Analysis of Cable Parameters using a 40GBASE-T PHY-to-PHY Channel Model

Mike Grimwood, Broadcom

IEEE P802.3bq 40GBASE-T Task Force
Victoria, BC, Canada
May 16, 2013

Acknowledgements

- Thanks to Commscope and Panduit for providing cable channel measurements in support of this presentation.

- Thanks to Pulse and Bel for providing magnetics measurements in support of this presentation.

Supporters

- Thuyen Dinh, Pulse
- Yakov Belopolsky, Bel Stewart
- Brian Buckmeier, Belfuse
- Bob Wagner, Panduit
- Ron Nordin, Panduit
- George Zimmerman, CME Consulting/Commscope
- Wayne Larsen, Commscope
- Paul Kish, Belden
- Peter Wu, Marvell
- Brad Booth, Dell

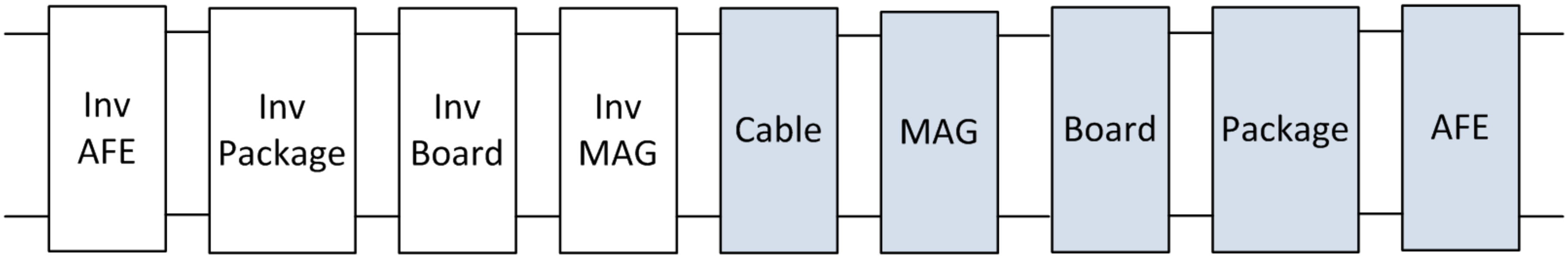
Overview

- A PHY-to-PHY channel model is presented.
- The model is used to analyze the receiver dynamic range requirements.
- Cable model NEXT and Return Loss limits are adjusted to investigate the impact on dynamic range and analog power.

Assumptions

- Assume that for 40GBASE-T that the worst-case Peak-to-Average Ratio (PAR) will be the same as it was for 10GBASE-T (likely pessimistic).
- Assume for 40GBASE-T that the code margin from capacity is 5 dB.
- Assume that the implementation margin from capacity is 11 dB (an additional 6 dB on top of the code margin).
- Assume a first-order receive low-pass filter corner at 37.5% of the symbol rate and first order receive high-pass cutoff at 6.25% of the symbol rate.

