Scrambler Choices to Meet Emission Requirement for 1000BASE-T1

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Outline

- Peak emission, measured on100KHz bandwidth is bounded by CISPR25 testing requirements and industry set levels.
- While scramblers are used to reduce peak emission, it was shown in chini_3bp_01_0714 that scramblers with higher order polynomials produce higher peak emission than some lower order ones.
- *N*-bit scramblers allow any sequence of *N* bits including some correlated patterns. Longer runs of correlated signal generate larger peak emission. Similarly, very short scramblers have correlation due faster repetition. A good scrambler choice should avoid both extremes.
- Scrambler size and mapping are optimized for minimizing peak emission given 2D-PAM3 modulation for 1000BASE-T1.
- The Master/Slave scramblers are verified to train DSP both in HDX and FDX operations.

TX PSD Peak Guide Line Derivation

TX PSD Peak Guide Line (dBm/Hz) = ***Peak Emission Limit*** (dBm/Hz) – ***Emission Transfer Function*** (dB)

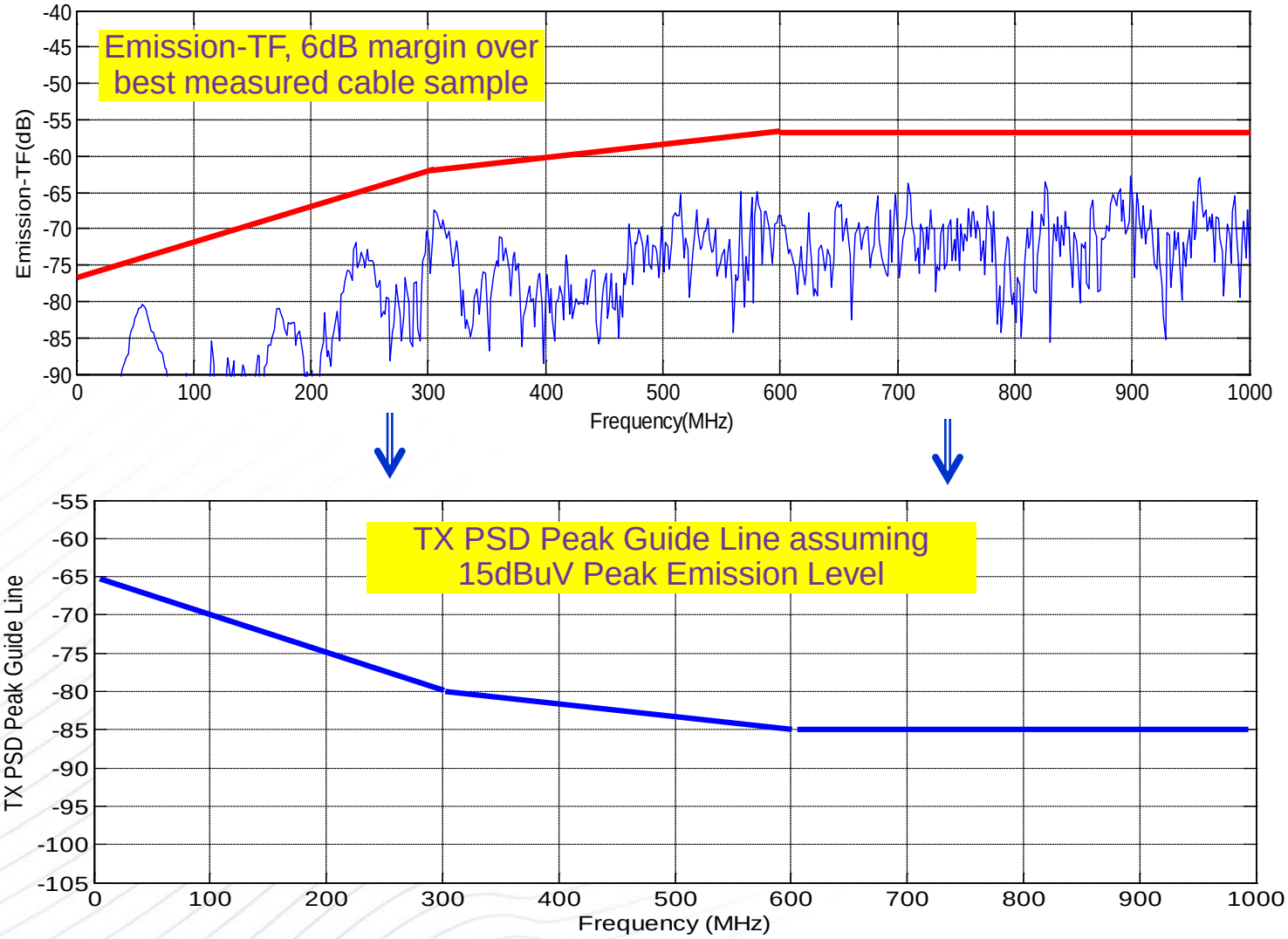
Peak Emission Limit (dBm/Hz) = 15 (dBuV) – 157 = -142 (dBm/Hz)

