10GBASE-T Channel Criteria

Phy Vendor's Perspective

Multi-vendor presentation:
Broadcom
Vativ Technologies
Marvell

10GBASE-T Phy Feasibility

Primary goal: Define necessary channel requirements for multiple vendors to agree to the feasibility of a 10G phy implementation

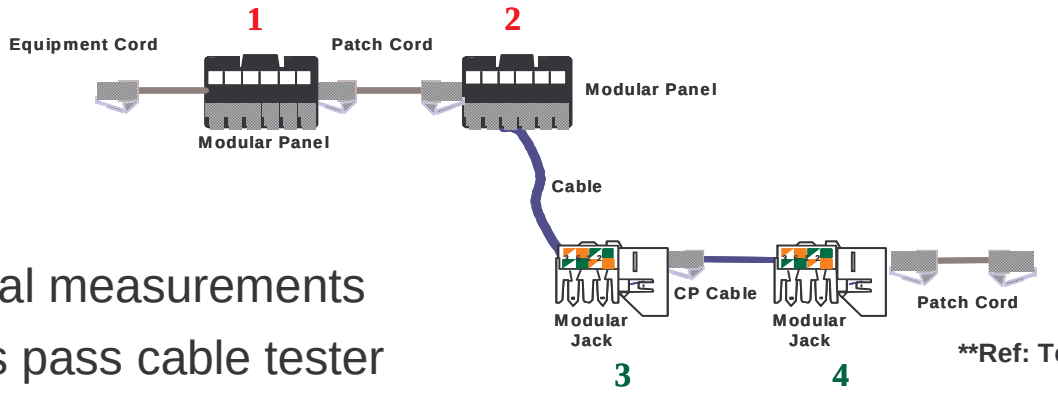
1. **Compute theoretical capacity on standardized cable channels**
   - Cat 5e, Cat 6, Cat 7 (classes D,E,F)
   - Based on unscaled measured data
2. **Channel requirements needed for 10G**
   - “Fantasy” Cat 6

Standardized Cable Channels

Cat 5e, Cat 6, Cat 7

Measurement Set-up

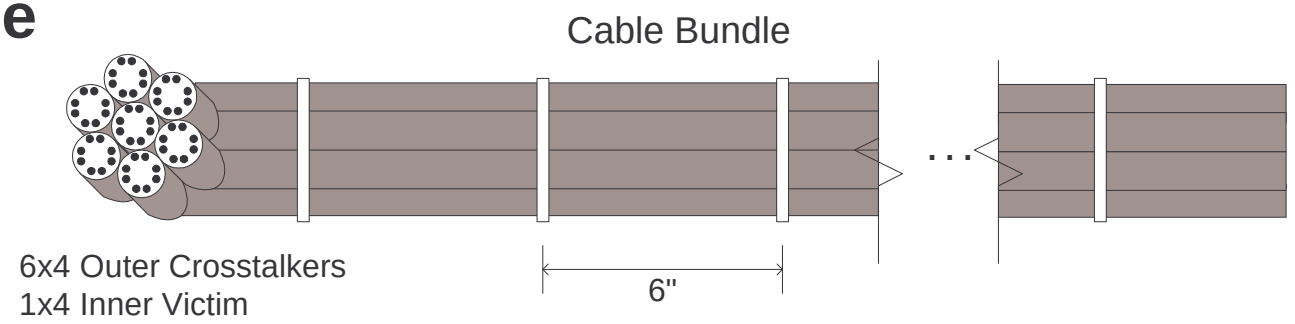
- **Standard 2 or 4** connector 100m terminated channel**



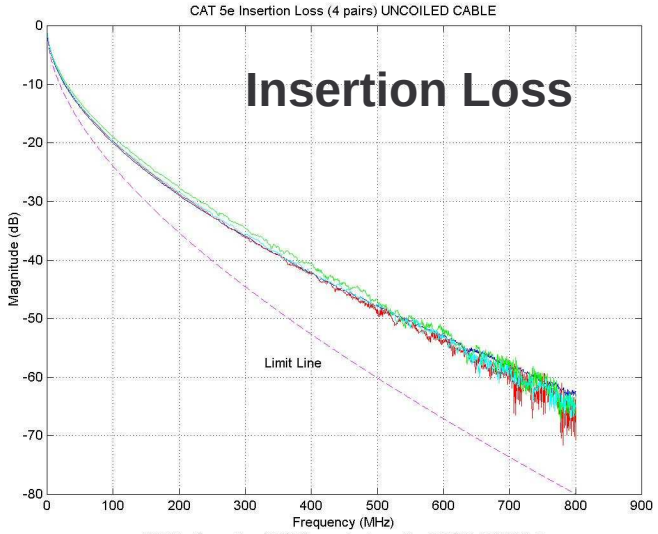
  - Differential measurements
  - Channels pass cable tester

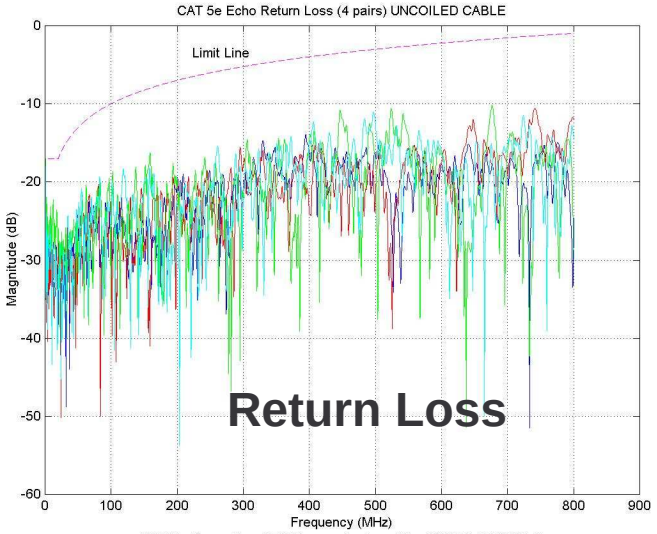
**Ref: Terry Cobb, Avaya, 2003

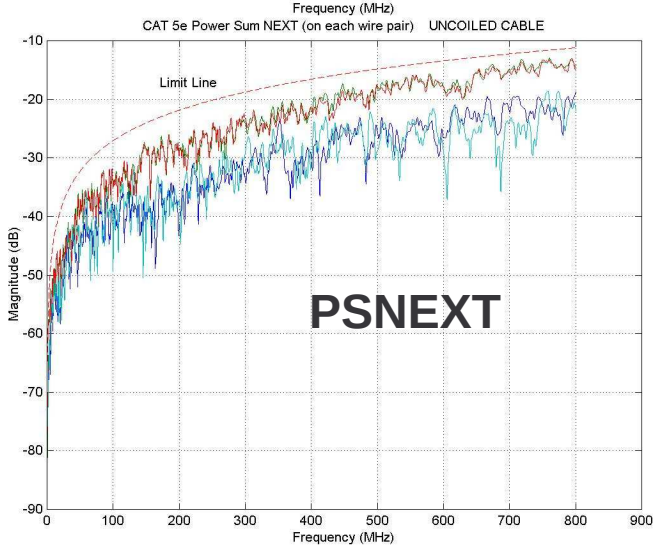
- **Alien crosstalk measured as power sum from 7 cable bundle**

