SNR Margin Analysis of 802.3dg

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Acknowledgment

- George Zimmerman, CME Consulting/APL Group, Cisco, CommScope, Marvell, OnSemi, SenTekSe
- Steffen Graber, Pepperl+Fuchs
- Piergiorgio Beruto, OnSemi

Goal of this presentation

- PHY analysis has been presented in zimmerman_3dg_01_11_02_2022.pdf based on the link segment parameters in graber_3dg_01_08302022.pdf and Schicketanz_3dg_01a_10122022.pdf.
- In this presentation, link segment models suggested by Larsen (Larsen_3dg_11_09_2022.pdf) and Graber (graber_3dg_01_08302022.pdf, graber_3dg_01_01182023.pdf), are considered to provide a further vision on the trunk link parameters and the corresponding optimal bandwidth.
- Preliminary SNR margin analysis of 200m spur and 100m motor feedback communication link is also given.
- FEC with improved burst error capability is suggested to deal with EFT noise.

Background of SNR Margin

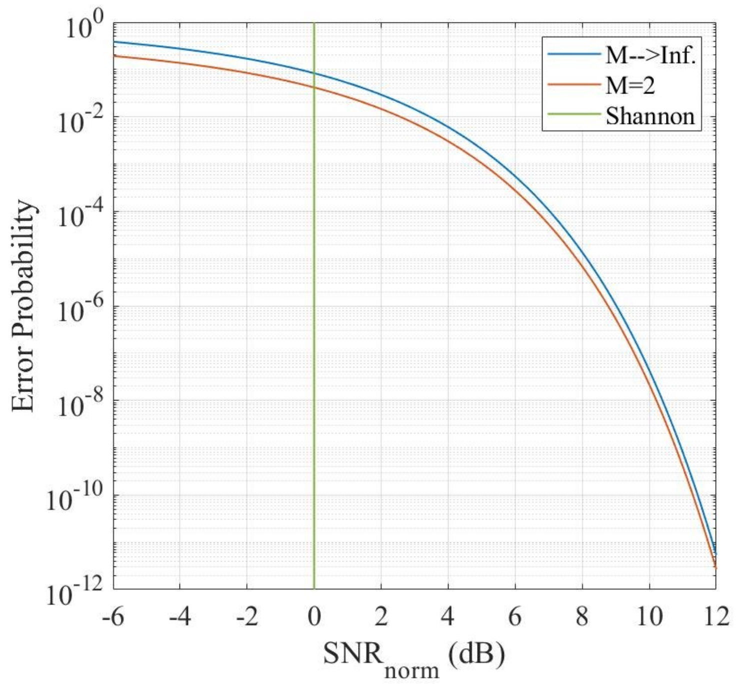
- SNR Margin can be calculated from the difference between Salz SNR and the required SNR.
- Salz modeling (zimmerman_3bz_02a_0915) is well established and useful for link segment baseline. In the case of colored noise, Salz SNR is obtained by folding the SNR around Nyquist frequency as

$$SNR_{\text{Salz}} = 10log_{10}\left[\sum_{n=0}^{N-1}\exp\left(\frac{1}{W}\int_0^W \ln\left(1+SNR\left(\frac{n}{T}+(-1)^n f\right)\right)df\right)\right].$$

- In this presentation, we focus on baseband PAM with low number of levels due to simpler hardware implementation. At BER of 10^{-10}, the Shannon gap for PAM with large M is 11.44 dB (only 0.14dB higher than PAM2). The required SNR for different PAM can be obtained as

$$SNR_{\text{req}} = 11.44 + 6.02 * log_2 M \quad (\text{dB}).$$

- In this analysis, we assume a 2nd-order butterworth filter at Nyquist Frequency, -140 dBm/Hz AWGN, good AFE with 12-bit ENOB ADC and 50dB Echo suppression.