PHY-to-PHY Channel

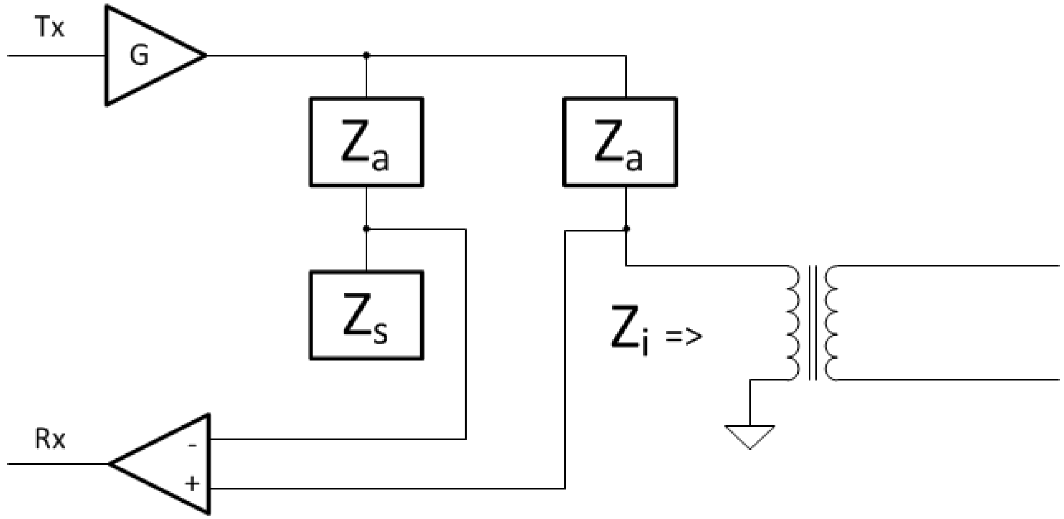


- Cascade S-parameters for composite channel.
- "Cable" is the two-connector channel model.
- "Mag" includes the transformer, common-mode chokes and MDI connector.
- "AFE" is the Analog Front End of the PHY and includes circuits between the package connections and the ADC and DAC.
- "Inv" indicates that the transpose S-parameter matrix should be used since the model may be asymmetric.

Models Used for PHY-to-PHY Channel

- **AFE:** 2-port S-parameters extracted from 10GBASE-T PHY Design
- **Package**: 16-port S-parameters extracted from 10GBASE-T PHY
- **Board:** 4-port S-parameters extracted from 10GBASE-T high-density system.
- **Magnetics**: 4-port S-parameters from preliminary transformer and choke measurements.
- **Cable:** 16-port S-parameters from preliminary Cat8 measurements of the two connector cable channel.
- To standardize any future measurements, propose the following:
  - Touchstone S16P format with frequency range of at least 1 MHz to 2 GHz.
  - In relation to the shaded blocks on slide 6, define S-parameter Ports 1 though 8 on the left side of the component and Ports 9 through 16 on the right.
  - For example, for “Mag”, Ports 1 through 8 connect to the “Cable” channel and Ports 9 through 16 connect to the “Board” model.

Hybrid Cancellation Simplified Model

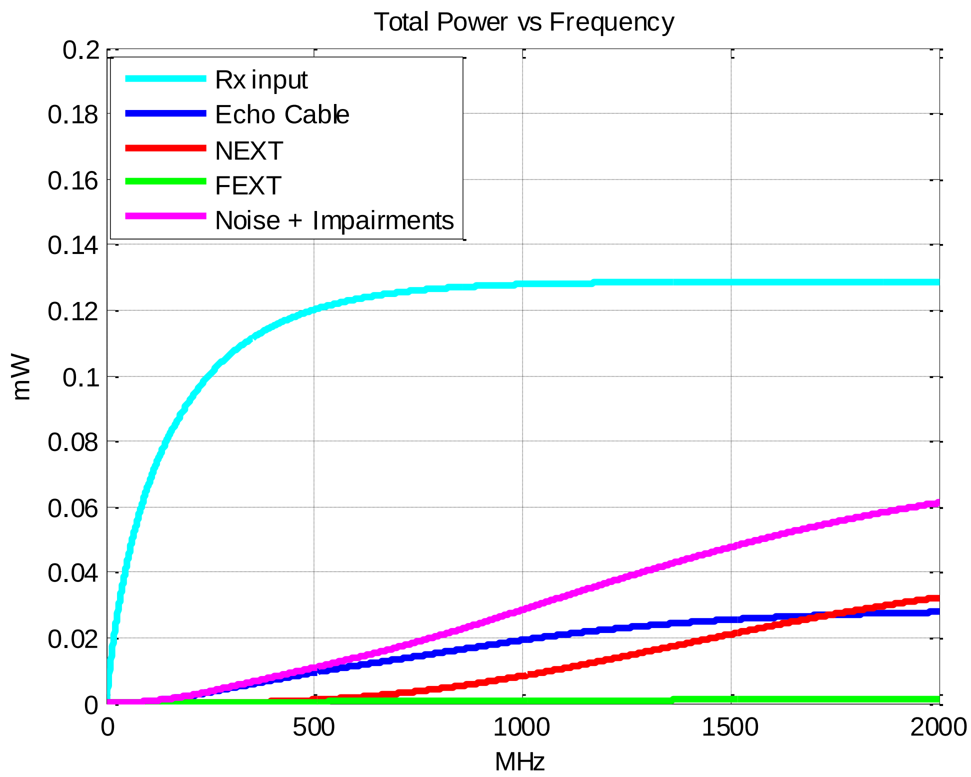


- Input impedance, Z_i, includes AFE parasitics, package, board, magnetics and cable.
- Hybrid Residual is minimized with Z_s set to Z_i:

$$\frac{Rx}{Tx} = \frac{GZ_a(Z_i - Z_s)}{(Z_a + Z_i)(Z_a + Z_s)}$$

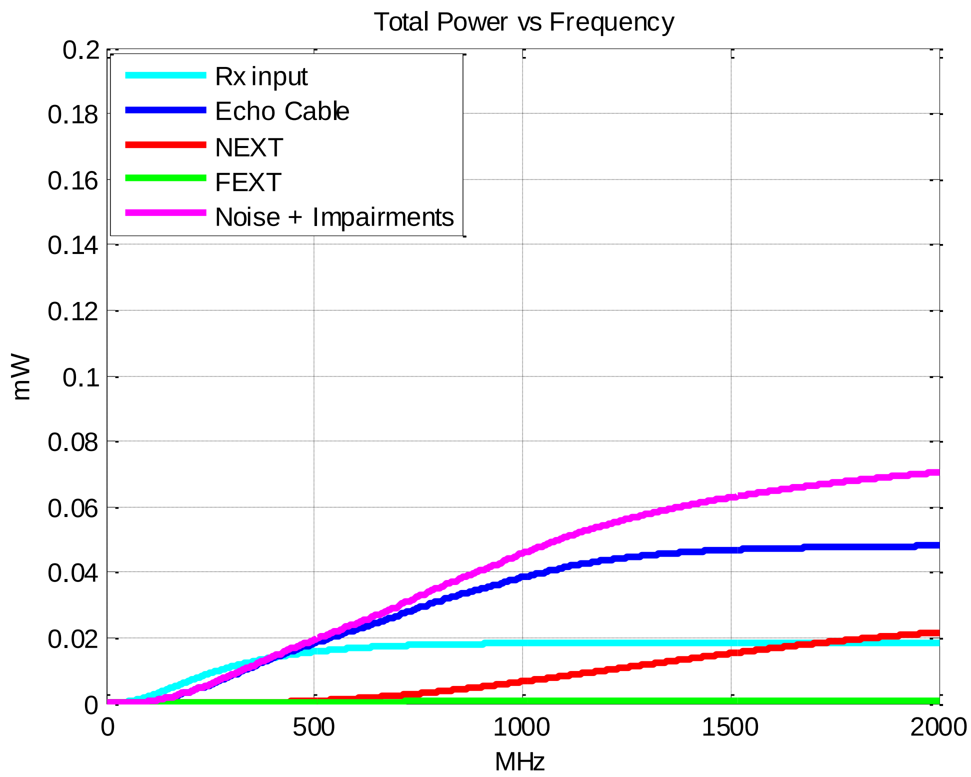
- Practical differential implementations typically use multiple DACs to provide the matched paths.

40GBASE-T Noise and Impairment Analysis – Case #1



- Using the same parameters as in zimmerman_01_0313_NGBT.pdf.
- 3500 MHz symbol rate, 0.5*Fs LPF, DAC zero-order-hold, 30m TIA CAT8 cable, and 10 dB echo reduction due to hybrid.

40GBASE-T Noise and Impairment Analysis – Case #2



- Same as case 1 but also considering the following:
- PHY-to-PHY channel (board, magnetics, chip) + hybrid cancellation simulation + Rx HPF.