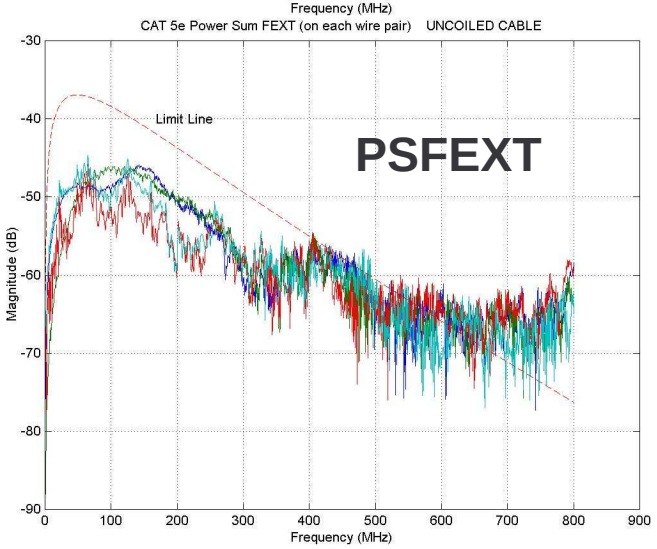


Cat 5e 100m 2 Connector



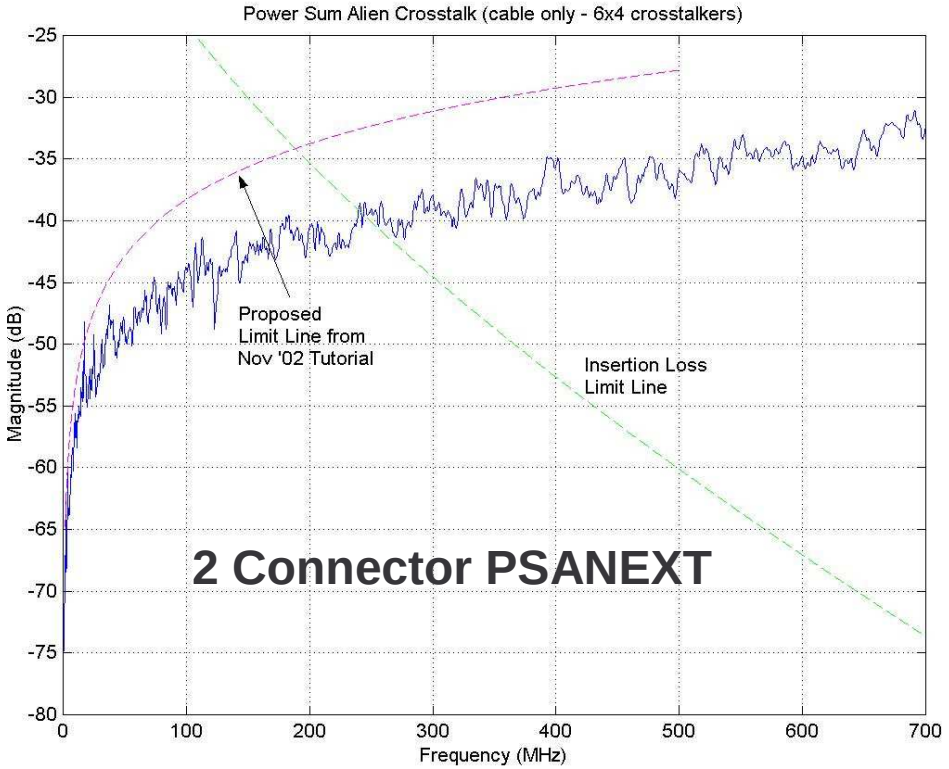


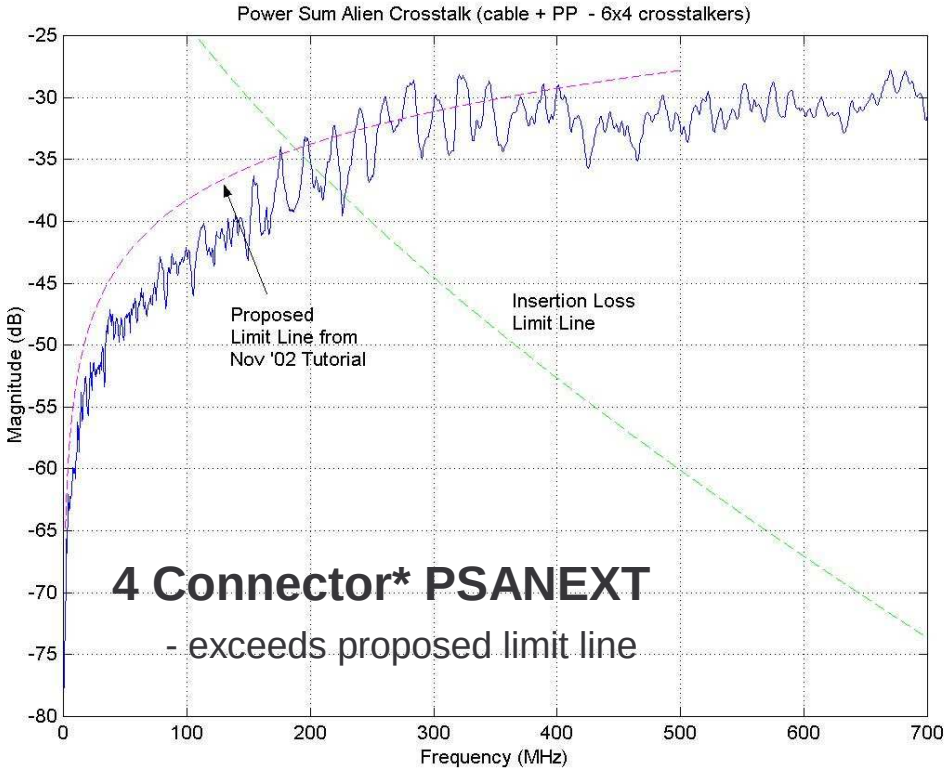




- **Limit lines extrapolated after 100MHz**

Cat 5e Alien Crosstalk

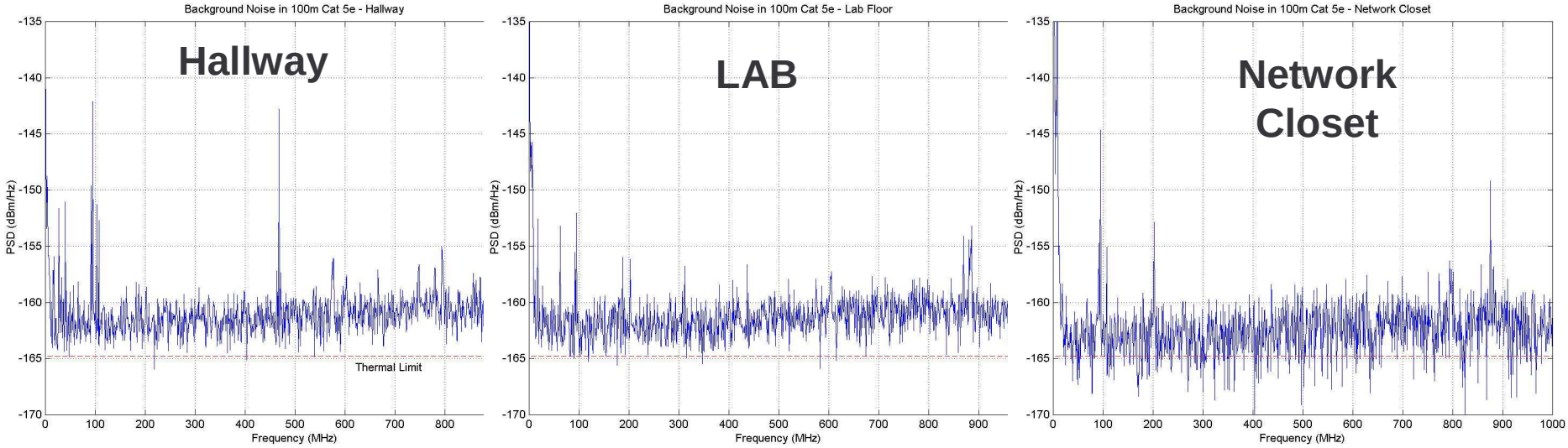




***2 near end connectors only**

- **Both channels pass Cat 5e cable tester**

