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Transmission Strategies for 10GBase-T over CAT- 6 Copper Wiring

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The Pennsylvania State University
Department of Electrical Engineering
Center for Information & Communications Technology Research (CICTR)
University Park, PA. 16802

E-mail: mkavehrad@psu.edu
Phone: (814) 865-7179

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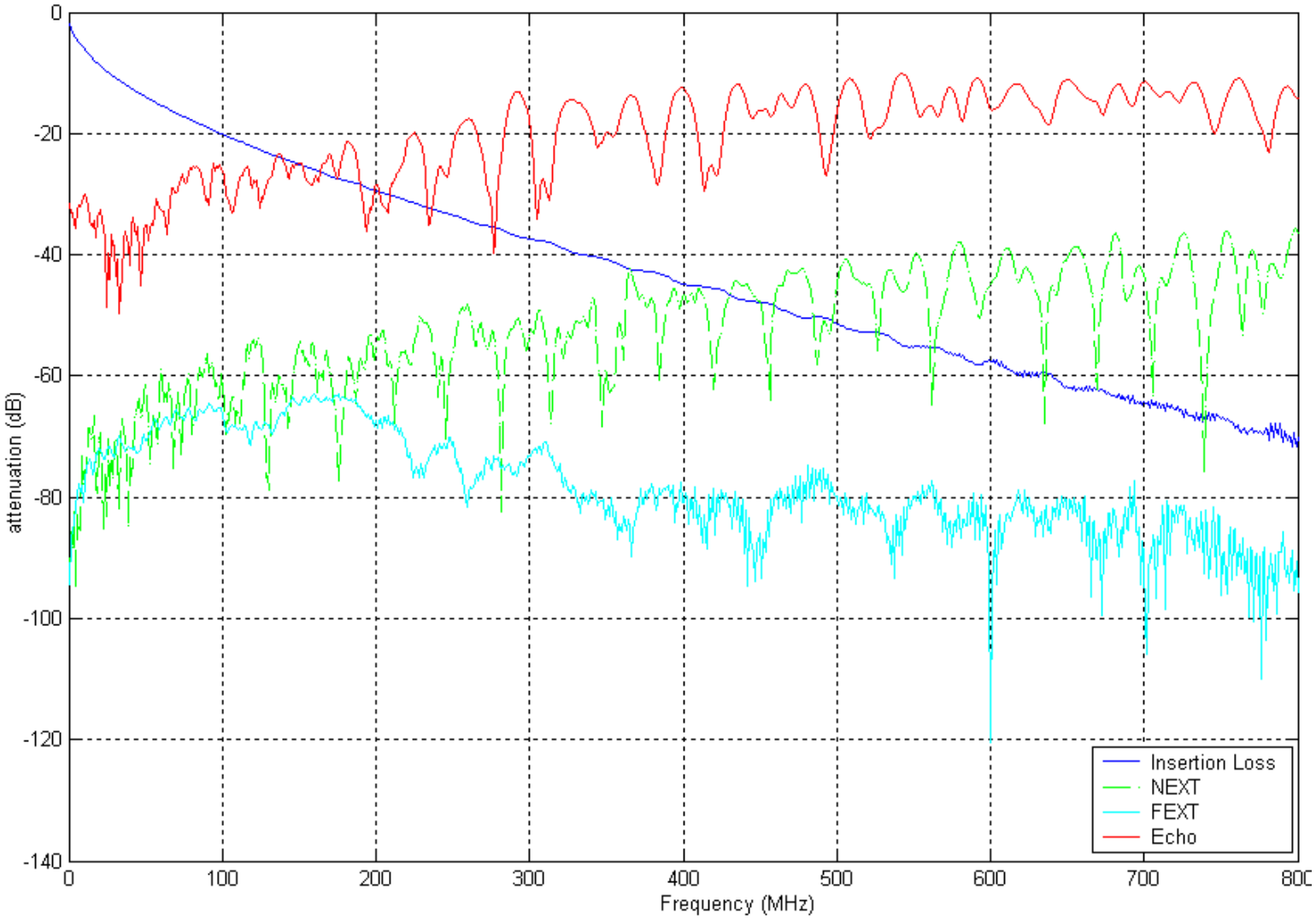
Outline

- Transmission Model
- Capacity
- Interference Cancellation
- Combined Channel Equalization and Coding: Iterative (Turbo) Structures
- Future work

Signal and Systems Impairments

Signal Impairment	Mitigation Technique
Dispersion	Channel Equalization (using DFE)
Near-End Cross-Talk (NEXT)	NEXT Cancellation
Far-End Cross-Talk (FEXT)	FEXT Cancellation
Return Loss (ECHO)	ECHO Cancellation
Alien-NEXT	A-NEXT Compensation
Residual Noise/Insertion Loss	Channel Coding

Channel Characteristics for CAT- 6
Measured data provided by Nexans



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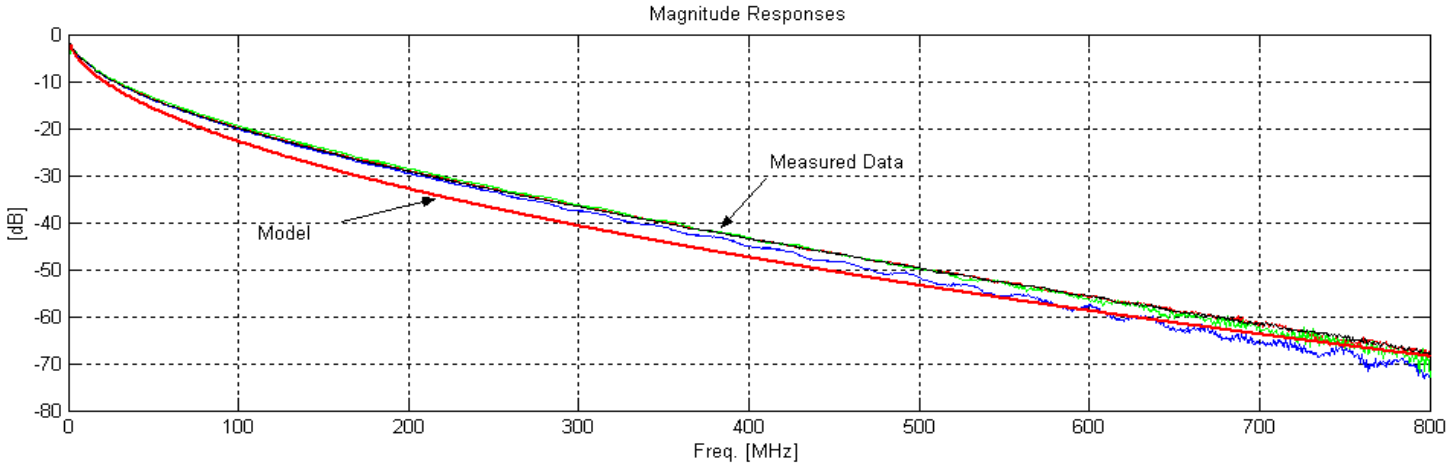
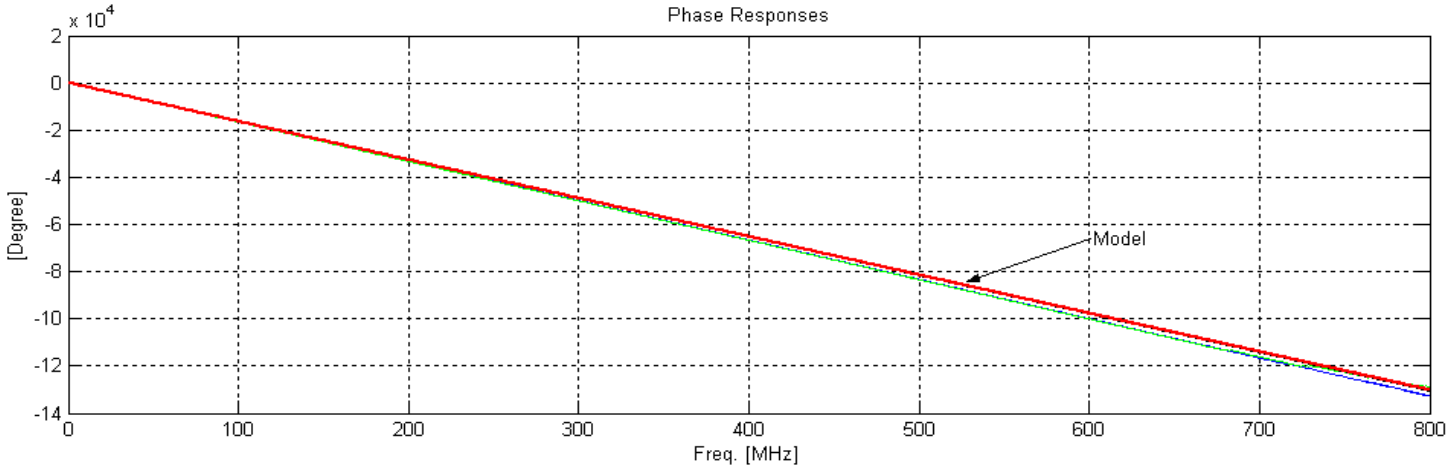
CAT- 6 Insertion Loss Responses

Measured data provided by Nexans

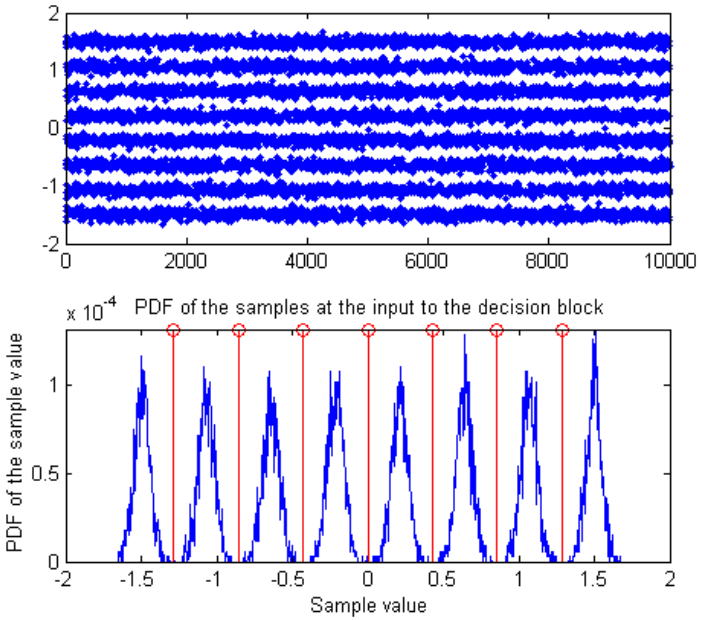




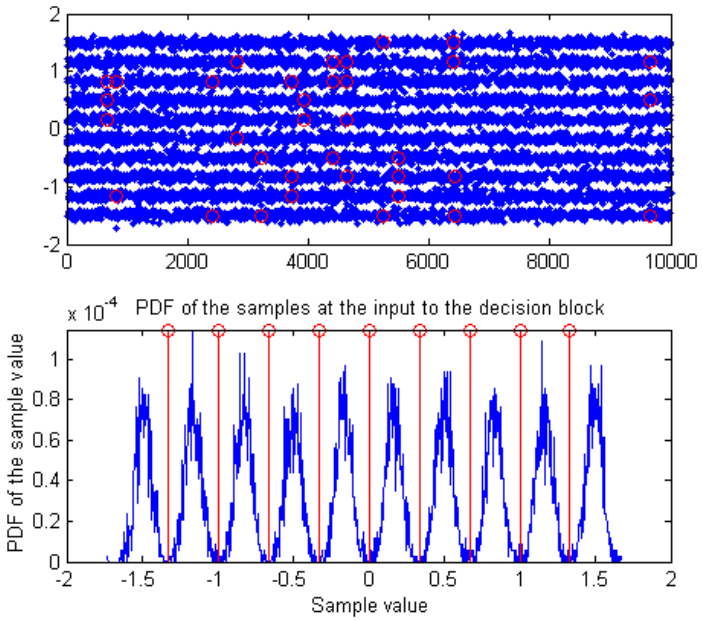
MIMO DFE Output

ISI Channel (~100 T) → DFE

40 dB SIR, 8-PAM



40 dB SIR, 10-PAM



- *10 Gbps Transmission Requires 3 bits/sym at 833 M-Symbols/sec*
- *10-PAM (3 bits/sym + parity) Signaling with TCM*
- *Eye-Closure due to the increased No. of PAM levels ⇒ High coding gain needed*