Assumed industry limit

Convert dBuV to dBm/Hz given 100KHz measurement bandwidth

Emission Transfer Function (dB) measured and defined per “tazebay_3bp_01a_0113.pdf“ is a measure of differential (transmitted signal) to common mode (emission) conversion using strip lines.

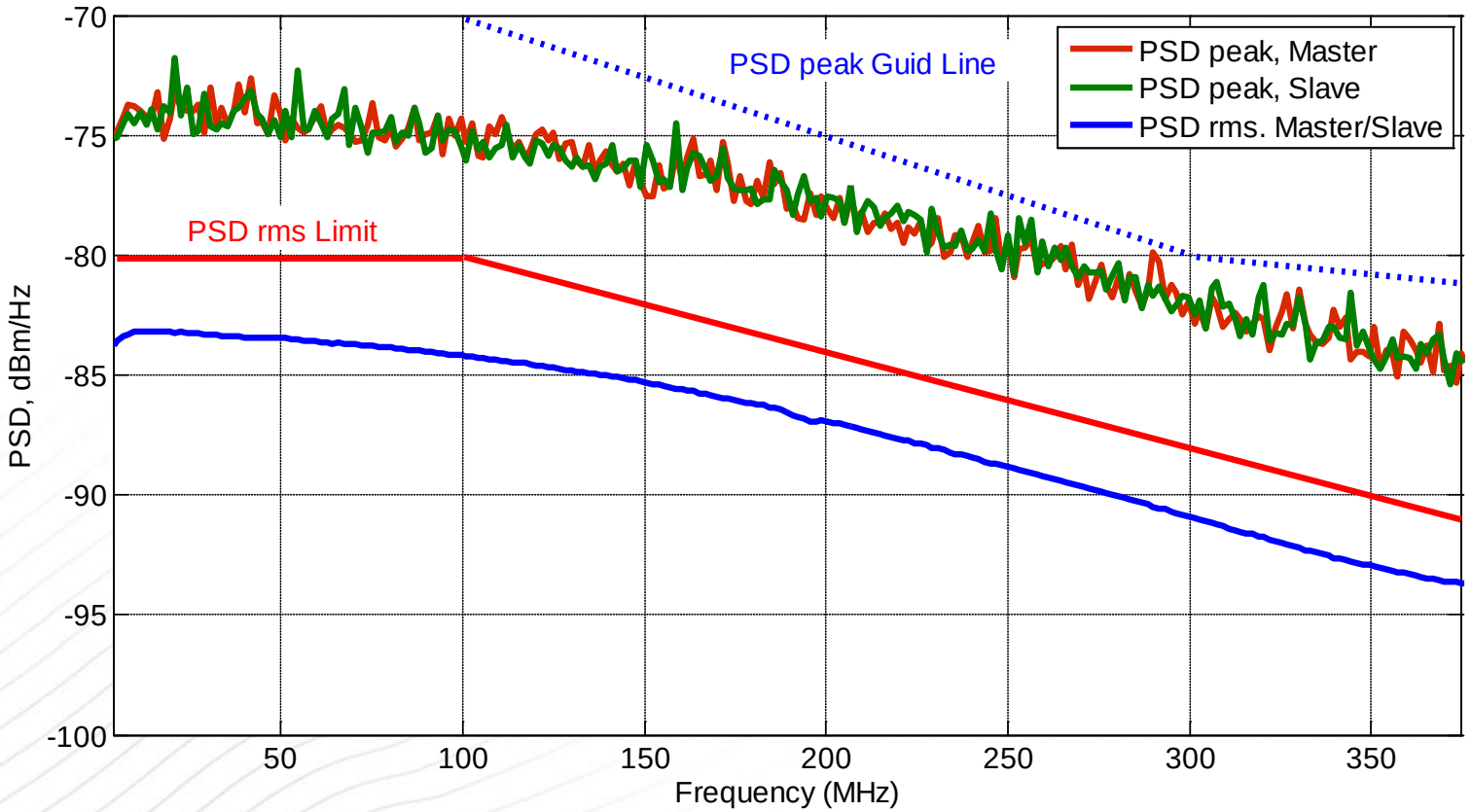
TX PSD Peak Guide Line



Measurement Set-up and Assumptions

- An arbitrary Waveform Generator (AWG) and a Spectrum Analyzer used to generate and measure TX PSD under various conditions.