Cable Measurement Scaling

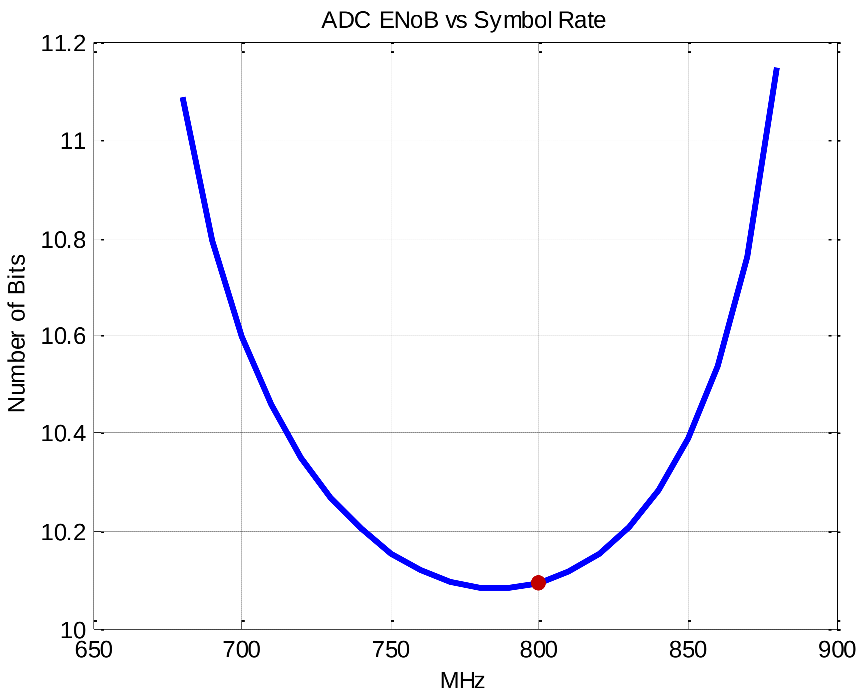
- **All frequencies at the specified limit**
  - Scale cable measurements at each frequency such that the magnitude of each impairment exactly reaches the specified limit line or the limit line plus some margin. This is denoted on subsequent plots as "all freq @limit".
  - Magnitude is identical to that used with previous limit-line analysis, but phase information is retained.
  - May not be very realistic for some parameters, but creates a bound for PHY designers.

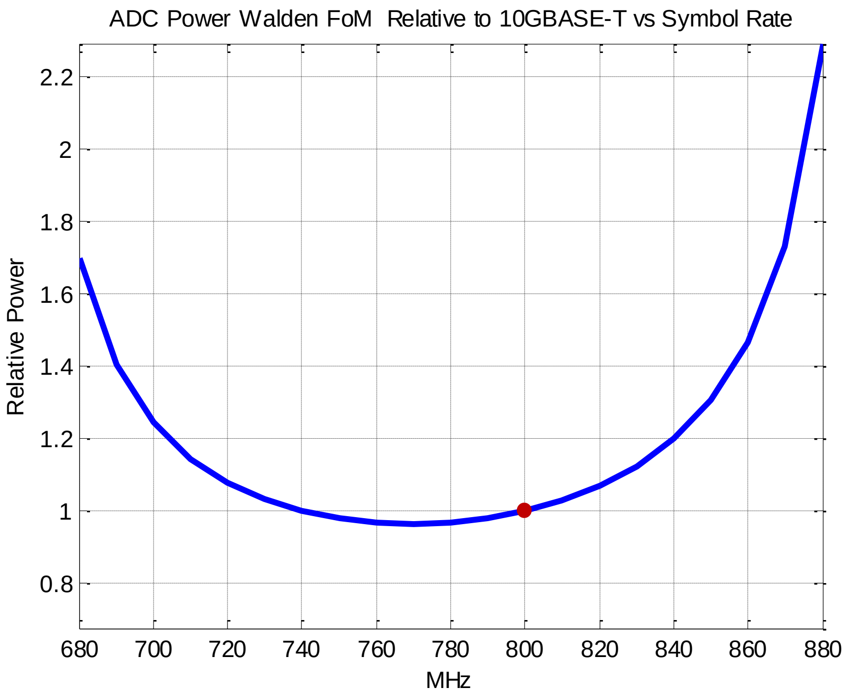
- **Touch the limit**
  - Alternatively, cable measurements are scaled such that the worst-case value (or values) exactly touch the limit or the limit line plus margin. This is denoted as "touch limit" on subsequent plots.
  - More realistic, but not worst-case.

Analysis Approach

- Perform noise and impairment analysis at each symbol rate.
- Determine the amount that noise and impairments increase the receive dynamic range.
- Determine the required signal to quantization noise ratio (SQNR) based on the symbol rate, combined impairments, and assumed margin to capacity.
- Sum the PAR, dynamic range expansion due to impairments, and SQNR to determine the receive dynamic range requirement.
- Compute the ENoB and apply the ADC power figure of merit (FoM).

