Time-domain simulation for different AWGN levels

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Introduction

- AWGN level with PSANEXT and PSAFEXT for only 100m 100BASE-T1L disturbers is calculated in the same way as George did in zimmerman_3dgah_01a_01292024.
- AWGN level achieved with slightly modified method, which considers baud rate dependent corner frequency and roll-off for TX PSD and Nyquist averaging bandwidth, is also discussed for comparison.
- Time-domain simulations using PAM3 and PAM4 with different AWGN levels are presented.

AWGN level estimation

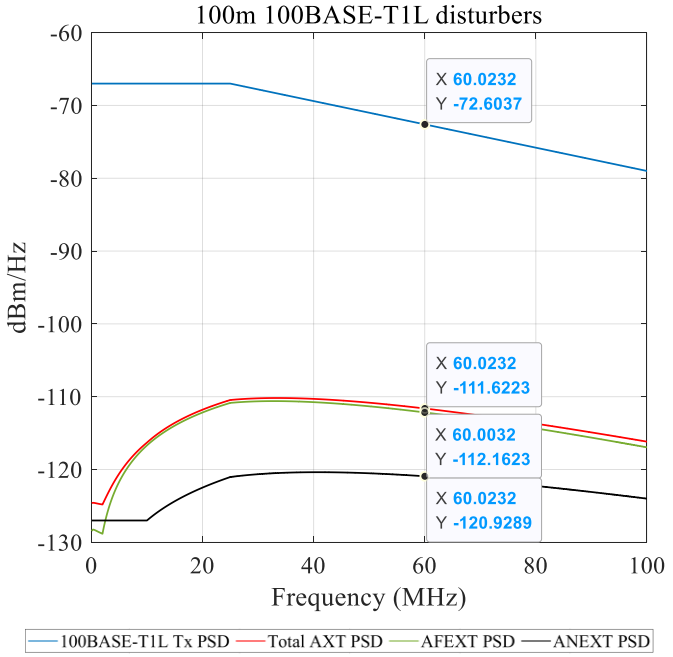
- In the case of single noise source, AWGN level estimation (zimmerman_3dgah_01a_01292024) for only 100BASE-T1L or mixed 10BASE-T1L and 100BASE-T1L disturbers can be summarized as following:
  - Step1: Assume Tx PSD for 100BASE-T1L, by referring to 10BASE-T1L Tx PSD with proper frequency scaling.
  - Step2: Obtain AXT PSD contributed by each type of disturbers, by subtracting the corresponding AXT from each Tx PSD. Only for mixed disturber case, each Tx PSD is reduced by 3dB to account for fewer disturbers.
  - Step3: AWGN level for different symbol rates is achieved by averaging the combined AXT PSD over 60MHz at 75MBaud and then include frequency scaling of 10log10(f_{baud}/75).
- The three-step method gives a closed form of AWGN level, makes time-domain simulation easier. We may also try the following to compare AWGN level difference:
  - Original Tx PSD has considered frequency scaling for only the flat PSD level. If corner frequency and roll-off for different symbol rates are also taken into account, the resulted Tx PSD may be expressed as:

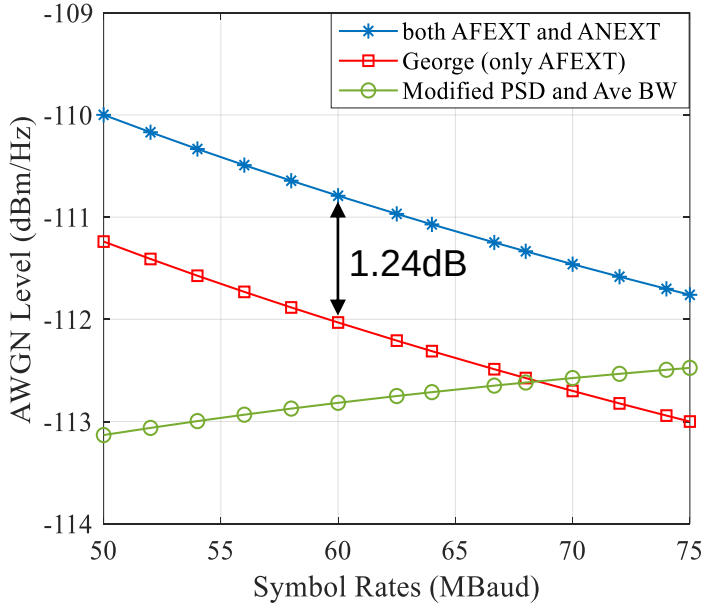
$$\mathrm{TXpsd}(f) = \begin{cases} -57 - 10log_{10}\left(\frac{f_{\mathrm{baud}}}{7.5\mathrm{MHz}}\right)\mathrm{dBm/Hz}, & 0 < f < \frac{f_{\mathrm{baud}}}{3} \\ -57 - 10log_{10}\left(\frac{f_{\mathrm{baud}}}{7.5\mathrm{MHz}}\right) - \frac{7.5\mathrm{MHz}}{f_{\mathrm{baud}}} * 1.6 * \left(f - \frac{f_{\mathrm{baud}}}{3}\right)\mathrm{dBm/Hz}, & \frac{f_{\mathrm{baud}}}{3} \le f < 125\mathrm{MHz} \end{cases}$$