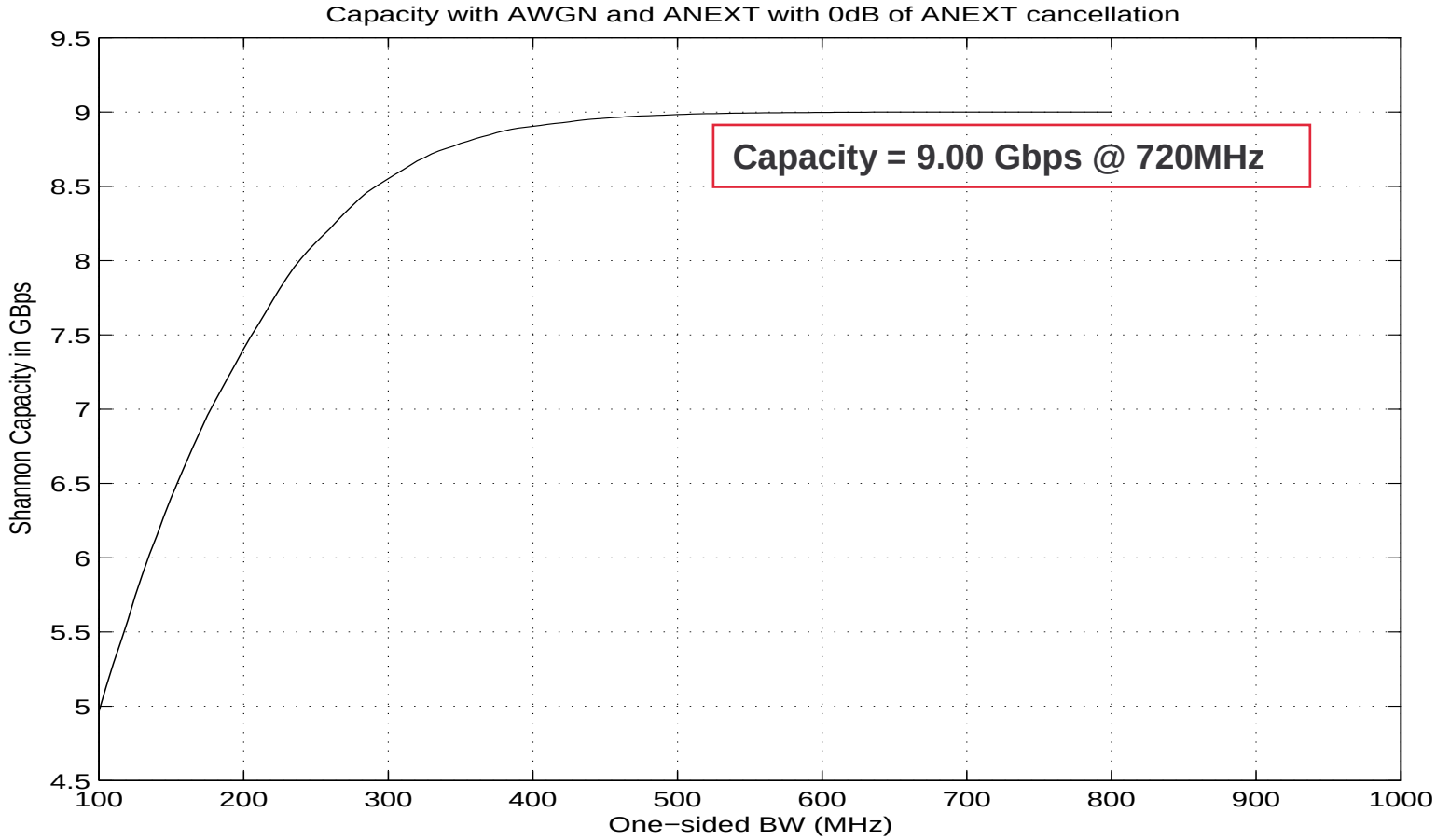
100m Cat 5e 2-connector Background Noise



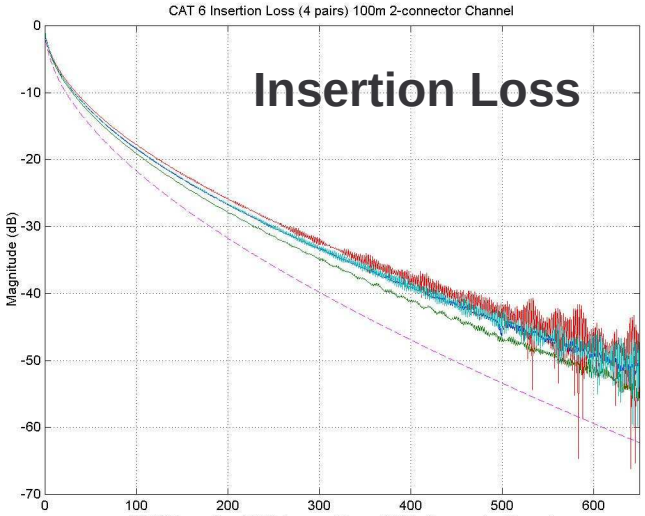
- **Cable terminated in 100 ohms**
- **Narrowband interferers have insignificant impact on theoretical capacity**
- **Broadband noise level below -155 dBm/Hz**
  - Similar results for Cat 6