Link Segment Models

- In this presentation, we consider three different communication links: a) 500m trunk, b) 100m motor feedback, and c) 200m spur. Though the spur link is not included in the objective of 802.3dg right now, it is worth to investigate SNR margin.
- For 500m trunk, the insertion loss has been agreed as:

$$IL_{\text{Trunk}} = 4.92 * \sqrt{f} + 0.04 * f + \frac{0.8}{\sqrt{f}} + 5 * 0.02 * \sqrt{f}, \qquad 0.3\text{MHz} \le f \le 60\text{MHz}.$$

- For motor feedback communication, 100m AWG22 cable is usually deployed (xu_3dg_01a_1116_2022.pdf). The diameter for AWG16 and AWG22 at 20 ℃ is 1.290858mm and 0.643795mm respectively. With gauge factor taken into account, IL in this case is modified to:

$$IL_{\text{Motor}} = \frac{2}{5}\left(4.92 * \sqrt{f} + 0.04 * f + \frac{0.8}{\sqrt{f}}\right) + 5 * 0.02 * \sqrt{f}, \qquad 0.1\text{MHz} \le f \le 60\text{MHz}.$$

- The insertion loss of the cable in the spur side is 59% (in dB) of the trunk according to 802.3cg/10BASE-T1L. Given the fact that the trunk insertion loss for 802.3dg is decided from 500m AWG16 cable, the worst case *IL* of the spur link with up to four inline connectors can be written as:

$$IL_{\text{spur}} = 2.4 * \left(1.23 * \sqrt{f} + 0.01 * f + \frac{0.2}{\sqrt{f}}\right) + 5 * 0.02 * \sqrt{f}, \qquad 0.1\text{MHz} \le f \le 60\text{MHz}$$

- For the spur link, a peak-to-peak voltage of 1V is used due to intrinsic safety requirements, while 2.4V employed to the trunk and motor feedback communication.

Link Segment Models

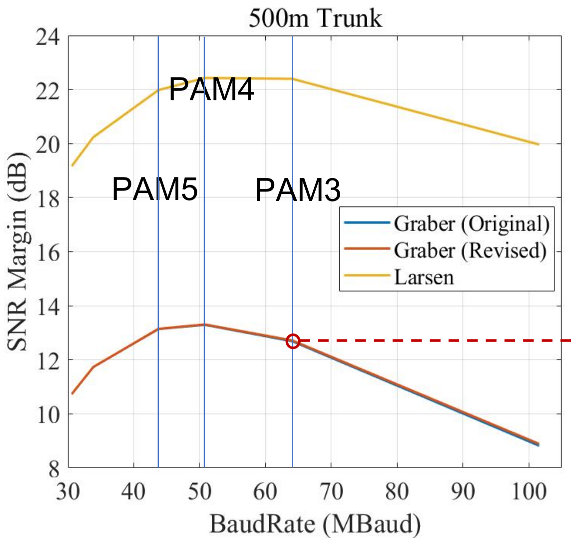
- For RL, PSANEXT, and PSAFEXT/PSAACRF, the models from Graber (graber_3dg_01_08302022.pdf, graber_3dg_01_01182023.pdf) and Larsen (Larsen_3dg_11_09_2022.pdf) are used in this work, summarized as following:

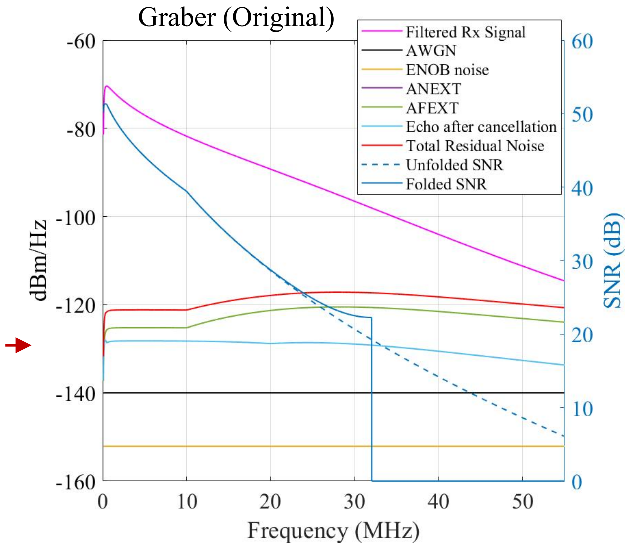
Link Segment Parameters	Graber's Models	Larsen's Models
RL	**Original Model:** $\begin{cases} 9+8*f, & 0.1\text{MHz} \le f < 0.5\text{MHz} \\ 13, & 0.5\text{MHz} \le f < 20\text{MHz} \\ 13-\mathbf{10}*\boldsymbol{log_{10}}\left(\frac{f}{20}\right), & 20\text{MHz} \le f \le 60\text{MHz} \end{cases}$ **Revised Model:** $\begin{cases} 9+8*f, & 0.1\text{MHz} \le f < 0.5\text{MHz} \\ 13, & 0.5\text{MHz} \le f \le 60\text{MHz} \end{cases}$	$RL = \begin{cases} 9+10*f, & 0.1\text{MHz} \le f < 1\text{MHz} \\ 19, & 1\text{MHz} \le f < 10\text{MHz} \\ 24-5*log_{10}(f), & 10\text{MHz} \le f < 40\text{MHz} \\ 16, & 40\text{MHz} \le f \le 100\text{MHz} \end{cases}$
$PSANEXT$	$PSANEXT = \begin{cases} 60, & f < 10\text{MHz} \\ 60-15\log_{10}\left(\frac{f}{10}\right), & 10\text{MHz} \le f \le 60\text{MHz} \end{cases}$	$PSANEXT = 60-10\log_{10}\left(\frac{f}{100}\right)$
$PSAFEXT$	$PSAFEXT = \begin{cases} 60, & f < 10\text{MHz} \\ 60-15\log_{10}\left(\frac{f}{10}\right), & 10\text{MHz} \le f \le 60\text{MHz} \end{cases}$	$PSAACRF = 70-20*\log_{10}(f)$, $PSAFEXT = PSAACRF + IL$

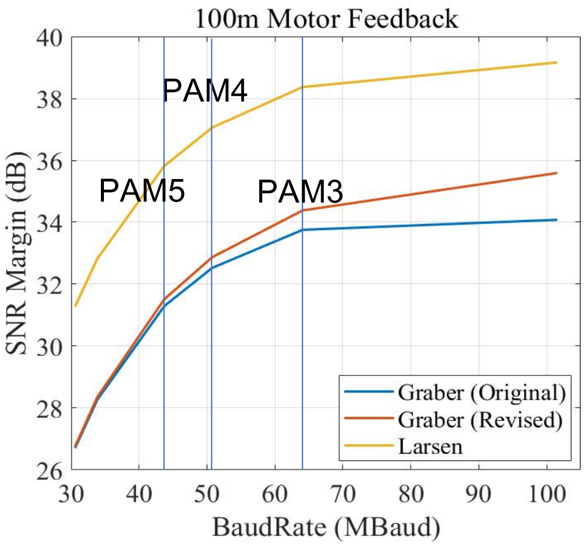
- The original and revised RL models become diverse when the frequency is over 20MHz.
- For motor feedback communication, alien crosstalk noise is very small (xu_3dg_01a_1116_2022.pdf), therefore, can be ignored.

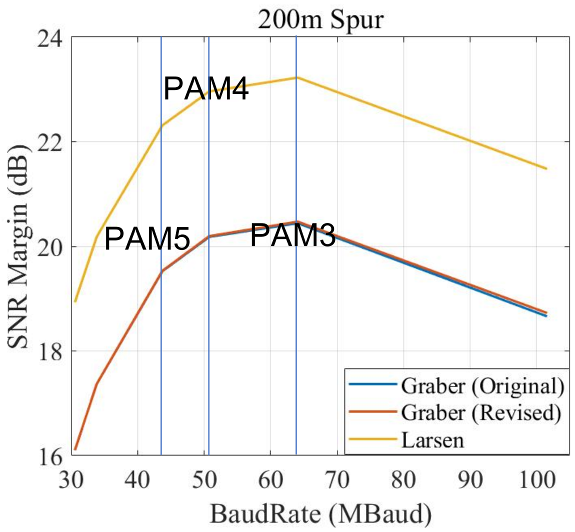
SNR Margin Analysis

- SNR performance based on Graber’s models is almost the same for both trunk and spur links, while differs for motor feedback in the case of low-order PAMs. This is attributed to different dominated noise (alien crosstalk or residual echo).
- For 500m trunk using Graber’s models, the maximum achievable SNR margin is 13.3dB for PAM4, but not much difference between PAM3, PAM4, and PAM5. Larsen’s proposal imposes higher requirement on the link segment quality. The resulted optimal bandwidth is right shifted, with SNR margin increased to 22.4dB.
- For 100m motor feedback communication with negligible alien crosstalk, SNR margin is over 30 dB and decreases with PAM level. 200m spur link with smaller insertion loss and lower transmit power biases PAM3, giving SNR margin larger than 20dB.
- Generally, 10dB SNR margin is sufficient for PHY design, relaxing the requirements on the cable and connectors. In the case of similar SNR margin for PAM3, PAM4, and PAM5, PAM3 may be preferable due to better compatibility with 10BASE-T1L, 100BASE-T1, and 1000BASE-T1.