DFE "open eye" performance

CAT- 6 : 100m , Measured Data , No Error Correction Coding

	40 dB SIR	Remarks
625 M Symbols/sec	**16-PAM** **625 Msym/sec * 4 bit/sym = 2.5 Gbps** **2.5 Gbps * 4 Lines = 10 Gbps**	SER: 1.08×10^{-3}
833 M Symbols/sec	**8-PAM** **833 Msym/sec * 3 bit/sym = 2.5 Gbps** **2.5 Gbps * 4 Lines = 10 Gbps**	SER: 7.8×10^{-6}
833 M Symbols/sec	**10-PAM** **833 Msym/sec * 3 bit/sym = 2.5 Gbps** **2.5 Gbps * 4 Lines = 10 Gbps**	SER:3.9×10^{-4}

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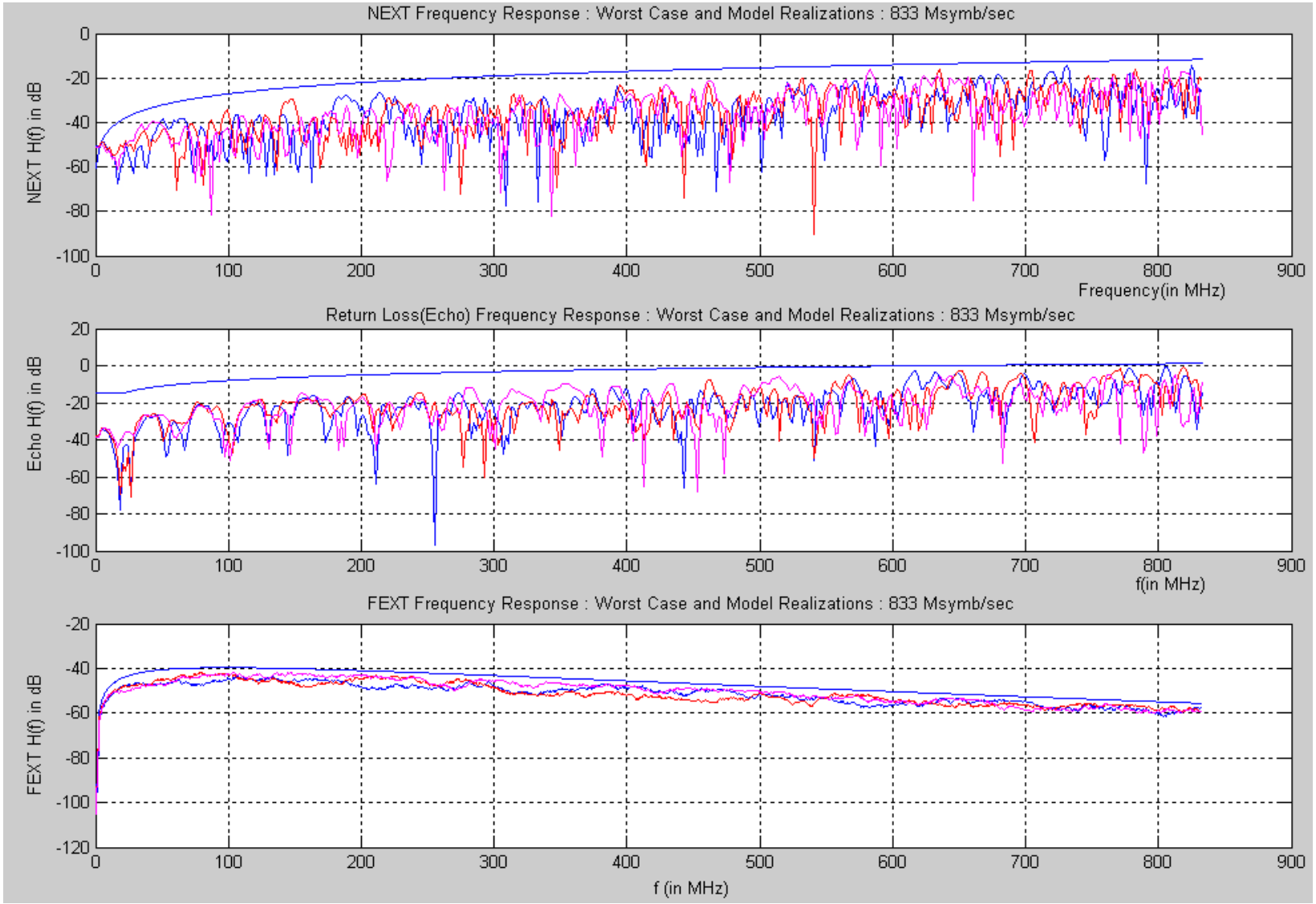
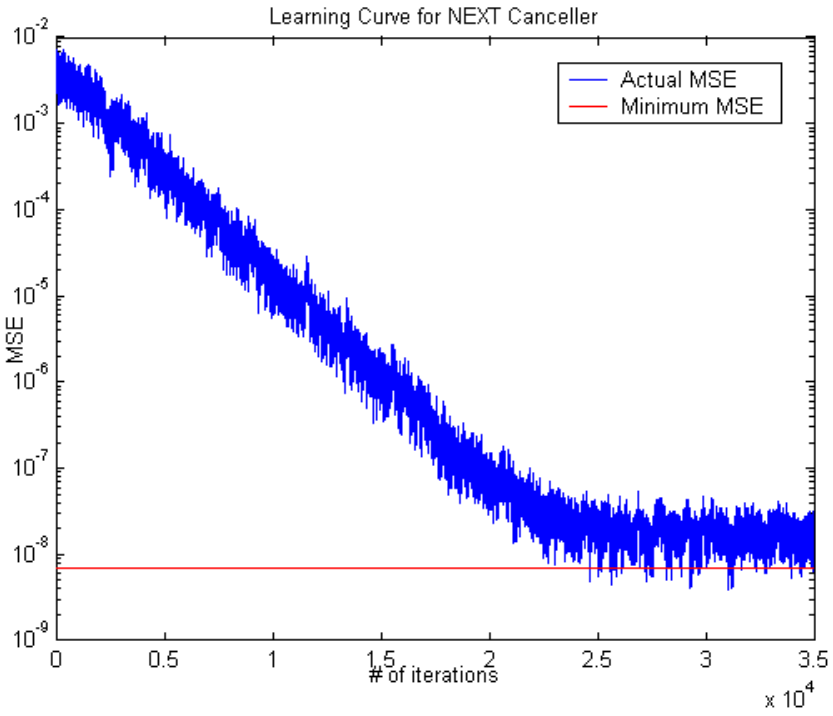
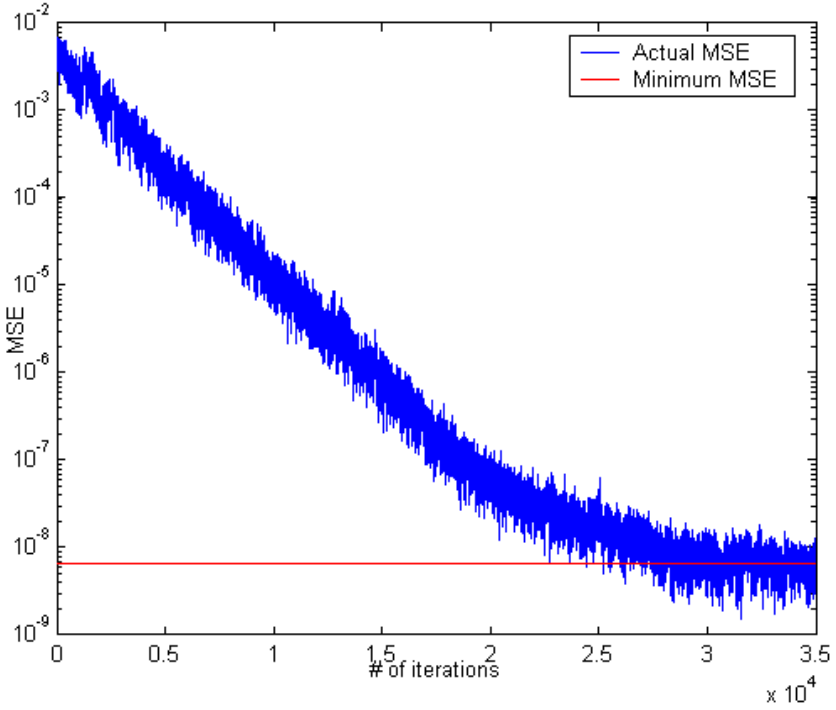
Frequency Responses



