Performance comparison study for Rx vs Tx based equalization for C2M links

Karthik Gopalakrishnan, Basel Alnabulsi, Jamal Riani, Ilya Lyubomirsky, and Sudeep Bhoja, Inphi Corp.

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Supporters

- Jane Lim, Cisco
- Upen Reddy Kareti, Cisco
- Pirooz Tooyserkani, Cisco
- Jeremy Stephens, Intel
- Ali Ghiasi, Ghiasi Quantum LLC
- Venugopal Balasubramonian, Marvell

Outline

- AWGN theory on Tx vs. Rx equalization
- Simulation results based on realistic channels and SerDes models

Assumptions for Theoretical Model

- Channel amplitude response has linear roll-off in dB
- Infinite length linear equalization
- Zero forcing solution
- Noise modeled as AWGN

Equalization Penalty

- Rx Linear Equalization Penalty:

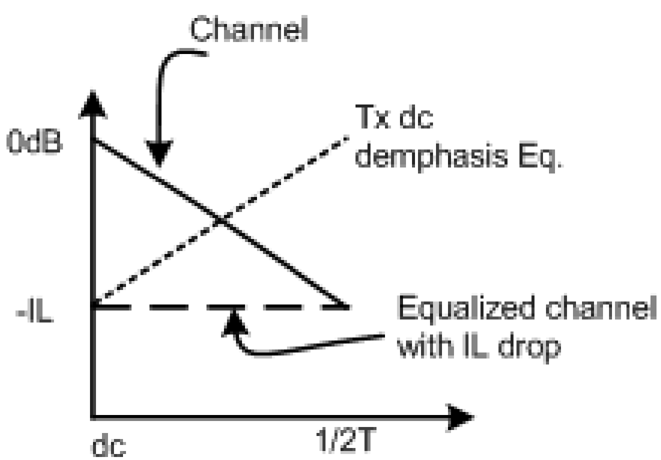
$$Rx\_P = 10\log10\left(T\int_{-1/2T}^{1/2T} 1/\left|H(f)\right|^2 df\right)$$

where $|H|=10^{(-2T*f*IL/20)}$ and IL is the insertion loss at Nyquist.

$$Rx\_P = 10\log10\left(\frac{10^{IL/10}-1}{IL.\ln(10)/10}\right)$$

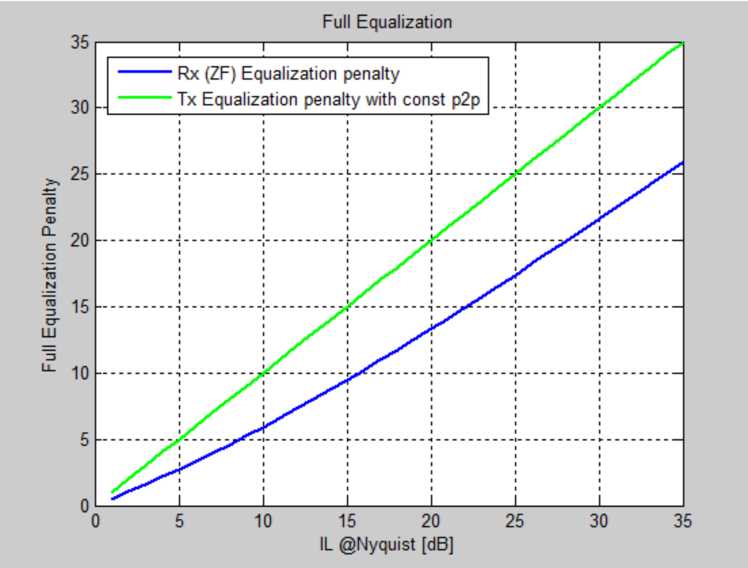
- Tx Equalization Penalty:

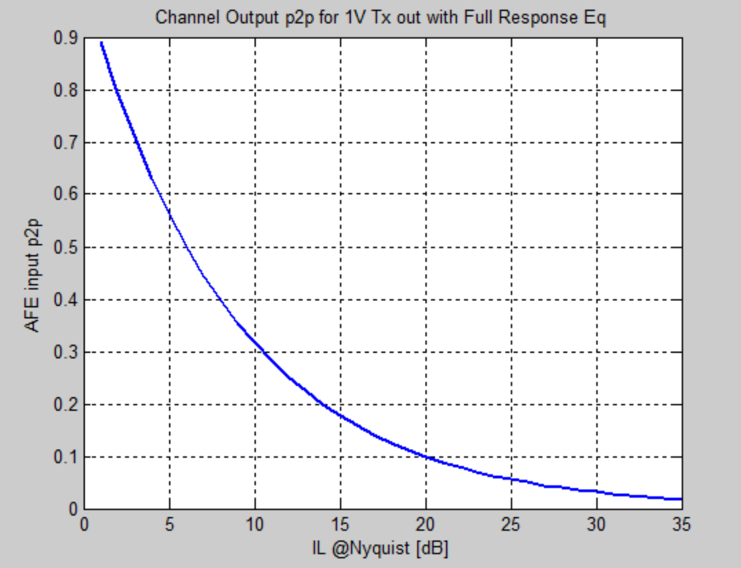
$$Tx\_P = IL$$



Theoretical Equalization Penalty Comparison

- Tx equalization is worse than Rx equalization. Rx Eq penalty follows L2-norm of 1/|H| and Tx Eq penalty follows Infinite-norm of 1/|H|.
- At IL=12dB, Tx penalty is 12dB but Rx penalty is 7.3dB. 4.7dB delta.
- With say IL=12dB, with Tx equalization, the Rx input p2p is only 250mvp2p for 1Vp2p @ Tx out.