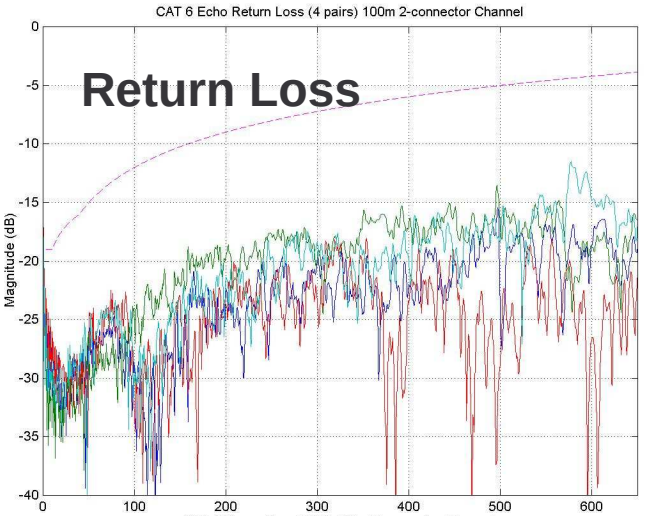
Cat 5e Capacity

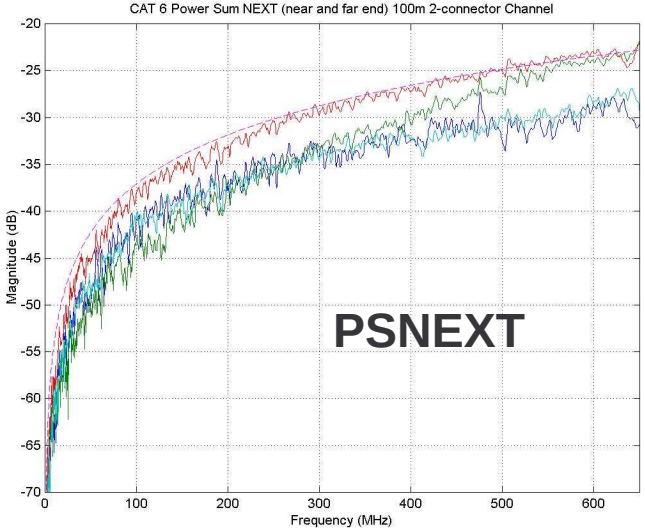
- **Based on unscaled measured data from 100m - 2 connector channel**
  - Background noise –155dBm/Hz
  - Not representative of worst case channel

