06-419r0 SAS-2 Reference Transmitter and Receiver Specification Proposal

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SAS-2 Phy Working Group

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Outline

- Present an Evaluation of all Published SAS-2 Channels
  - Clarify the Definition of Transmit De-Emphasis

- Provide a Basis for the Selection of the Transmit De-Emphasis Specification

- Provide a Basis for the Selection of the Reference Transmitter & Receiver

- Propose Initial Transmitter and Receiver Specifications

- References:
  - 06-206R2   SAS-2 Data Eyes vs. De-Emphasis
  - 06-053R0   Roadmap to SAS-2 Physical Layer Specification
  - 06-052R0   Enhanced SFF-8470, SFF-8086 and SATA Cable at 6Gbps
  - 05-204R1   Towards a SAS-2 Physical Layer Specification
  - 05-426R0   SAS-2 Cable Reach Objective and Crosstalk
  - 05-425R1   SAS-2 Channel Model Simulations
  - 05-342R0   SAS-2 Adaptive Equalizer Physical Layer Feasibility
  - 05-341R1   Updated Test and Simulation Results in Support of SAS-2
  - 05-203R0   SAS-2 6Gbps Test Results

SAS-2 Channels Analyzed

VITESSE

- 28 Channels Submitted

- 0→10 dB De-Emphasis

- 0→10 Taps DFE

- 3,388 Simulation Cases

- Behavior Simulation

ID Used in Plots

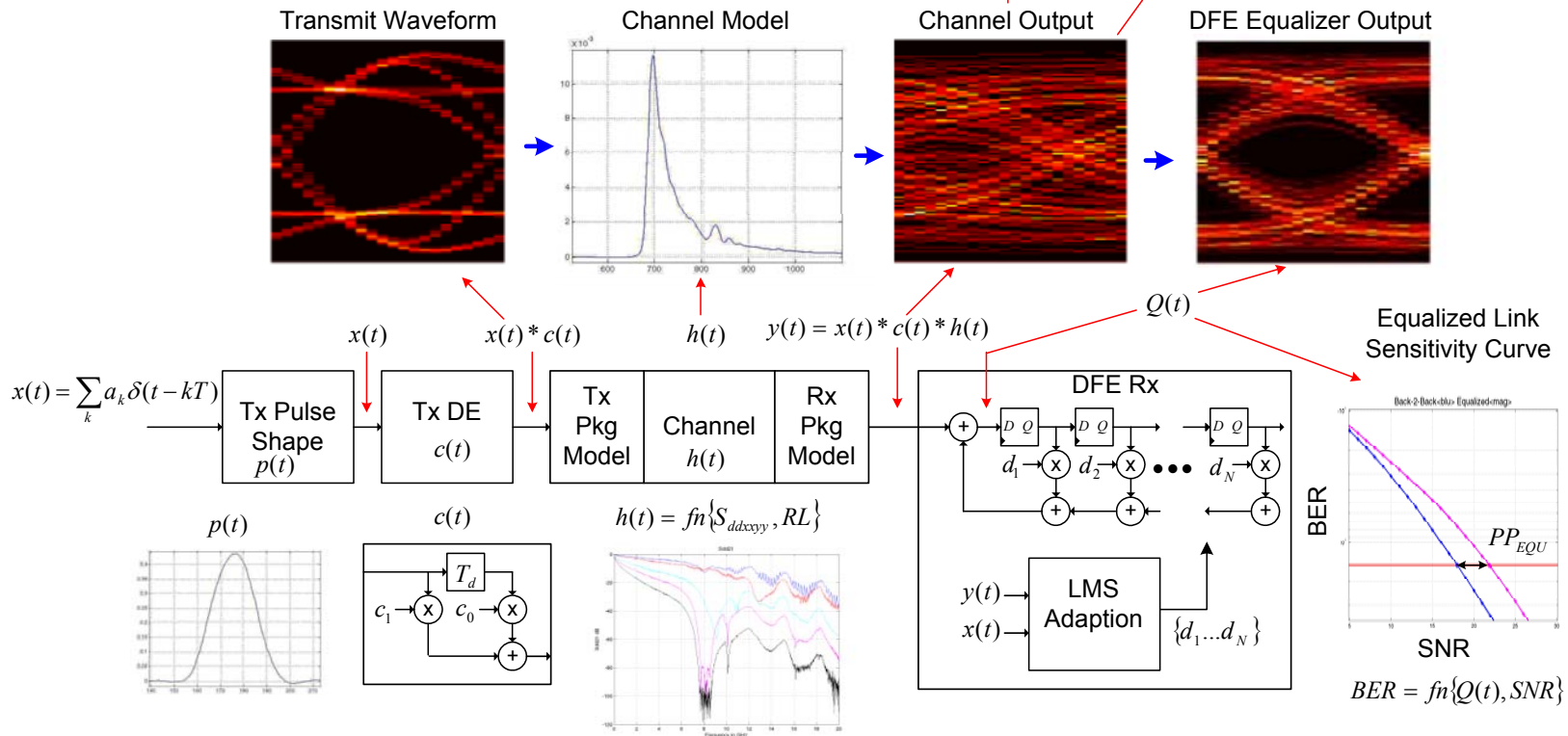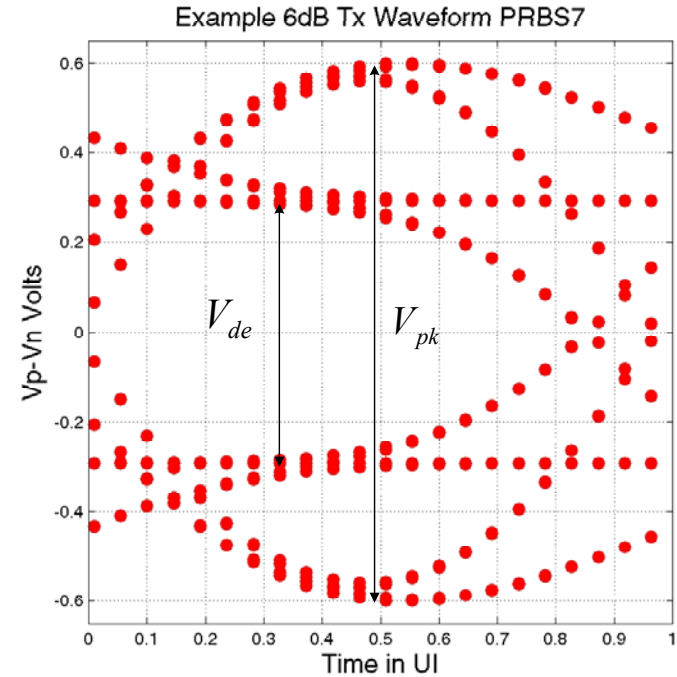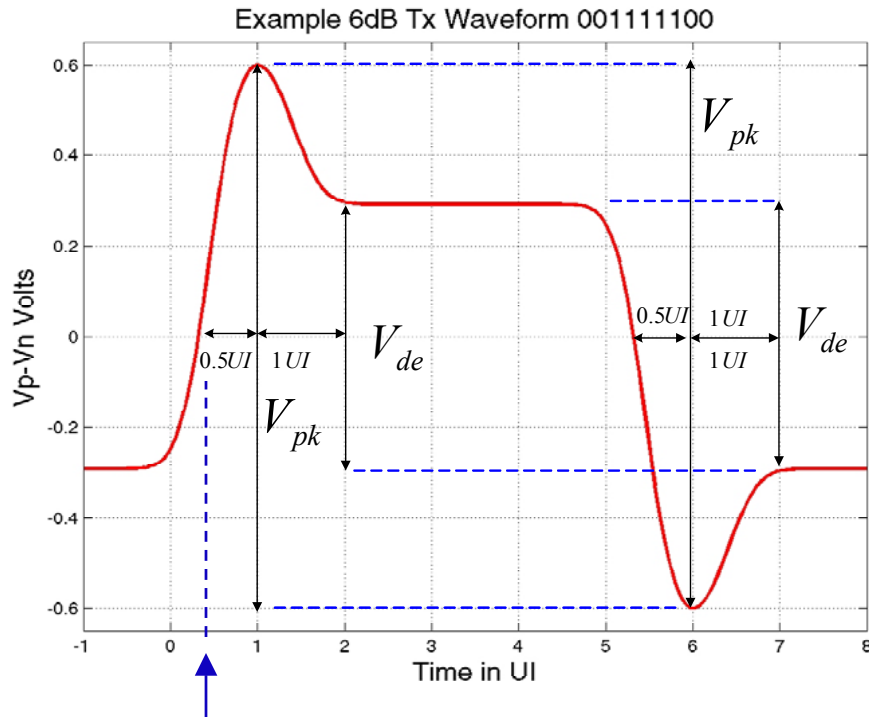| ID	T10 Doc #	Source	Description	Type
