Multi-Vendor Agreement on Precoder Proposal

A Channel Equalization Approach for 10GBASE-T

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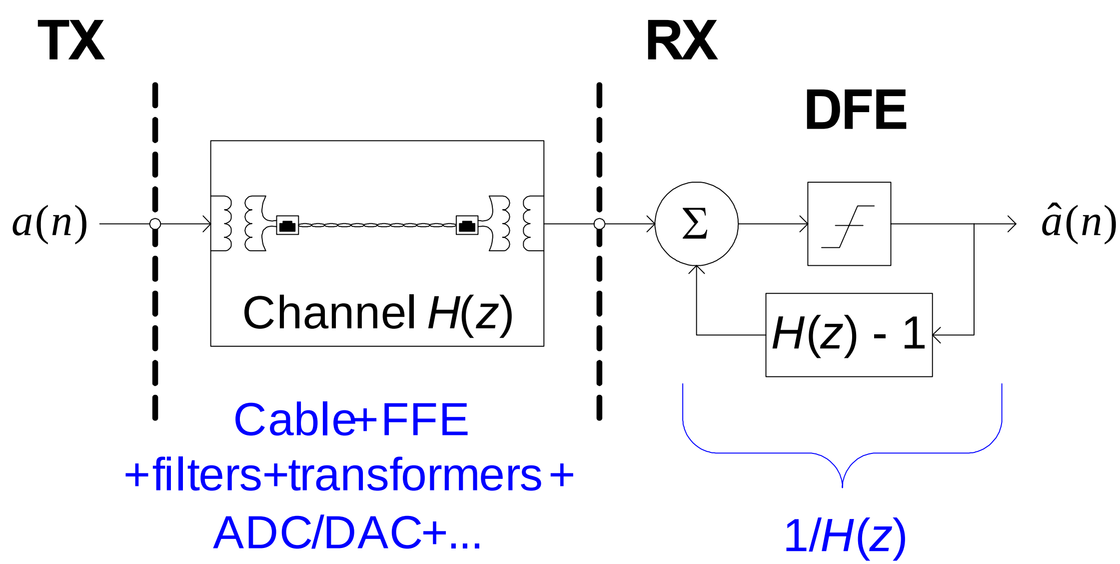
Multi-Vendor Precoder Proposal