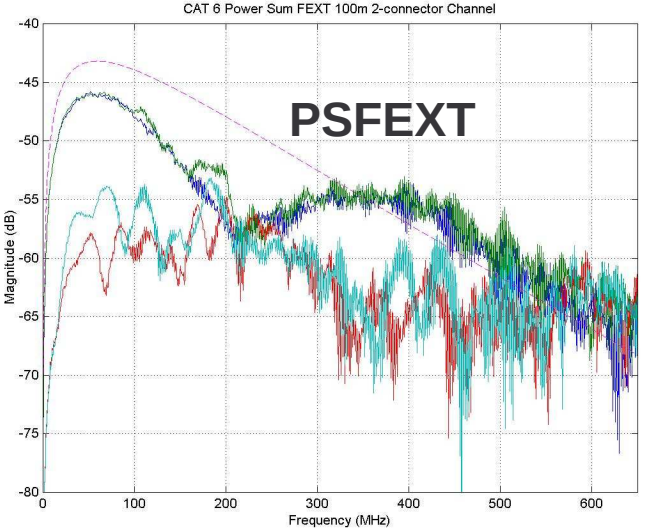


Cat 6 100m 4 Connector

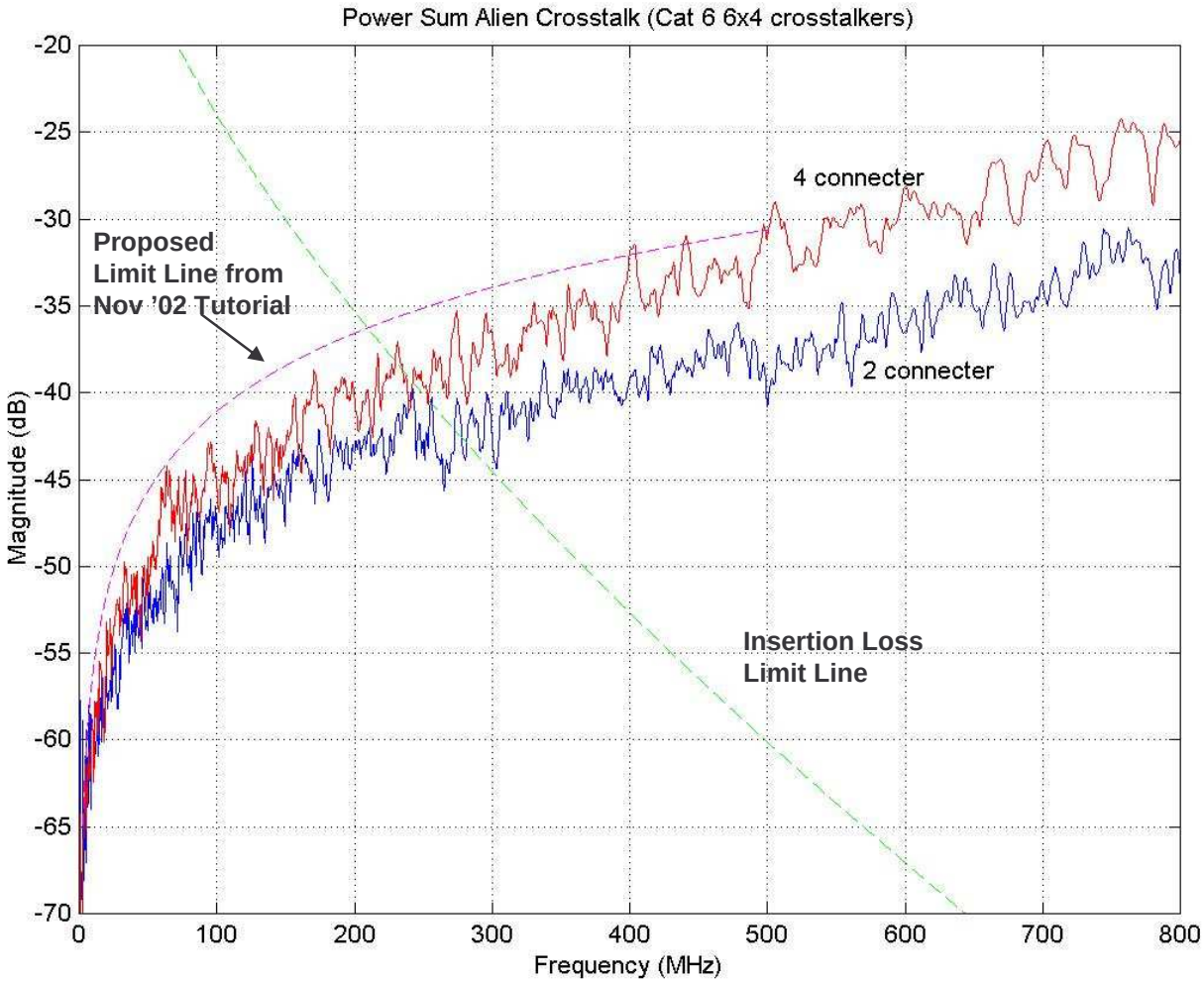








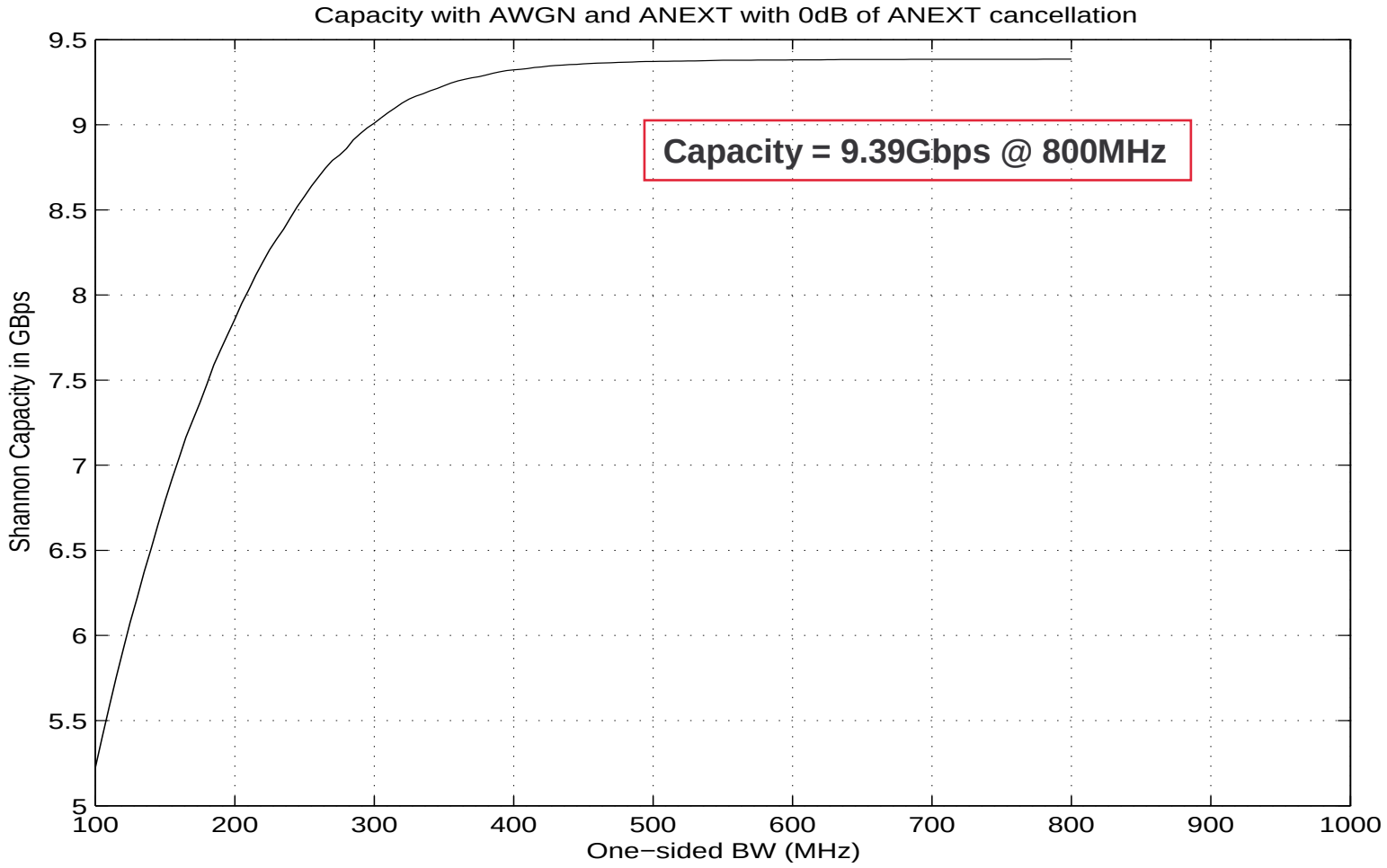
Cat 6 Alien Crosstalk



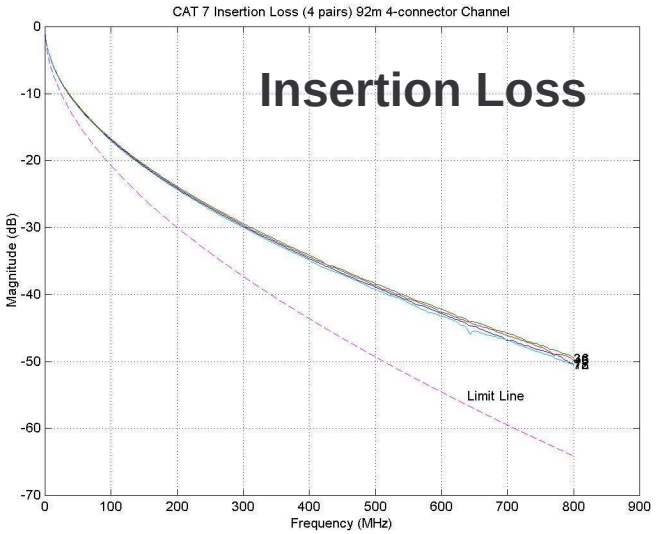
- 4 Connector channel exceeds proposed ANEXT limit line

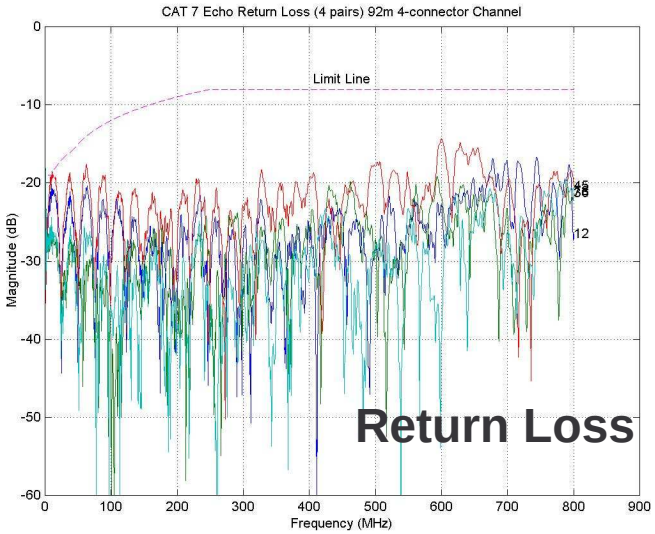
Cat 6 Capacity

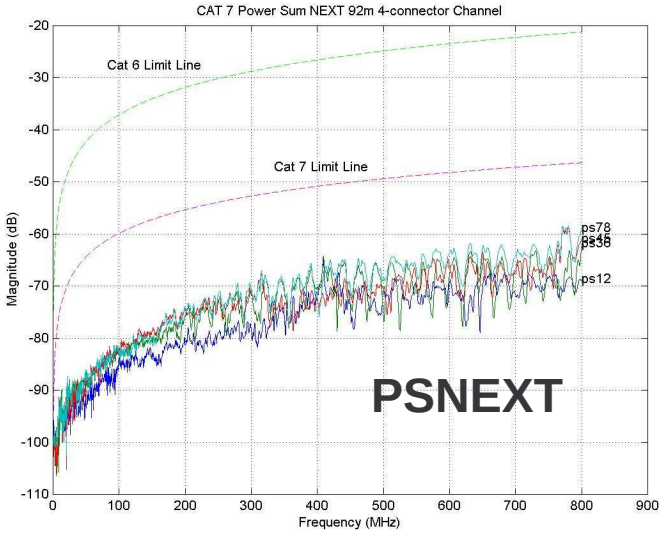
- **Based on unscaled measured data from 100m - 4 connector channel**
  - Background noise –155dBm/Hz

