

Technical Feasibility of 10GBE Over Copper: Measurements, Models, and Capacity

Bijit Halder
Telicos Corporation

E-Mail: bijit@telicoscorp.com

*IEEE802.3-10GBT Interim Meeting
May 2003, Portsmouth, NH*

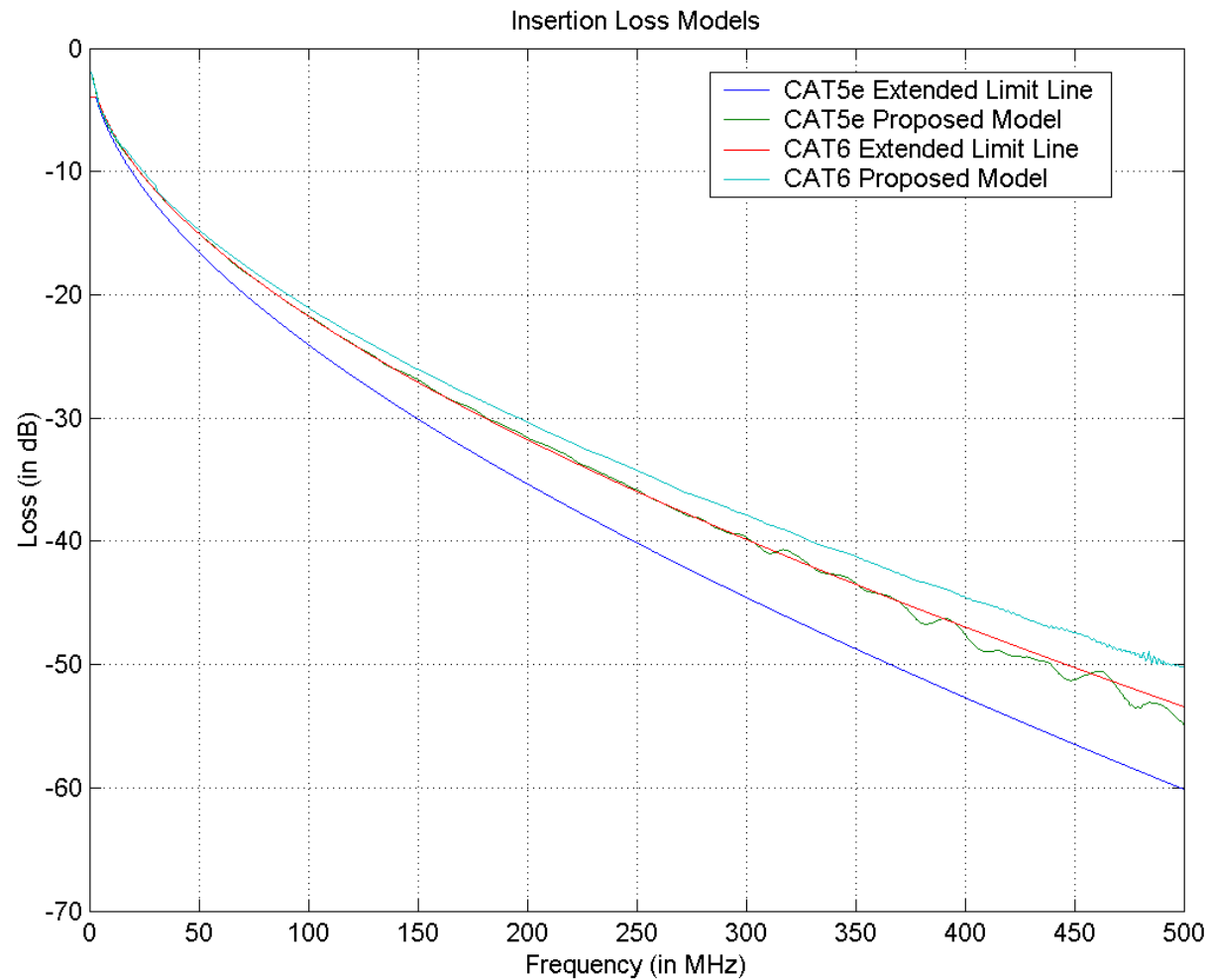
Overview

- The question: Is 10GBE over copper technically feasible?
 - First step towards addressing the feasibility question is to calculate system capacity
- Capacity with new models
 - Capacity with system parameters proposed by the modeling Ad Hoc in March '03 (Dallas)
 - Effect of various parameters on system capacity
- Models vs. limit lines
 - Effect on capacity
 - Models critical for capacity
- How much capacity is adequate for technical feasibility?
- Issues for technical feasibility