☞ **Benefits of Precoding**

- **Common Criticisms of Precoding**
- **Summary, Q&A**
- **Motion/Straw Poll**

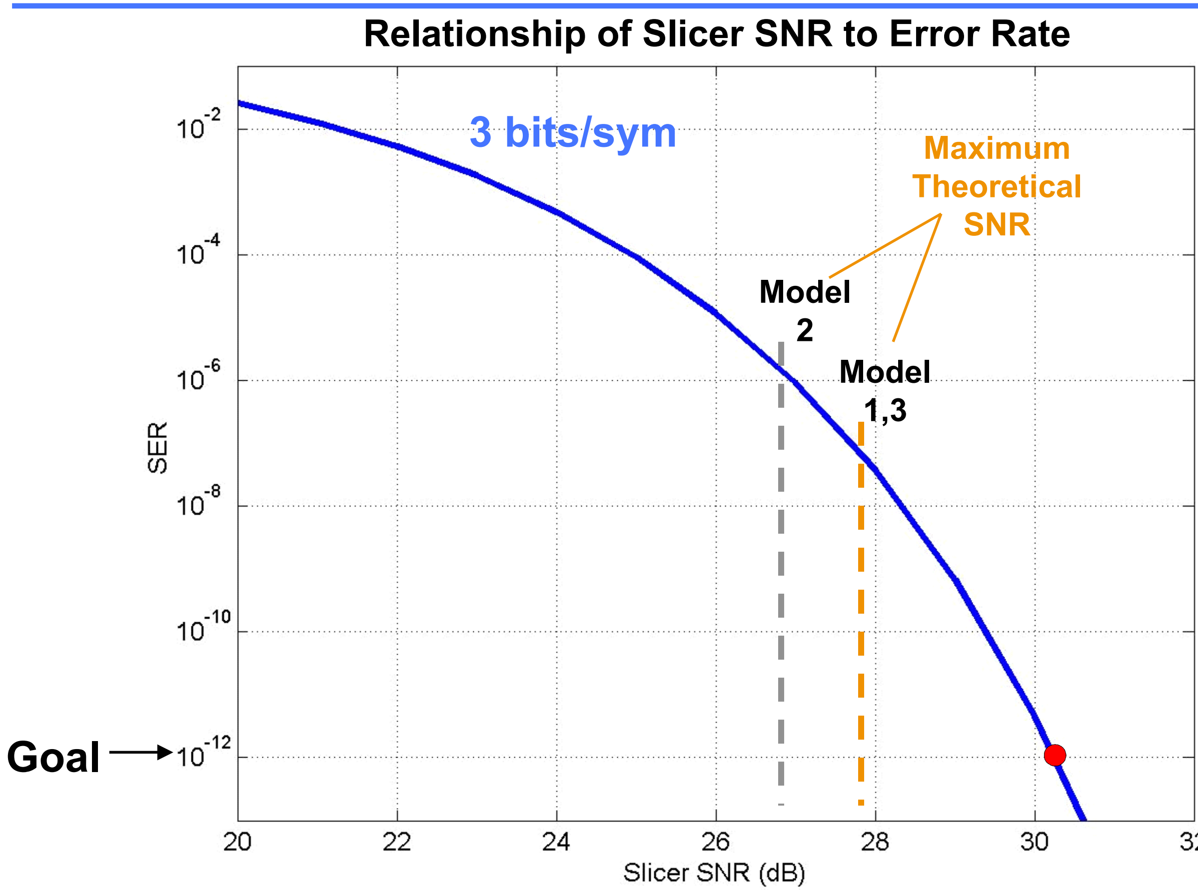
Channel Equalization via DFE

- **Decision feedback equalization (DFE) is known to be asymptotically optimum for band limited channels***
  - **Optimally equalizes ISI and simultaneously whitens noise**
  - **DFE cascaded with FEC obtains same coding gain over ISI channel as over an ideal AWGN channel**
    - This is true only in the absence of slicer decision errors



*** Cioffi, et.al., "MMSE Decision-Feedback Equalizers and Coding," *IEEE Trans. On Comm.*, Oct. 1995**

Required Coding Gain



* Matlab model from "solarsep_varlen7a.m"

* Channel models from kasturia_2_0304.pdf & 11801

- Channel model includes NEXT/ECHO/FEXT/ANEXT/Bkn
- Channel model excludes ADC/DAC/ISI/jitter/distortion/…

