Impact of Cable Specifications on NGBASE-T Margin to Capacity

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Overview

- SNR margin to capacity is defined and utilized to individually analyze the impact of existing cable specifications on 40GBASE-T performance and complexity.
- **Presentation considers cable specifications, not measurements**.
- SNR margin is computed as a function of insertion loss and design bandwidth and for cable lengths in the range of 20m to 30m for Category 6a, 7a and proposed Category 8 cabling for the following channel specifications:
  - Pair-to-pair crosstalk using PSACRF and PSNEXT limits
  - Return Loss
  - Alien Crosstalk using PSAACRF and PSANEXT limits

Reference Specification Documents

- Category 6a and 7a specifications are from ISO/IEC 11801 edition 2.0 unless otherwise noted.
- IEEE 802.3 Clause 55 link segment specifications take precedence for 10GBASE-T analysis.
- Category 7a specifications above 1 GHz are from ISO/IEC JTC 1/SC 25 N 2076 and are derived by applying Clause 6 up to 1.6 GHz and then extrapolating to 2 GHz. The application of the Clause 7 Class 1 and Class 2 limits is an area for future study.
- Category 8 specifications are from TR-42.7-2012-115 Draft 0.5

Assumptions

- Effects due to board, magnetics and associated connectors not considered.
- For each specification, consider the effect without cancellation or equalization.
- Assume a 2-connector channel model for 40GBASE-T.
- Assume that the CAT7a specifications can be extrapolated from 1 GHz to 2 GHz.
- For crosstalk analysis, ignore the disturber/disturbed transmit power level differences at the MDI.
- The signal spectrum is assumed to be limited to the design bandwidth

SNR Margin to Capacity Definition

- Let *BW* be the design bandwidth in Hz.
- Let *C'* be the desired capacity per twisted pair in b/s (=10Gb/s)
- From Shannon-Hartley the theoretical min SNR in dB is given by

$$SNR_C = 10log_{10}(2^{(C'/BW)} - 1)$$

- For each cable parameter, define the SNR margin to capacity, ***SNR_margin$_{cable_param}$(BW)***, as the required constant change in loss across all frequencies in order to reach SNR_C.

SNR Margin to Capacity Equation

- From Shannon-Hartley,

$$C = \int_0^{BW} log_2\big((S(f)/N(f)) + 1\big)df$$

- For reasonable bandwidths, S(f)/N(f) >> 1 at capacity.
- Express *C'* as a function of $SNR\_margin_{cable\_param}(BW)$:

$$C' = \int_0^{BW} log_2\left((S(f)/N(f)) * 10^{\left(-SNR\_margin_{cable\_param}(BW)/10\right)}\right)df$$

- Solve for $SNR\_margin_{cable\_param}(BW)$ to get the following:

$$SNR\_margin_{cable\_param}(BW) = \frac{(C - C') * 10log_{10}(2)}{BW}$$

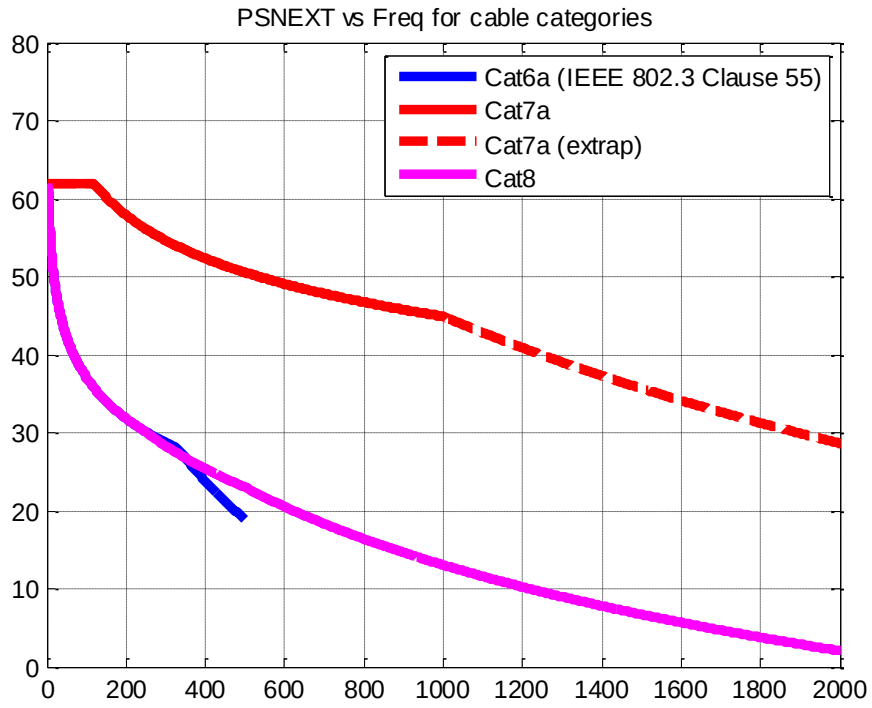
Pair-to-Pair Crosstalk Analysis Overview and Assumptions

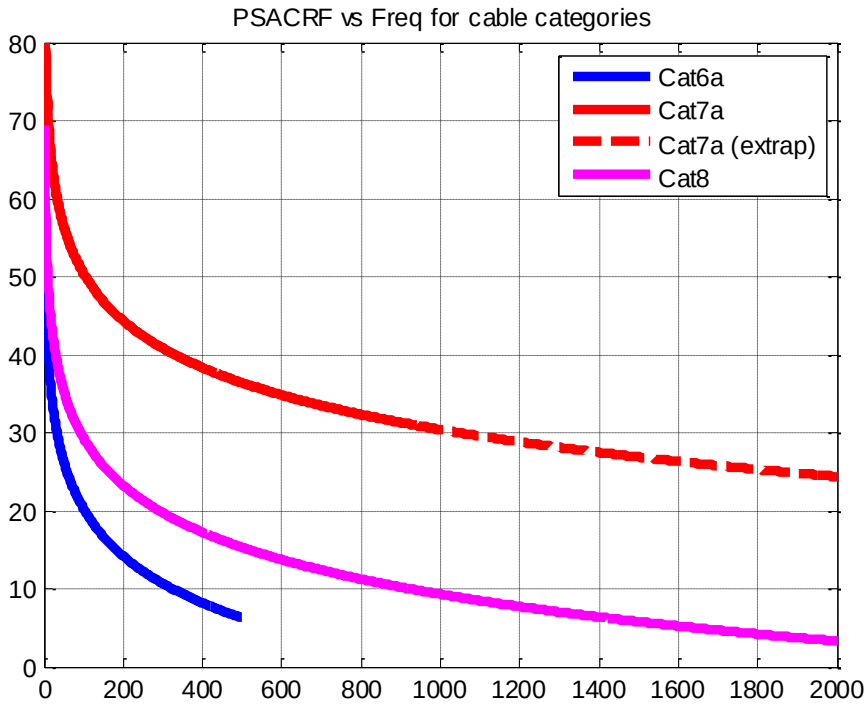
- Investigate the impact of crosstalk for different cable categories as a function of bandwidth and cable length.
- Apply Insertion Loss (IL), PSNEXT and PSACRF limits (PSELFEXT for 10GBASE-T).
- For cable length, L, compute PSFEXT from PSACRF limit as follows:

