols



- PAM-3 spectrum shows a difference between the min and max amplitude spectrum in the mid-range of about 0.3 dB, increasing to 1.4 dB with PAM-2
- No real concern here with respect to ESD requirements of behaviour of the transmit spectrum

Spectrum of PAM-2 4b6B–Swap (– + + + + + +) → (– + – + + + +)



- With the alternative code the difference between the PAM-2 min and max amplitude spectrum increases to 1.6 dB
- Very small difference in the transmit spectrum between the two sets of PAM-2 codes
  - ➢ Compared to existing less at DC and more at Nyquist

Summary

- The existing table of 4b6B NND code-groups for PAM-2 training result in a difference between the running disparity bound during PAM-2 training (+/-7) and normal operation (+/-5)
- Running disparity was added to 10BASE-T1L and 100BASE-T1L to support Intrinsically Safe applications
  - Without running disparity the diodes in the system would clamp and introduce non-linearities
  - A worse running disparity bound in training could result in increased non-linearity
- The existing PAM-2 table results in longer runs of 1's or -1's in training than during normal operation
  - We used PAM-2 during training to aid start-up, but chose a set of codes that is worse for timing
- As there are many other PAM-2 codes available to use with a disparity of 2, this difference in running disparity bound is unnecessary
- Comment 231 proposes a resolution to this issue by replacing the 6-tuple [-1 1 1 1 1] for entry [0 0 1 0] in Table 190-8 with the 6-tuple [-1 1 -1 1 1]

Questions ?