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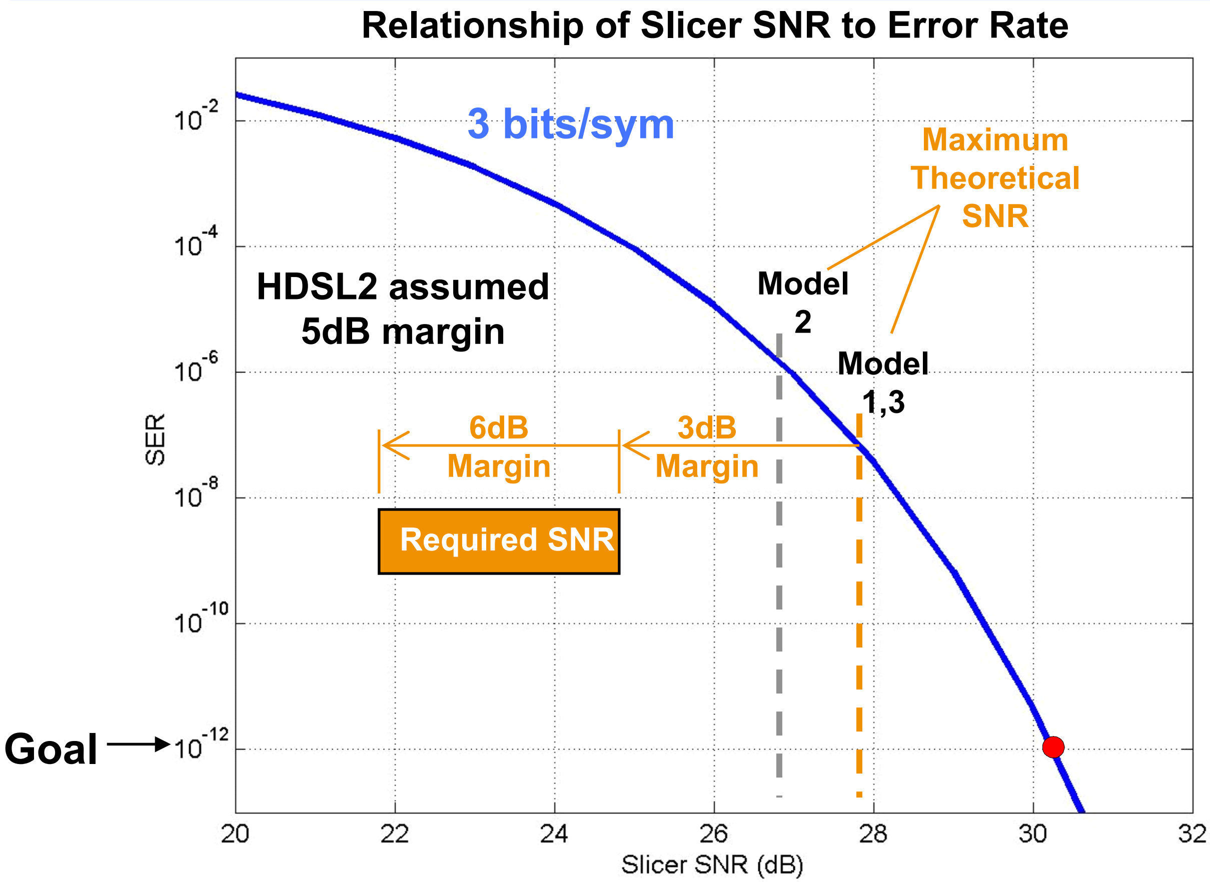

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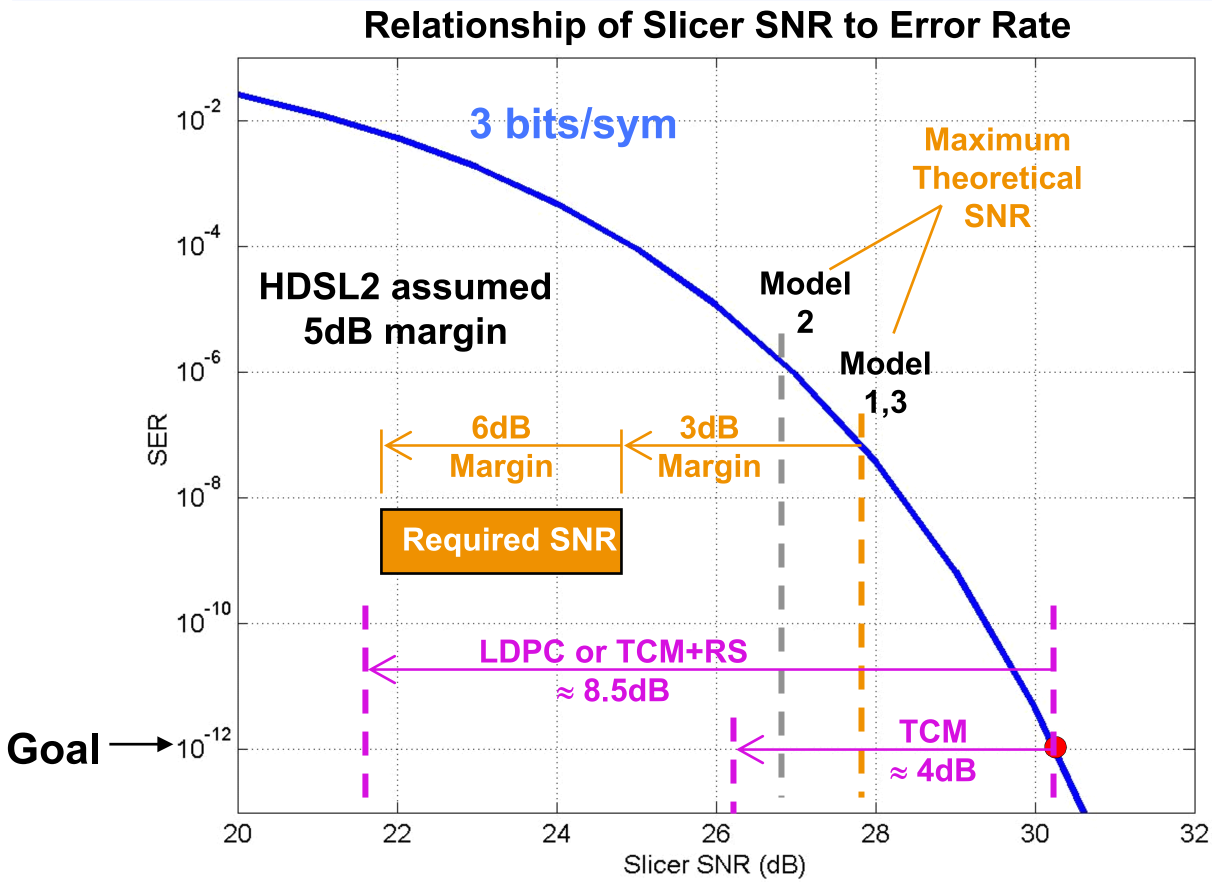