  $$PSFEXT(f,L) = PSACRF(f) + IL(f,L)$$

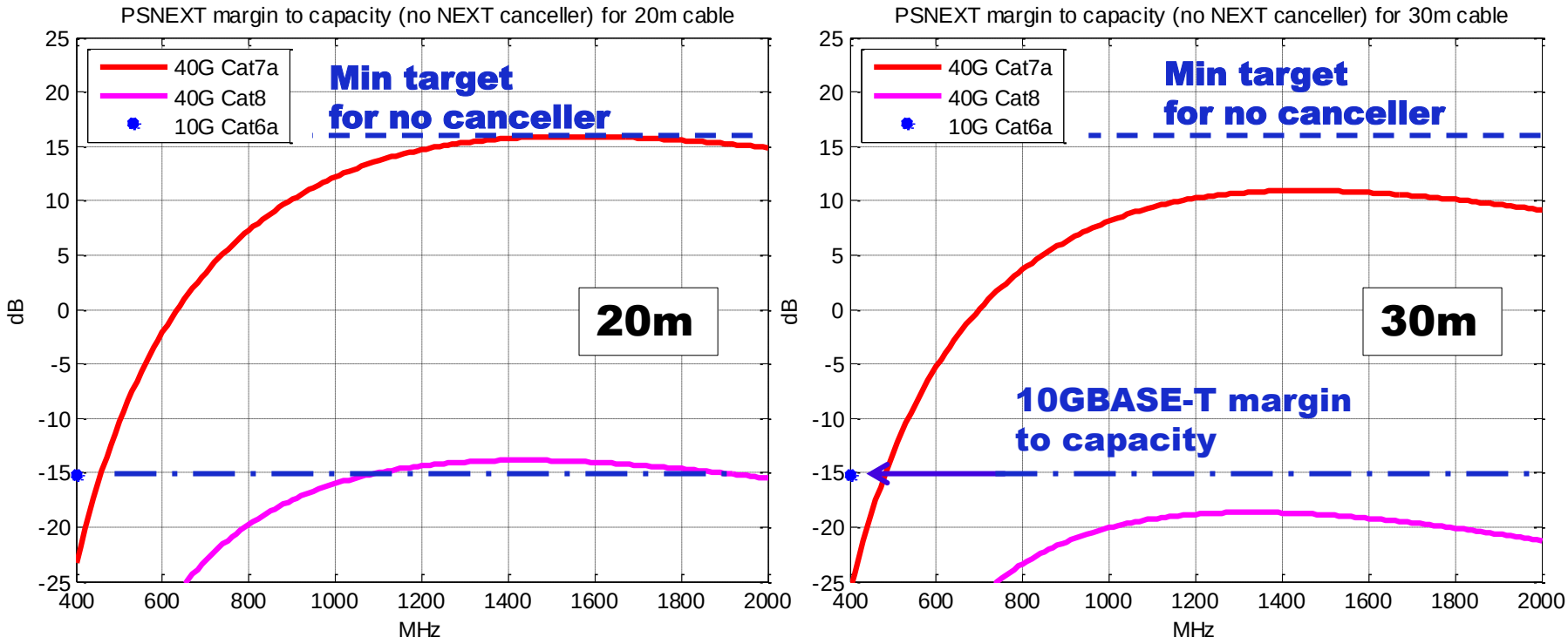
  [PSACRF permanent link is scaled by -10*log10(L/Lmax). See "Measurement and Length Scaling Considerations for Next Generation BASE-T Cable", Trent Hayes and Wayne Hopkinson]
- Examine NEXT/FEXT cancellation requirements for different cable categories.
- Define the implementation margin specific to NEXT/FEXT such that *(code_margin* + $impl\_margin_{NEXT/FEXT}$*)* represents the target minimum margin to capacity for the residual NEXT/FEXT in order to eliminate NEXT/FEXT cancellers.
- Set the respective implementation margin budgets as follows:
  - $impl\_margin_{NEXT}$ = 12 dB
  - $impl\_margin_{FEXT}$ = 12 dB

Crosstalk Specifications: PSNEXT and PSACRF



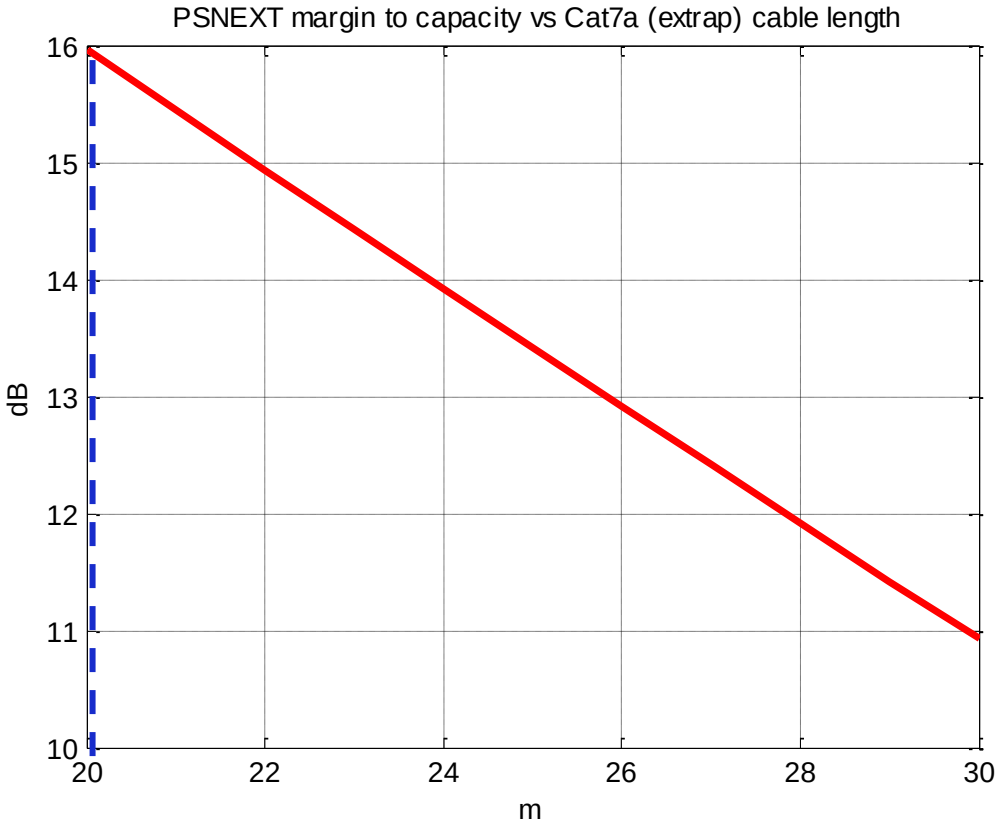


PSNEXT Margin to Capacity



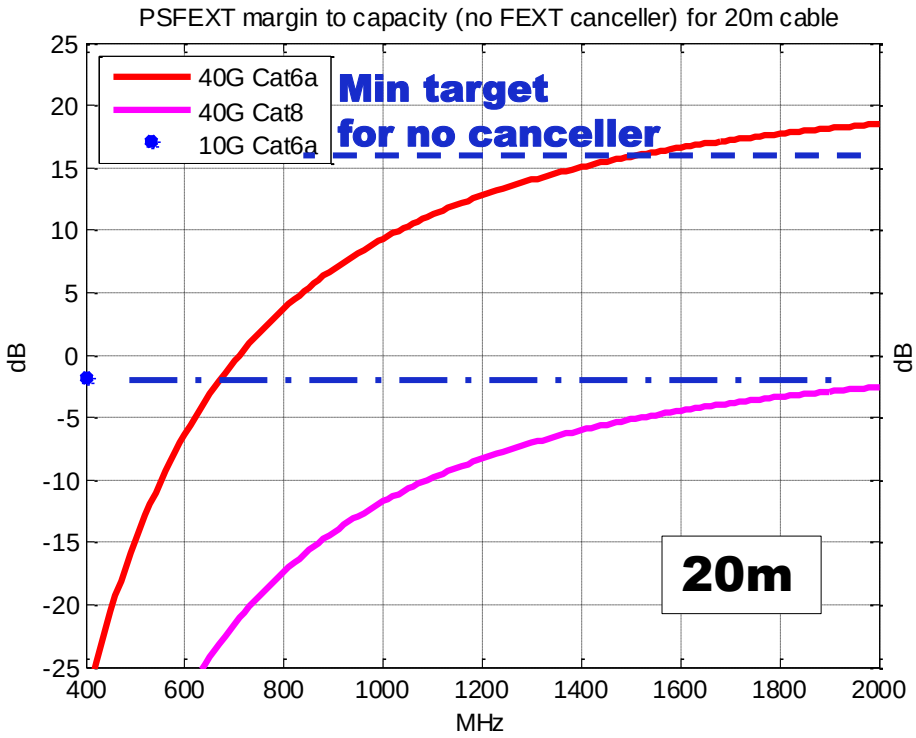
- For CAT8, cable NEXT cancellation requirements are similar to 10GBASE-T.
- For no cancellation, target minimum limit for SNR_margin_{NEXT} = $(code\_margin + impl\_margin_{NEXT})$ = 16 dB
- For this 16 dB target it may be possible to eliminate NEXT cancellers for 20m Cat 7a, but not for 30m.
- **Board, magnetics, and package crosstalk may dominate – requires additional investigation**