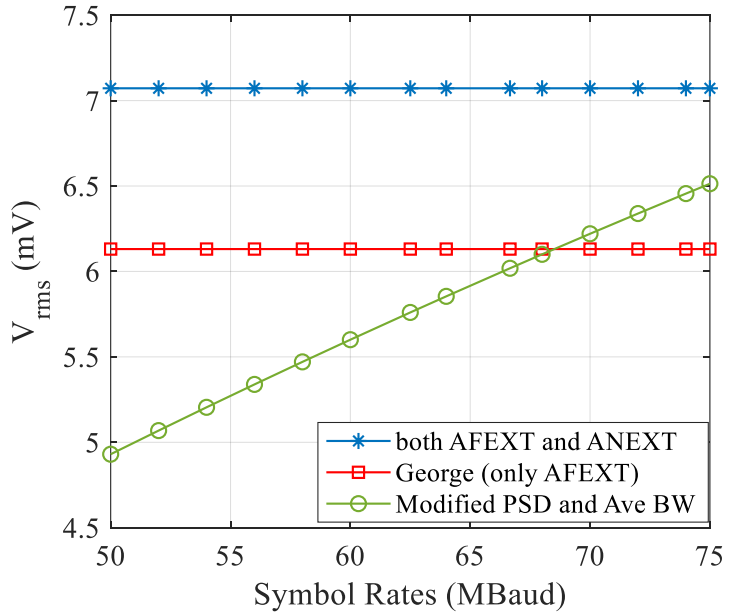
  - For each baud rate, AWGN level is calculated by averaging the total AXT PSD over Nyquist band.

AWGN Level Comparison for only 100m 100BASE-T1L disturbers

- N= 2 is used for baseline PSANEXT and PSAFEXT calculation, in the case of 500m victim.
- With both PSANEXT and PSAFEXT considered, AWGN level achieved with original method is 1.24dB higher than -113dBm/Hz. It is acceptable according to the reflector discussion.
- With modified Tx PSD and averaging BW, the resulted AWGN level increases with symbol rate. The trend for both AWGN level and the corresponding rms voltage is opposite to that using original method.







-111.76-10log10(f_{baud}/75) dBm/Hz for overall AXT,
0.46dB lower (-112.22 dBm/Hz) for only AFEXT