- TX Voltage of 1Vpp assumed at MDI.
- TX PSD shaping of $(0.75 + 0.25\ Z^{-1})$ was applied.
- Baud rate of 750Msps assumed.
- Every three bits of scrambler assigned to a 2D-PAM3 symbol with gray mapping.
- TX PSD peak was compared against PSD Peak Guide Line for different scrambler sizes.
- Effect of un-scrambled parity bits in FEC is measured.
- Effect of 80/81 Idle code is measured.

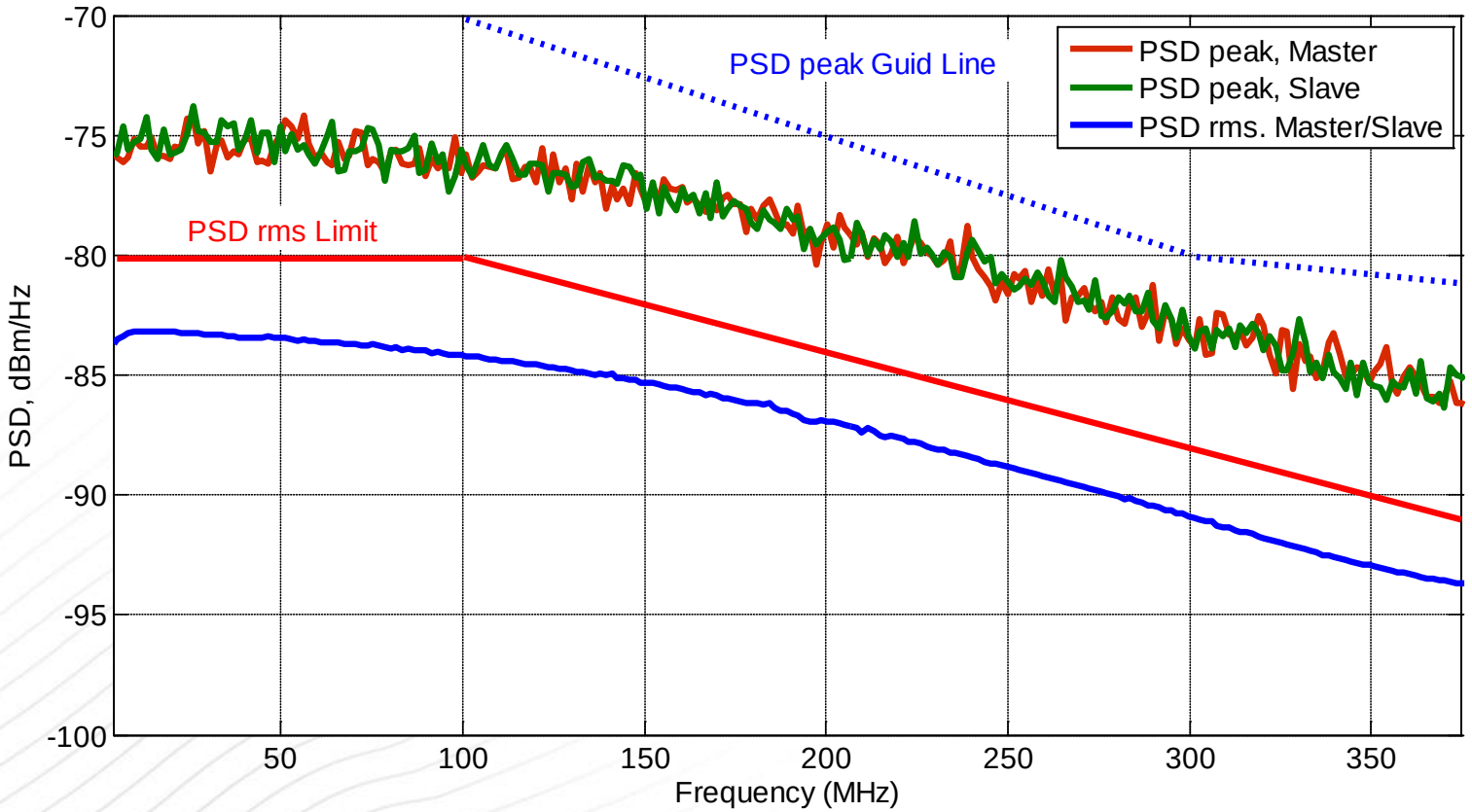
TX PSD Peak: 17-bit Scramblers after FEC, zero data