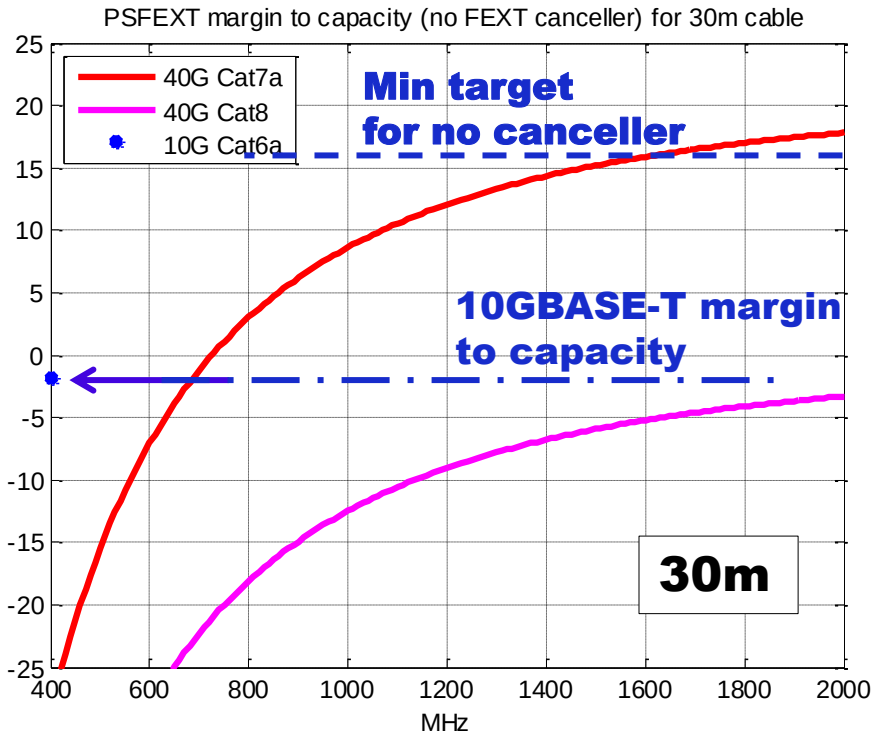
PSNEXT Margin to Capacity vs Length for Optimized Bandwidth



- The defined minimum SNR_margin_{NEXT} to consider eliminating NEXT cancellation is met with <20m Cat 7a (extrapolated) cable.

PSFEXT Margin to Capacity





- For CAT8 cable FEXT cancellation requirements are similar to 10GBASE-T.
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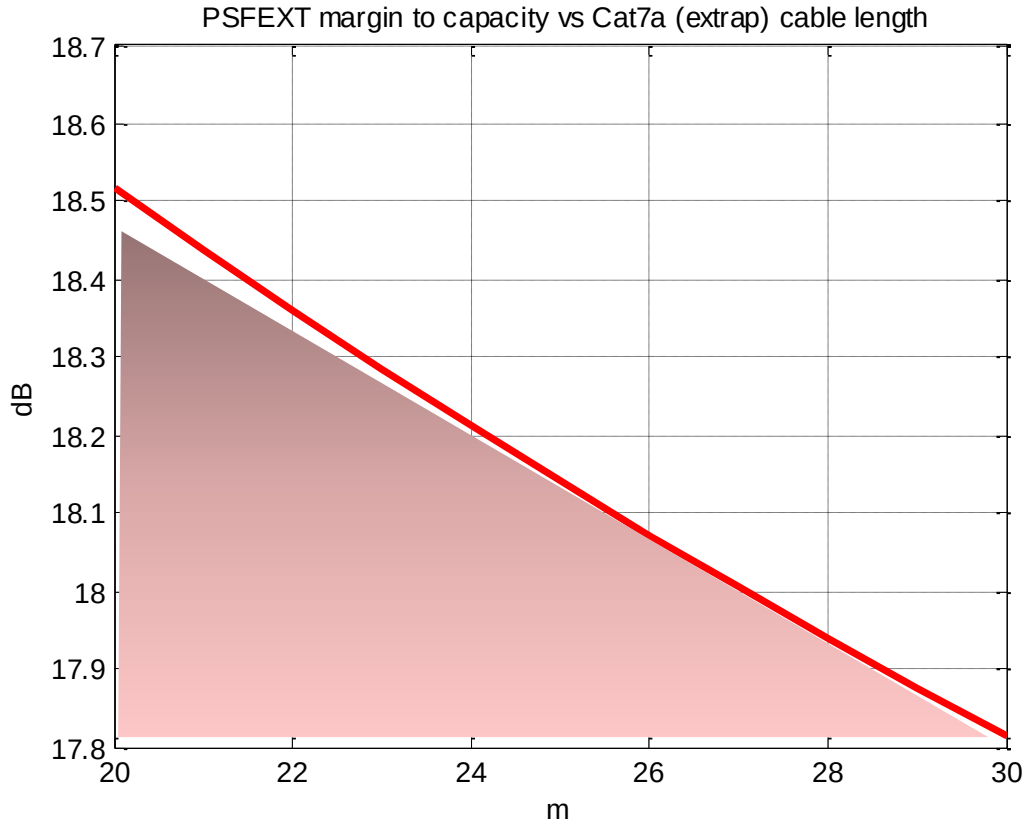
PSFEXT Margin to Capacity vs Length for Optimized Bandwidth