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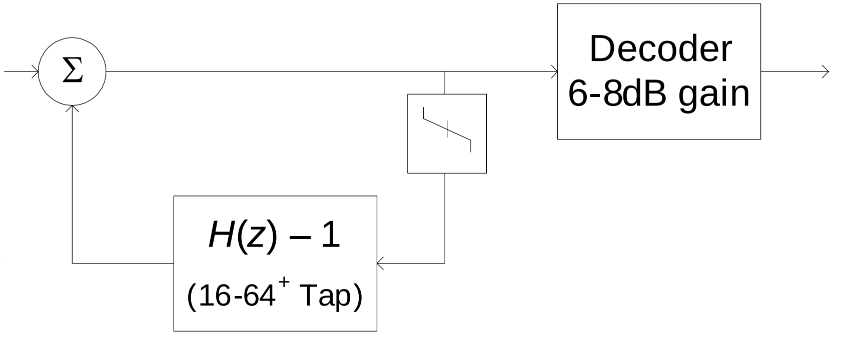
More powerful coding than TCM necessary

- Channel model includes NEXT/ECHO/FEXT/ANEXT/Bkn
- Channel model excludes ADC/DAC/ISI/jitter/distortion/…

Rx-Based DFE and Channel Coding

- **DFE/FEC cascade is known to cause problems with severe ISI channels***
  - **Error propagation substantially reduces coding gain**
  - **Primary reason this configuration was not used in 1000BT**



*M.V. Eyuboglu, "Detection of Coded Modulation Signals on Linear, Severely Distorted Channels using Decision Feedback Noise Prediction with Interleaving," IEEE Trans. Comm., Apr. 1988