Learning Curves for LMS (NEXT) MIMO Canceller



(a) : Constant Step Size



(b) : Varying Step Size

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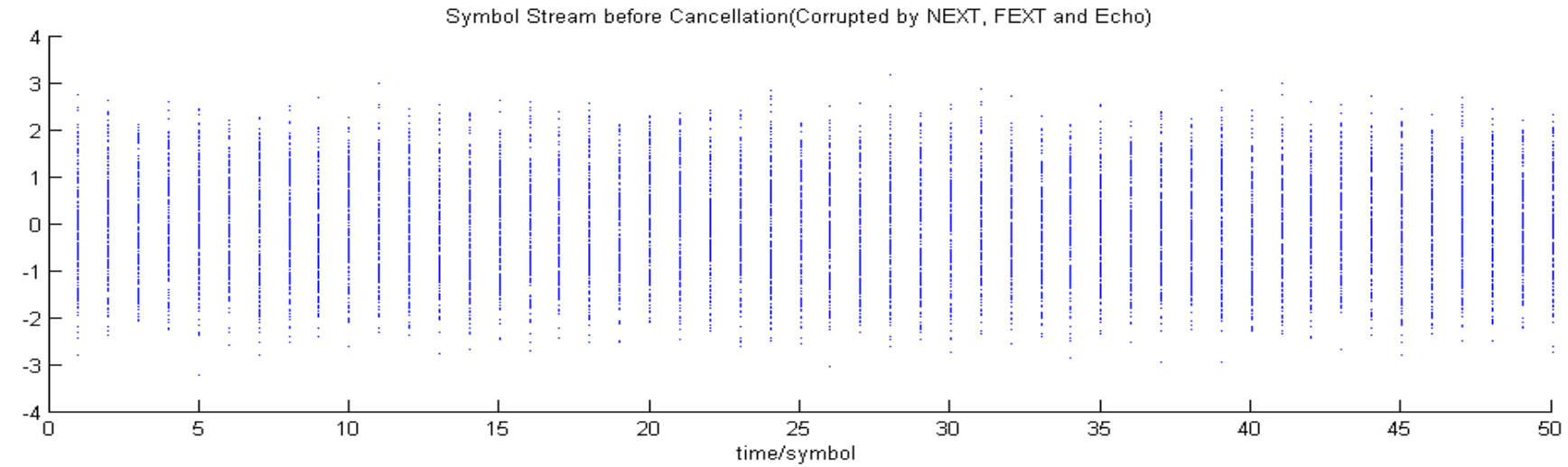
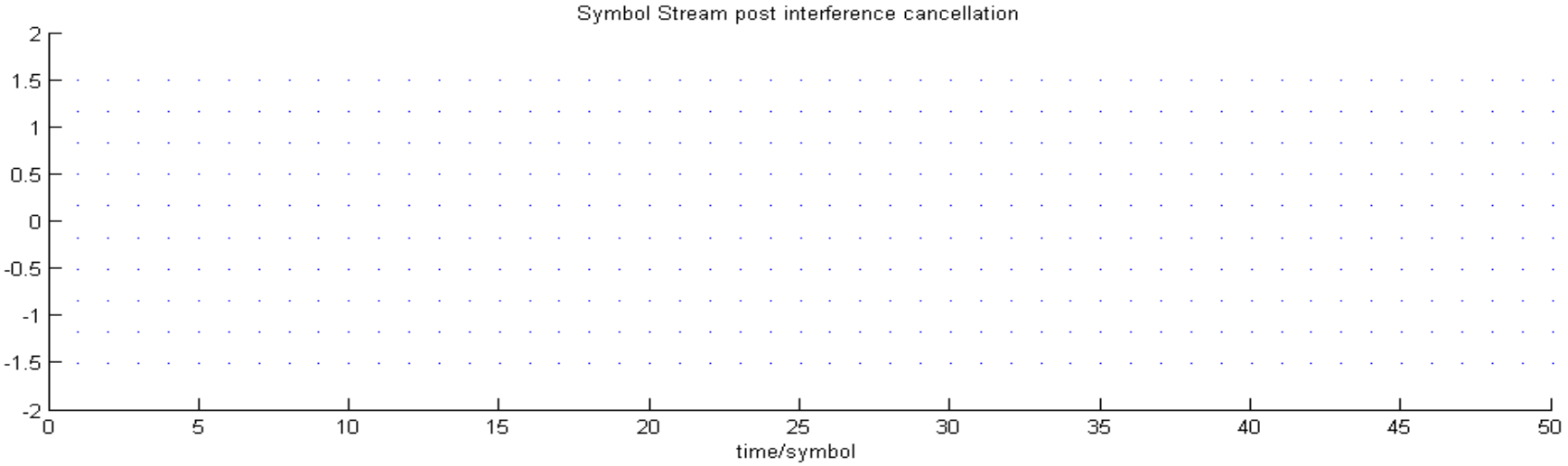
Results using LMS MIMO Cancellers

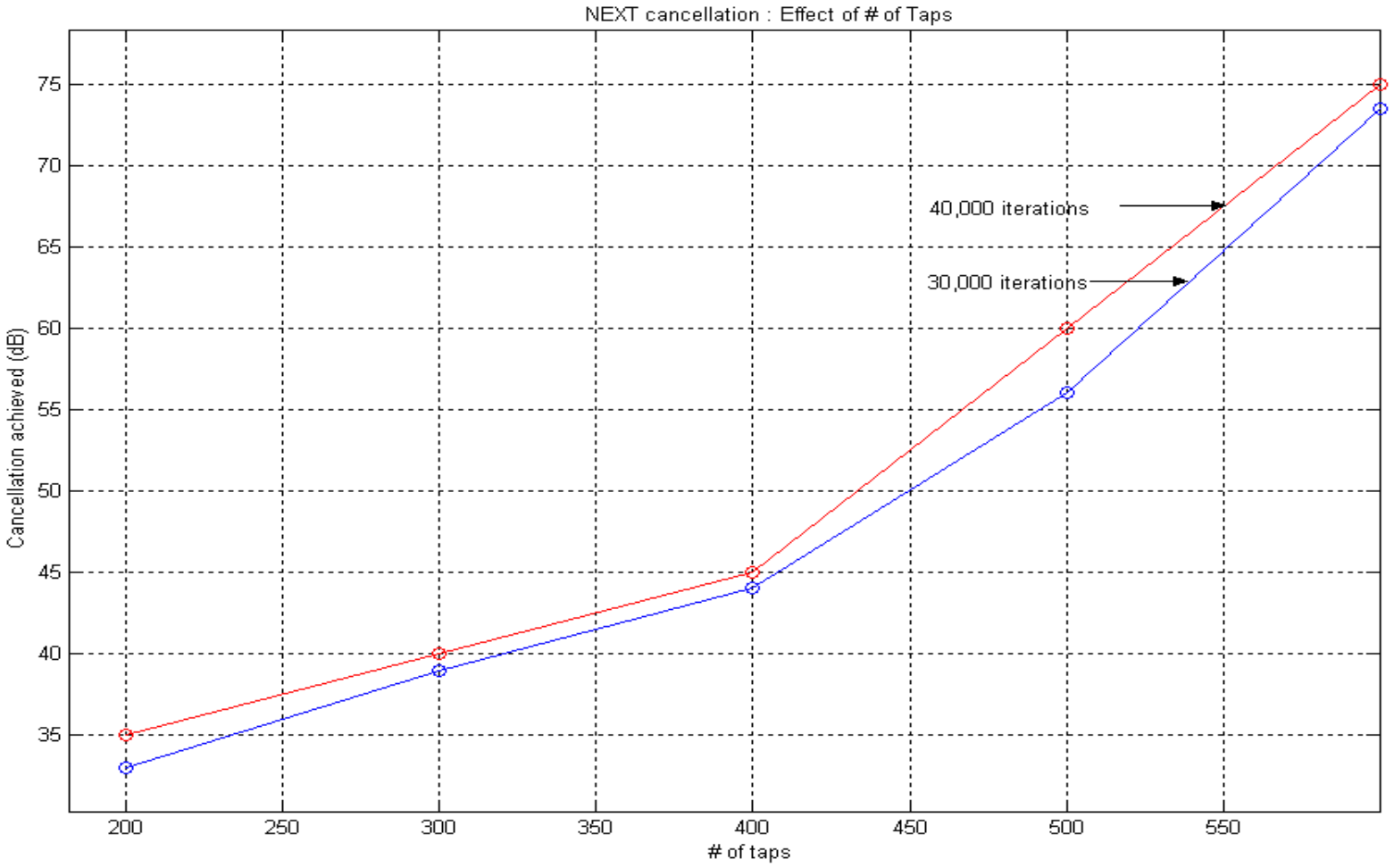




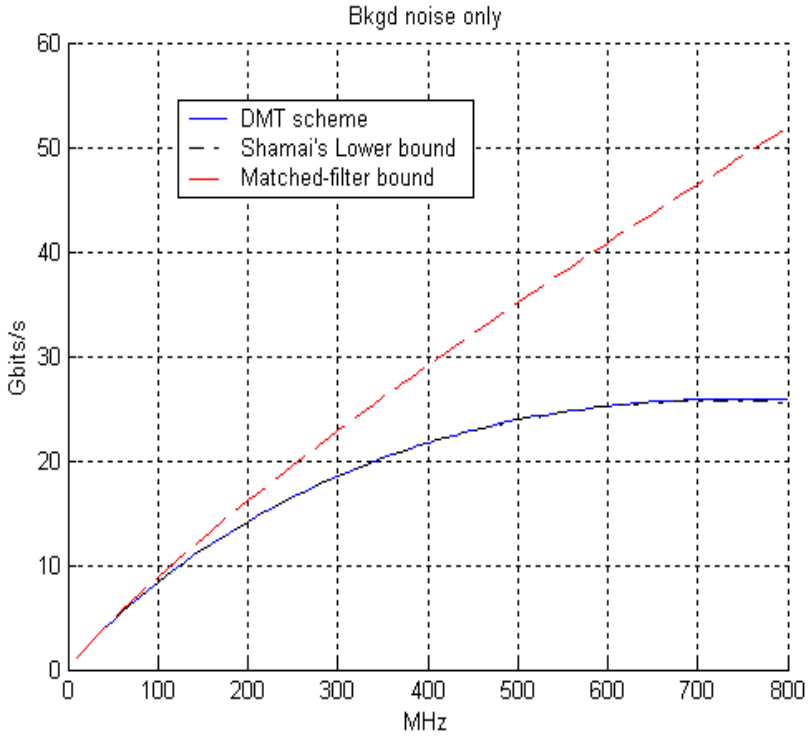
Features of LMS MIMO Cancellers

	NEXT Cancellers	FEXT Cancellers	Echo Cancellers
# of taps	530	570	515
# of iterations	40000	40000	40000
Algorithm	LMS	LMS	LMS
No. of cancellers required	3	3	1
Cancellation achieved	60dB	34dB	76dB

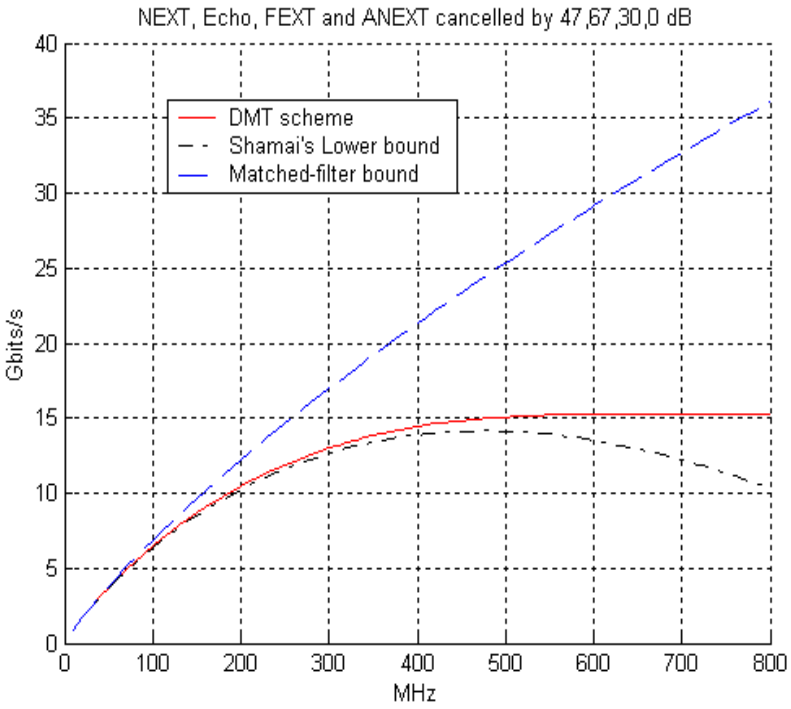
Effect of Number of MIMO Cancellers Taps on SIR Performance



Theoretical CAT- 6 Cables Capacity



Total capacity with "AWGN only" VS bandwidth of the CAT-6 cable.



Total capacity with "AWGN and residual interference" VS bandwidth of CAT-6 cable.