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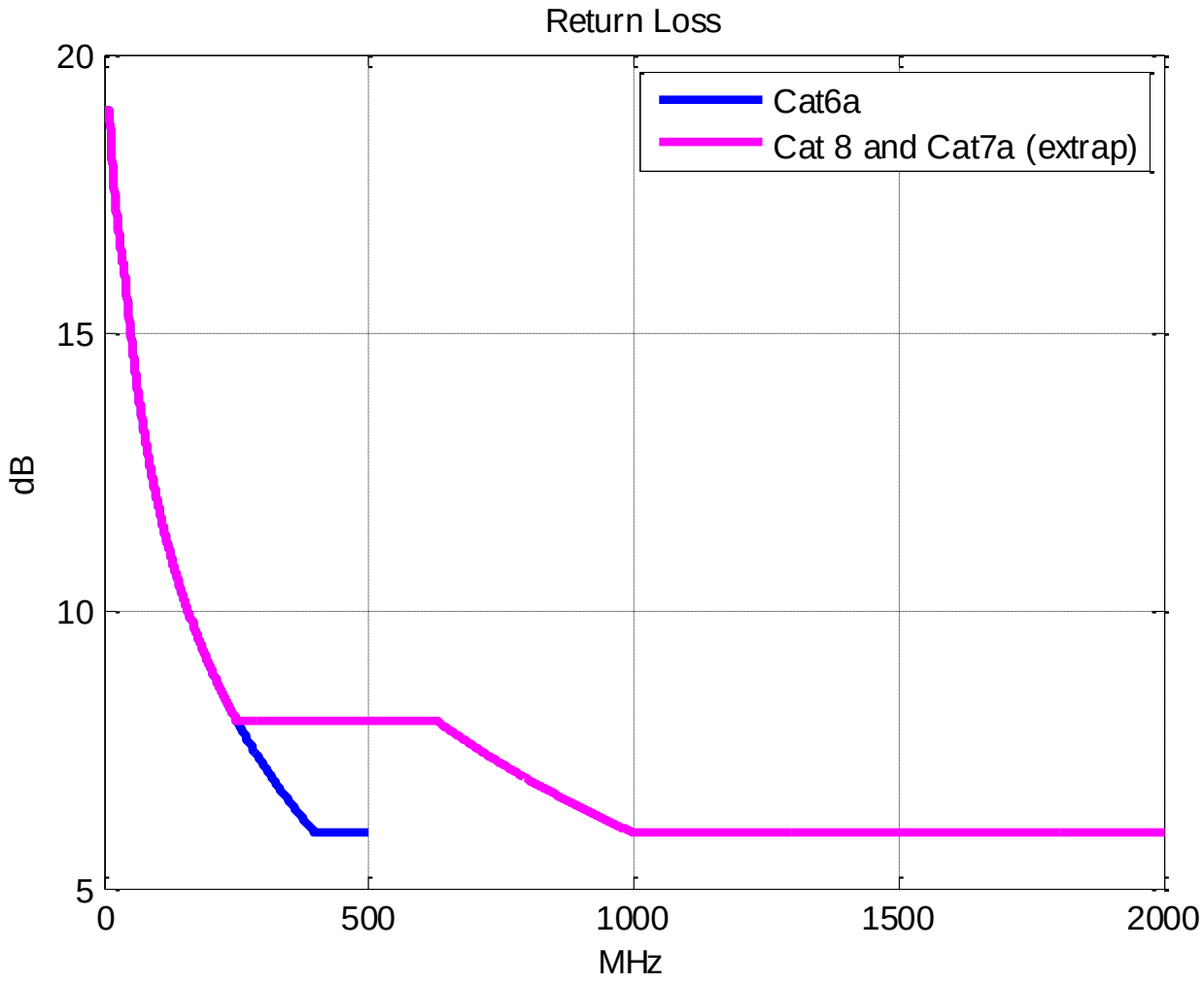
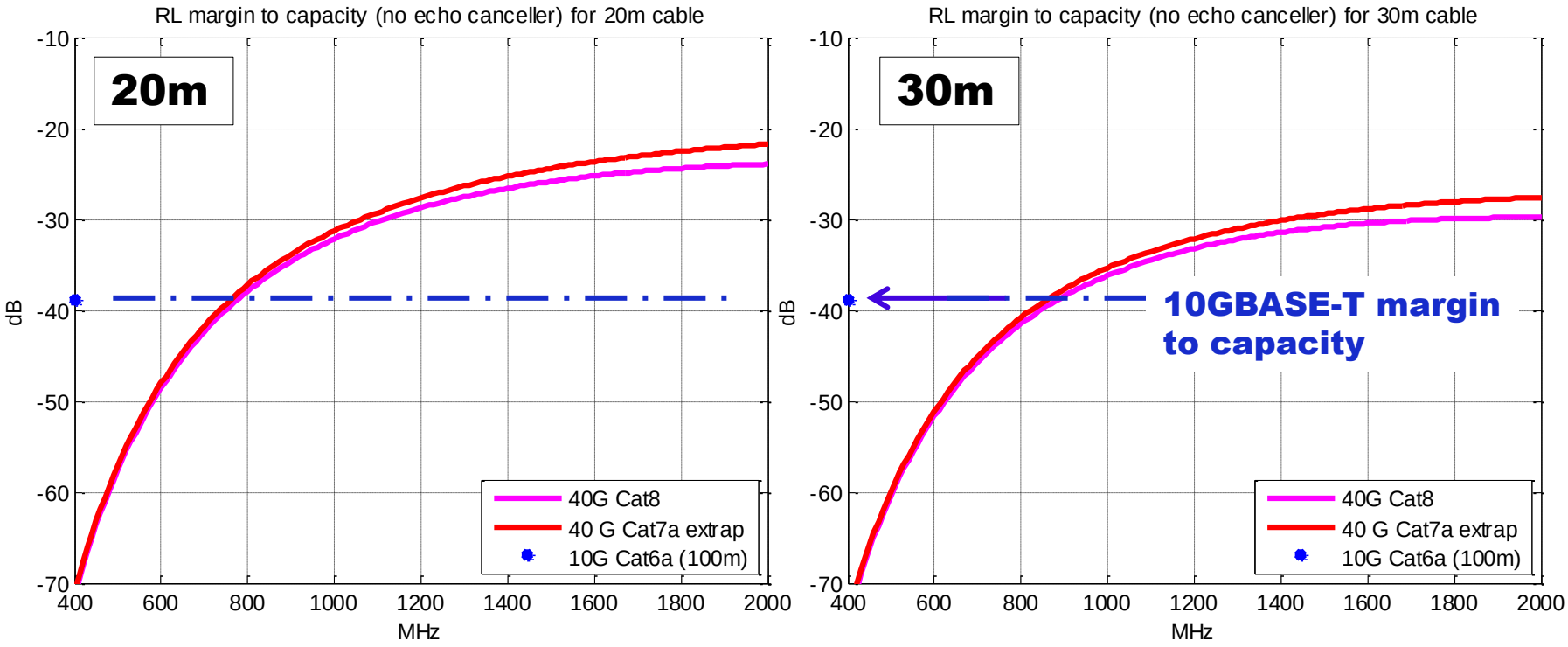
Return Loss Overview

- Analyze combined effect of return loss and insertion loss.
- Determine the margin to capacity, SNR_margin_{RL}, based on the ratio of the far-end signal to the local echo.
- Provide a simple model for the PHY power to cancel echo.
- Define the implementation margin for return loss cancellation ($impl\_margin_{RL}$) to be 12 dB.
  - For 10GBASE-T target limit SNR_margin_{RL} =($code\_margin$ + $impl\_margin_{RL}$) = 16 dB
  - For 40GBASE-T target limit SNR_margin_{RL} = ($code\_margin$ + $impl\_margin_{RL}$) = 16 dB

Return Loss Specifications



Return Loss Margin to Capacity



- Required Echo Cancellation = *code_margin* + $impl\_margin_{RL}$ – SNR_margin_{RL}. (55 dB for 10G)
- Over the analyzed frequency range and cable lengths, the margin improves with increasing bandwidth.
- Example from plot: For BW > ~870 MHz for 30m cable, echo canceller suppression requirement is less than for 10GBASE-T.

Return Loss Relative Power Model

- Define a new power model that reflects the relative power consumption due to echo cancellation:

$$P_{RL} \propto BW * 2^{\left(\frac{code\_margin+impl\_marginRL-SNR\_margin_{RL}(BW)}{20*log10(2)}\right)}$$

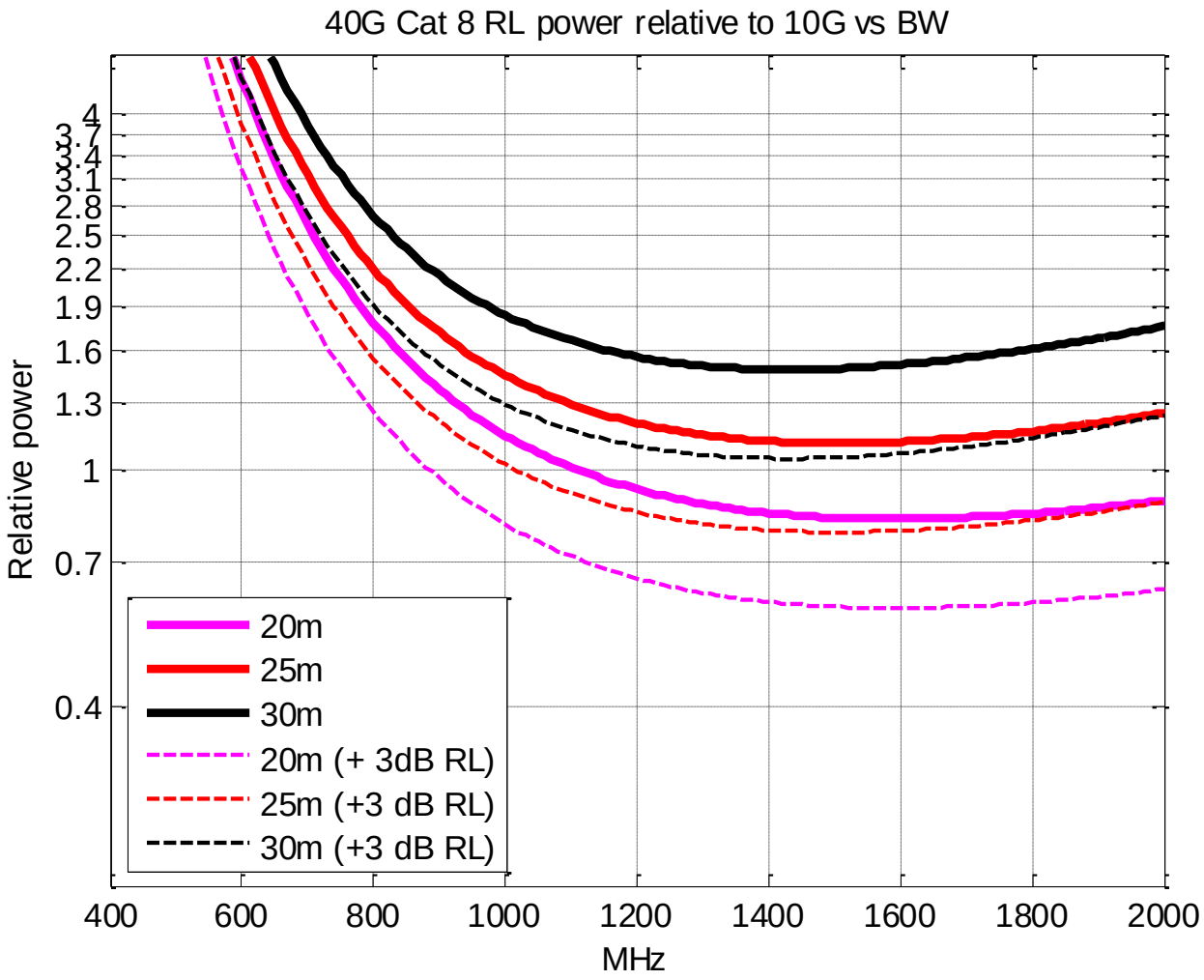
- The term (*code_margin* + *impl_margin*$_{RL}$ – *SNR_margin*$_{RL}$*(BW)*) reflects the degree of cancellation required and therefore relates to the dynamic range requirement.