1	05-398r0	Molex	0.5m MiniSAS	Measured
2	05-398r0	Molex	1 m MimiSAS	Measured
3	05-398r0	Molex	3 m MimiSAS	Measured
4	05-398r0	Molex	3 m MimiSAS	Measured
5	05-398r0	Molex	10 m MimiSAS	Measured
6	05-384r0	HP1	3 Connector Board 2 board	Measured
7	05-384r0	HP2	3 Connector Board 2 board	Measured
8	05-384r0	HP3	3 Connector Board 2 board	Measured
9	05-384r0	HP4	3 Connector Board 2 board	Measured
10	05-384r0	HP5	3 Connector Board 2 board	Measured
11	05-384r0	HP6	3 Connector Board 2 board	Measured
12	05-384r0	HP7	3 Connector Board 2 board	Measured
13	05-384r0	HP8	3 Connector Board 2 board	Measured
14	05-389r0	HP9	4 connector Board to Board	Measured
15	05-389r0	HP10	4 connector Board to Board	Measured
16	05-389r0	HP11	4 connector Board to Board	Measured
17	05-390r0	HP12	Board 1m Cable Backplane Drive	Measured
18	05-390r0	HP13	Board 6" Cable Backplane Drive	Measured
19	05-390r0	HP14	Board 6" Cable Backplane Drive	Measured
20	06-017r0	HP24	4 connector Board to Board	Measured
21	06-017r0	HP25	4 connector Board to Board	Measured
22	06-017r0	HP26	4 connector Board to Board	Measured
23	05-384r2	HP27	Board to board 3 connector	Measured
24	05-384r2	HP28	Board to board 3 connector	Measured
25	05-393r0	Dell 1	Bottom Trace 19"	Model
26	05-393r0	Dell 2	Bottom Trace 8"	Model
27	05-393r0	Dell 3	Top Trace 8"	Model
28	05-393r0	Dell 4	Top Trace 19"	Model