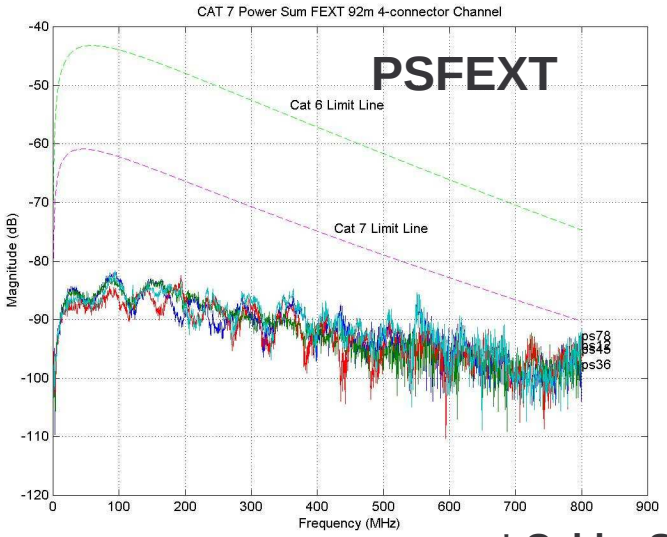


Cat 7 4 Connector*



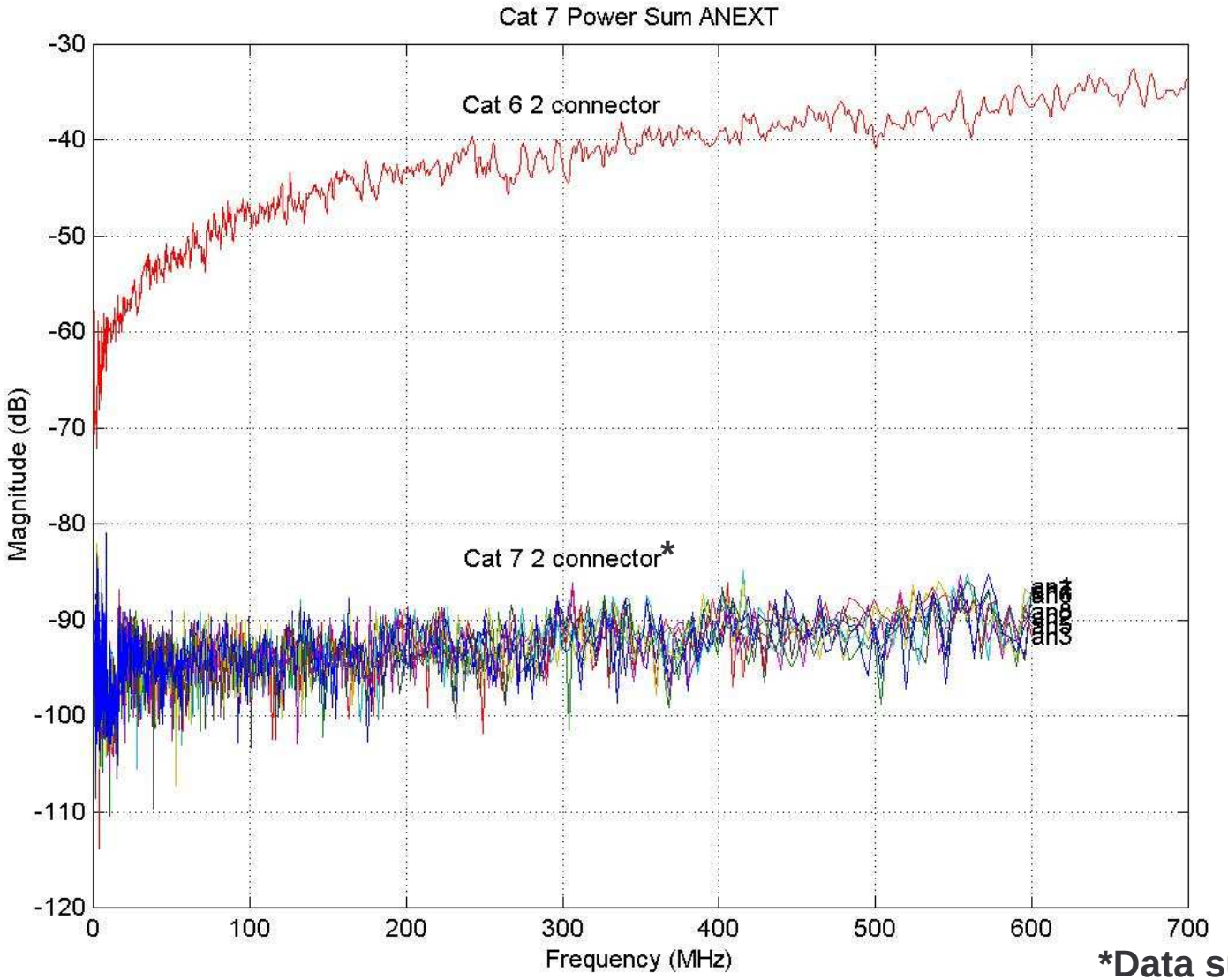






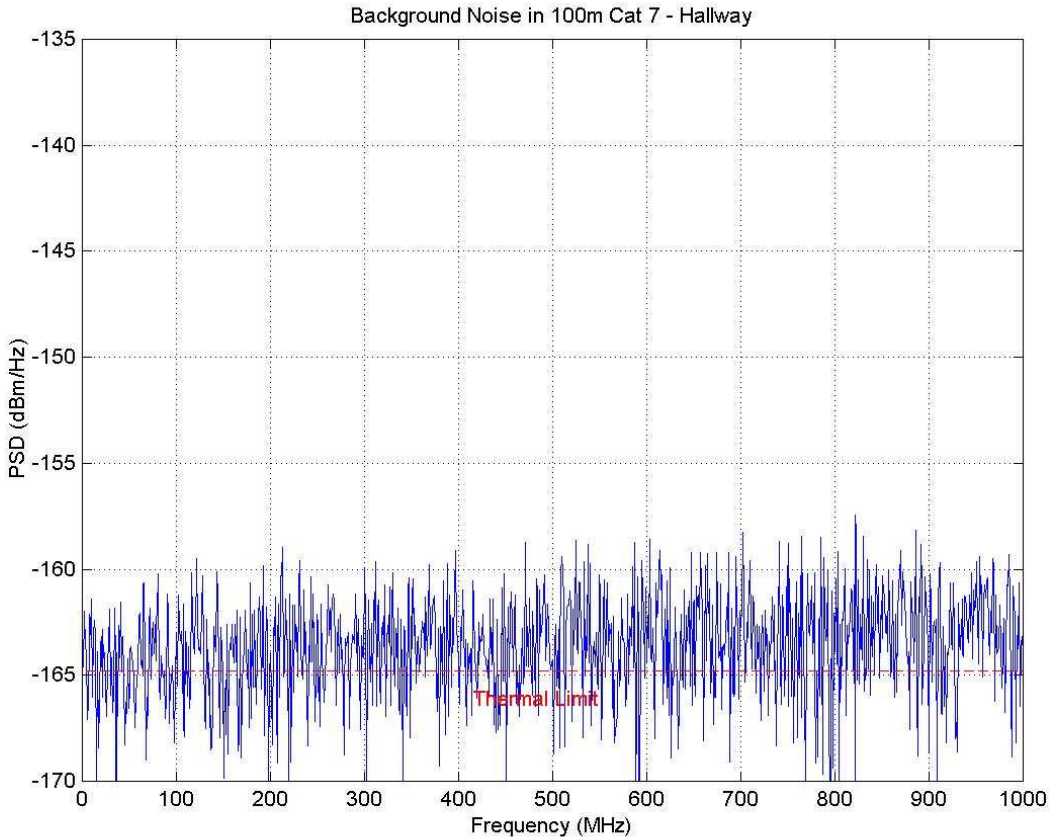
* Cable: Siemon Co.
Cat 7 TERA Channel

Cat 7 2 Connector ANEXT



*Data supplied by Nexans

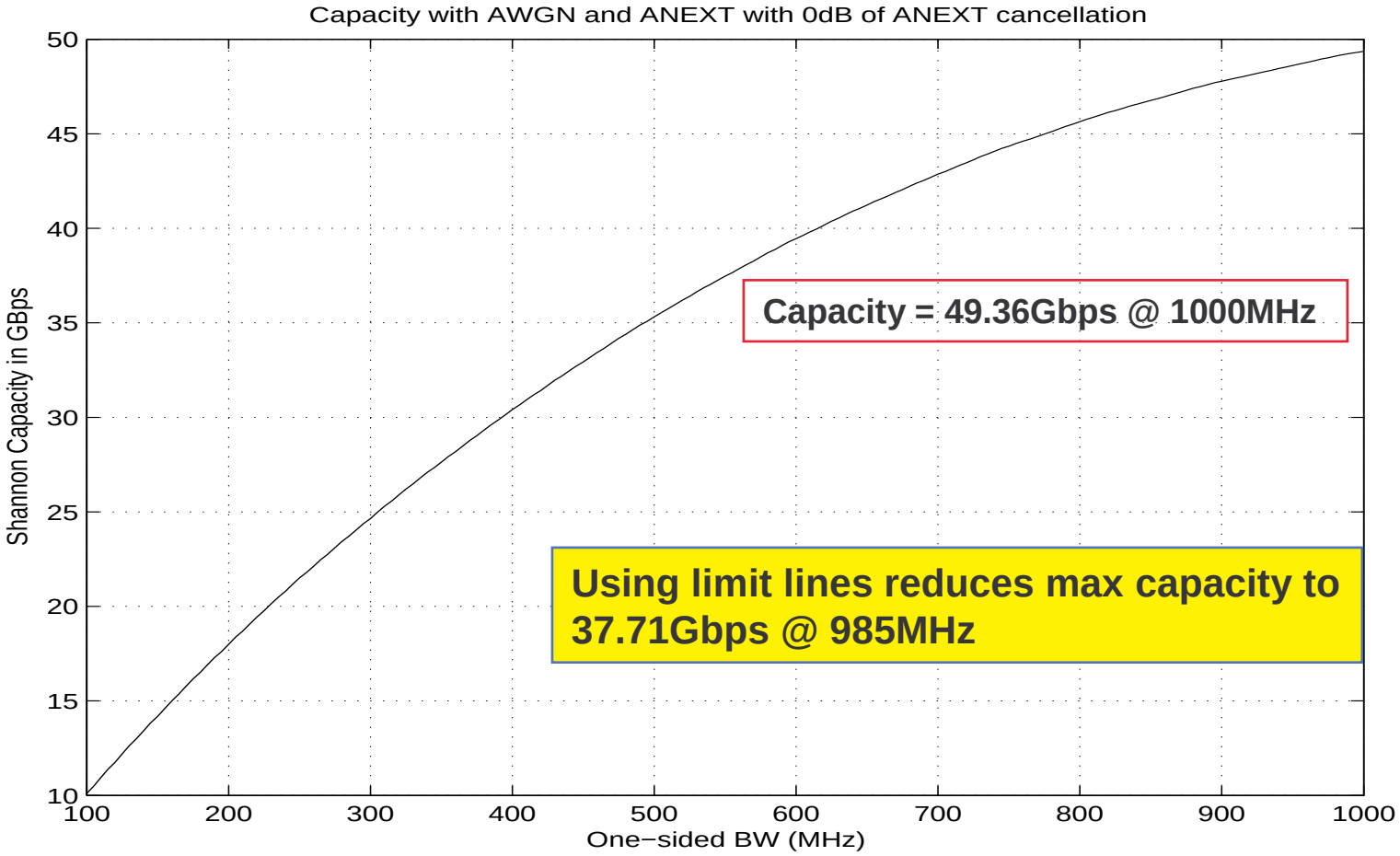
Cat 7 Background Noise



- Narrowband interferers suppressed
- Broadband noise level well below –155 dBm/Hz

Cat 7 Capacity

- **Based on unscaled measured data from 100m - 4 connector channel**
  - Background noise at –160dBm/Hz
  - ANEXT = measured Cat 6 reduced by 40 dB



10G over Existing Cables: *Conclusion*

- **Capacity calculations with measured data indicate that 10 Gigabit data transmission over 100m Cat 5 or Cat 6 UTP cables is not feasible**
  - Many basic implementation impairments neglected in this simplified analysis
    - Actual capacity will be worse
- **Alien crosstalk is a fundamental limit**
  - Must be reduced by some means – suggestions are welcome
  - Is disallowing cable bundles, adjacent patch panel locations, or multi-connector channels an acceptable marketplace solution ?
- **Capacity calculations with measured data indicate 10 Gigabit data transmission over 100m Cat 7 may be possible**
  - Further investigation with actual line codes and more accurate models warranted