- For a fixed bandwidth, a change in *SNR_margin*$_{RL}$ results in the following percentage change in P_{RL}:

$$\Delta P_{RL}\% = \ 100 * \ [2^{\left(-\Delta SNR_{margin_{RL}}/6.02\right)} - 1]$$

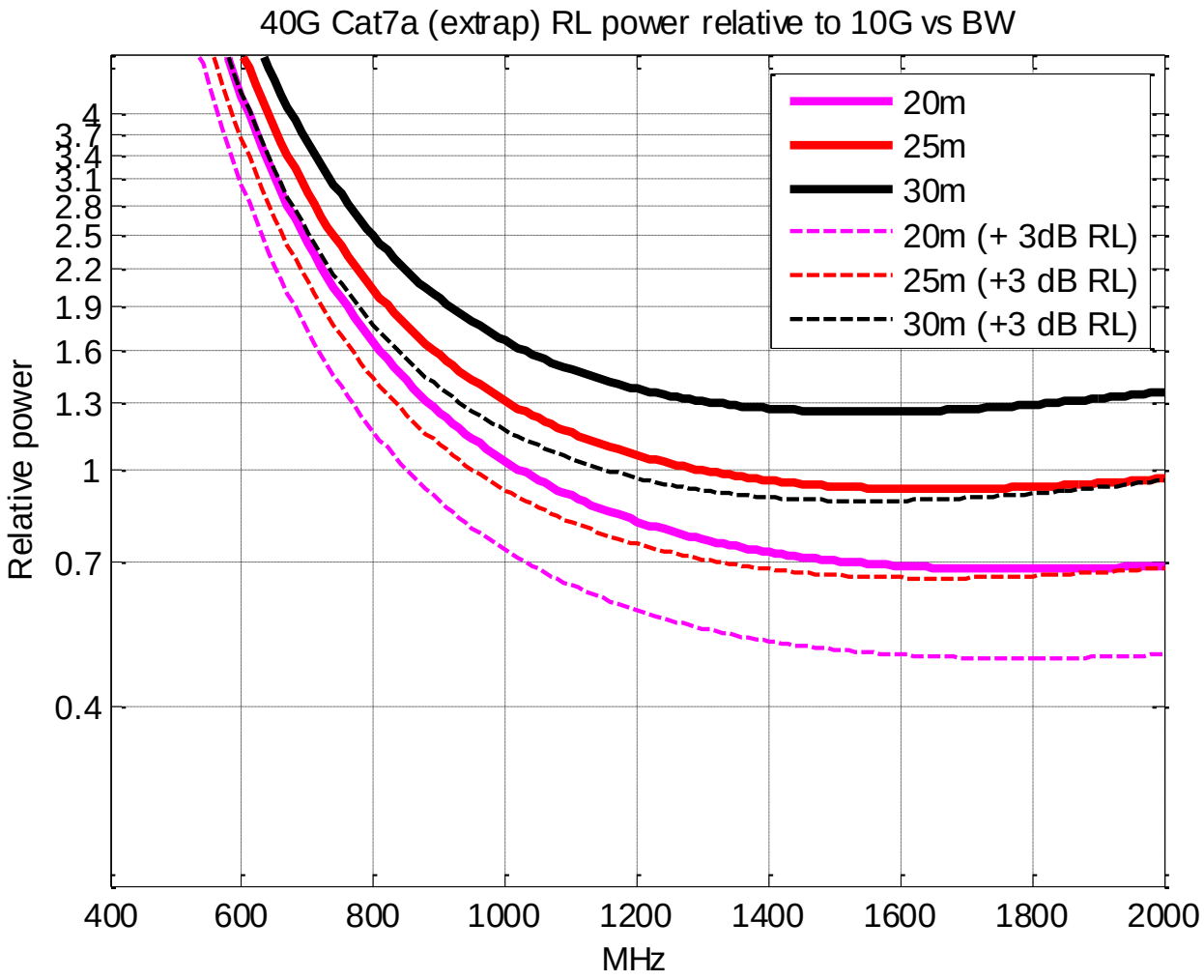
- As an example, with a 3 dB increase in *SNR_margin*$_{RL}$, the echo canceller power decreases by 29%.

40G/10G Cat8 Return Loss Relative Power as a Function of Bandwidth



A 3 dB increase in return loss decreases the return loss cancellation relative power by ~29%