Models Used For Calculations

- We used the models provided by the cabling Ad Hoc
- The following models are provided by the cabling Ad Hoc
 - CAT5e: IL, RL, PSDNEXT, PSFEXT, ANEXT
 - CAT6: IL, RL, PSDNEXT, PSFEXT
- Models for RL, NEXT, FEXT, and ANEXT are obtained by scaling the measurements
- IL loss model is not scaled
- We show the models for reference and comparison

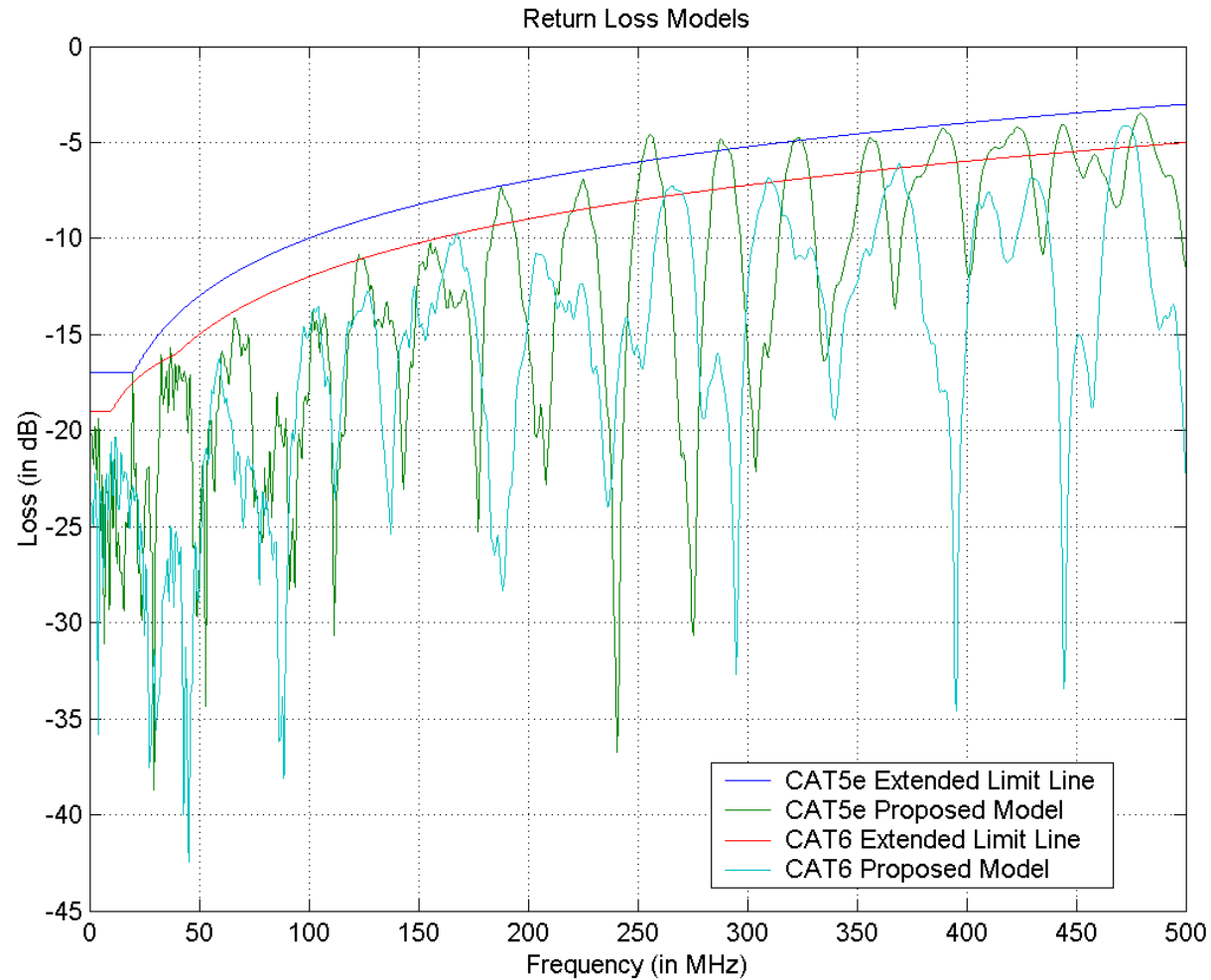
Insertion Loss Models



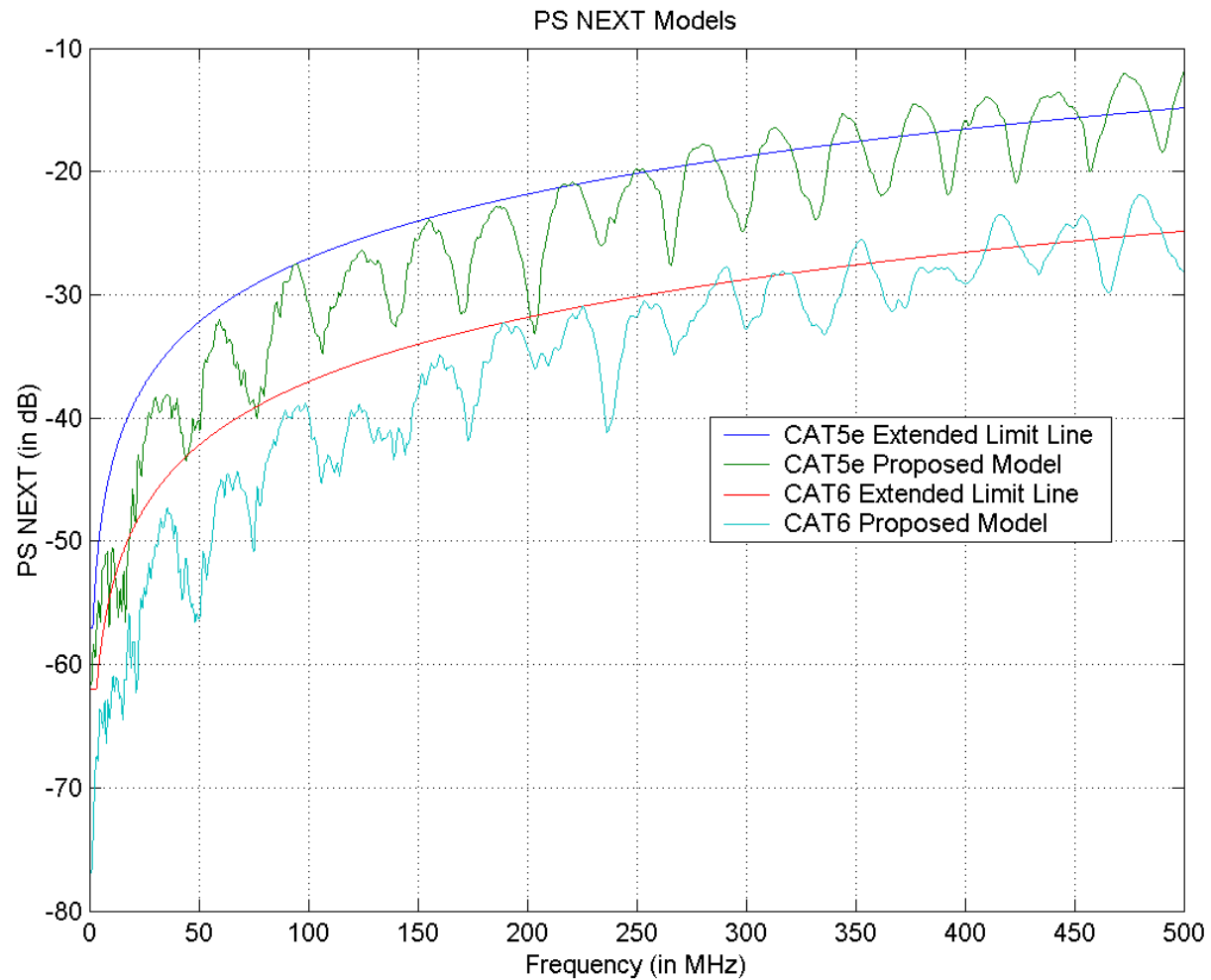
Observations About IL Models

- Proposed CAT5e model is close to CAT6 limit line
 - Better than CAT5e limit line even for frequencies $< 100\text{MHz}$
- For CAT5e the gap between proposed model and limit line is greater than the corresponding gap for CAT6
- Do the proposed IL models represent the worst case or some typical case?
 - Limit line represents the worst case: all of installed base
 - Typical case: A fraction of installed base. What fraction is covered by the proposed model?
 - Directly relates to market potential