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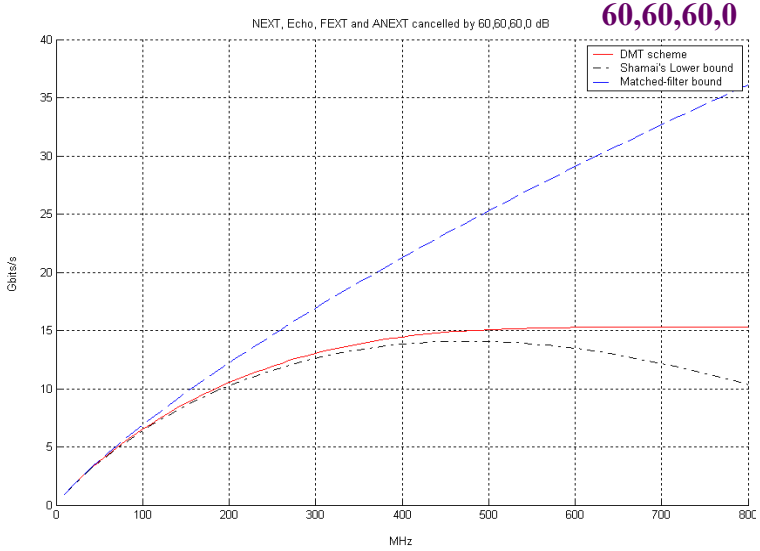
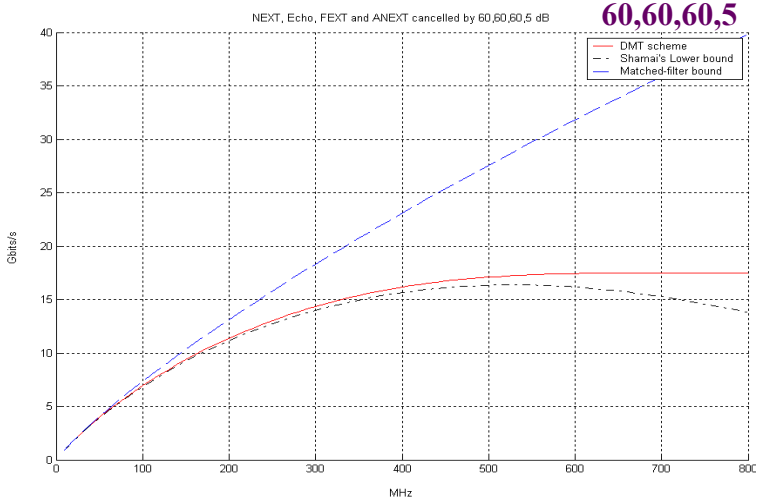
Theoretical CAT- 6 Cables Capacity

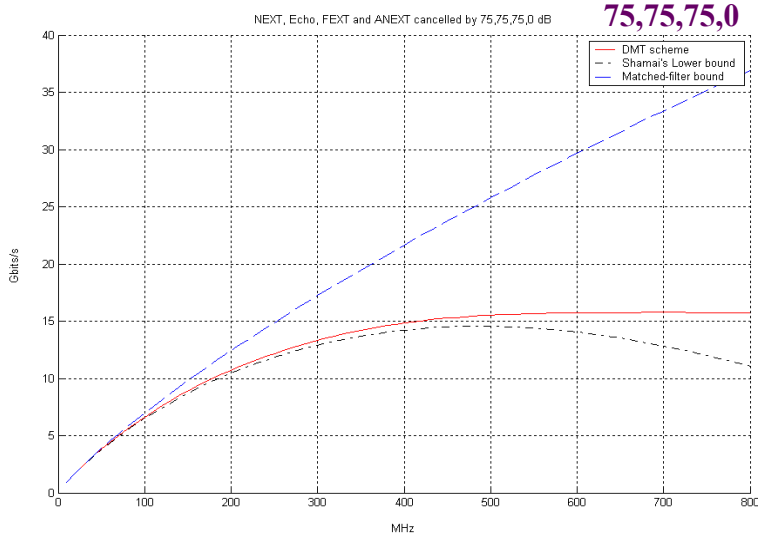
60,60,60,0



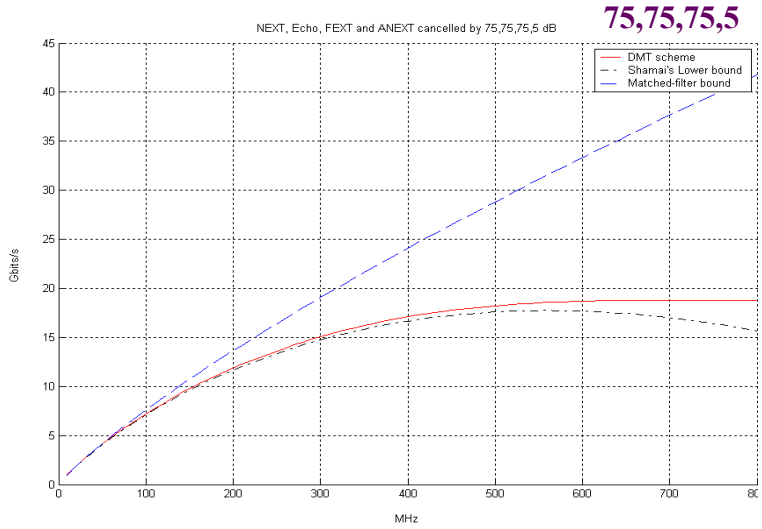
60,60,60,5



75,75,75,0



75,75,75,5



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System Parameters

Modulation:	**PAM**	**[M = 10]**
Pulse Shape:	**Raised cosine**	**[α = 8%]**
MIMO Cancellers:	**LMS**	**[~ 500 taps]**
MIMO Equalizer:	**DFE**	**[120 FF, 100FB]**
Baseline FEC:	**TCM**	**[4-D]**
Launch Power:		**10dBM (3V P-P)**
Background Noise Level :		**-150dBm/Hz**

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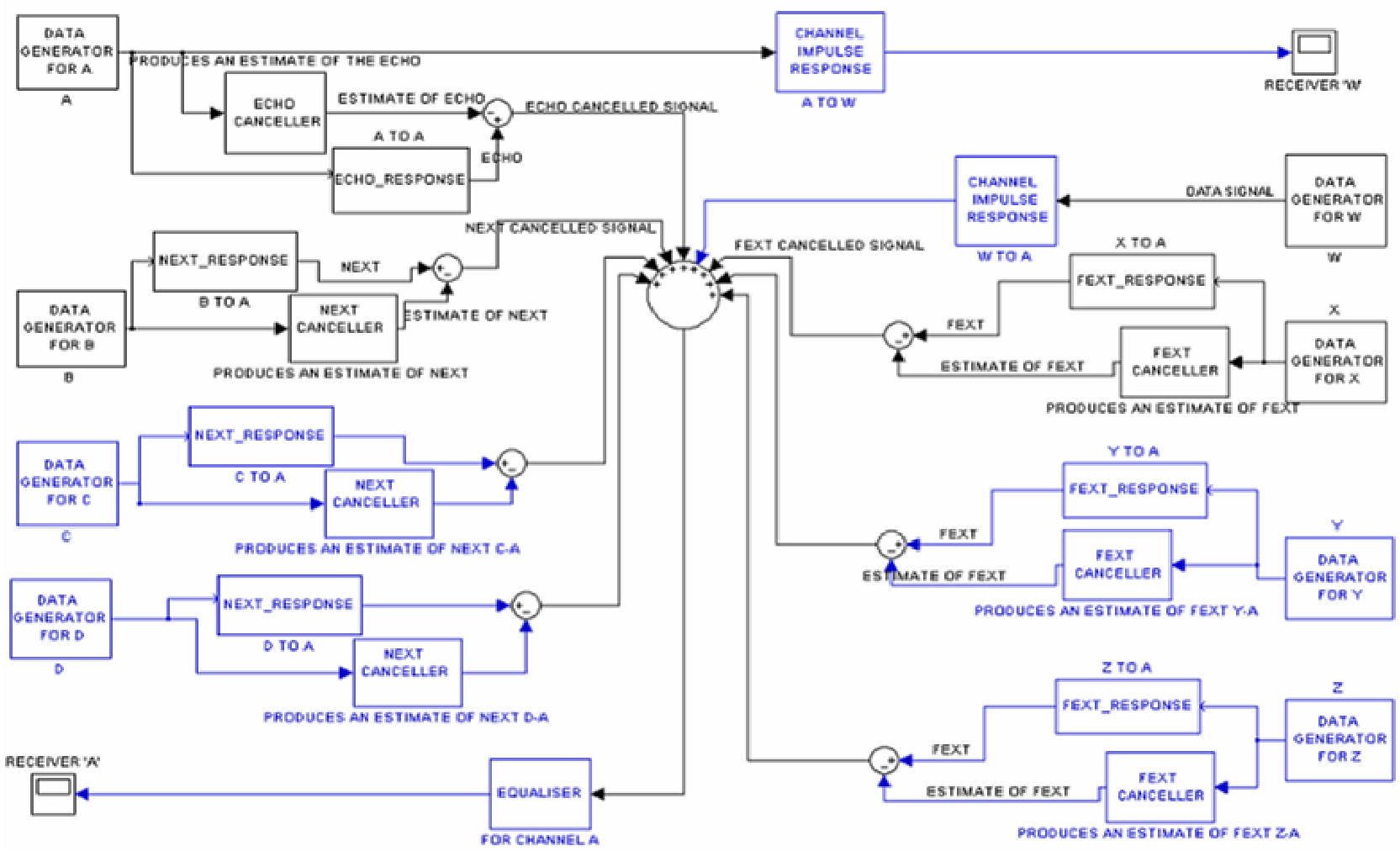
MATLAB Blocks



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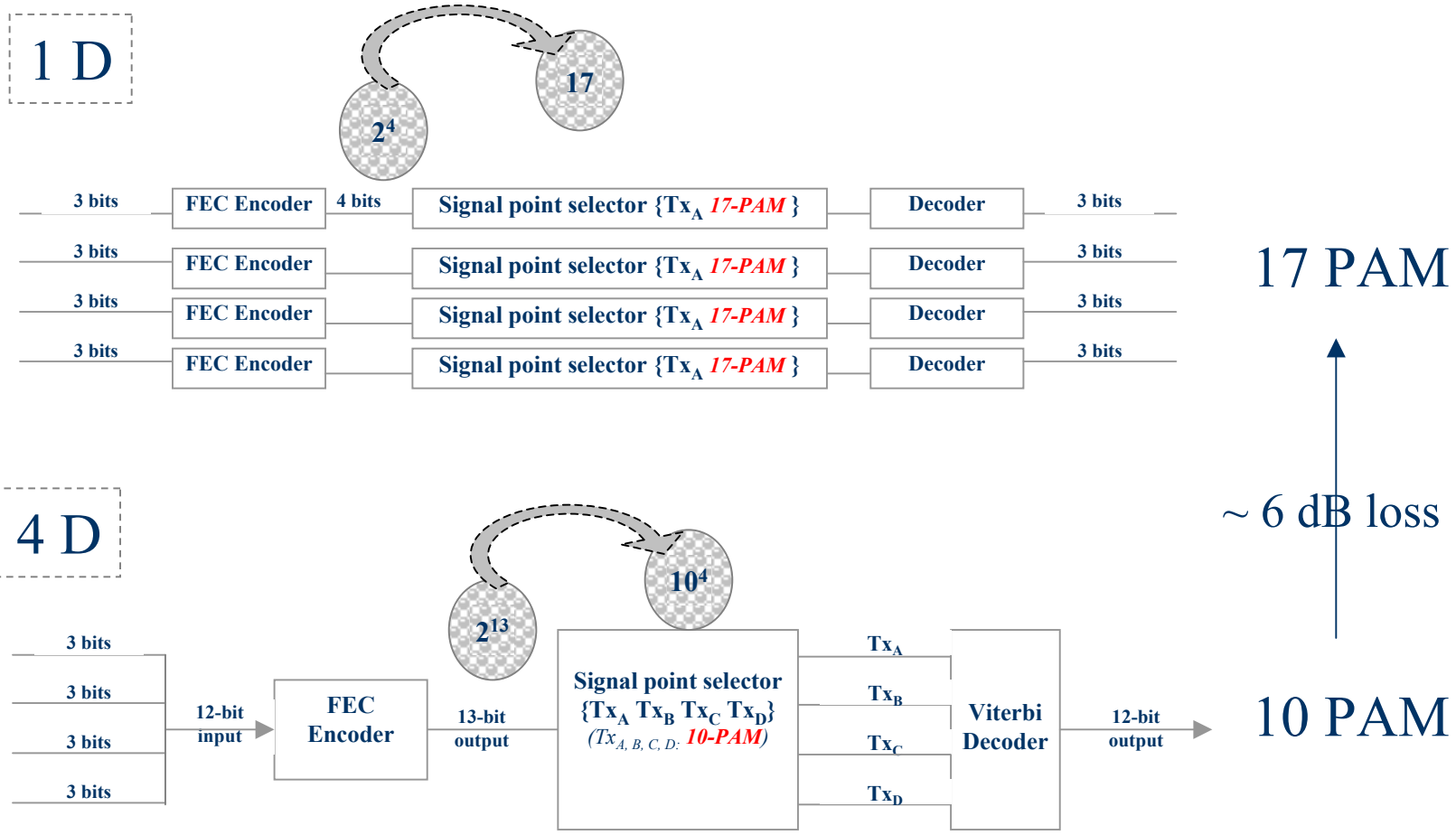
Why Multi Dimensional