40G/10G Cat7a RL Relative Power as a Function of Bandwidth



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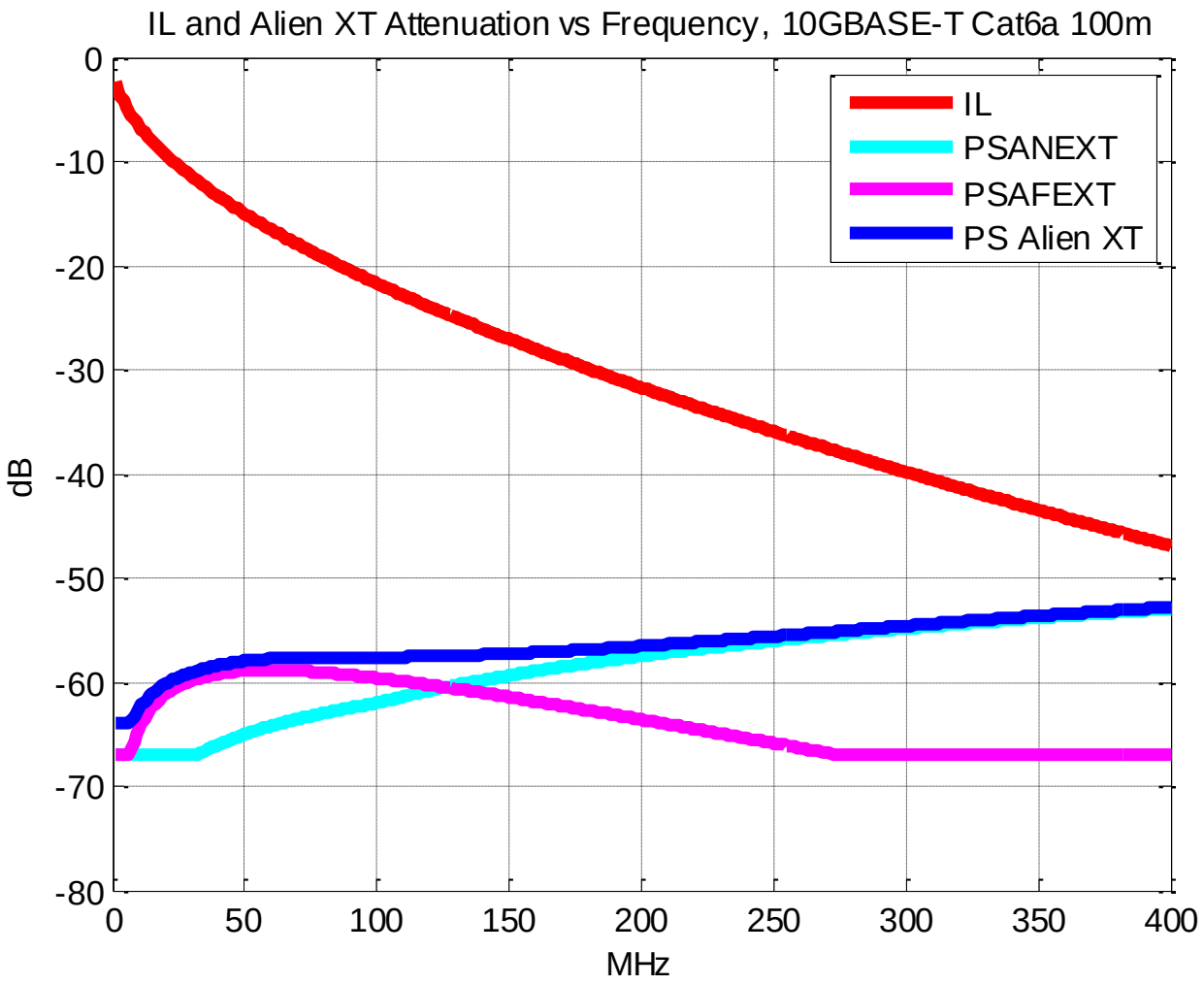
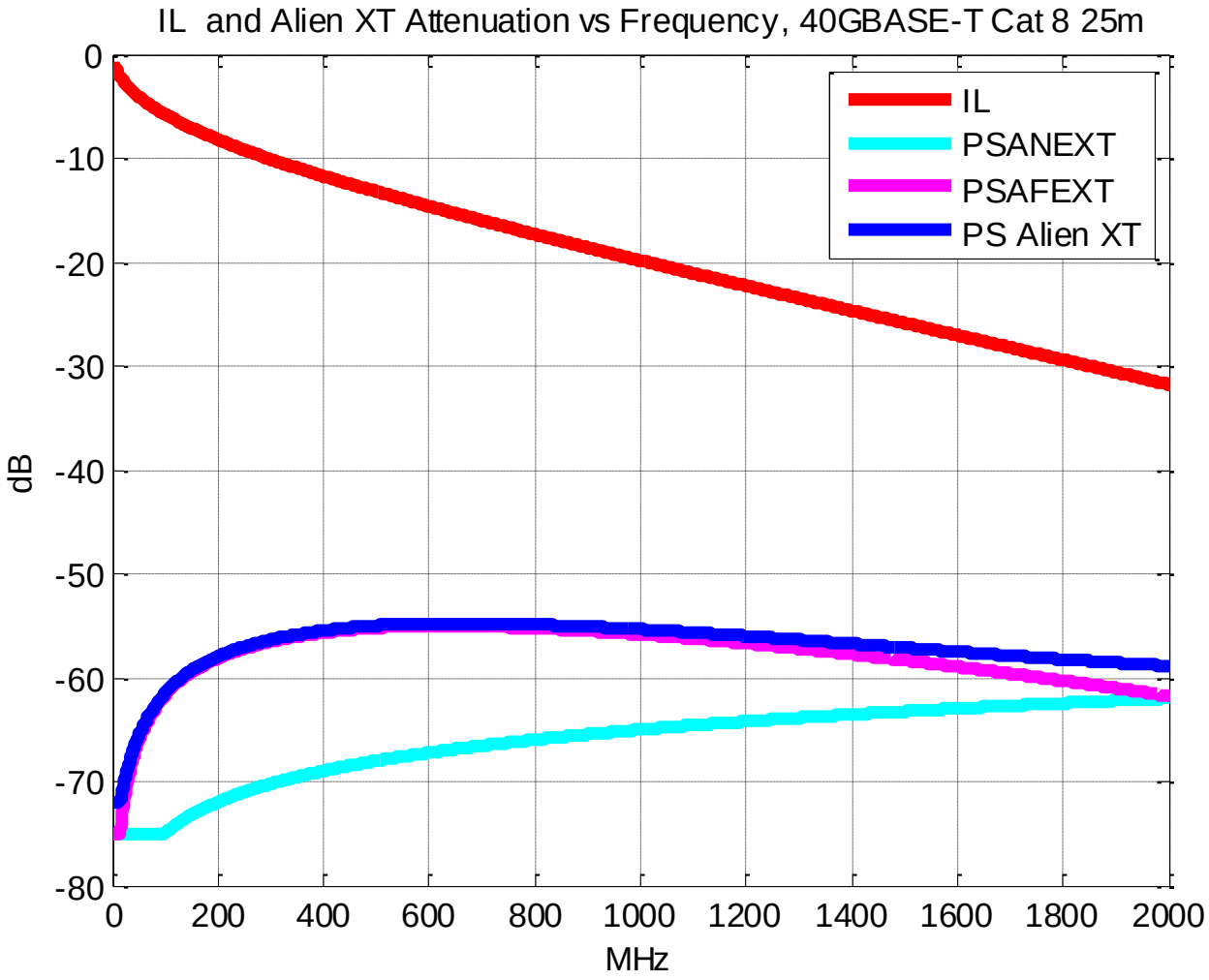
Alien Crosstalk Analysis Overview and Assumptions

- Define $margin_{AXT}$ as the target performance margin of the Alien Crosstalk relative to the *code_margin*.
- For < 0.3 dB degradation, $margin_{AXT}$ < 11.5 dB
  - For 40GBASE-T target limit SNR_margin_{AXT} ($code\_margin + margin_{AXT}$) = 15.5 dB
- Use PSANEXT, IL, and PSAACRF specification limit lines as the basis for the performance analysis.
- PSAFEXT is computed from the specified PSAACRF as follows:
  - PSAFEXT(f,L) = PSAACRF(f,L) + IL(f,L)

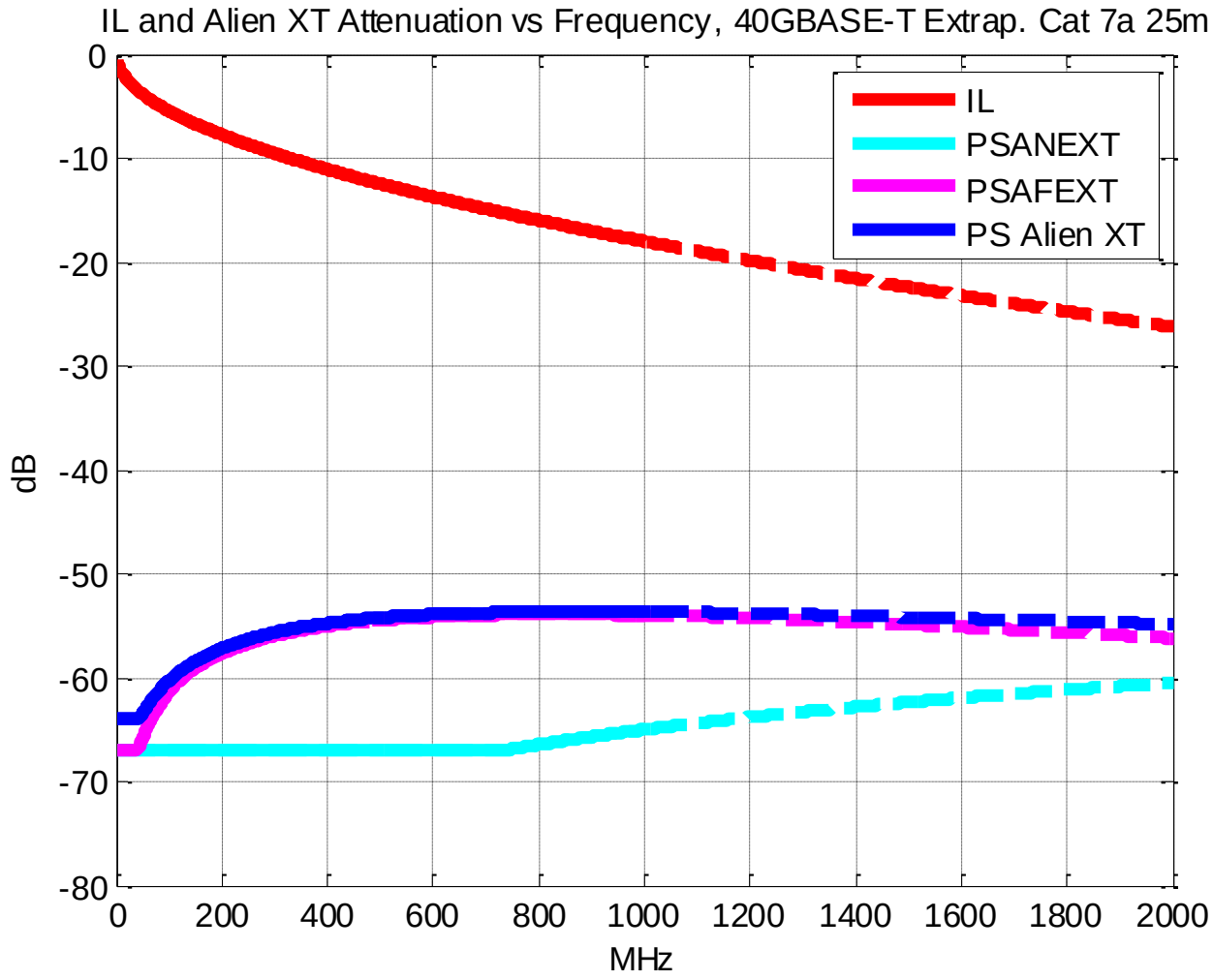
10GBASE-T 100m Cat 6a Insertion Loss and Alien Crosstalk