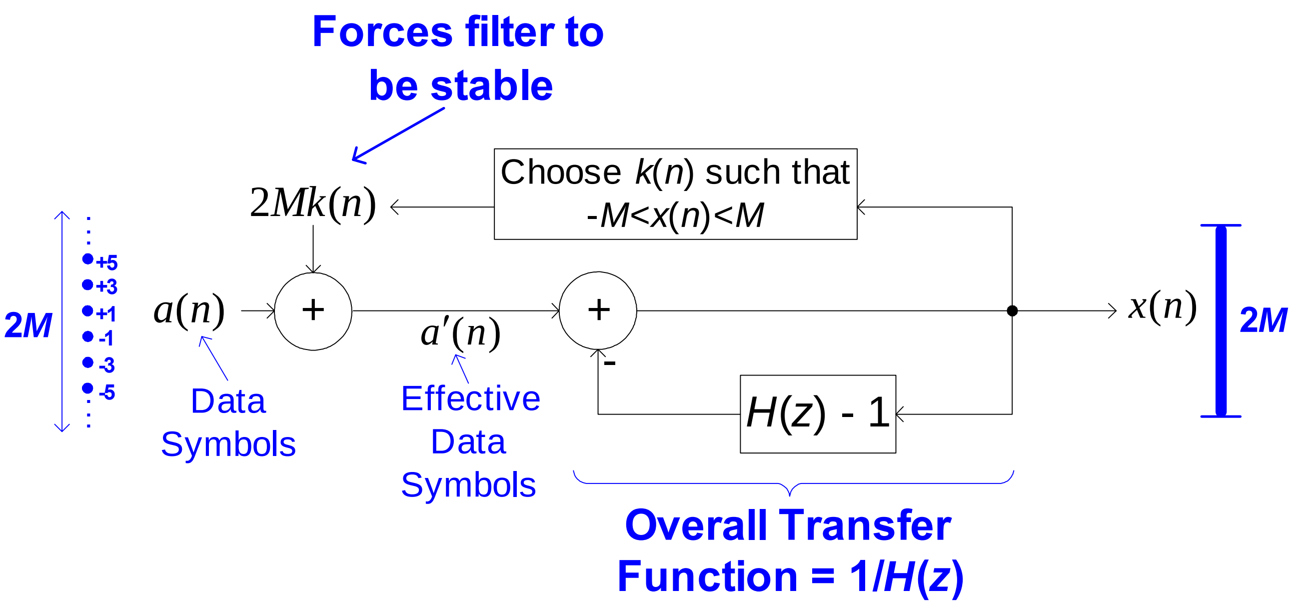
- **Techniques for mitigation usually require placing some portion of decoder inside the feedback loop**
  - **Introduces a critical timing path ⇒ limits max baud rate**
  - **Incompatible with high performance block or iterative codes**
  - **Restricts asymptotic coding gain to <4.1 dB (PAM-10 DFSE)**

Decoupling FEC from Equalization

- **Precoding is a well-known technique for decoupling channel equalization from channel coding**
  - **Necessary for LDPC or concatenated coding schemes**
- **Previously proposed to task/study group**
  - **www.ieee802.org/3/10GBT/public/nov03/rao_1_1103.pdf**
  - **www.ieee802.org/3/10GBT/public/mar04/powell_1_0304.pdf**
  - **www.ieee802.org/3/10GBT/public/mar04/rao_1_0304.pdf**
- **Implicit to block code presentations**
  - **www.ieee802.org/3/10GBT/public/mar04/dabiri_1_0304.pdf**
  - **www.ieee802.org/3/10GBT/public/mar04/powell_1_0304.pdf**
  - **www.ieee802.org/3/10GBT/public/mar04/ungerboek_1_0304.pdf**
  - **www.ieee802.org/3/10GBT/public/mar04/seki_1_0304.pdf**

Tx-Based Equalization

- **Precoding moves postcursor equalization to the transmitter** M. Tomlinson March 1971, H. Harashima & H. Miyakawa August 1972