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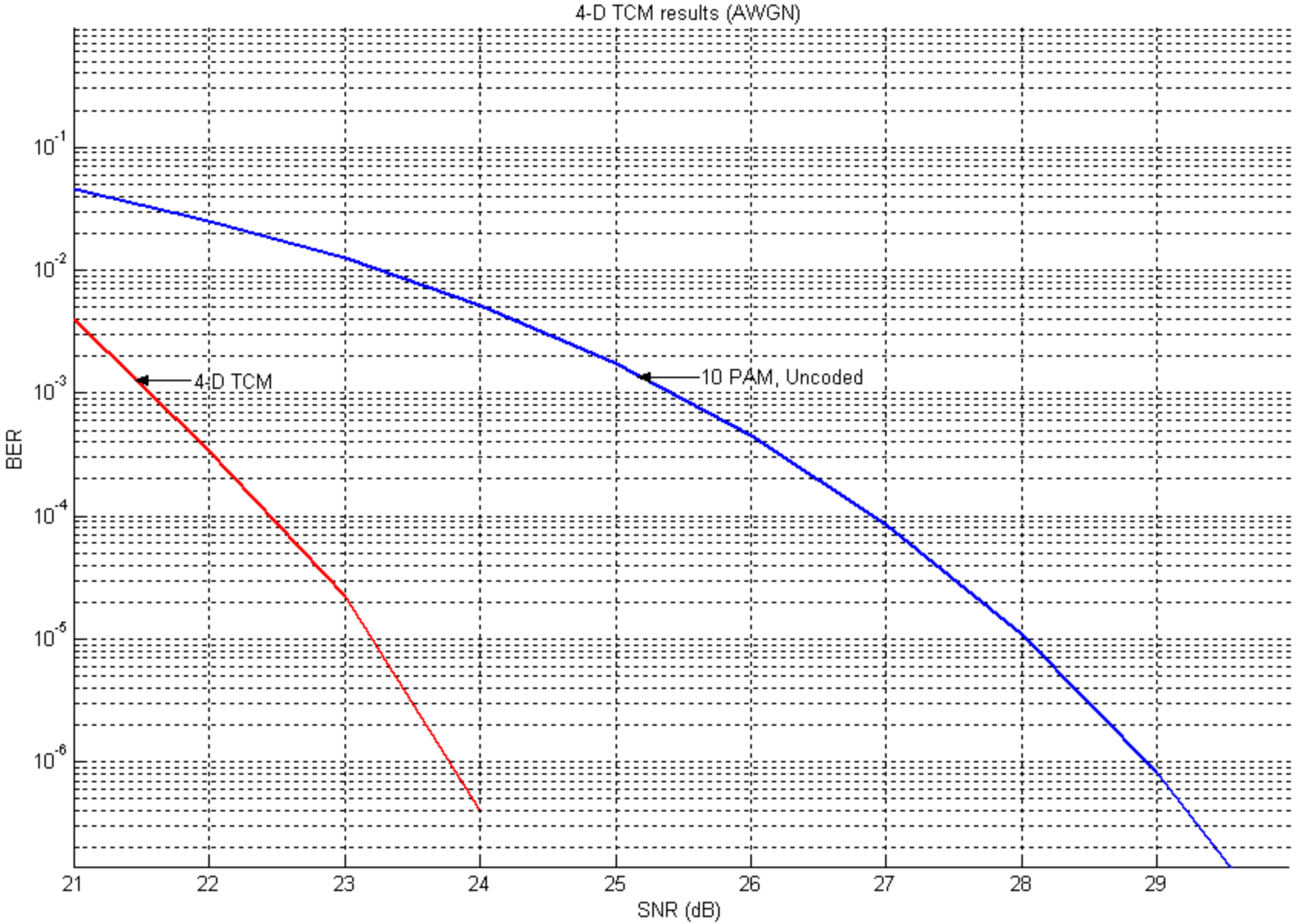
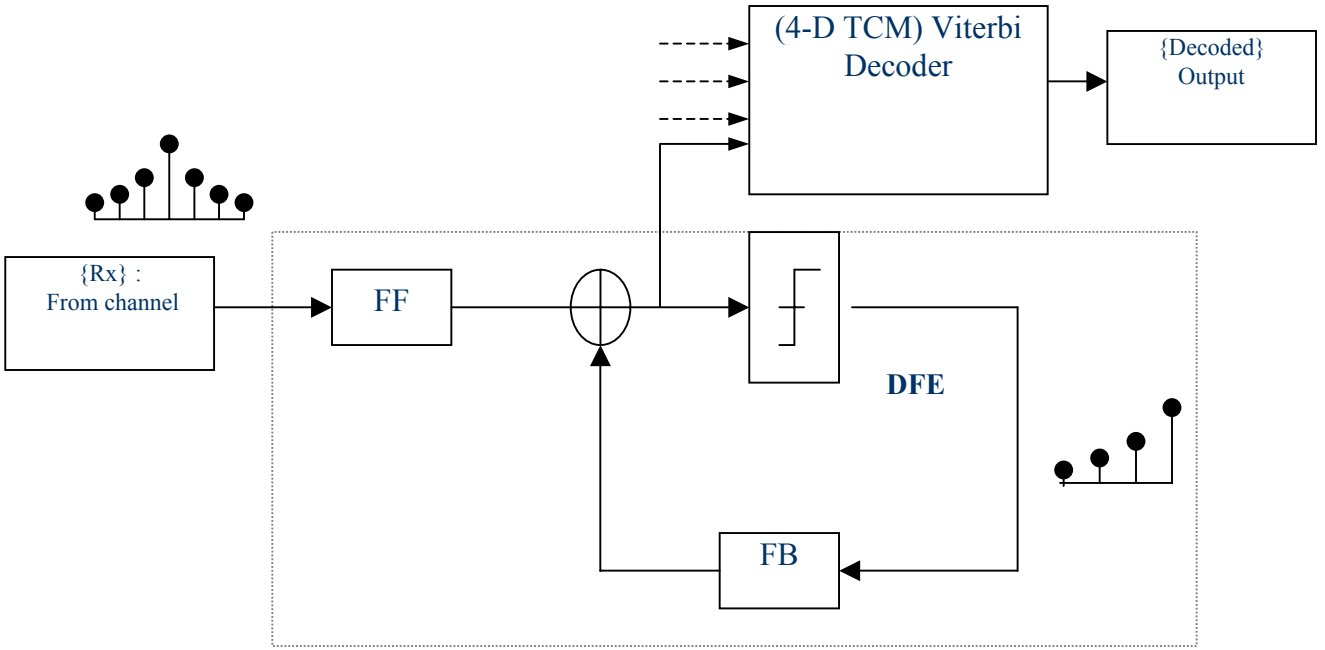
4D TCM (AWGN)

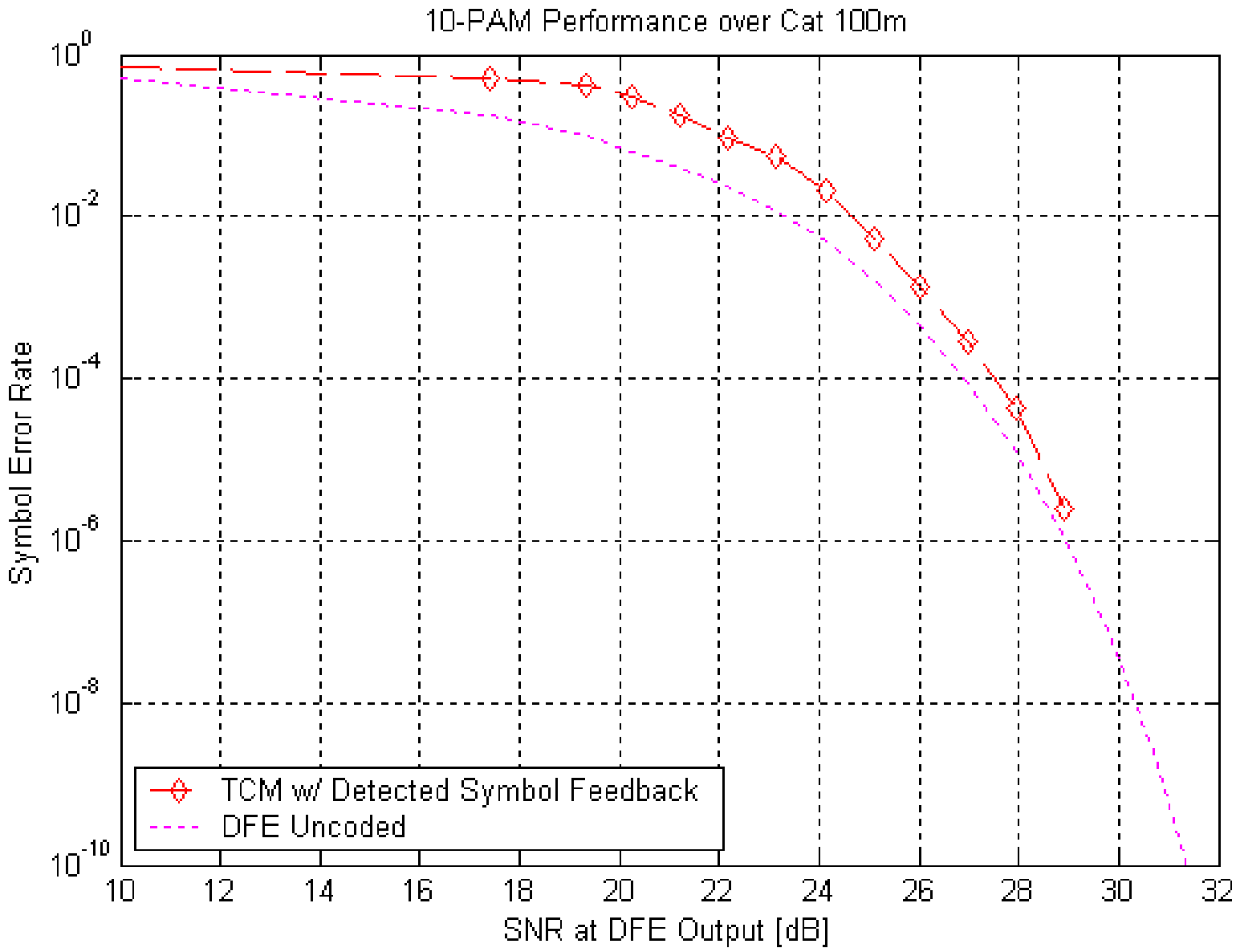


….. the same scheme was tested on CAT- 6 (ISI) channel ….