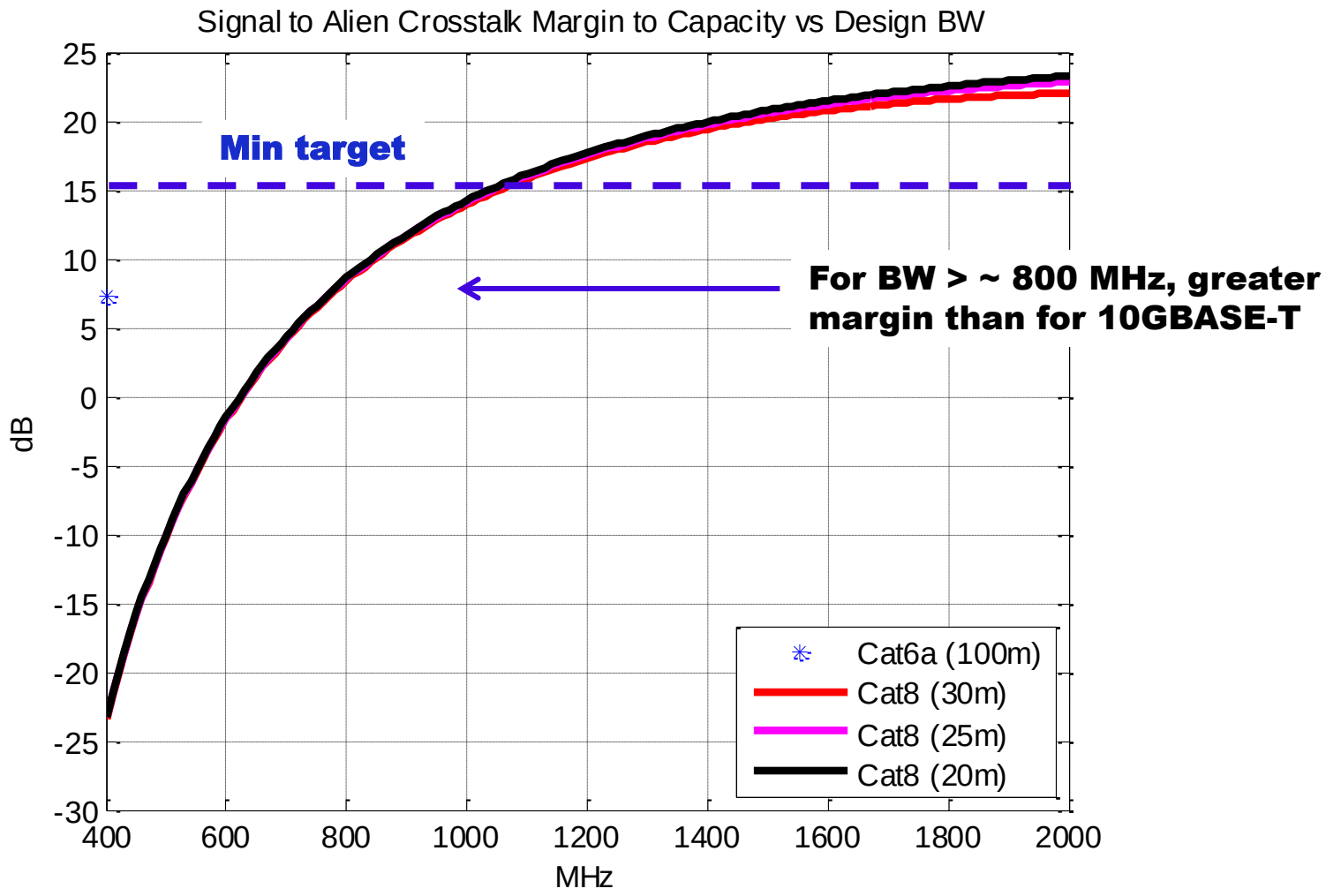
40GBASE-T 25m CAT 8
Insertion Loss and Alien Crosstalk



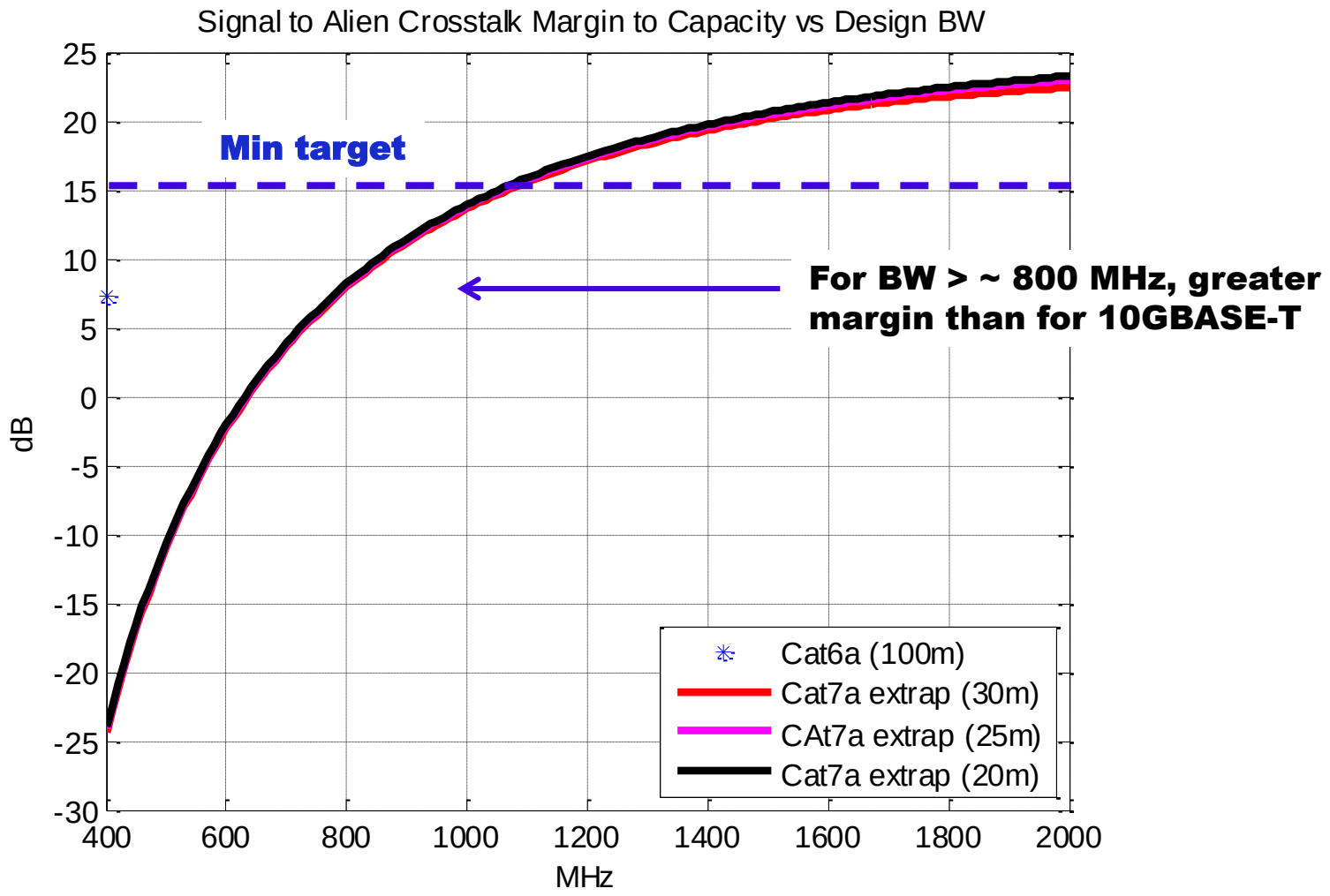
40GBASE-T 25m CAT 7a (extrap.) Insertion Loss and Alien Crosstalk