Master Scrambler Polynomial: $X^{17}+X^{6}+1$

Slave Scrambler Polynomial: $X^{17}+X^{11}+1$

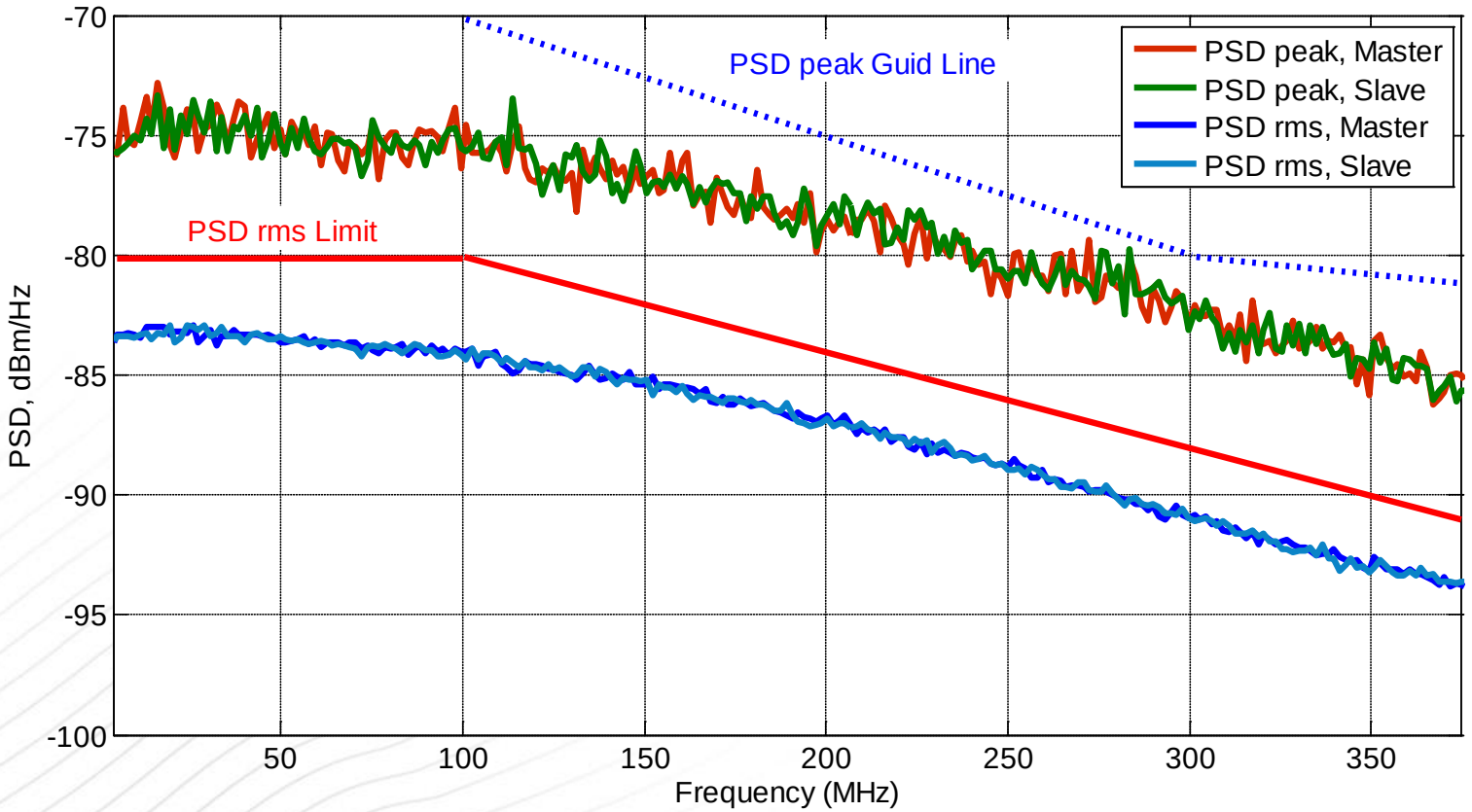
TX PSD Peak: 15-bit Scramblers after FEC, zero data