- **S-Parameter Channel Models (28 Channels)**
- **Sweep Tx De-Emphasis 0→10dB**
- **Sweep # Rx DFE Taps 0→10 Taps**
- **Tx Pulse Shape Based on 6Gbps Test Chip**
- **Mellitz Capacitive Package Model RL~7dB @ 3GHz**
- **Semi-Analytic BER Used to Estimate Sensitivity Plot**
- **Observe: Channel DJ, Uncompensated & Equalized Power Penalty vs DE and #Taps DFE**

Unequalized Link Sensitivity Curve

Back-2-Back<blu> Unequalized<mag>

BER

PP_{CH}

SNR

Unequalized Jitter Estimate DJ

Transmit Waveform

Channel Model

Channel Output

DFE Equalizer Output

$Q(t)$

Equalized Link Sensitivity Curve

$x(t)$ 　 $x(t)*c(t)$ 　 $h(t)$ 　 $y(t)=x(t)*c(t)*h(t)$

$$x(t)=\sum_k a_k \delta(t-kT)$$

| Tx Pulse Shape $p(t)$ | Tx DE $c(t)$ | Tx Pkg Model | Channel $h(t)$ | Rx Pkg Model |

DFE Rx

d_1 d_2 $\bullet\bullet\bullet$ d_N

$p(t)$

$c(t)$

T_d

c_1 c_0

$h(t)=fn\{S_{ddxxyy},RL\}$

$y(t)$ 　 LMS Adaption 　 $\{d_1...d_N\}$

$x(t)$

Back-2-Back<blu> Equalized<mag>

BER

PP_{EQU}

SNR

$$BER=fn\{Q(t),SNR\}$$

Tx De-Emphasis Details

De-Emphasis Can Be Measured From 0000011111110000011111 Waveform

Example 6dB Tx Waveform 001111100

Example 6dB Tx Waveform PRBS7

All Voltage Measurements Referenced to Zero Crossing

$$DE_{dB} = 20Log_{10}\left(\frac{V_{pk}}{V_{de}}\right)$$

$$Cutback = \frac{V_{pk} - V_{de}}{V_{pk}}$$

Example

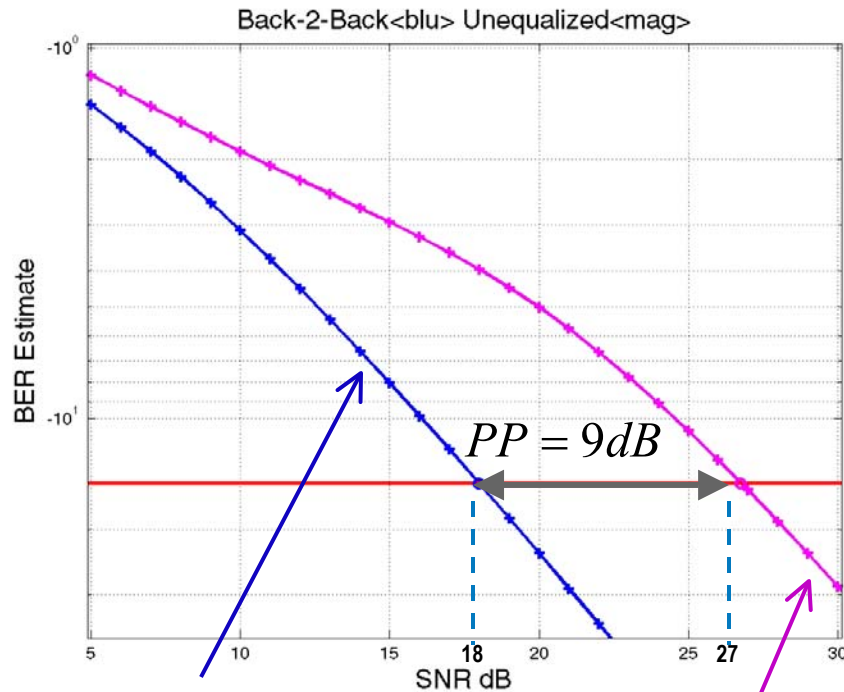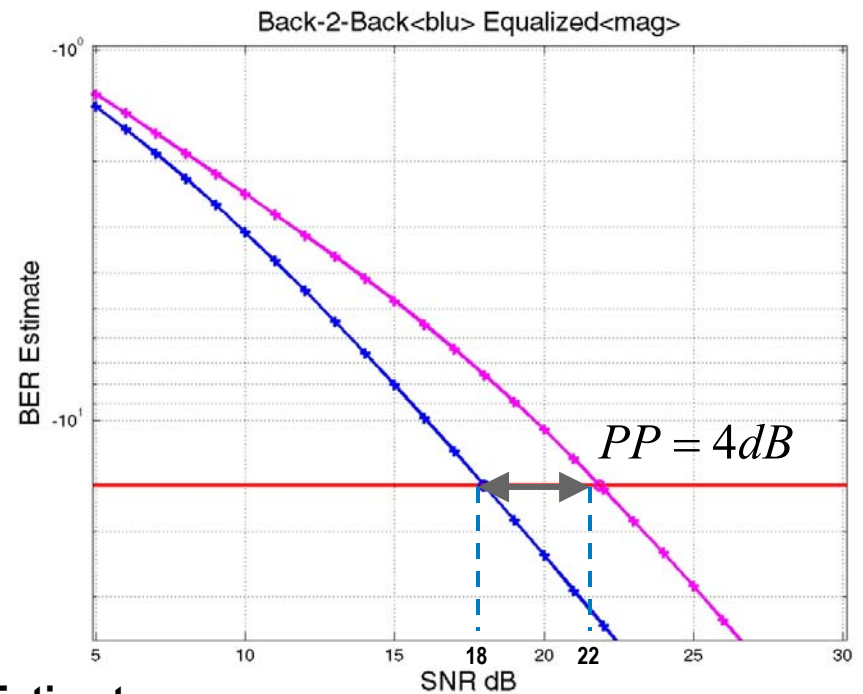| Vpk mV	Vde mV	DE (dB)	CutBack (%)
1200	850	3	29
1200	757	4	37
1200	675	5	44
1200	601	6	50
1200	536	7	55
1200	478	8	60

📚 The Power Penalty Indicates How Much Additional SNR is Required to Overcome the Residual ISI After Equalization to Operate at the Target BER of 1e-15.

📚 Example

Theoretical for NRZ Link   **Semi-Analytic BER Estimate**

Reference: Simulation of Communication Systems Modeling, Methodology and Techniques, M. C. Jeruchim, 2000