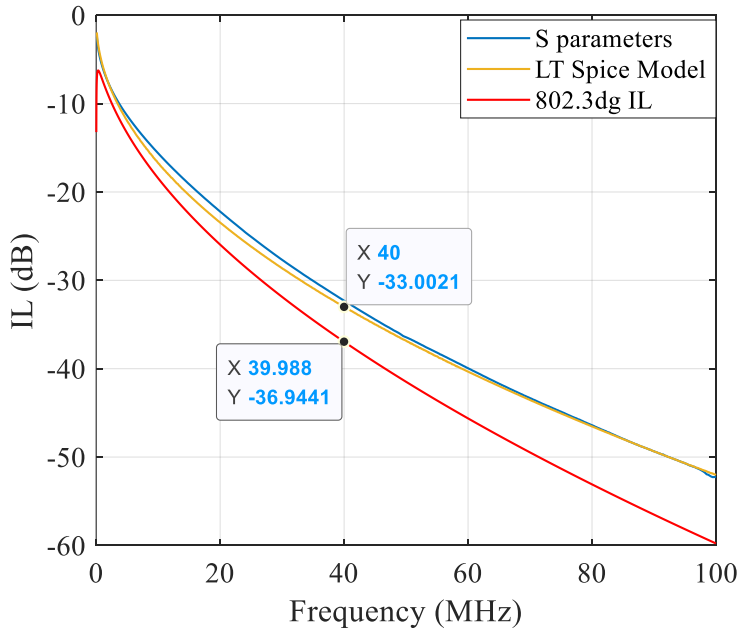
Time-domain simulation parameters

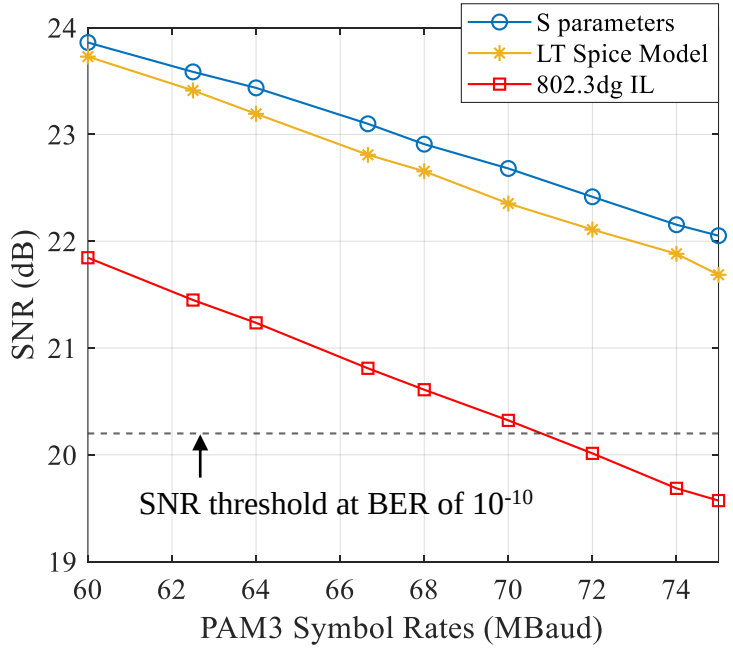
Very ideal time-domain simulation. Only AWGN and ISI induced by IL are considered:

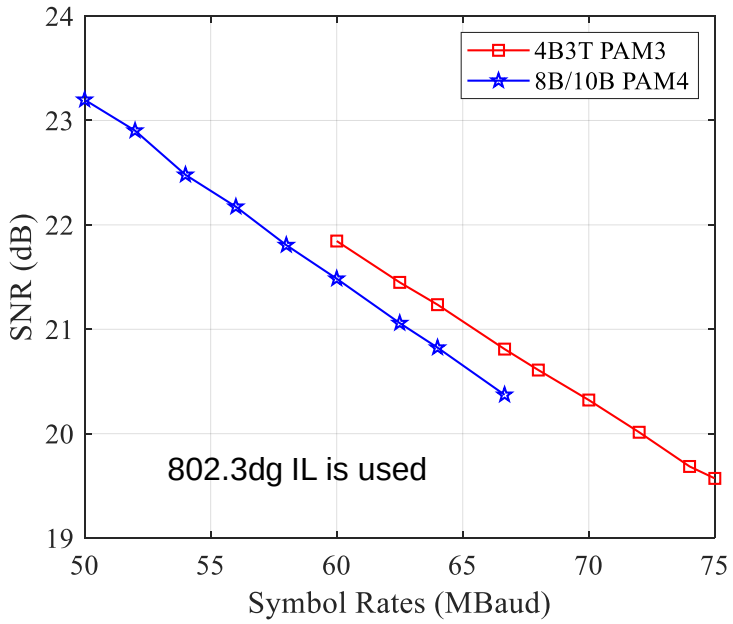
- Insertion loss:
  - dg limit: $\left(5.42 \times \sqrt{f} + 0.044 \times f + 1.76/\sqrt{f}\right) + 5 \times 0.02 \times \sqrt{f}$
  - S parameter of 500m AWG18 provided by Francois Beauregard
  - 500m LT Spice model
- Take 4B3T PAM3 and 8B10B PAM4 as DC-free coding examples, just use the at-hand code for quick simulation.
- 2.4V transmit level
- Ideal line driver, 12-bit DAC and ADC
- Simulation bandwidth is set to the same as symbol rate, eliminating the use of LPFs.
- AWGN levels on Page 4. The rms voltage is calculated over simulation bandwidth.
- 30-tap FFE and 5-tap DFE

SNR for AWGN level of -113-10log10(f_{baud}/75) dBm/Hz

- Similar IL of 500m AWG18 cable provided by Francois as the LT Spice model. Both are smaller than 802.3dg IL limit. Therefore, using dg IL gives lowest SNR for PAM3.
- At the same symbol rate, V_{pp}, and AWGN level, SNR of PAM3 is about 0.5dB higher than PAM4, which is close to the PAPR difference of 0.8dB as expected.