10GBASE-T ENoB and Power FoM vs. Symbol Rate (sanity check)

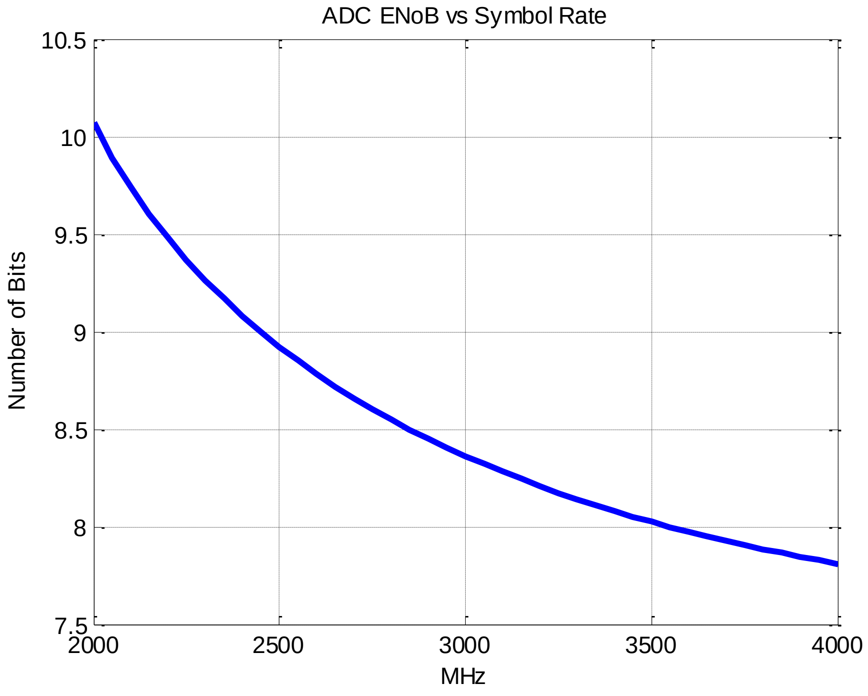


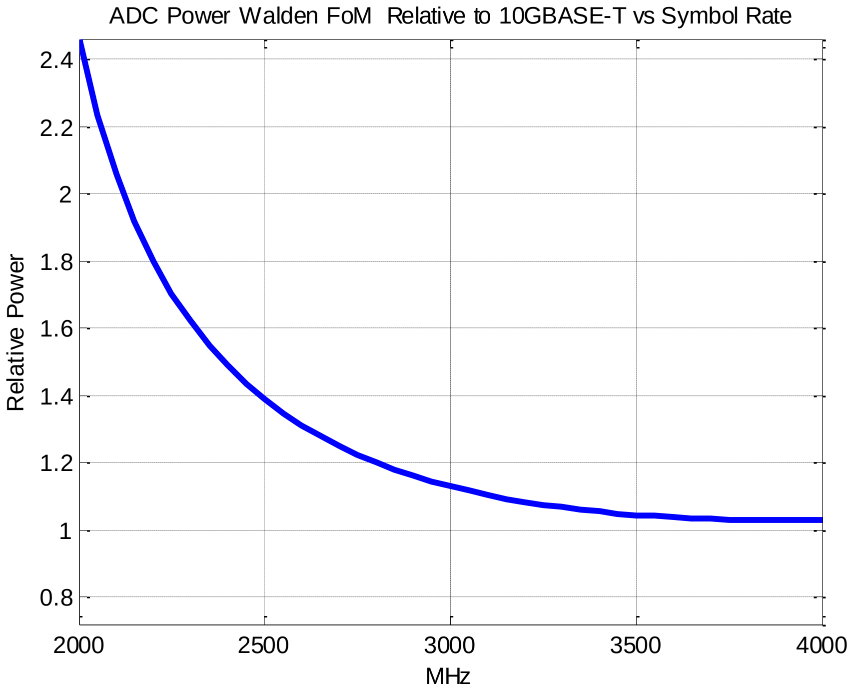