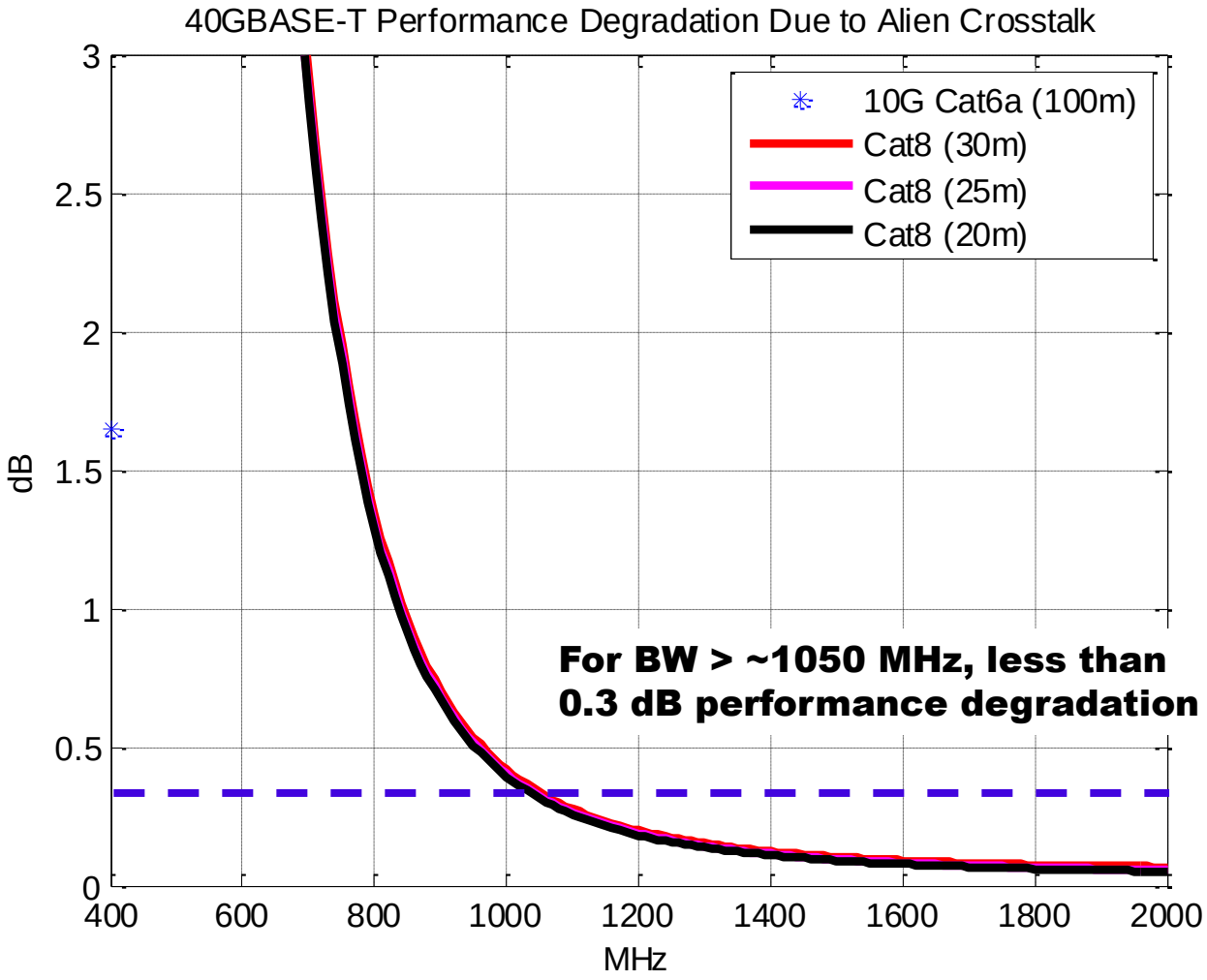
Alien Crosstalk Margin to Capacity Cat 6a and Cat 8



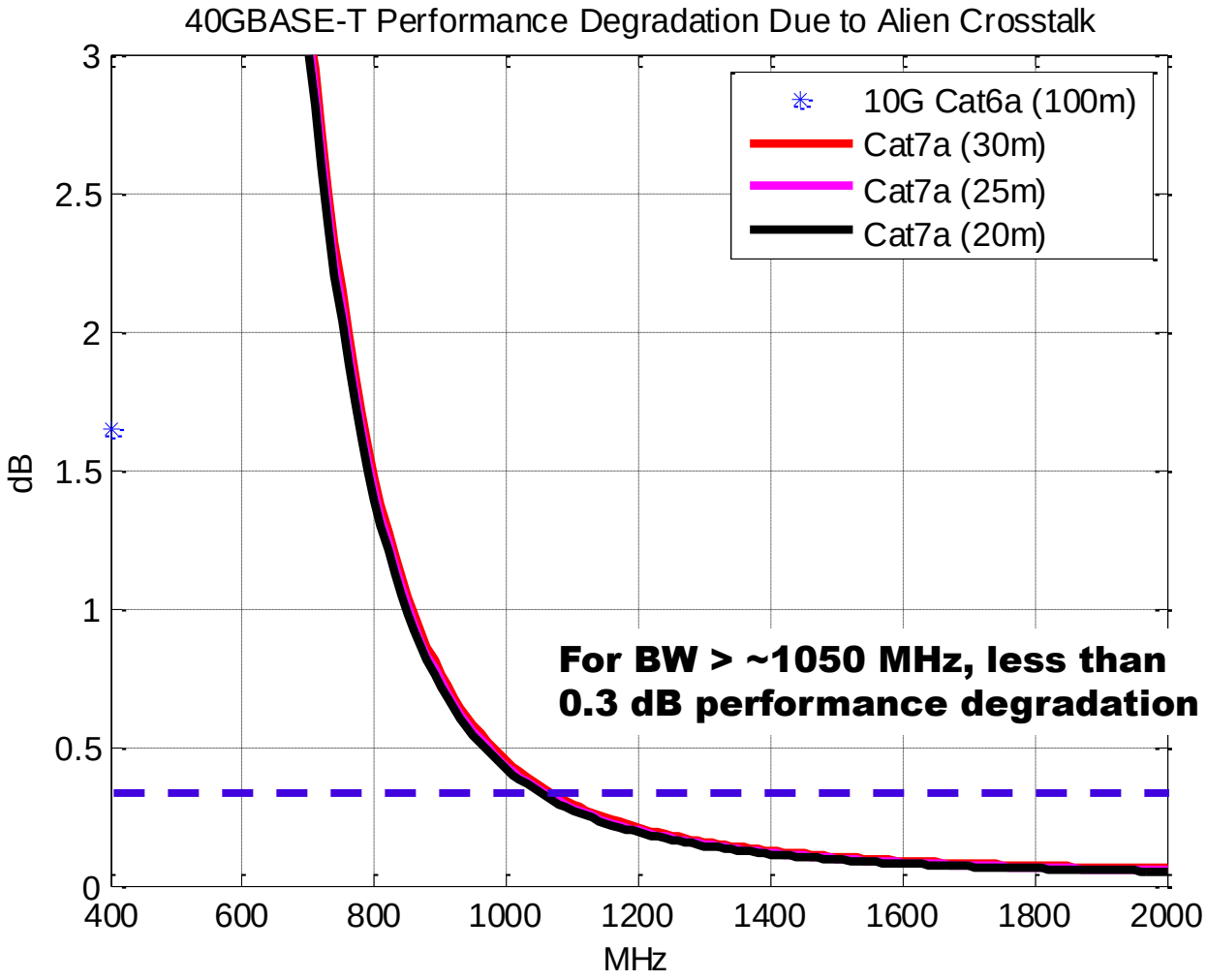
Alien Crosstalk Margin to Capacity Cat 6a and Cat 7a (extrapolated)



Alien Crosstalk Degradation Relative to 4 dB Code Margin Cat6a and Cat8



Alien Crosstalk Degradation Relative to 4 dB Code Margin Cat6a and CAT7a (extrapolated)



Alien Crosstalk Specification Observations

- With either the CAT7a or CAT8 specifications, the margin to capacity considering Alien Crosstalk is better for 40GBASE-T than for 10GBASE-T, when the 40GBASE-T bandwidth is greater than about 800 MHz.

- Cable length variation in the range 20 to 30m has little impact on the overall degradation.

- The Alien Crosstalk margin to capacity is similar for CAT8 and CAT7a (extrapolated).

- The effects of Alien Crosstalk are not negligible, but are reduced as the design bandwidth is increased.

Thank you