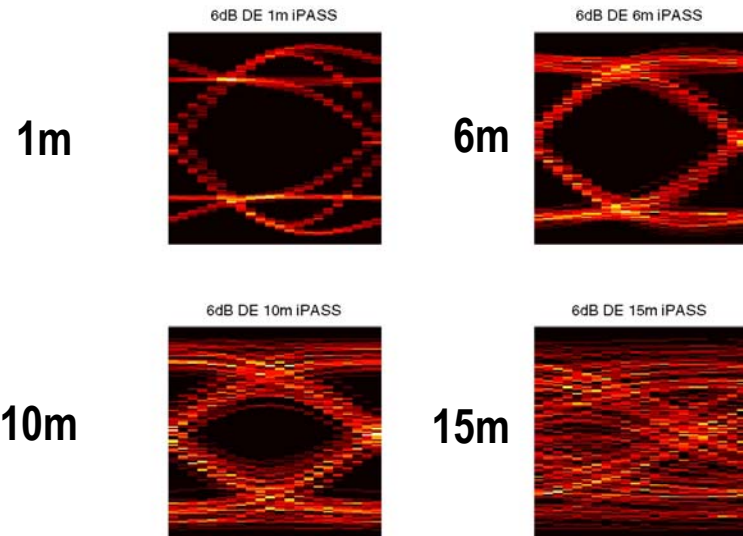# Visual Check of Simulation Methodology

VITESSE

- Simulation vs. Measured
  - 6 Gbps Output Driver Test Chip
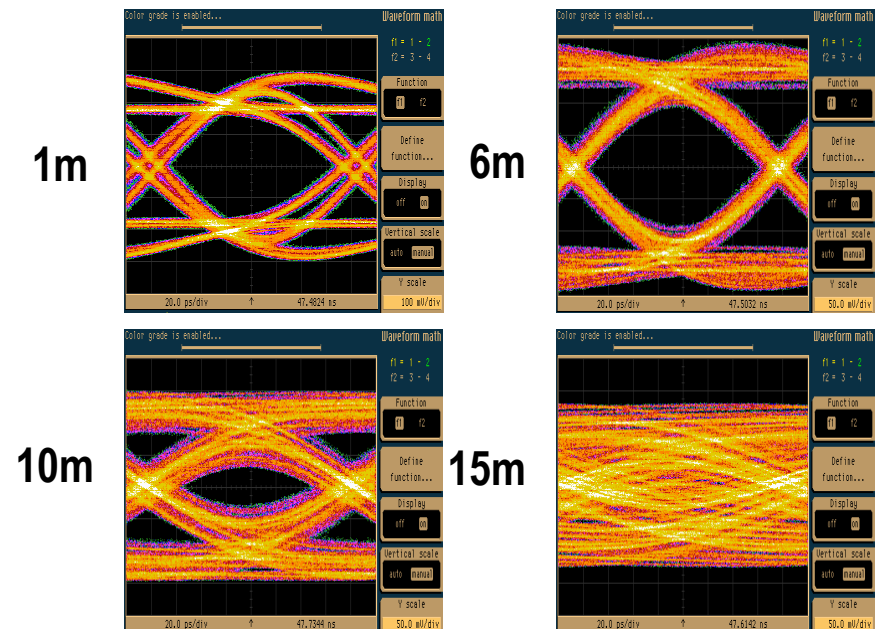 - 6dB 2 Tap De-Emphasis

- Good Agreement With Measured
  - Eye Opening and Eye Shape
  - Jitter at Zero Crossing

6dB De-Emphasis Simulated Eyes
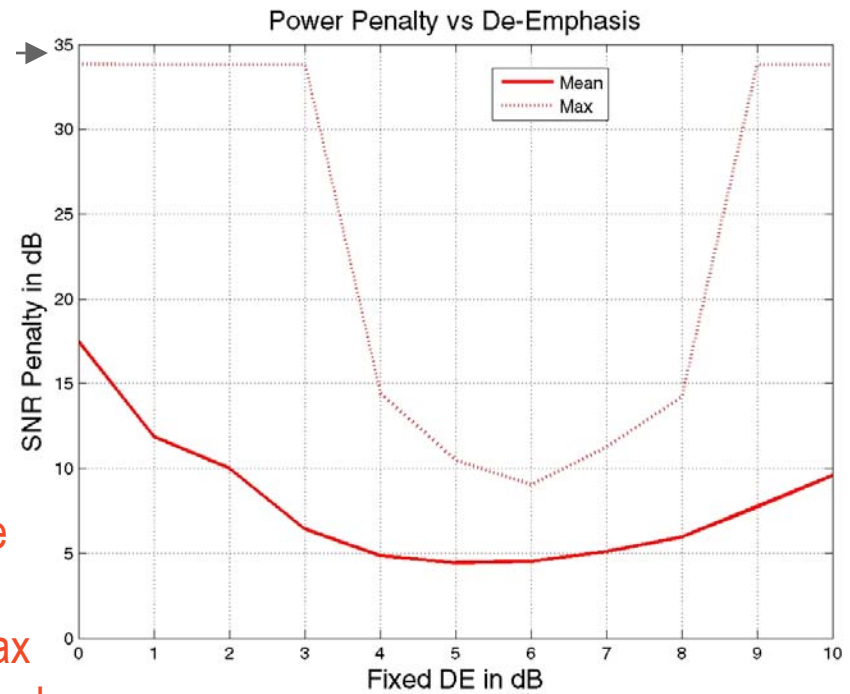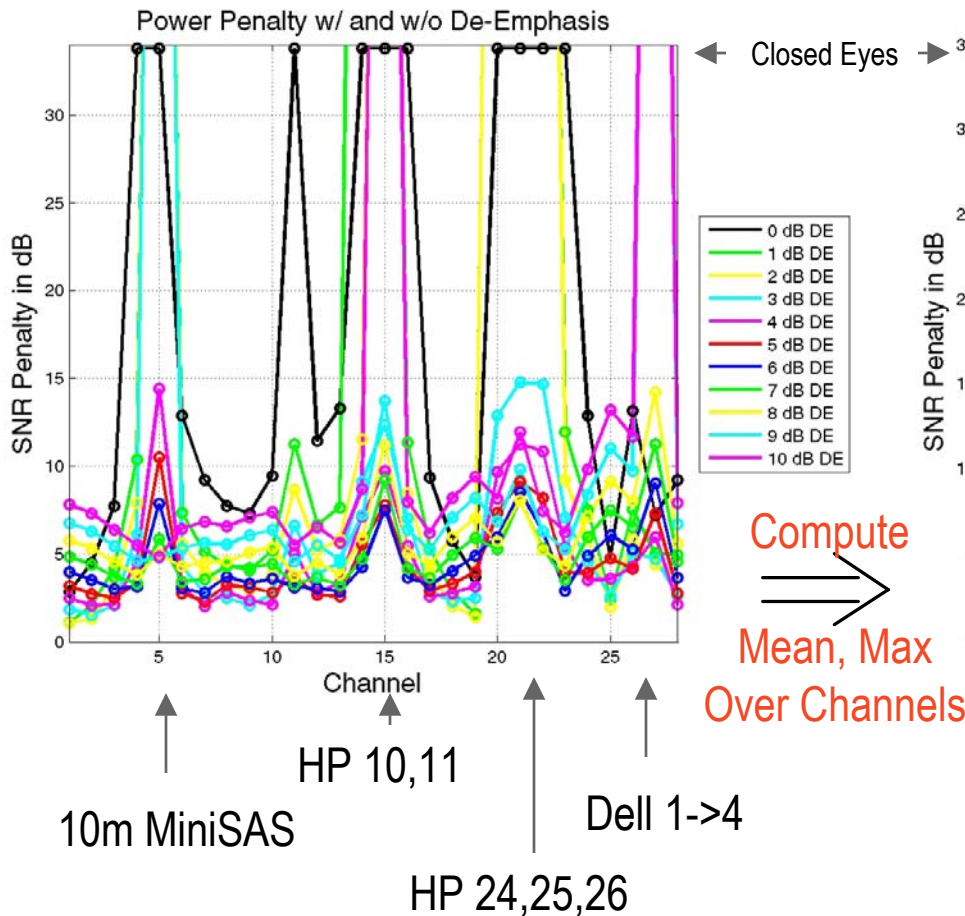

1m   6m

10m   15m

6dB De-Emphasis Measured Eyes

1m   6m

10m   15m

What is the Optimal De-Emphasis Setting?