Master Scrambler Polynomial: $X^{15}+X^{4}+1$

Slave Scrambler Polynomial: $X^{15}+X^{11}+1$

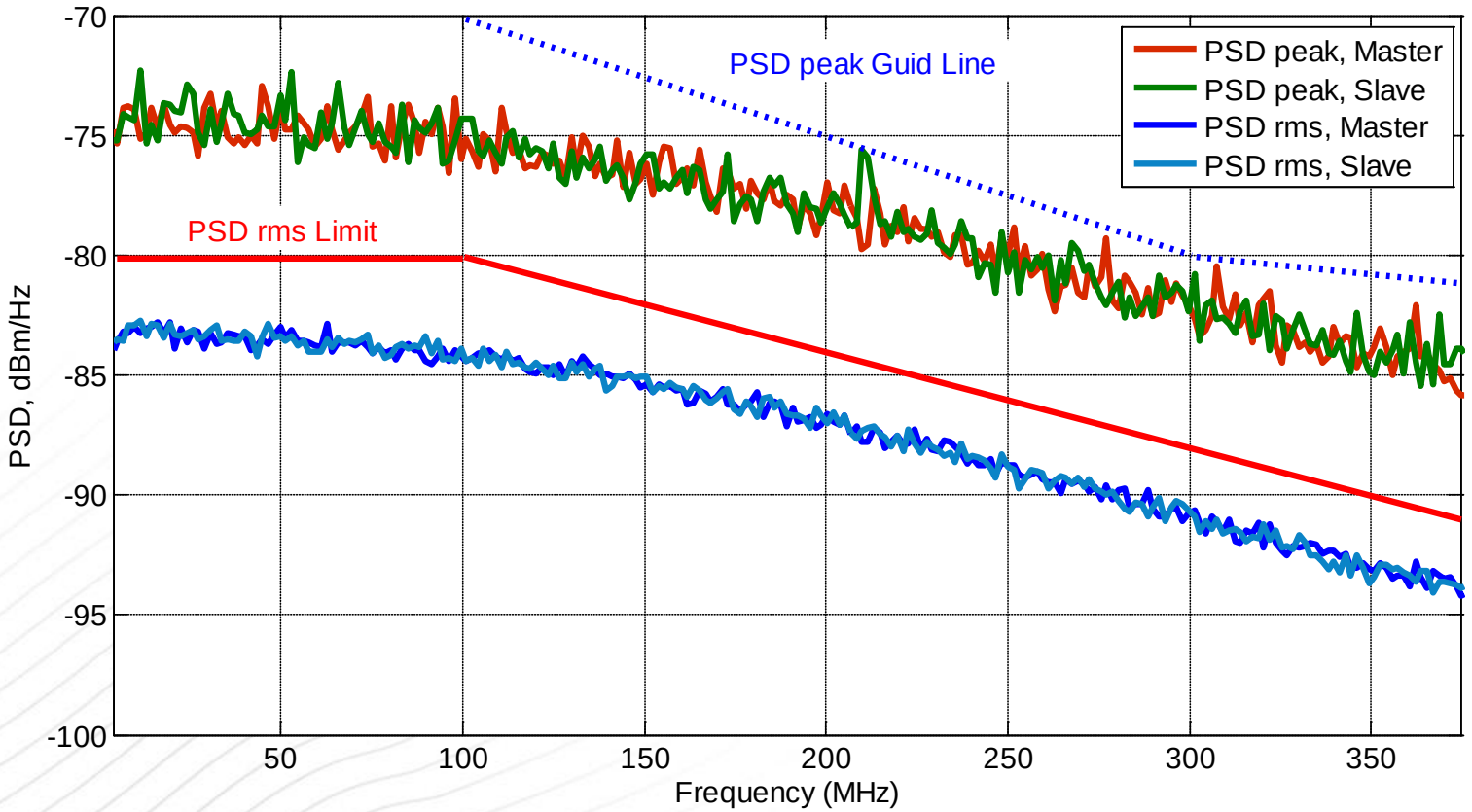
TX PSD Peak: 15-bit Scramblers before FEC, zero data