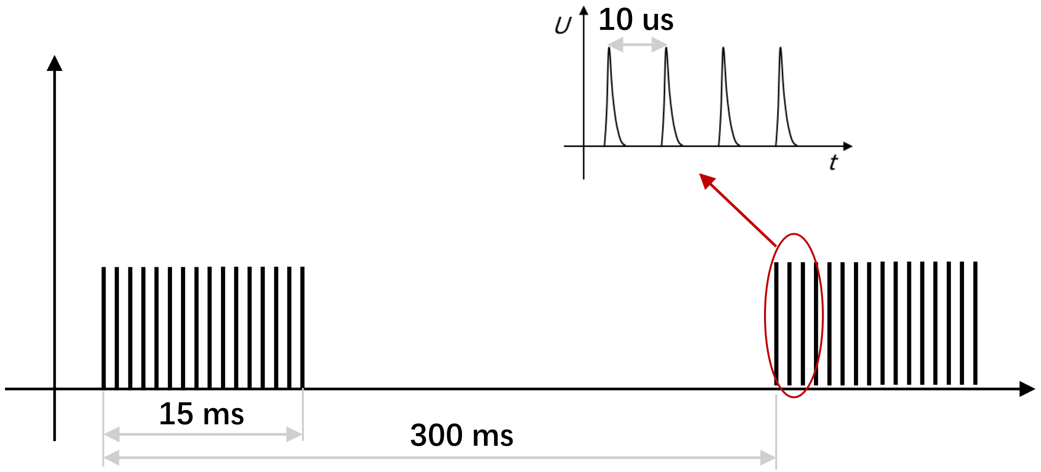






Noise Environment

- Noise Environment for 802.3dg is dominated by impulse and RF noise (beruto_3dg_01_20220711):
  - IEC61000-4-6 specifies the RF tone with frequency range from 150 KHz to 80 MHz, and the base (unmodulated) amplitude selected among 1 Vrms, 3 Vrms, 10 Vrms. The CW goes through MC loss and may be mitigated by specially designed circuits.
  - IEC61000-4-4 specifies the Electrical fast transient (EFT) / burst immunity test (beruto_3dg_01_20220711) with calibrated pulses up to 2kV (CM), duration of 50 ns, burst rate of 100 kHz (10 μs), burst duration of 15 ms, repeated every 300 ms.
    - For data rate increased from 10Mbps to 100Mbps, the influence of single burst pulse duration of 50ns increases from less than 1 bit to 5 bits. Measurement of EFT noise coupling to the link segment needs to be done.
    - TCM coding used in 1000BASE-T has poor tolerance to burst errors. FEC with improved burst error correction may be required.



Conclusion

- This presentation compares SNR margin for different PAMs based on the link segment models from Graber and Larsen and has considered three different types of links (i.e. 500m trunk, 100m motor feedback, and 200m spur).
- Revised RL model (from Graber) does not change the results for trunk and spur, while increases SNR at low-order PAMs for motor feedback communication.
- The maximum achievable SNR margin for 500m trunk based on Graber’s model is the smallest among the three links. However, it is larger than 10dB and sufficient for PHY design, indicating reasonable limit on the link segments. Not much difference between PAM3, PAM4, and PAM5 is observed.
- 200m spur link prefers PAM3 with the largest SNR margin. For 100m motor feedback communication with negligible crosstalk, SNR margin decreases with PAM level. With all results taken into account, PAM3 may be preferable due to its better compatibility with 10BASE-T1L, 100BASE-T1, and 1000BASE-T1.
- FEC with improved burst error correction may be required to deal with EFT noise.

Thank you!