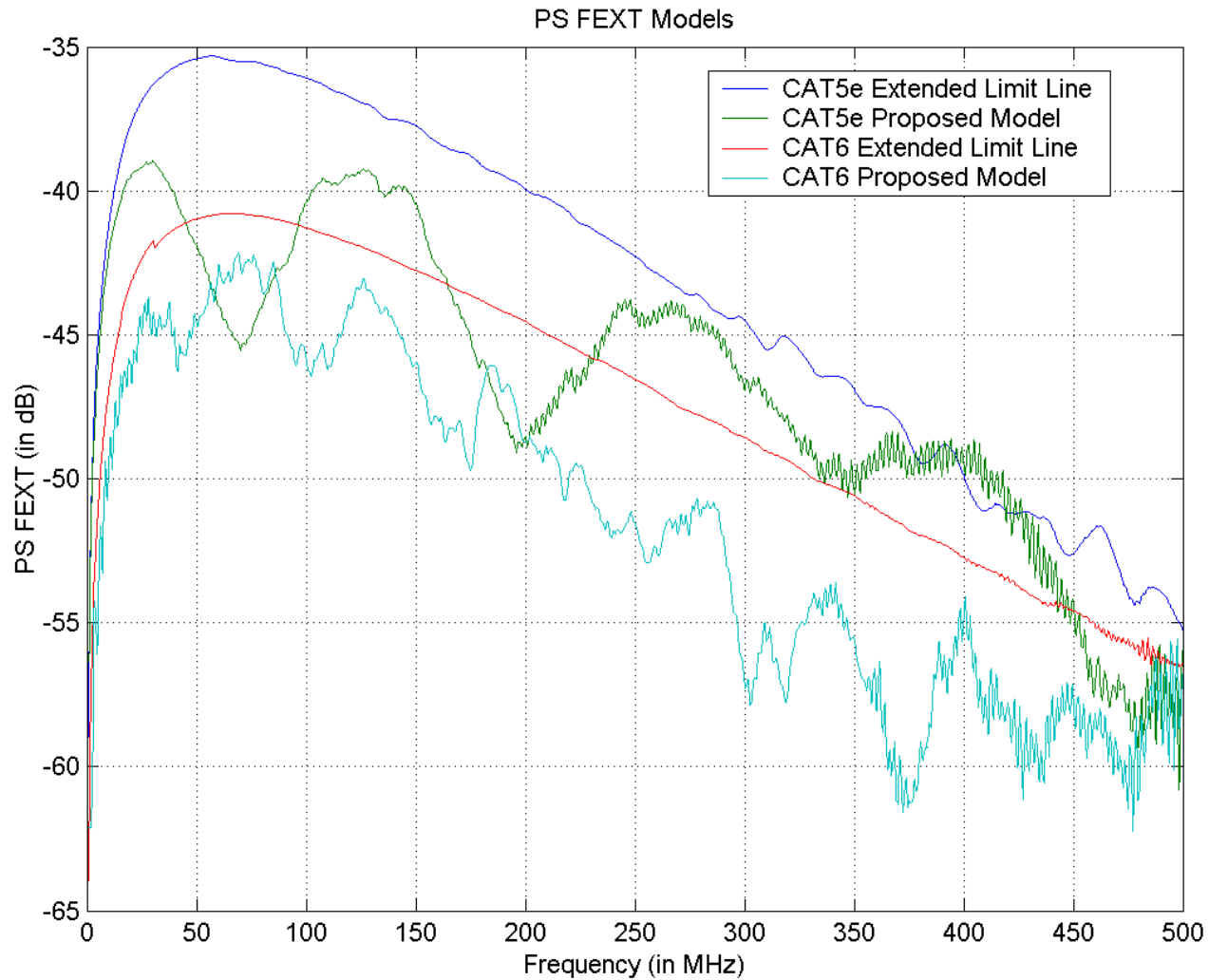
Return Loss Models



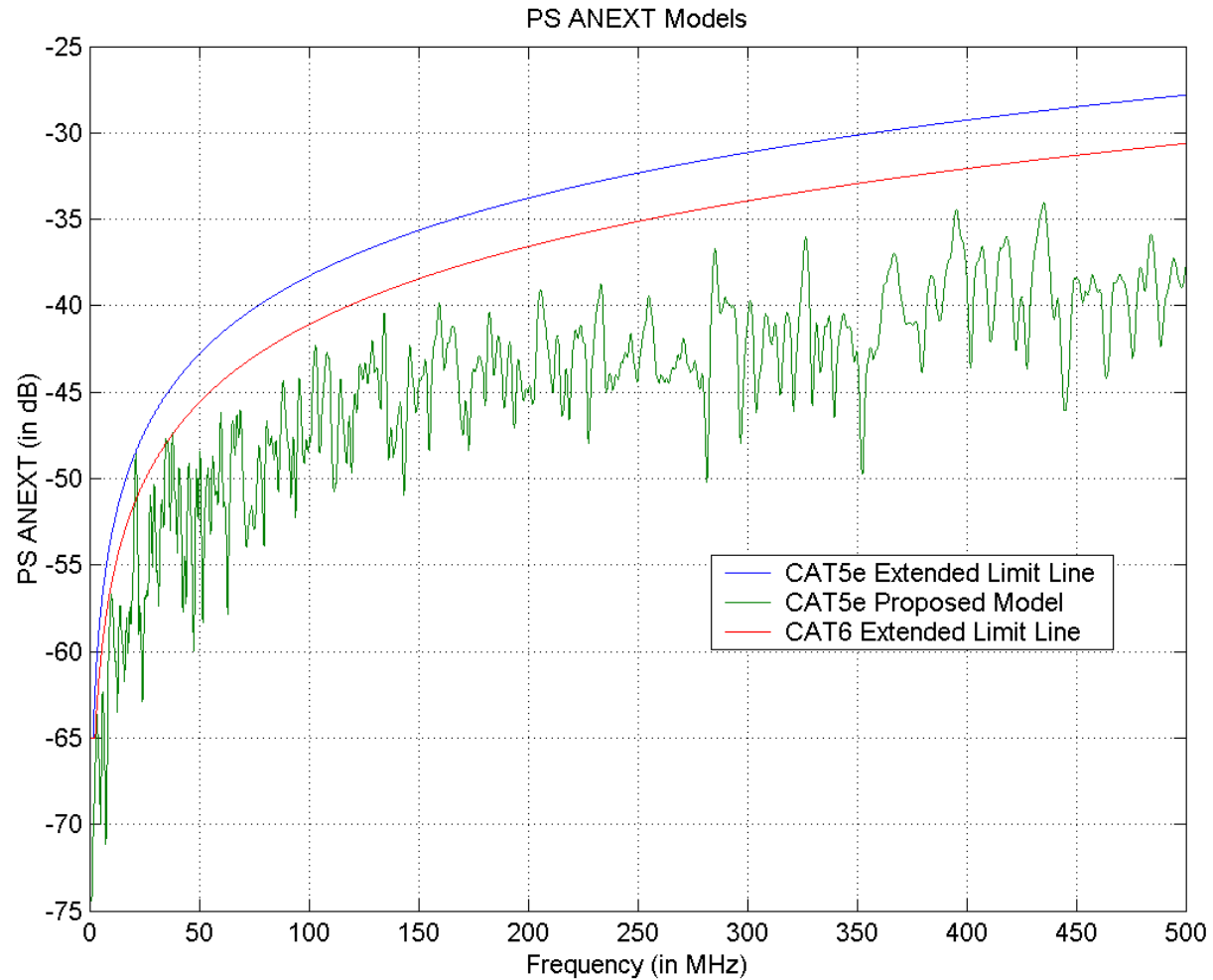
PSNEXT Models



PSFEXT Models



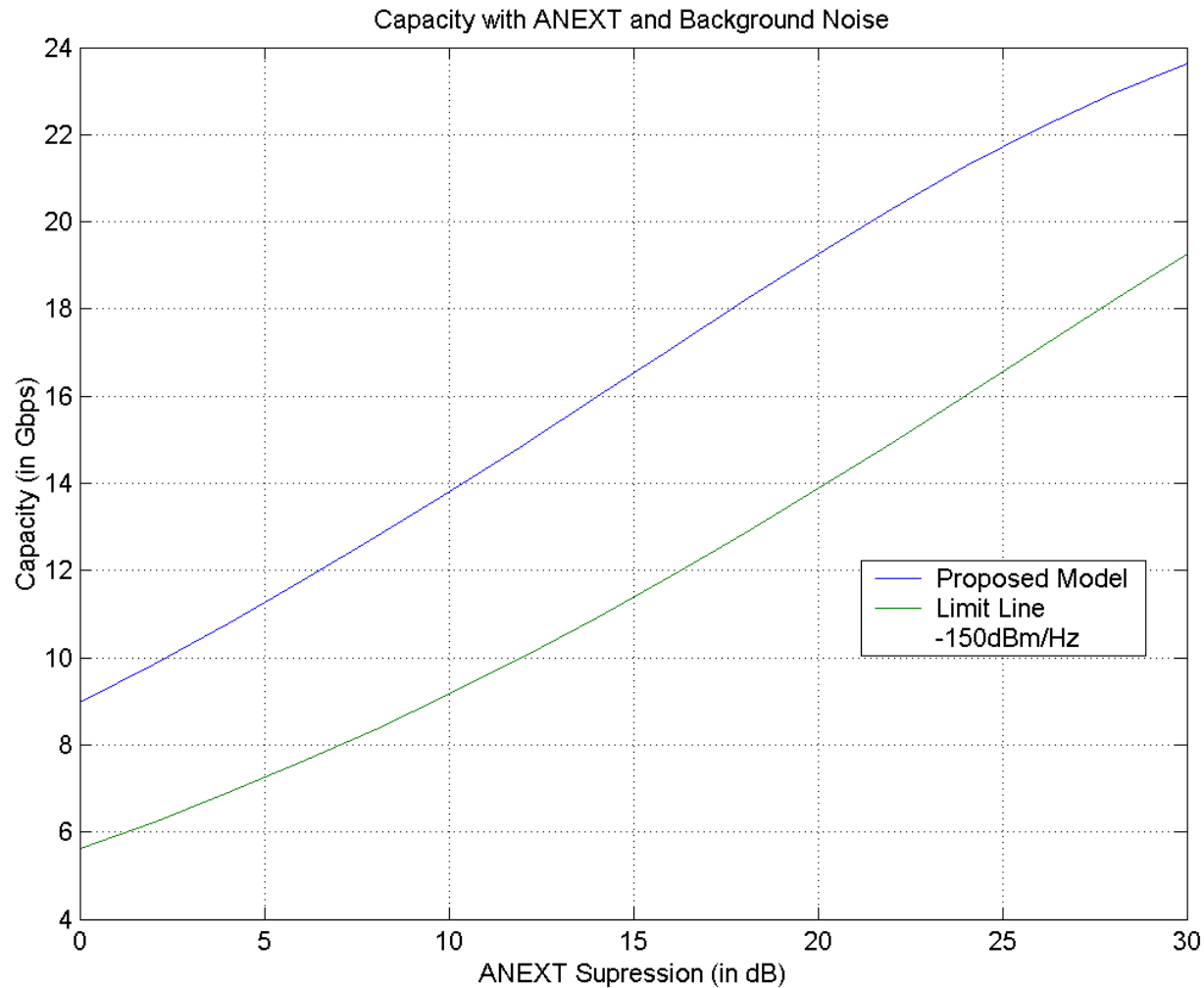
ANEXT Model



System Capacity

- All results are for CAT5e
 - CAT5e technical feasibility implies CAT6 feasibility
 - CAT6 results will be presented after the ANEXT model is available
- We used the following assumptions, as agreed in March Meeting, for capacity calculations
 - Bandwidth: 500MHz
 - Flat transmit spectrum
- Capacity with ANEXT and background noise only
 - As a function of ANEXT cancellation level
- Capacity with ANEXT, Echo, NEXT, FEXT, and background noise (BGN)
 - For various agreed combinations of suppression levels

Capacity: ANEXT and BGN Only



ANEXT and BGN: Observations