- **Denotes 10GBASE-T Symbol Rate**

Power FoM α Fs*2^{ENoB}

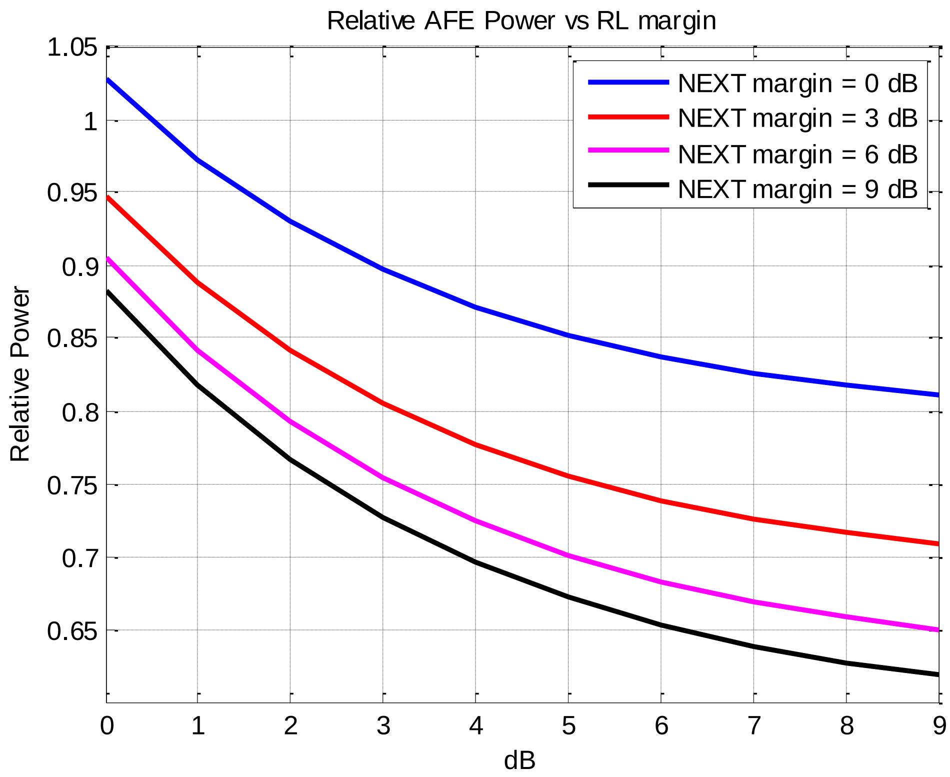
40GBASE-T ENoB and Power FoM vs. Symbol Rate