VITESSE

- SNR Penalty vs. De-Emphasis (no DFE)
  - What is the Best De-Emphasis Setting to Minimize SNR Power Penalty
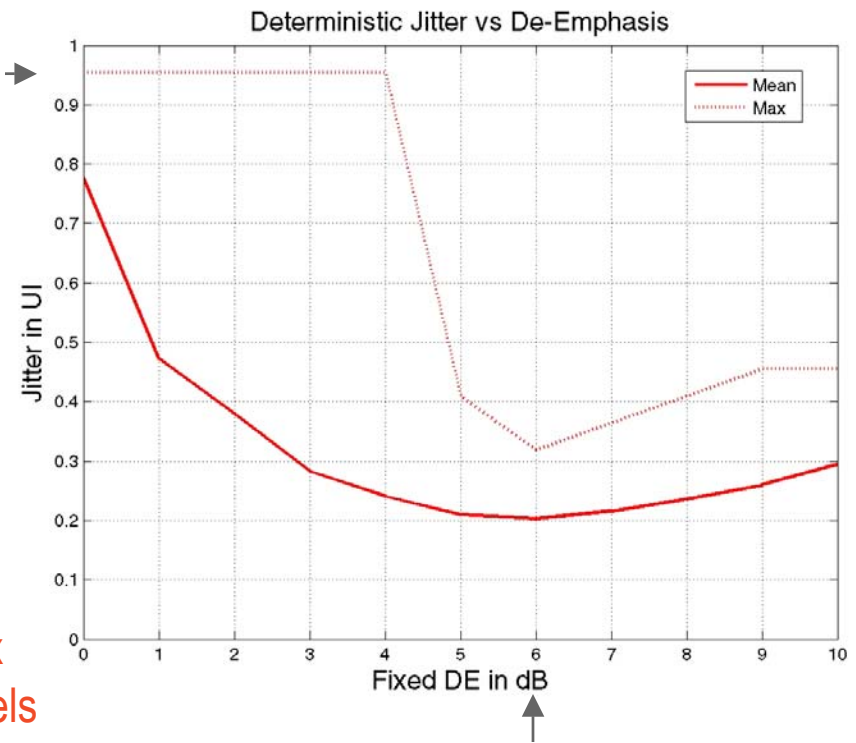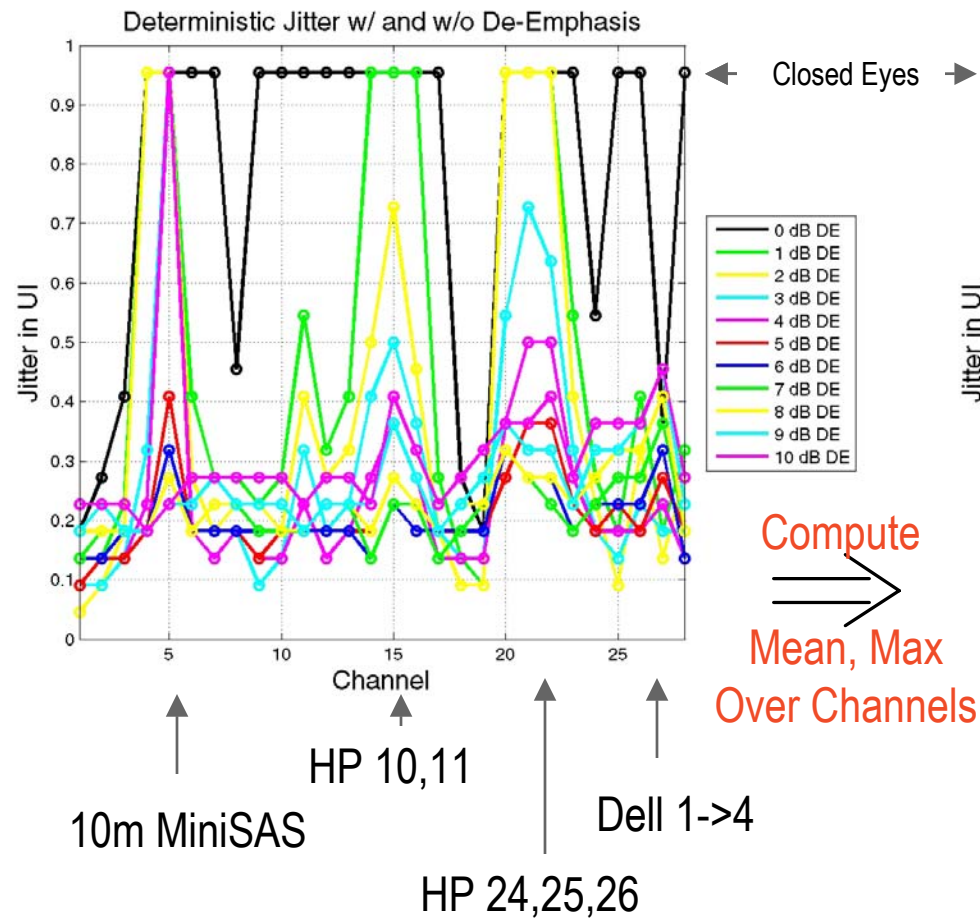 - Look at Average & Max Penalty vs DE Setting

Compute
⟹
Mean, Max
Over Channels

6 +/- 1 dB De-Emphasis
Appears Optimal

8

What is the Optimal De-Emphasis Setting?