Master Scrambler Polynomial: $X^{15}+X^{4}+1$

Slave Scrambler Polynomial: $X^{15}+X^{11}+1$

TX PSD Peak: 15-bit Scramblers before FEC, 80/81 Idle



Master Scrambler Polynomial: $X^{15}+X^{4}+1$

Slave Scrambler Polynomial: $X^{15}+X^{11}+1$

80/81 Idle Pattern:

1_00001010_10001010_01001010_11001010_00101010_10101010_01101010_11101010_00011010_10010010

Other considerations for scrambler selection

- TX PSD should meet defined PSD rms limit.
- Need to have low cross correlation between Master and Slave scramblers in order to a robust echo cancellation in full duplex operation.
- Need to have a good auto correlation to resolve ISI and Echo given 15m cable length.
- No cross talk cancellation required (Single pair communication).

Computer Simulations for 1000BASE-T1 channels confirmed proper training of DSP in full duplex operations using 17-bit and 15-bit scramblers when compared to 33-bit scramblers.

Killer Packets?

- Probability of having a random data sequence matching the 15-bit scrambler sequence is (1/2)^ (2^15-1) which is practically zero.

- Probability of having a match between scrambler and data sequence in a shorter length exists for **any scrambler** design and need to be addressed in receiver. For example the probability of having a match of length 60 bits is 8.7e-19 which takes more than 48 years to happen with baud rate of 750MHz. A match half this length (30 bits) may happen every second!

- Killer packets are discussed in the past for 100BASE-TX which uses a 11-bit scrambler over two pairs. Existing 100BASE-TX receivers are designed to survive killer packets. Killer packets do not kill anymore!

Summary

- Various scrambler sizes and polynomials studied for 1000BASE-T1. Two 15-bit scramblers shown in this document are seen to pass peak emission requirement and able to train system in full duplex format.

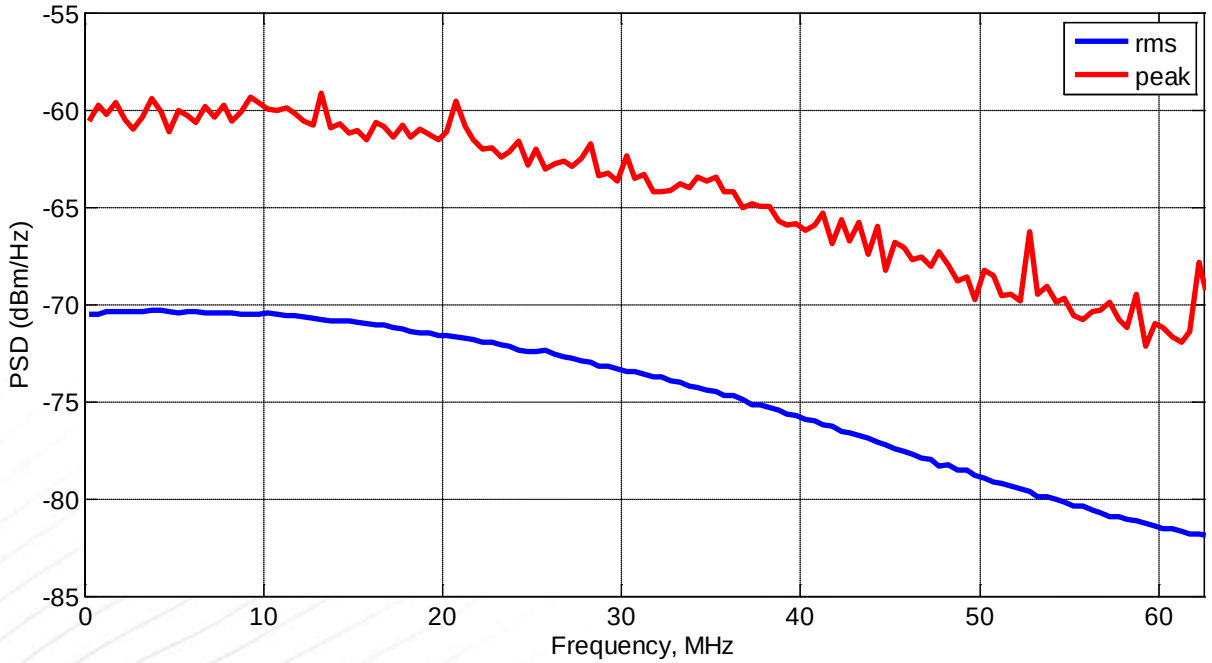
- It is proposed that the following 15-bit polynomials are used for scrambling in Idle and Data modes.
  - **Master Scrambler Polynomial : $X^{15}+X^{4}+1$**
  - **Slave Scrambler Polynomial : $X^{15}+X^{11}+1$**