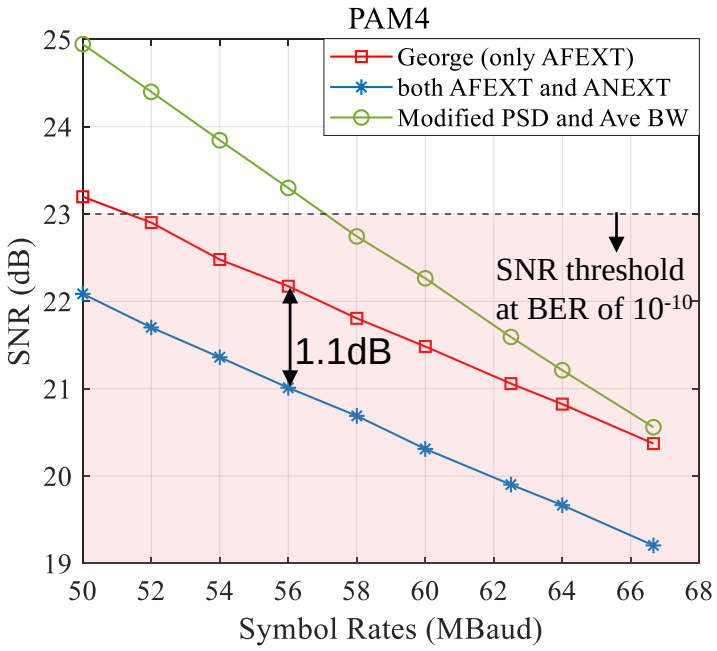


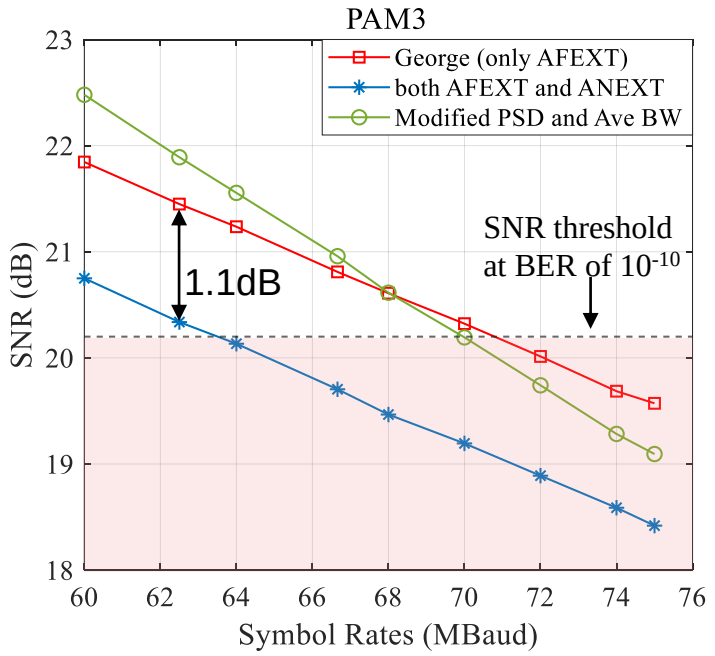




SNR for different AWGN levels using 802.3dg IL

- Inclusion of PSANEXT increases AWGN level by 1.24dB, decreasing SNR by 1.1dB.
- Points in the red shadow region need error correction to provide extra SNR margin for reliable communication.
  - The symbol rate limit for PAM3 is as low as 63.5MBd. Even for the complicated 15B10T, allowing minimum symbol rate, error correction is required.
  - PAM4 is even worse due to higher SNR requirement. For AWGN-limited system, low-order PAM is preferred. This is consistent with SNR margin analysis in previous meetings.





DC-free PAM3 Coding

mB	nT	Redundancy	Symbol Rate	IL @ $f_{Nyquist}$
4	3	0.16	75MBd	35.7dB
5	4	0.21	80MBd	37dB
7	5	0.12	71.4MBd	34.9dB
8	6	0.16	75MBd	35.7dB
10	7	0.10	70MBd	34.5dB
13	9	0.09	69.2MBd	34.3dB
15	10	0.05	66.7MBd	33.6dB

Coding Complexity ↑

Conclusion

- Current time-domain simulation has only considered AWGN and ISI induced by IL, and shows that lower-order PAM is more advantageous due to lower SNR requirement.

- Adding impulsive noise to the simulation model still needs to be done before making the line coding decisions.

- Considering both PSANEXT and PSAFEXT, AWGN level increases to -111.76dBm/Hz. DC-free PAM3 (with minimum symbol rate >63.5MBd) and PAM4 all need error correction methods to provide extra SNR margin. This further increases signal bandwidth and results in higher IL (>34dB).

Thank you!

SNR Comparison of different PAM3 coding

- AWGN level: -111.76-10log10(f_{baud}/75) dBm/Hz
- 802.3dg IL
- About 0.1dB SNR difference between 4B3T and 7B5T at the same symbol rate, indicating negligible coding impact on the simulation results.