VITESSE

Deterministic Jitter vs. De-Emphasis (no DFE)

- What is the Best De-Emphasis Setting to Minimize Jitter Generation
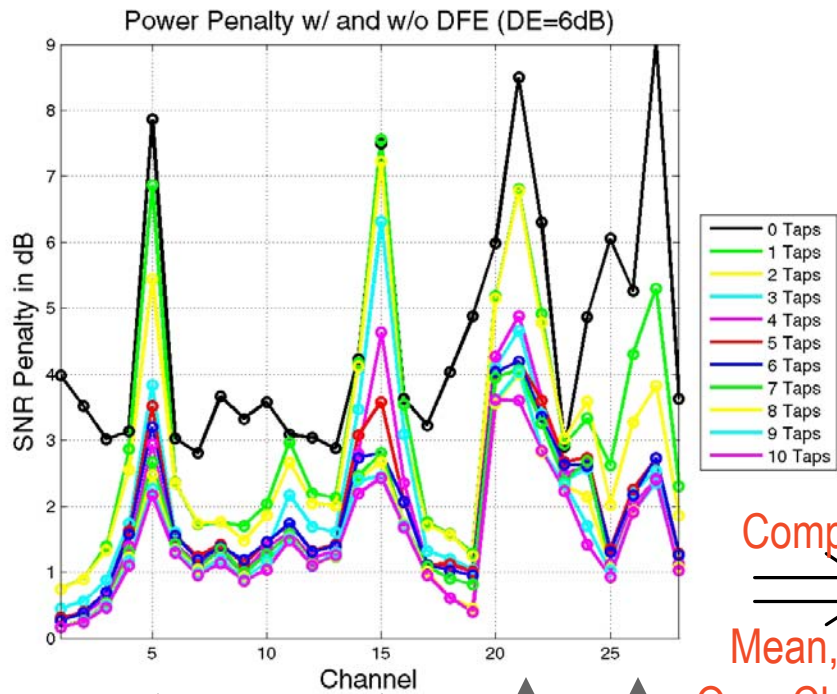- Look at Average & Max Jitter Generation vs. DE Setting

Closed Eyes

Compute
⟹
Mean, Max
Over Channels

10m MiniSAS

HP 10,11

HP 24,25,26

Dell 1->4

6 +/- 1 dB De-Emphasis
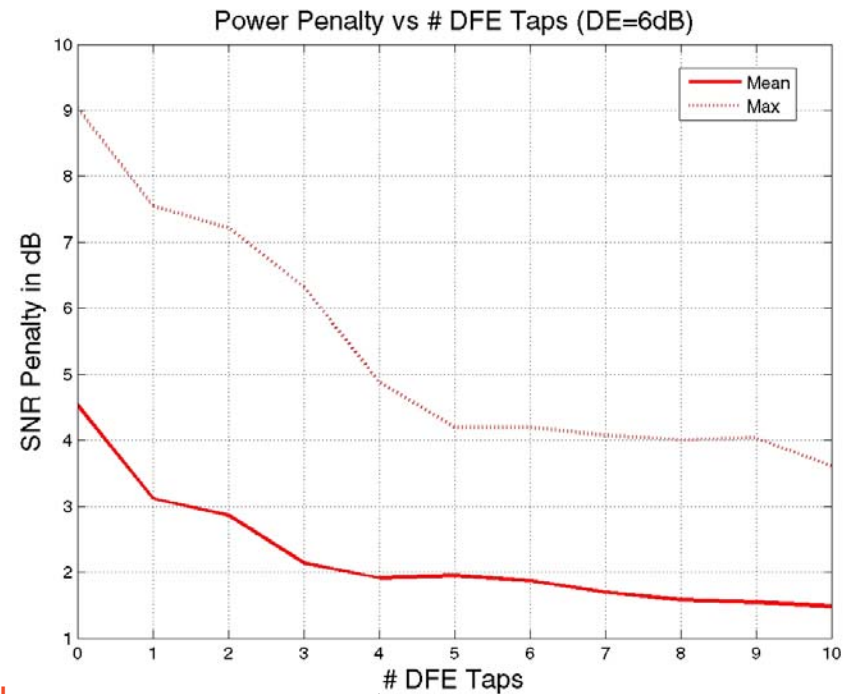Appears Optimal

9

SNR Penalty vs. # DFE Taps (With 6 dB De-Emphasis)

- What is the Best De-Emphasis Setting to Minimize SNR Power Penalty
- Look at Average & Max Penalty vs. DE Setting