- The suggested 15-bit scrambler polynomials are expected to improve peak emission by up to 3dB as compared to 33-bit scramblers and even more when compared to a 58-bit scrambler.

Appendix

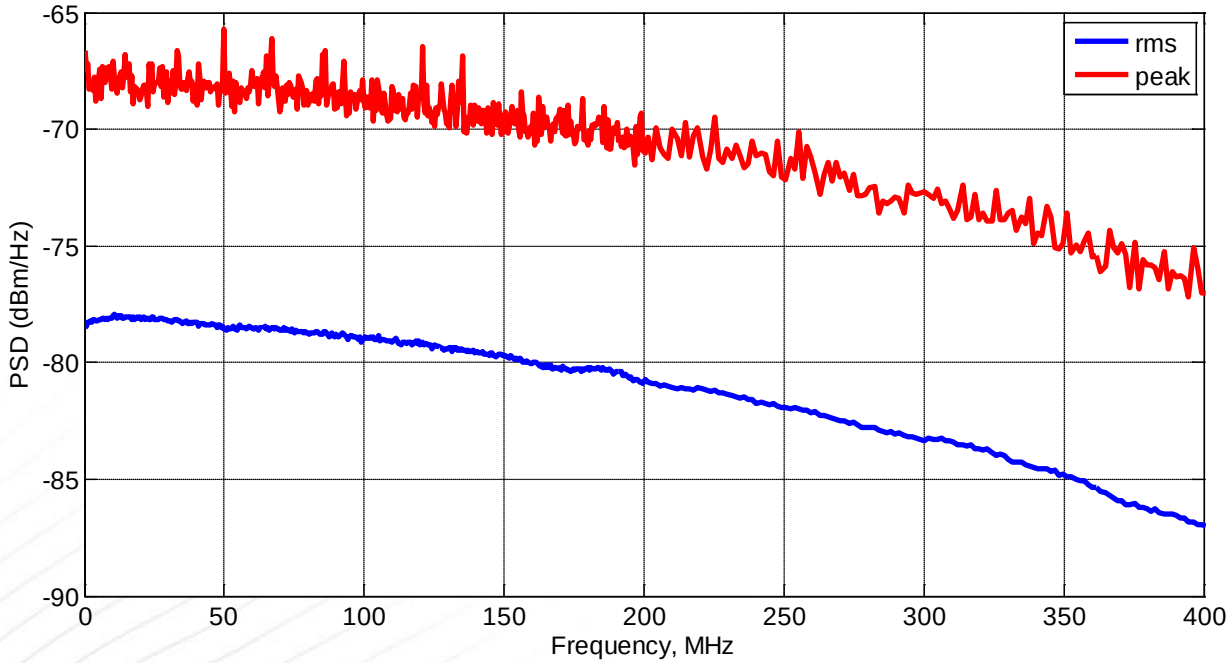
Earlier reported measurements on 1000BASE-T and 10GBASE-T

1000BASE-T: Forced Master Idle



- Peak PSD values measured for 1000BASE-T in forced master mode (PAM3 with 33bit scrambler) on 100KHz RBW are seen larger than rms by more than 10dB.

10GBASE-T: Test Mode 1 (PAM2 wo/THP)



- Peak PSD values measured for 10GBASE-T in test mode 1 (PAM2 without THP) and on 100KHz RBW are seen larger than rms by more than 10dB. This mode uses PRBS 33 training pattern (33bit scrambler).