Channel Requirements for 10G

Fantasy Cat 6

Determining an ANEXT Spec

- **10GBASE-T may be possible on newly specified improved UTP cable with sufficiently low alien cross talk**
  - "Fantasy Cat 6"
- **ANEXT is only one part of the overall noise budget**
  - ANEXT must be sufficiently small to permit realizable levels for other impairments
- **ADC quantization noise and sample clock jitter are the next largest impairments**
  - Residual NEXT/FEXT/echo/ISI, round off noise, transmit distortion, adaptation noise, background noise, etc. also contribute

ADC Requirements

- **Assuming a cable with sufficiently low ANEXT, analog-to-digital conversion is the next dominant noise source**
  - Determined by the resolution and timing jitter of the ADC
  - Reduces noise budget available for ANEXT
- **Assume:**
  - Quantization noise is AWGN
  - Background noise is AWGN
  - ANEXT is the only other uncancelled noise source
  - 416 MHz baseband PAM

Target SNR Calculations

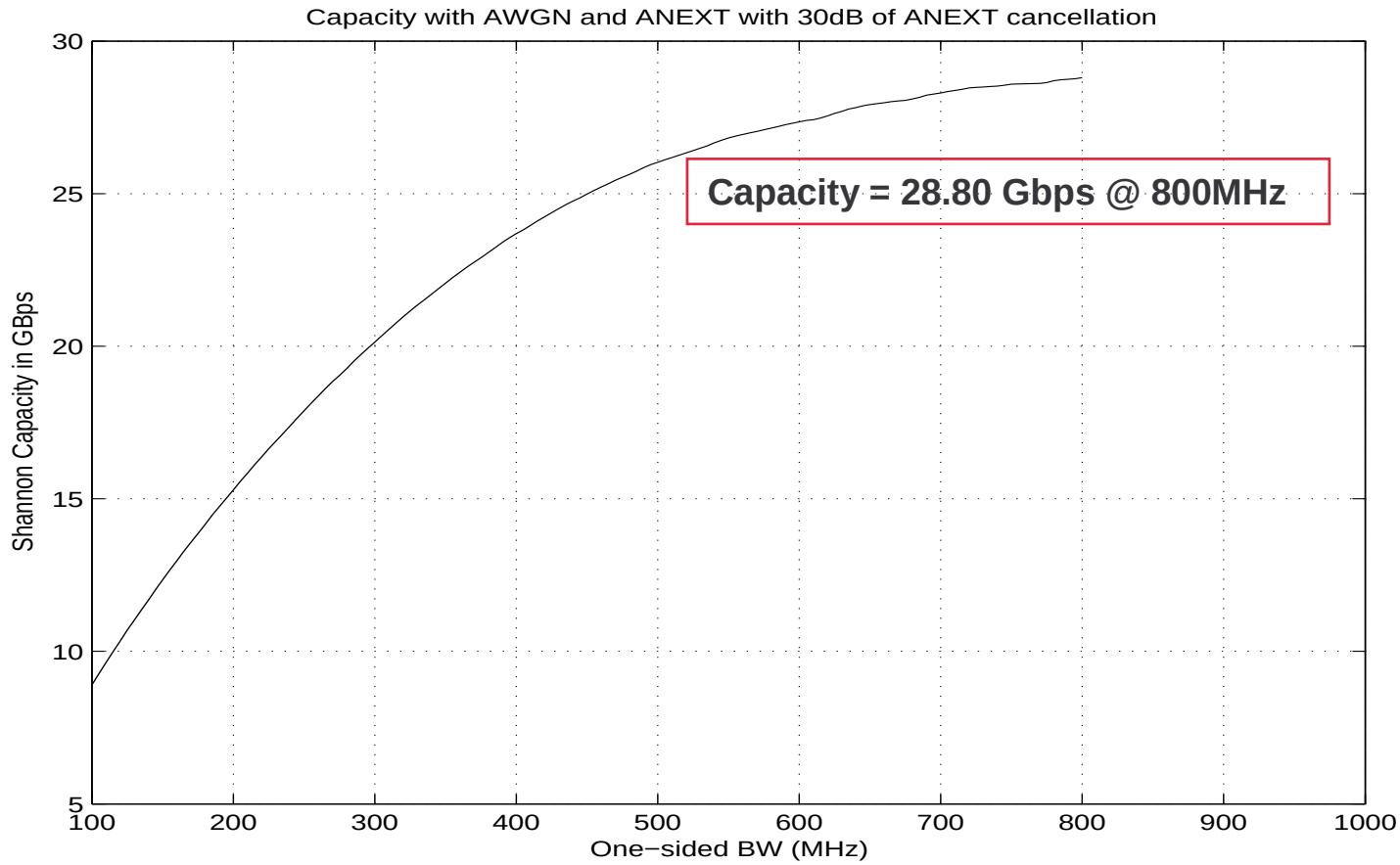
- Slicer symbol SNR* = the average PAM-modulated symbol SNR to achieve SER=10^{-12}
- PAM10 SNR* = 32.21 dB
- MMSE–DFE $SNR_{MMSE} = \exp\{\int \ln(1+SNR(f))df/B\} - 1$ and the corresponding channel capacity $C = \int \log_2(1+SNR(f))df$
  - Channel SNR(f) is determined by insertion loss, alien crosstalk, quantization noise (Vpp=2V) and background noise (-155dBm/Hz)
  - Target SNRMMSE=SNR*–coding gain+design margin
  - Coding gain = 6dB (TCM),
  - Design margin should cover the impact of all real-world system defects, including:
    - ü <6dB coding gain
    - ü Clock jitter
    - ü Uncancelled echo/NEXT/FEXT/ISI
    - ü Analog non-linearities
    - ü Analog noise
    - ü Arithmetic noise
    - ü "Other" – system margin

Capacity Study PAM10

ADC ENOB (bits)	Design Margin (dB)	Target SNR_{MMSE} (dB)	Measured data		Limit line	
			ANEXT reduction (dB)	Channel Capacity (Gbps)	ANEXT reduction (dB)	Channel Capacity (Gbps)
10	6	32.21	24.1	17.8	NA	NA
	9	35.21	NA	NA	NA	NA
	12	38.21	NA	NA	NA	NA
11	6	32.21	18.9	17.8	29.1	17.8
	9	35.21	23.5	19.5	40.8	19.5
	12	38.21	30.7	21.1	NA	NA

Fantasy Cat 6 Capacity

- **Based on unscaled measured data from 100m- 4 connector Cat 6 channel with**
  - 30dB ANEXT reduction
  - –155dBm/Hz background noise



Conclusions

- **10GBASE-T is not feasible over a large portion of existing Cat 5e and Cat 6 cable plants**
  - ANEXT is the fundamental limit
- **A new cable matching Cat 6 performance with sufficiently reduced ANEXT could support 10GBASE-T**
  - 30-35dB ANEXT reduction necessary
  - Requires characterization beyond current 250MHz Cat 6 spec
  - ENOB > 10 bits for PAM10
- **Existing standard Class F cable could support 10GBASE-T**
  - No further characterization necessary
  - ENOB >10 bits for PAM10
- **Once the appropriate channel medium is selected, a coded modulation scheme needs to be chosen to optimize performance**