Compute

⟹

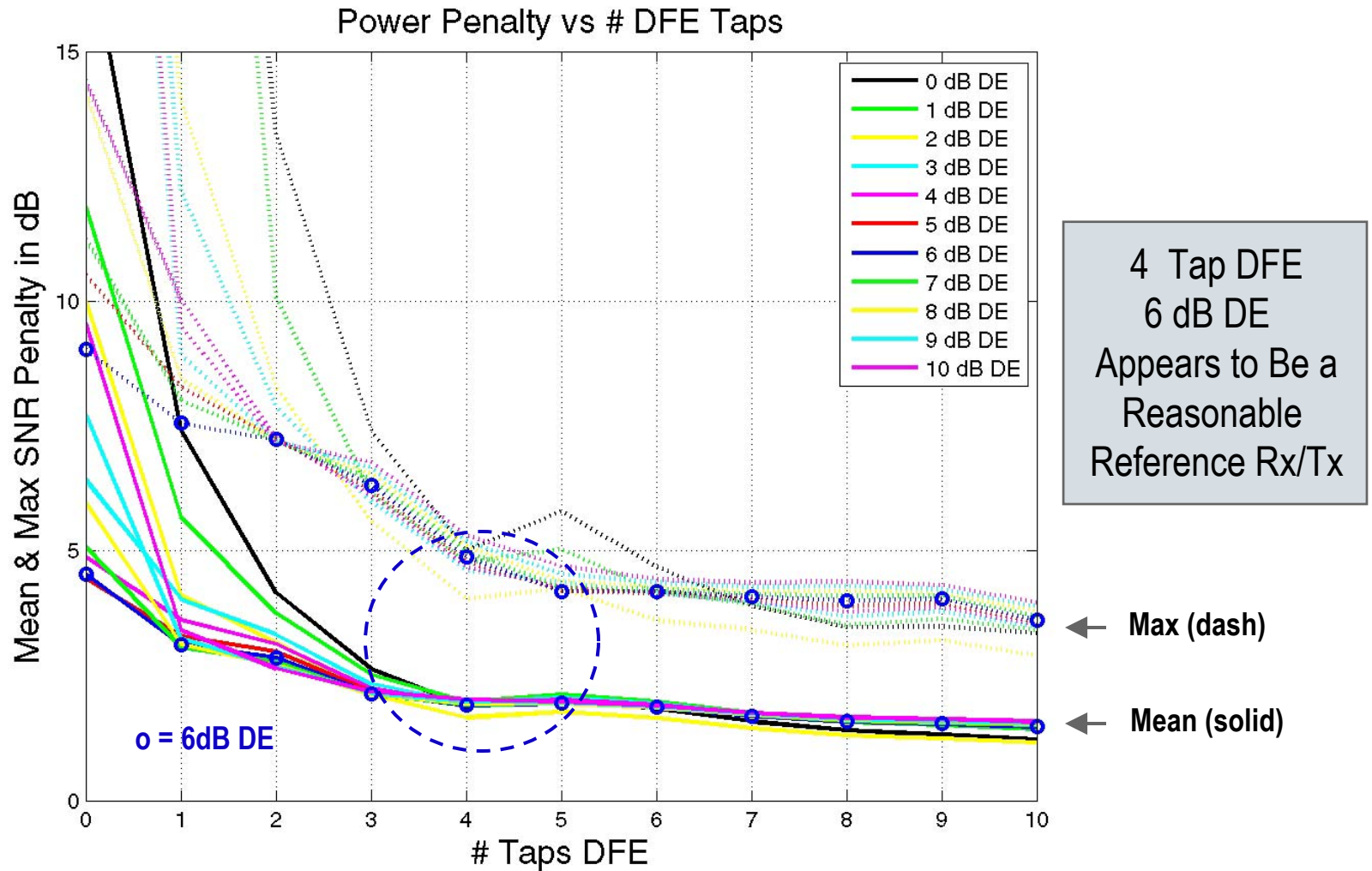Mean, Max
Over Channels

10m MiniSAS

HP 10,11

HP 24,25,26

Dell 1->4

4 +/- 1 Tap DFE
Appears Near Point Of
Diminishing Return

Look at all 3388 Power Penalty Results as a Family of Curves vs. # DFE Taps

Power Penalty vs # DFE Taps

4 Tap DFE
6 dB DE
Appears to Be a
Reasonable
Reference Rx/Tx

Look at all 3388 Power Penalty Results as a Family of Curves vs. De-Emphasis

With Enough DFE We Do Not Need De-Emphasis

**But the Link Would Be More Susceptible to DFE Error Propagation**

Increasing # DFE Taps

Power Penalty vs DEs

Legend:
- 0 Taps
- 1 Taps
- 2 Taps
- 3 Taps
- 4 Taps
- 5 Taps
- 6 Taps
- 7 Taps
- 8 Taps
- 9 Taps
- 10 Taps

Mean SNR Penalty in dB

o = 4 tap DFE

DeEmphasis in dB

Power Penalty vs DeEmphasis

Max SNR Penalty in dB

o = 4 tap DFE
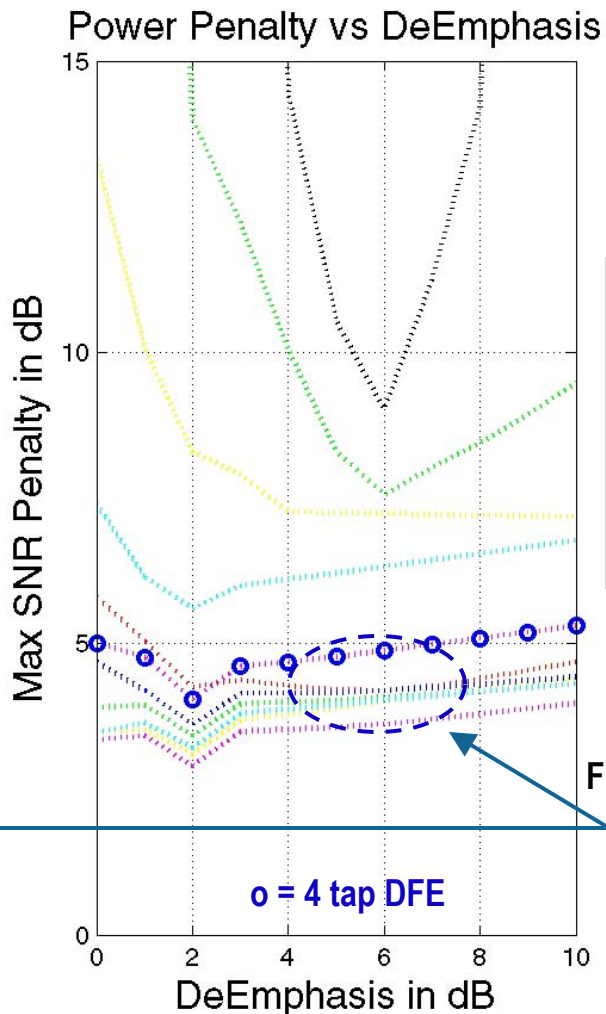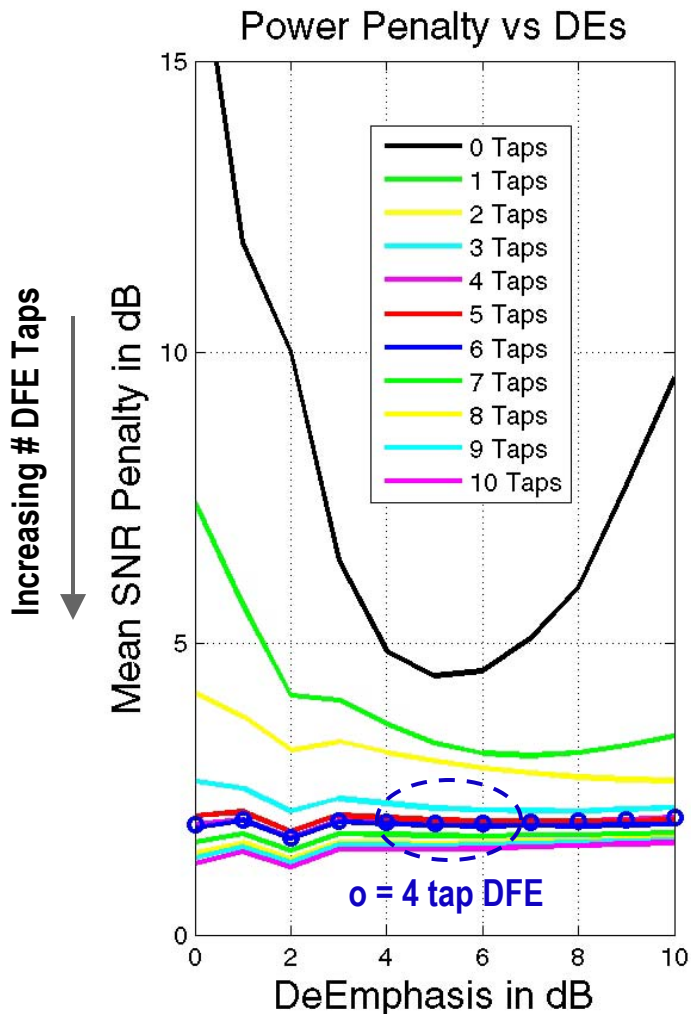
DeEmphasis in dB