- The proposed model is about 10dB better than limit line
 - Requires ~10dB less suppression
- We need some level of ANEXT suppression
 - Even with the proposed model 10dB of ANEXT suppression provides ~14 Gbps capacity
 - What level of ANEXT suppression is realistic?

Capacity: New Models, 10dBm

Tx Pow	BGN level	ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	Capacity
10 dBm	-150	05	50	40	15	10.39
10 dBm	-150	05	50	40	25	10.92
10 dBm	-150	05	50	60	15	10.46
10 dBm	-150	05	50	60	25	11.00
10 dBm	-150	05	70	40	15	10.49
10 dBm	-150	05	70	40	25	11.05
10 dBm	-150	05	70	60	15	10.57
10 dBm	-150	05	70	60	25	11.13
10 dBm	-150	15	50	40	15	13.16
10 dBm	-150	15	50	40	25	14.50
10 dBm	-150	15	50	60	15	13.56
10 dBm	-150	15	50	60	25	15.00
10 dBm	-150	15	70	40	15	13.65
10 dBm	-150	15	70	40	25	15.18
10 dBm	-150	15	70	60	15	14.26
10 dBm	-150	15	70	60	25	15.96

telICos Corp.

**IEEE802.3-10GBT Interim Meeting
May 2003, Portsmouth, NH**

May 28, 2003

Slide: 13

Capacity: New Models, 7dBm

Tx Pow	BGN level	ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	Capacity
7 dBm	-150	05	50	40	15	10.38
7 dBm	-150	05	50	40	25	10.89
7 dBm	-150	05	50	60	15	10.44
7 dBm	-150	05	50	60	25	10.97
7 dBm	-150	05	70	40	15	10.48
7 dBm	-150	05	70	40	25	11.02
7 dBm	-150	05	70	60	15	10.55
7 dBm	-150	05	70	60	25	11.10
7 dBm	-150	15	50	40	15	13.13
7 dBm	-150	15	50	40	25	14.42
7 dBm	-150	15	50	60	15	13.52
7 dBm	-150	15	50	60	25	14.90
7 dBm	-150	15	70	40	15	13.61
7 dBm	-150	15	70	40	25	15.08
7 dBm	-150	15	70	60	15	14.21
7 dBm	-150	15	70	60	25	15.83