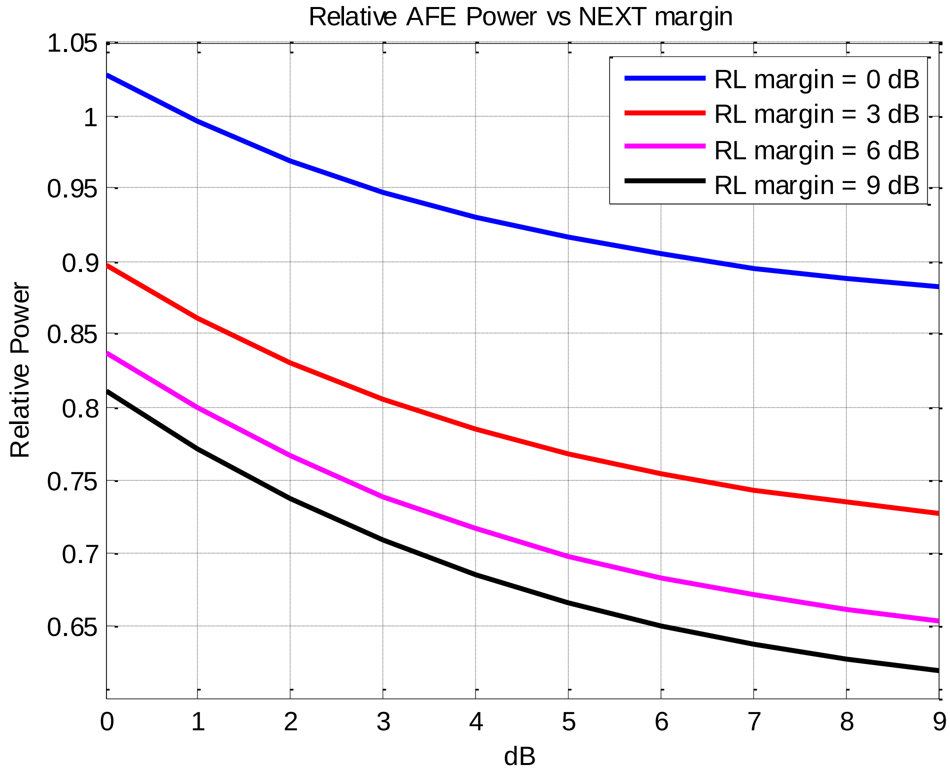
Power FoM α Fs*2$^{\text{ENoB}}$

40 GBASE-T Normalized Power FoM vs. Cable RL Margin – all freq @limit



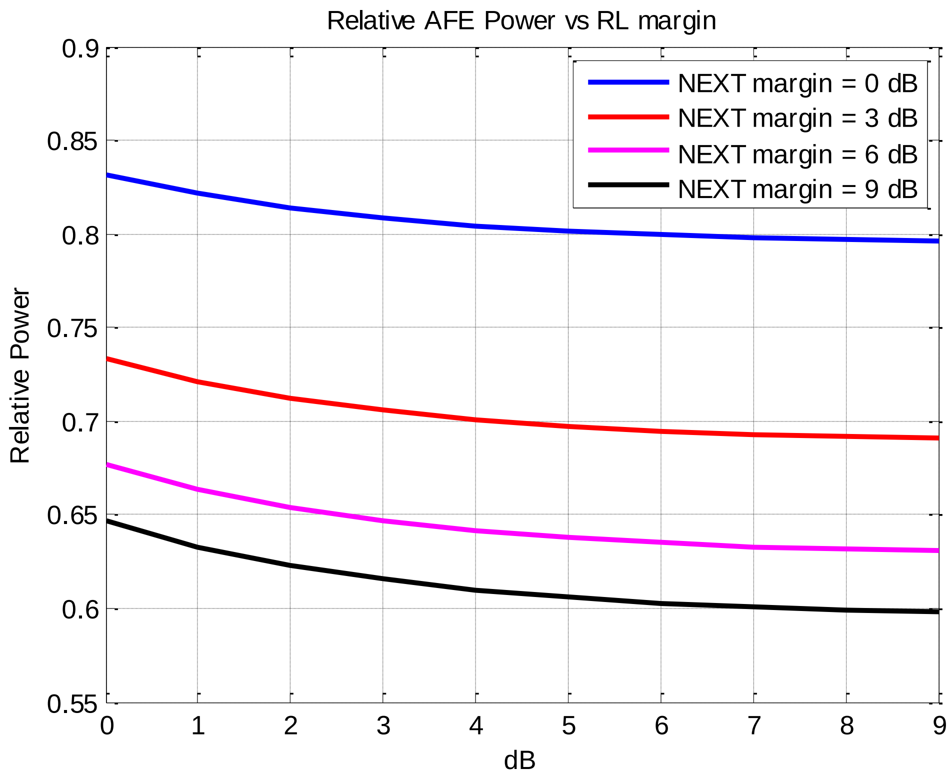
Optimal Fs
NEXT and RL @limit for all frequencies.
Power FoM α $Fs*2^{ENoB}$

40 GBASE-T Normalized Power FoM vs. Cable NEXT Margin – all freq @limit



Optimal Fs
NEXT and RL @limit for all frequencies.
Power FoM α $Fs*2^{ENoB}$

40 GBASE-T Normalized Power FoM vs. Cable RL Margin – "touch" RL limit



Optimal Fs
NEXT @limit for all frequencies.
RL touching the limit shifted by the margin shown on the horizontal axis.
Power FoM α Fs*2^{ENoB}

Conclusions

- Considering the worst-case limit-line analysis, improvements in the NEXT limits by 3 dB and in the RL limits by 6 dB yield an expected improvement in analog power by about 28%.
- Considering a single cable measurement scaled such that the cable specifications touch the limit line (at the worst-case frequency or frequencies), the expected improvement in analog power relative to a cable scaled at all frequencies to the worst-case limit line is 19%.
  - Using scaled measurement data for RL suggests that improvement of the limits for RL of greater than 4 dB provides minimal benefit.
  - The single scaled measurement is likely not worst-case; additional measurements or consideration of alternate approaches needed.
- Board trace and magnetics/connector 16-port S-parameter models are still needed to complete the PHY-to-PHY channel modeling.

Thank you