4 Tap DFE
6 dB DE
Appears to Be a
Reasonable
Reference Rx/Tx

Flatness Indicates No Need to Over Constrain the De-Emphasis

12

Reference Transmitter and Receiver Architecture Proposal

Reference Transmitter De-Emphasis

- **Minimum of 2 Tap De-Emphasis**
- **6dB +/- 1dB**
- **Examples**
  - **V_{pk} = 1200 mV → {536 mV <= V_{de} <= 675 mV}**
  - **V_{pk} = 800 mV → {357 mV <= V_{de} <= 450 mV}**

Example 6dB Tx Waveform 001111100
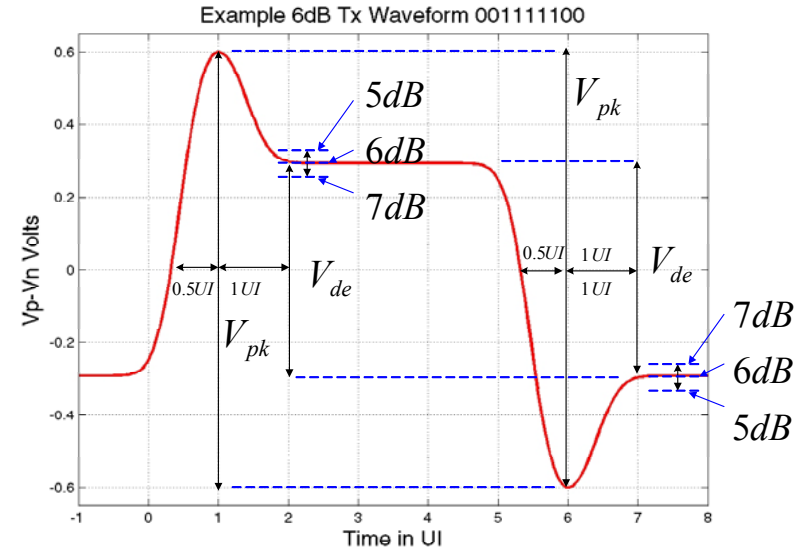
Reference Receiver (1)

- **4 Tap DFE**

1) **Receiver Implementation is Not Limited to a DFE Architecture, However, its' Equalization Capability Shall Be Equivalent to the Reference Receiver.**

Vpk mV	Vde mV	DE (dB)	CutBack (%)
1200	850	3	29
1200	757	4	37
1200	675	5	44
1200	601	6	50
1200	536	7	55
1200	478	8	60
800	566	3	29
800	505	4	37
800	450	5	44
800	401	6	50
800	357	7	55
800	318	8	60

SAS-2 Specification Proposed Numbers

❧ Reference Transmitter

Differential Return Loss (Similar to 10G Base-KR)

Transmitter	SAS-2		
	Min	Max	Units
Differential Voltage (pk-pk)	800	1200	mV
Transition Time (20%-80%)	50	90	ps
DC Output Impedance	60	115	ohm
DC Output Impedance Mismatch		5	ohm
Differential Return Loss		see Plot	dB
DC Common Mode Impedance	15	40	ohm
Common Mode Return Loss		see Plot	dB
Max. Intra-Pair Skew		15	ps
Random Jitter		0.15	UI
Deterministic Jitter		0.15	UI
Total Jitter		0.3	UI
# Taps De-Emphasis	2		Taps
De-Emphasis	5	7	dB

Details TBD

Details TBD

What is Missing?
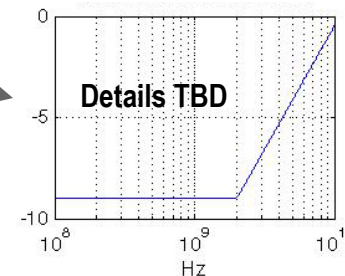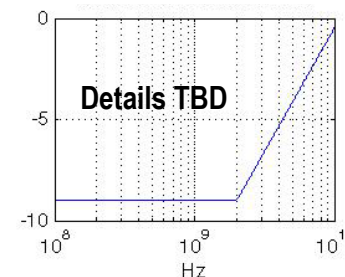
**Common Mode Return Loss
Like above but -6dB and TBD
Frequency Dependency**

📚 Reference Receiver

**Differential Return Loss
(Similar to 10G Base-KR)**

Receiver	SAS-2		Units
	Min	Max	
Reference Rx # DFE Taps (See Note 1)	4		taps
DC Differential Impedance	85	115	ohm
Differential Impedance Mismatch		5	ohm
Differential Return Loss		See Plot	
Common Mode Impedance	20	40	ohm
Common-Mode Tolerance (2-200MHz)	150		mV
Common Mode Return Loss		See Plot	
Max Operational Input Voltage	1200		mV
Max Non-Operational Input Voltage	2000		mV
Differential Return Loss		See Plot	dB

What is Missing?
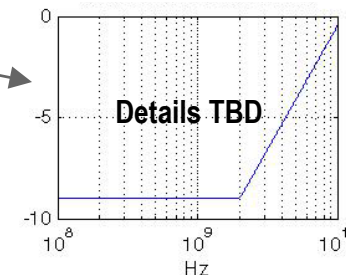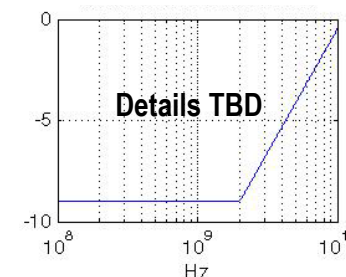
Notes:

1) Receiver Implementation is Not Limited to a DFE Architecture, However, its' Equalization Capability Must at Least Be Equivalent to the Reference Receiver.

Summary

- **Evaluation of all Published SAS-2 Channels Provided**
  - Definition of Transmit De-Emphasis Clarified.

- **Basis for the Selection of Transmit De-Emphasis Specification Provided**
  - 6+/- 1dB

- **Basis for the Selection of a Reference Receiver Provided**
  - 4 Tap DFE

- **Propose Reference Transmitter and Receiver Specifications**
  - Starting / Discussion Tables Provided for Development