Capacity vs. BGN Levels (10dBm)

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	-150dBm/Hz	-140dBm/Hz	% Change
05	50	40	15	10.39	10.27	1.15
05	50	40	25	10.92	10.72	1.85
05	50	60	15	10.46	10.34	1.12
05	50	60	25	11.00	10.79	1.87
05	70	40	15	10.49	10.37	1.16
05	70	40	25	11.05	10.83	2.00
05	70	60	15	10.57	10.44	1.21
05	70	60	25	11.13	10.91	2.01
15	50	40	15	13.16	12.87	2.21
15	50	40	25	14.50	13.91	4.07
15	50	60	15	13.56	13.23	2.46
15	50	60	25	15.00	14.34	4.38
15	70	40	15	13.65	13.31	2.50
15	70	40	25	15.18	14.46	4.77
15	70	60	15	14.26	13.84	2.96
15	70	60	25	15.96	15.09	5.43

Observations

- The Capacity does not show a meaningful improvement
 - Transmit power (3 dB increase yields <1% capacity increase)
 - Echo suppression (20 dB increase yields 1-6% capacity increase)
 - NEXT suppression (20 dB increase yields .7-5% capacity increase)
 - FEXT suppression (10 dB increase yields 4-10% capacity increase)
 - Back ground noise (10 dB decrease yields 1-6% capacity increase)
- The capacity improves significantly only with the ANEXT Suppression
 - 10 dB increase yields 21-31% capacity increase
- Remember, with everything being same, lower background noise PSD level requires higher ADC precision
 - Quantization noise vs. background noise

Model vs. Limit Line

- Capacity with the proposed models and the extended limit lines
- Compare capacity for the proposed model with capacity of the corresponding limit lines
- We consider the case with
 - 10 dBm of transmit power
 - -150 dBm/Hz background noise PSD

IL Loss: 10dBm Power, -150dBm

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	IL Model	Limit Line	% Change
05	50	40	15	10.39	8.92	14.18
05	50	40	25	10.92	9.44	13.52
05	50	60	15	10.46	8.97	14.27
05	50	60	25	11.00	9.50	13.64
05	70	40	15	10.49	9.00	14.20
05	70	40	25	11.05	9.55	13.54
05	70	60	15	10.57	9.06	14.32
05	70	60	25	11.13	9.62	13.60
15	50	40	15	13.16	11.27	14.34
15	50	40	25	14.50	12.60	13.11
15	50	60	15	13.56	11.58	14.57
15	50	60	25	15.00	13.00	13.31
15	70	40	15	13.65	11.68	14.44
15	70	40	25	15.18	13.20	13.06
15	70	60	15	14.26	12.16	14.73
15	70	60	25	15.96	13.84	13.31

ANEXT: 10dBm Power, -150dBm

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	ANEXT Model	Limit Line	% Change
05	50	40	15	10.39	7.05	32.13
05	50	40	25	10.92	7.20	34.06
05	50	60	15	10.46	7.05	32.56
05	50	60	25	11.00	7.20	34.50
05	70	40	15	10.49	7.07	32.65
05	70	40	25	11.05	7.22	34.66
05	70	60	15	10.57	7.07	33.12
05	70	60	25	11.13	7.22	35.10
15	50	40	15	13.16	10.44	20.65
15	50	40	25	14.50	11.05	23.82
15	50	60	15	13.56	10.49	22.62
15	50	60	25	15.00	11.10	25.98
15	70	40	15	13.65	10.53	22.82
15	70	40	25	15.18	11.17	26.40
15	70	60	15	14.26	10.59	25.74
15	70	60	25	15.96	11.23	29.62

RL Loss: 10dBm Power, -150dBm

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	RL Model	Limit Line	% Change
05	50	40	15	10.39	10.22	1.66
05	50	40	25	10.92	10.69	2.14
05	50	60	15	10.46	10.28	1.74
05	50	60	25	11.00	10.75	2.25
05	70	40	15	10.49	10.49	0.00
05	70	40	25	11.05	11.05	0.02
05	70	60	15	10.57	10.57	0.04
05	70	60	25	11.13	11.13	-0.01
15	50	40	15	13.16	12.57	4.50
15	50	40	25	14.50	13.56	6.45
15	50	60	15	13.56	12.85	5.25
15	50	60	25	15.00	13.89	7.43
15	70	40	15	13.65	13.64	0.06
15	70	40	25	15.18	15.17	0.08
15	70	60	15	14.26	14.25	0.07
15	70	60	25	15.96	15.94	0.16