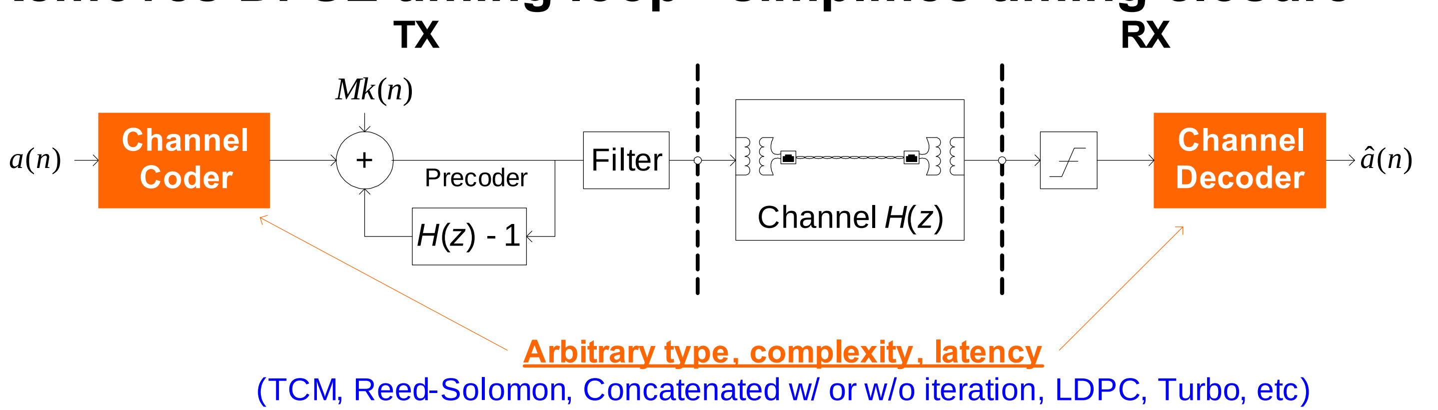


- **Flat transmit spectrum**
- **Does not preclude further filtering for EMI or capacity reasons**

- **Precoding achieves similar performance as DFE with correct decisions**
  - Precoder feedback symbols are known, not estimated
  - Equalization is independent of channel coding performance

Fundamental Benefits of Precoding

1. **Permits more powerful channel codes required to meet 10Gbps**
   - **Decouples equalization from channel coding**
2. **Retains asymptotic optimality of decision feedback equalization without error propagation**
3. **Does not affect transmitted spectrum (EMI)**
   - **Does not preclude any form of transmit filtering**
4. **Removes DFSE timing loop - simplifies timing closure**



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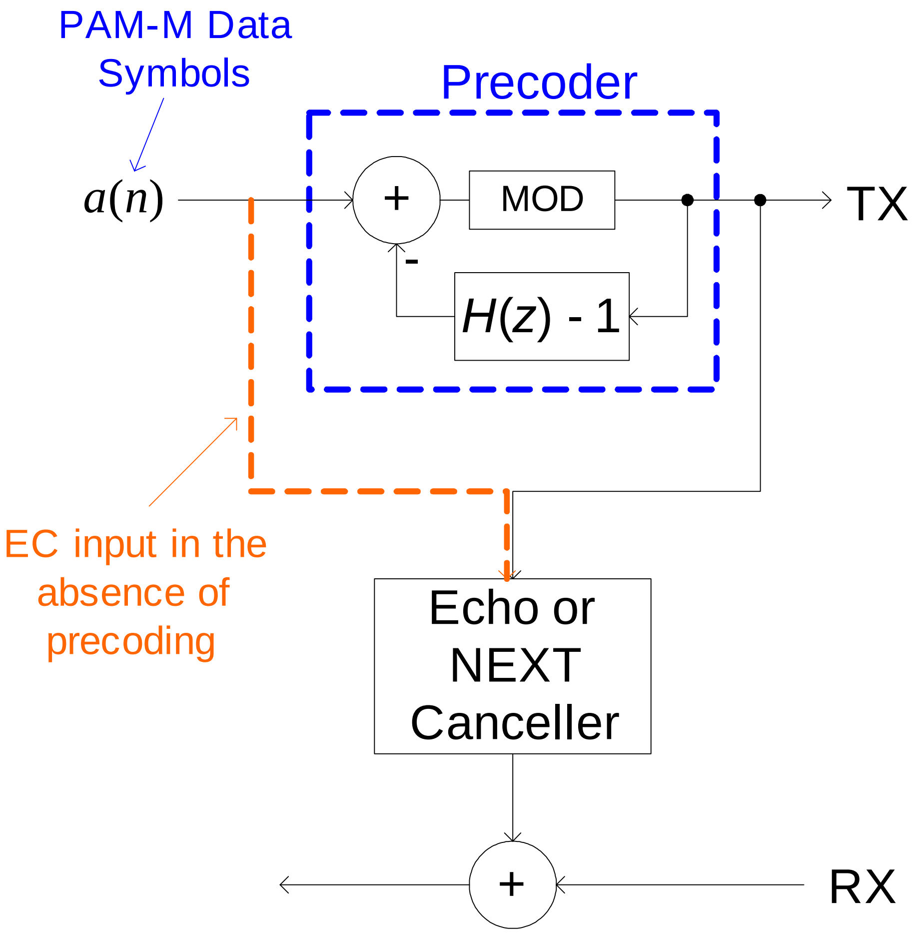
Echo/NEXT Canceller Complexity