TCM + DFE : Conventional structure



TCM + DFE Results *(CAT- 6 Channel)*

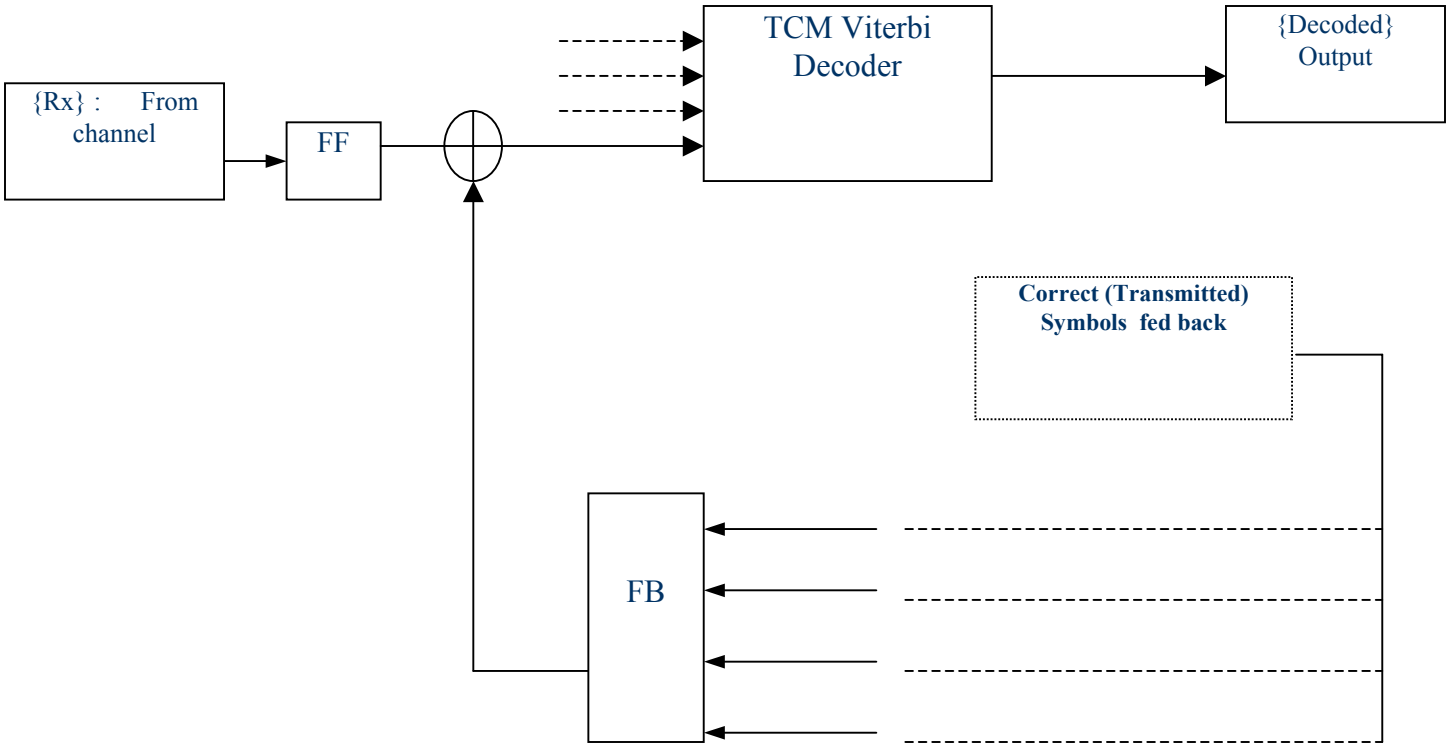


TCM + DFE over CAT- 6 Channel

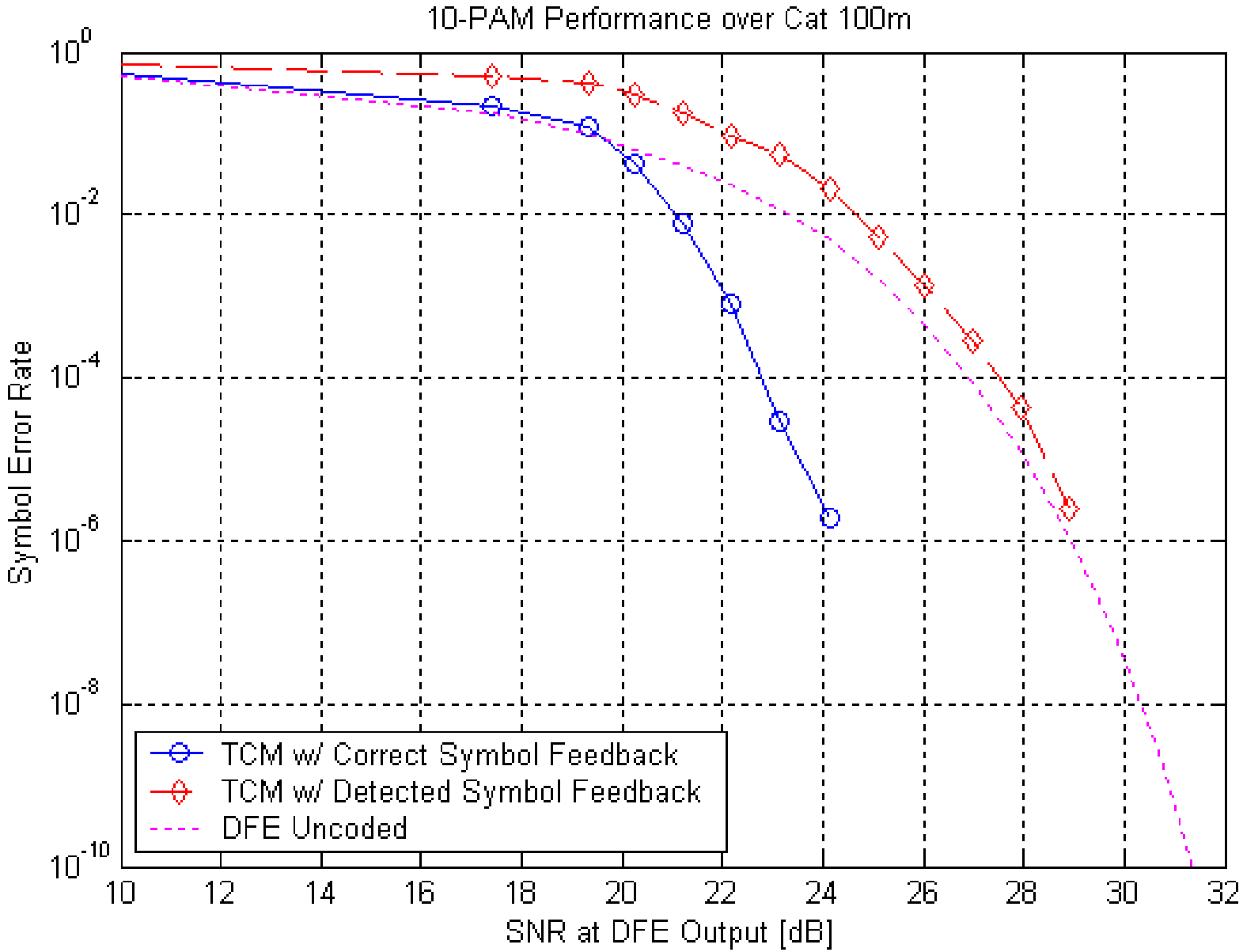
After examining various possibilities, it was found to be caused due to the error feedback and subsequent propagation in the FB section of the DFE.

This was confirmed by feeding back the correct symbols ….

TCM + DFE : Correct Symbol feedback



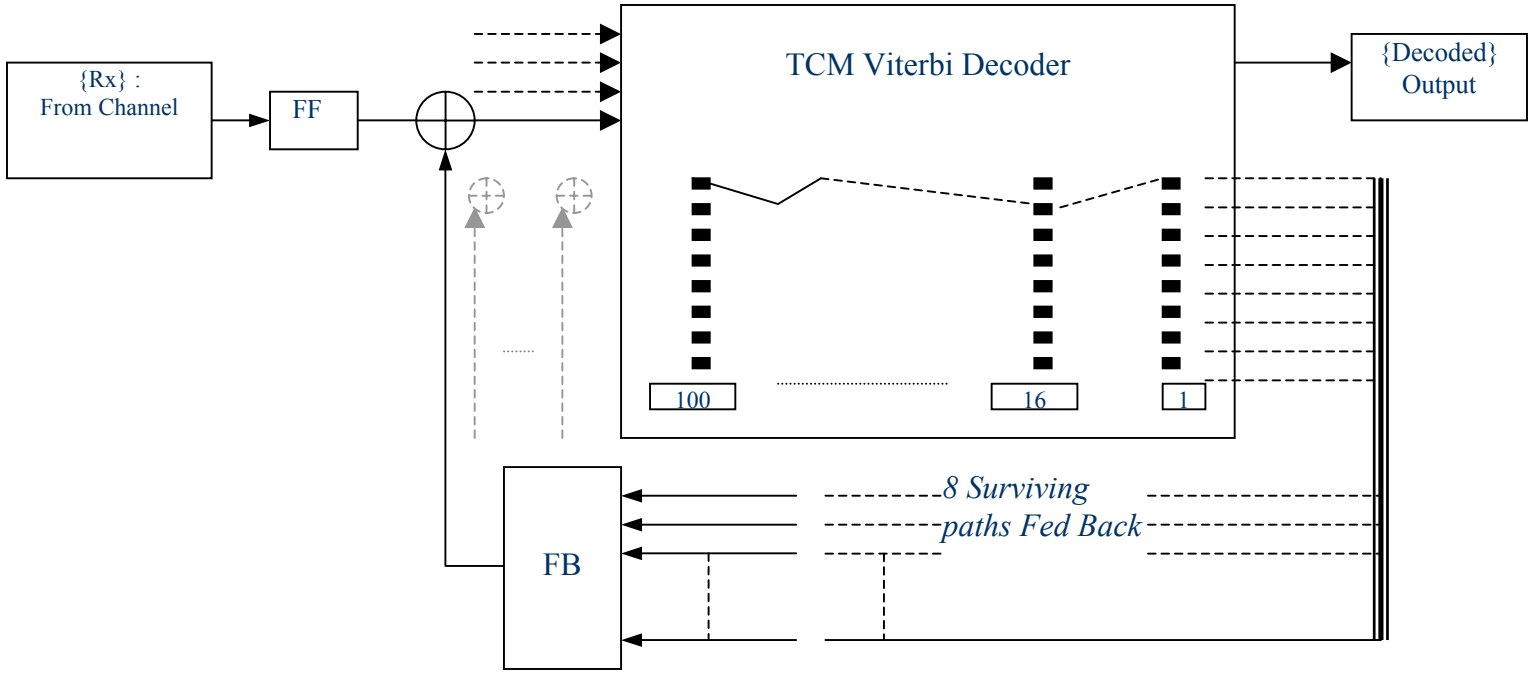
Correct Symbol feedback : Results



Joint Equalization and Decoding : SPFE

- The success of correct symbol feedback prompted us to place the decoder inside the DFE loop. This scheme of implementation is called the Survivor Path Feedback Equalizer (SPFE).