NEXT: 10dBm Power, -150dBm

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	NEXT Model	Limit Line	% Change
05	50	40	15	10.39	10.37	0.21
05	50	40	25	10.92	10.89	0.23
05	50	60	15	10.46	10.46	0.03
05	50	60	25	11.00	11.00	0.04
05	70	40	15	10.49	10.47	0.20
05	70	40	25	11.05	11.02	0.25
05	70	60	15	10.57	10.57	0.02
05	70	60	25	11.13	11.13	-0.03
15	50	40	15	13.16	13.08	0.63
15	50	40	25	14.50	14.35	1.01
15	50	60	15	13.56	13.56	-0.02
15	50	60	25	15.00	14.99	0.04
15	70	40	15	13.65	13.55	0.74
15	70	40	25	15.18	15.00	1.20
15	70	60	15	14.26	14.26	-0.01
15	70	60	25	15.96	15.95	0.03

FEXT: 10dBm Power, -150dBm

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	FEXT Model	Limit Line	% Change
05	50	40	15	10.39	10.13	2.53
05	50	40	25	10.92	10.86	0.55
05	50	60	15	10.46	10.19	2.53
05	50	60	25	11.00	10.93	0.61
05	70	40	15	10.49	10.23	2.52
05	70	40	25	11.05	10.99	0.58
05	70	60	15	10.57	10.30	2.54
05	70	60	25	11.13	11.07	0.56
15	50	40	15	13.16	12.71	3.41
15	50	40	25	14.50	14.30	1.41
15	50	60	15	13.56	13.12	3.21
15	50	60	25	15.00	14.79	1.43
15	70	40	15	13.65	13.19	3.40
15	70	40	25	15.18	14.94	1.55
15	70	60	15	14.26	13.82	3.07
15	70	60	25	15.96	15.71	1.57

Observations

- ANEXT and IL models yield significantly higher capacity compared to the corresponding limit lines
 - 20-35 % capacity difference between ANEXT model and limit line
 - 13-15 % capacity difference between IL model and limit line

- Use of proposed models do not increase capacity significantly for RL, NEXT, FEXT

Summary

- Only change in ANEXT suppression level significantly impacts the capacity
 - Change in transmit power, background noise PSD level, and Echo, NEXT, and FEXT suppression level has minimal impact on capacity
- Some level of ANEXT suppression is a must for 10G system
- The need for accurate model for IL and ANEXT is critical for technical feasibility
 - The IL and ANEXT models differ significantly from their respective limit lines
 - RL, NEXT, and FEXT models are close to their respective limit lines

Technical Feasibility And Capacity

- How much capacity is required to show technical feasibility?
 - Implementation loss
 - System margin
- Models vs. Margin
 - Worst case models requires less margin compared to models for typical case
- Too much or too little margin
 - Too much margin: hard to prove technical feasibility and hard to build the system
 - Too little margin: not a robust solution and reduced market potential

Capacity With Margin (10dBm, -150dBm/Hz)

ANEXT Sup	Echo Sup	NEXT Sup	FEXT Sup	0 dB	3 dB	6 dB	9 dB
05	50	40	15	10.39	8.99	7.70	6.54
05	50	40	25	10.92	9.52	8.23	7.06
05	50	60	15	10.46	9.04	7.75	6.58
05	50	60	25	11.00	9.58	8.28	7.10
05	70	40	15	10.49	9.08	7.78	6.61
05	70	40	25	11.05	9.63	8.33	7.15
05	70	60	15	10.57	9.14	7.84	6.65
05	70	60	25	11.13	9.70	8.39	7.20
15	50	40	15	13.16	11.51	9.97	8.55
15	50	40	25	14.50	12.84	11.29	9.86
15	50	60	15	13.56	11.86	10.27	8.80
15	50	60	25	15.00	13.29	11.68	10.19
15	70	40	15	13.65	11.95	10.36	8.89
15	70	40	25	15.18	13.48	11.88	10.39
15	70	60	15	14.26	12.49	10.83	9.27
15	70	60	25	15.96	14.18	12.50	10.92

Technical Feasibility: Issues

- Two critical questions for technical feasibility
- How reliable are the CAT5e IL and ANEXT models?
 - Worst case vs. typical installation
 - What fraction of the installed base is covered by these models?
- What is adequate capacity for a real 10G system?
 - Implementation loss
 - System margin
- The question of technical feasibility is not resolved by just showing adequate capacity, but rather, by finding a set of realistic requirements to achieve adequate capacity.

Q&A

Thanks

telICos Corp.

***IEEE802.3-10GBT Interim Meeting
May 2003, Portsmouth, NH***

**May 28, 2003
Slide: 28**