- **Precoding is compatible with echo, NEXT, and FEXT cancellation**
  - **Input to cancellers moved to output of precoder**



- **Complexity impact**
  - **Number of taps unchanged**
  - **Wordlength of input increased**
- **Potential for reduction**
  - **Little/no impact on frequency domain schemes**
  - **Investigate use of effective data symbols as input**

Transmit Peak-Average Power (PAR)

- **Small average power increase**
- **The peak power increase is approx 1dB**

MPAM Levels	Average Power Increase (dB)	Peak Power Increase (dB)	PAR increase (dB)
5	0.18	1.9	1.8
8	0.07	1.2	1.1
10	0.04	0.9	0.9
12	0.03	0.8	0.7

Dynamic Range of Received Signal

$$x(n) \longrightarrow \boxed{H(z)} \longrightarrow y(n)$$

channel

- **By Definition:** $y(n) = \sum_{k=0}^{N-1} x(n-k)h(k)$

$$|y|_{\max} \text{ occurs when } x(n-k) = |x|_{\max} \operatorname{sign}(h(k))$$

$$\Rightarrow \; y(n) \; \leq \; |x|_{\max} \sum_{k=0}^{N-1} |h(k)|$$

- **Precoded X_{max} = M, non-precoded X_{max} = M-1**
  - **Rx dynamic range increase < 1dB for PAM-10**

Constellation expansion from precoding does not significantly increase the dynamic range of the received signal

DAC Complexity*

*Sandeep Gupta

- DAC area and power similar for precoded or non-precoded system
  - Assume current steering DAC
  - Non-precoded PAM-8: INL/DNL ≈ 60dB, reduced number of levels
  - Precoded: INL/DNL ≈ 60dB, 10b DAC all levels
- Total area dominated by area of current sources
  - Similar for both cases
  - Small increase for 10b DAC due to increased digital logic complexity
- Power determined by full scale current, output loading, and swing requirements
  - Similar for both cases

Interoperability

- Interoperability and startup issues already solved in multiple standards
  - V.34, G.SHDSL, HDSL2, 802.3ah (EFM)
- HDSL2 approach is adopted by several standards
  - Generic Tomlinson-Harashima precoder (PAM-16)
  - Performance within a dB of optimal DFE achieved
  - Coefficients determined at startup then fixed
  - Reduced constellation (PAM-2) used at startup
- HDSL2 System validation performed with end-to-end performance tests
  - Task force will need to develop test modes to allow the transmitter to be checked for compliance

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Summary

- **Precoding permits powerful channel codes to be used for 10GBASE-T**
  - **Necessary to capture sufficient portion of available capacity**
- **Precoding advantages outweigh disadvantages**
  - **Most "disadvantages" are misconceptions or can be mitigated**
- **Supported by majority of PHY vendors as best channel equalization strategy for 10GBASE-T**

Questions ???

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☞ **Motion/Straw Poll**

Straw-Poll: Generic Precoding

- **Motion: 10GBASE-T adopt Tomlinson-Harashima precoding as the channel equalization strategy**

  - **PHY Vendors by company:**

    (“PHY Vendor” ≡ company planning to possibly develop 10GBASE-T transceivers))

PHY Vendor Company	Yes	No	Abstain
Broadcom			
Hitachi			
Intel			
Keyeye			
NEC			
Marvell			
Plato			
Sailesh Rao (Ind.)			
Solar Flare			
Teranetics			
TI			
Vativ			
Vitesse			
	#DIV/0!	#DIV/0!	#DIV/0!

- **Task Force Members: Y: N: A:**