Survivor Path Feedback Equalizer



- Each surviving path in the trellis is considered as a possible Tx
- 1st symbol has no pre curser ISI, if detected correctly, it can correct the ISI in 2nd symbol … and so on …

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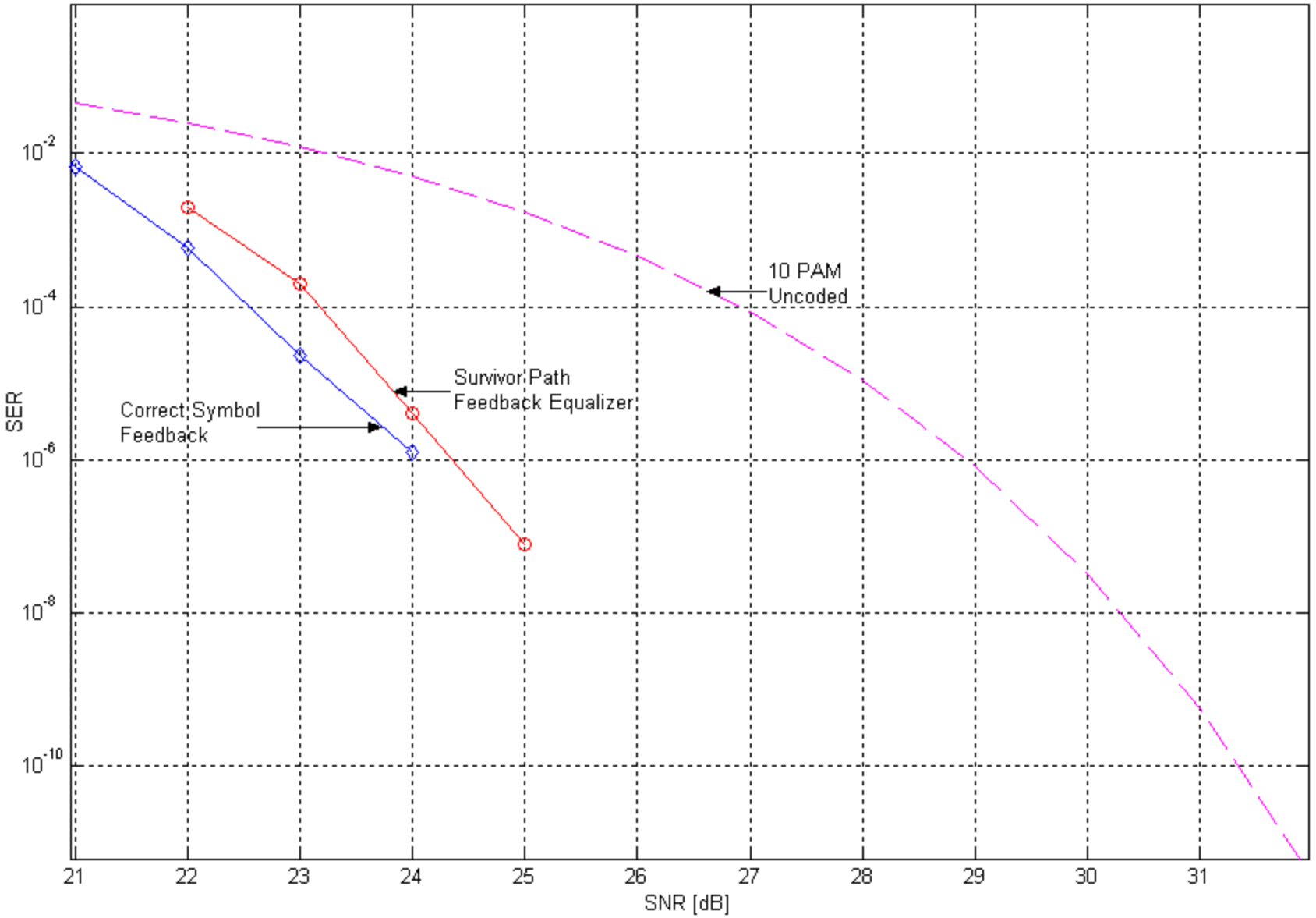
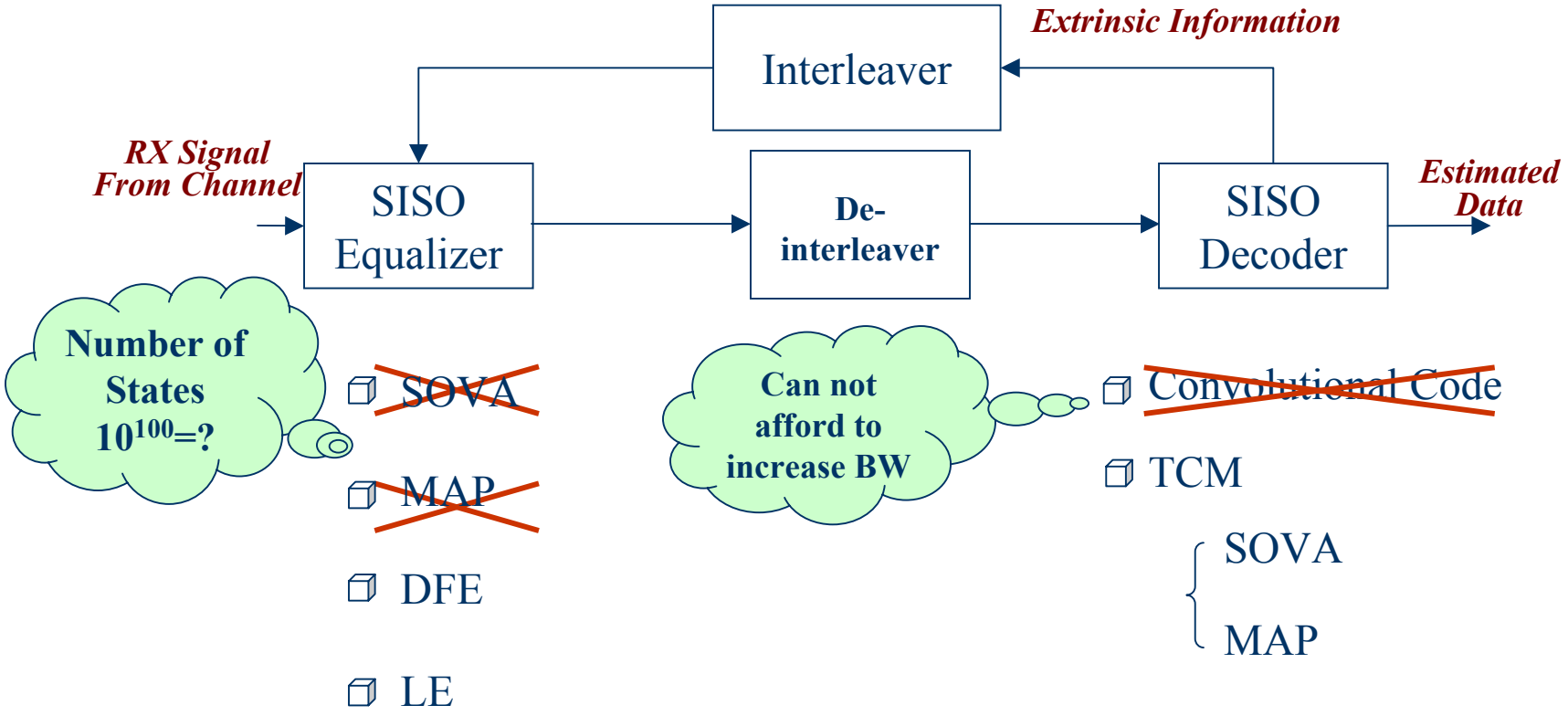
Survivor Path Feedback Equalizer :Results



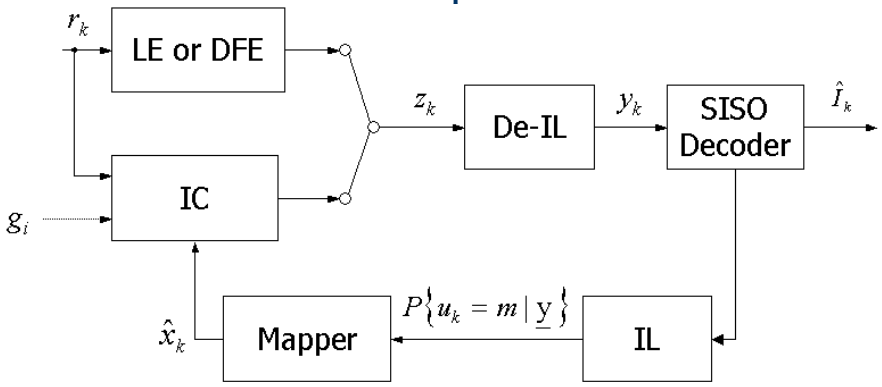
TURBO Equalizer

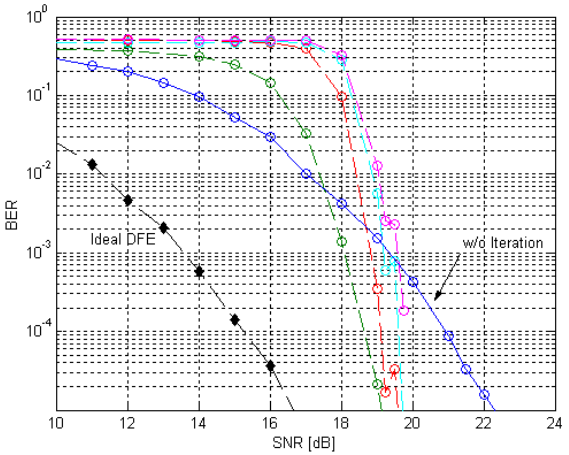


TURBO Equalization

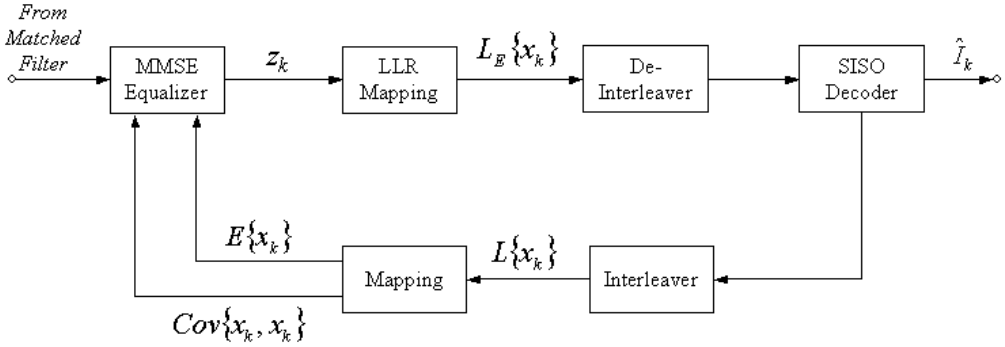
CAT- 6, BPSK , rate ½ code , 833Mbaud

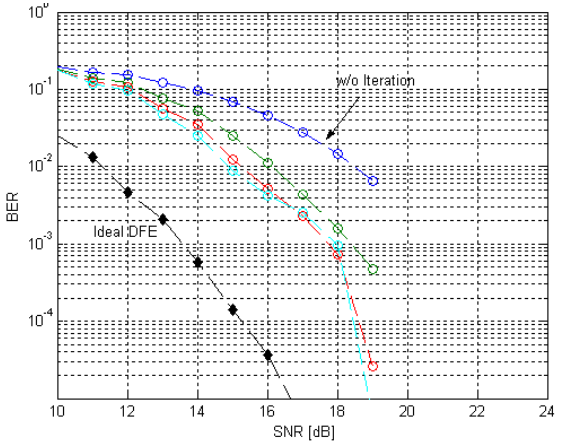
Soft IC based Turbo Equalization



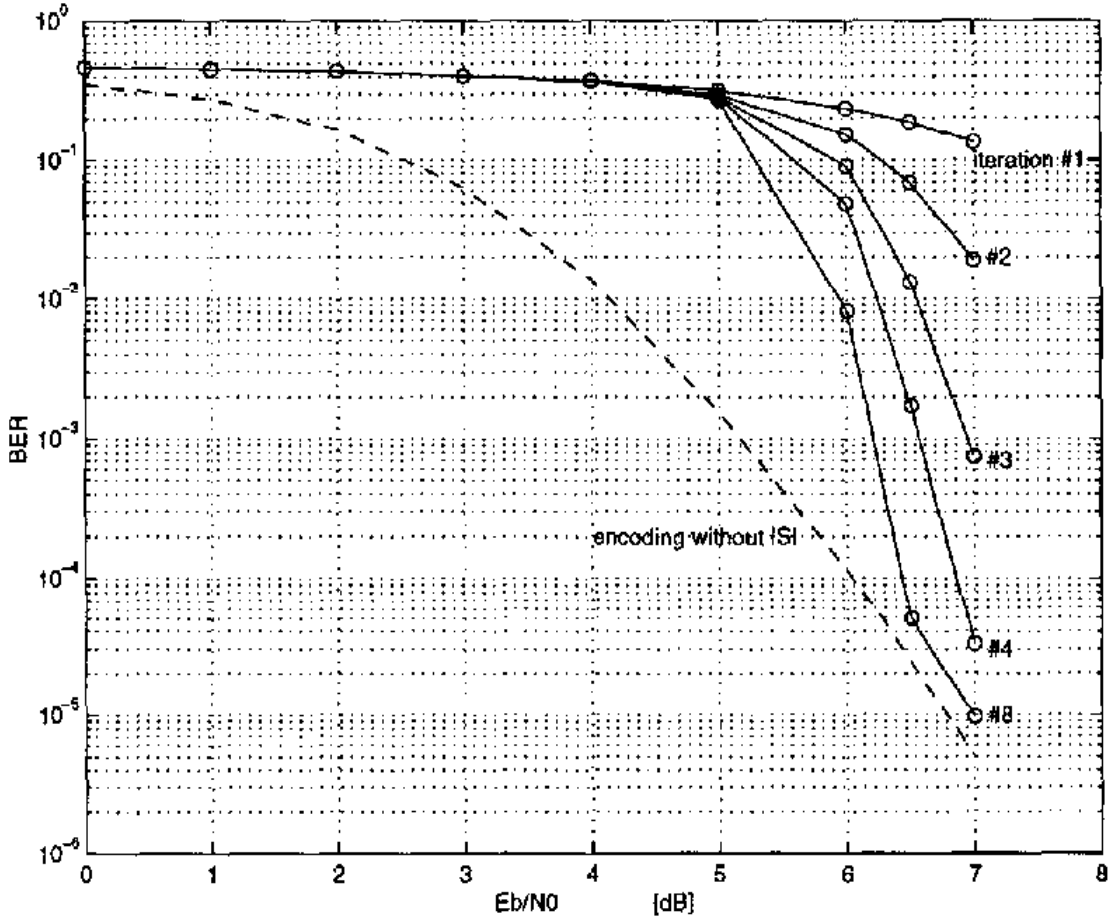


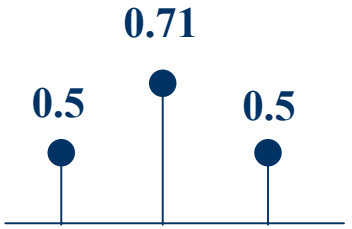
MMSE Equalization





TURBO Equalizer applied to TCM





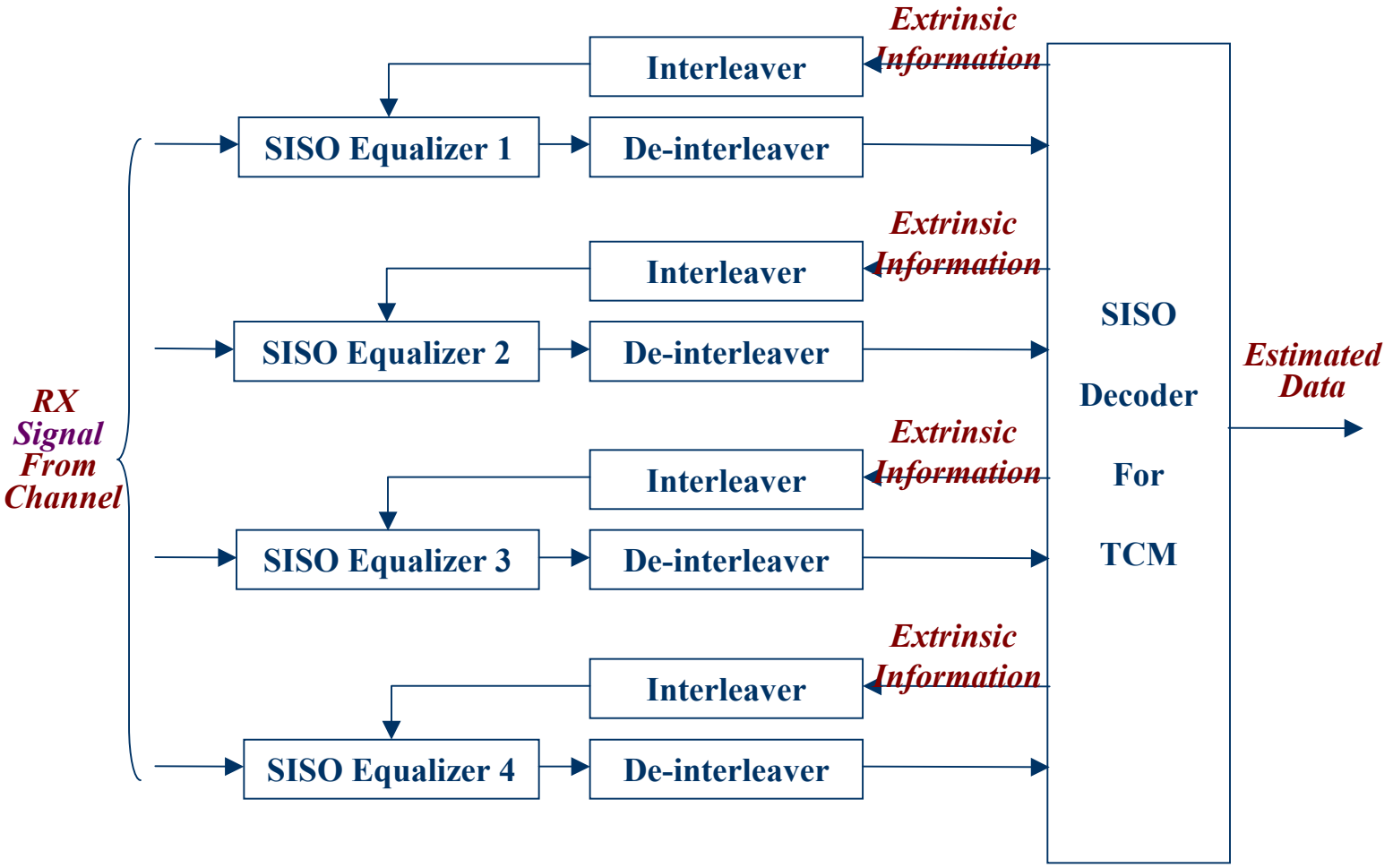
MAP Equalization

TCM

- **8-PSK**
- **2/3 Code Rate**
- **With memory m=3**

Magniez & Duhamel VTC'99

Anticipated RX structure

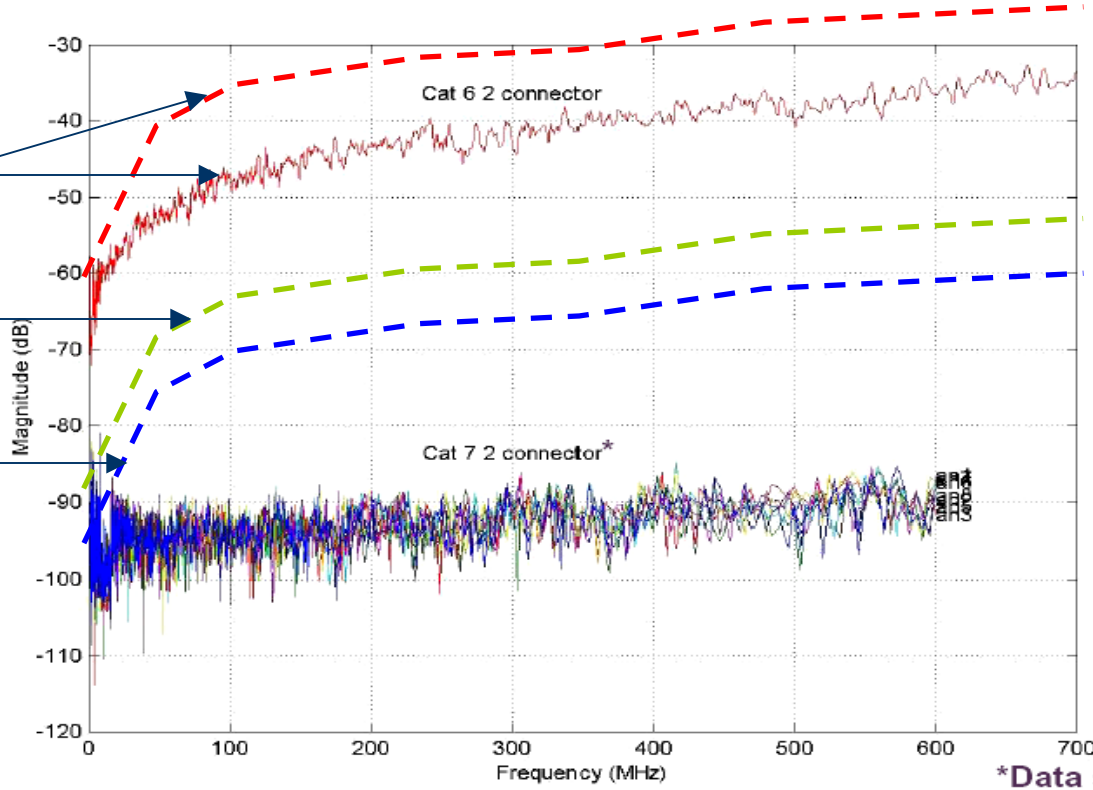


ANEXT Issue

Broadcom, Vativ, Marvell
May 2003

Avaya's Experimental Model
-60 + 10*log(f/100)

Solar Flare
(according to Sterling Vaden,
Superior Modular Products



*Data supplied by Nexans

Summary

- **Using recent ANEX measurements, there is every indication that 10Gbps transmission over 100m of CAT-6 is possible, given a target average BER of 10^{-12}.**

- **Since performance is ANEXT-limited, ANEXT specifications need be finalized ASAP.**

❋ Thank you ❋