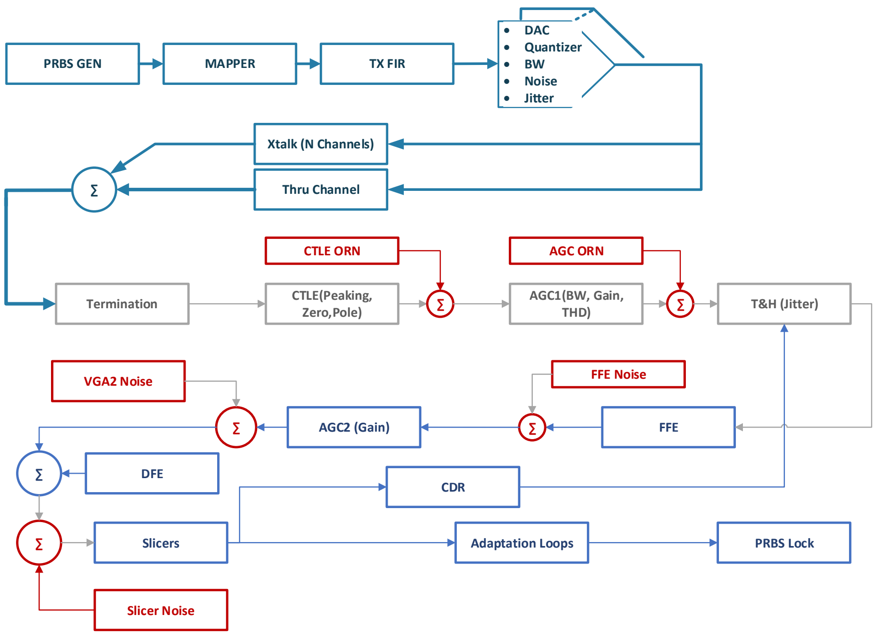
Specs used for the analysis

	High level specs used for analysis			Comments
	Buad Rate	53.125	Gbuad	
TX	TX Swing	0.8	Vdpp	
	RLM	0.95	-	
	SNDR	33	dB	
	RJ	175	fs rms	
	DJ	400	fs pk-pk	
	FIR	4	Taps	2 Pre
	TX Rise time	6.5	ps	20%-80%
RX	CTLE Boost	10	dB	
	CTLE 2nd Pole	40	GHz	
	Rx Noise	4	mV rms	actual density incorporated
	RJ	175	fs rms	
	DJ	600	fs pk-pk	
	Die CAP	130	fF	

Simulation Model

Model 1: “Rx EQ”

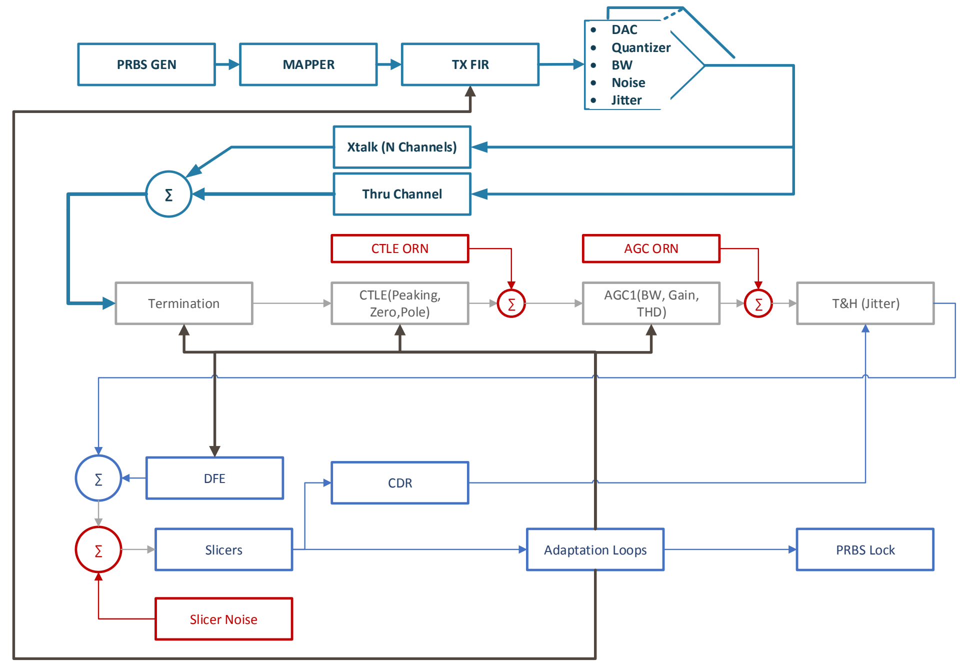
Tx 4 Tap FIR



Rx 6 Tap FFE

Model 2: “Tx EQ”

Tx 11 Tap FIR



No Rx FFE

Noise contribution of AFE blocks added at the appropriate location in the link

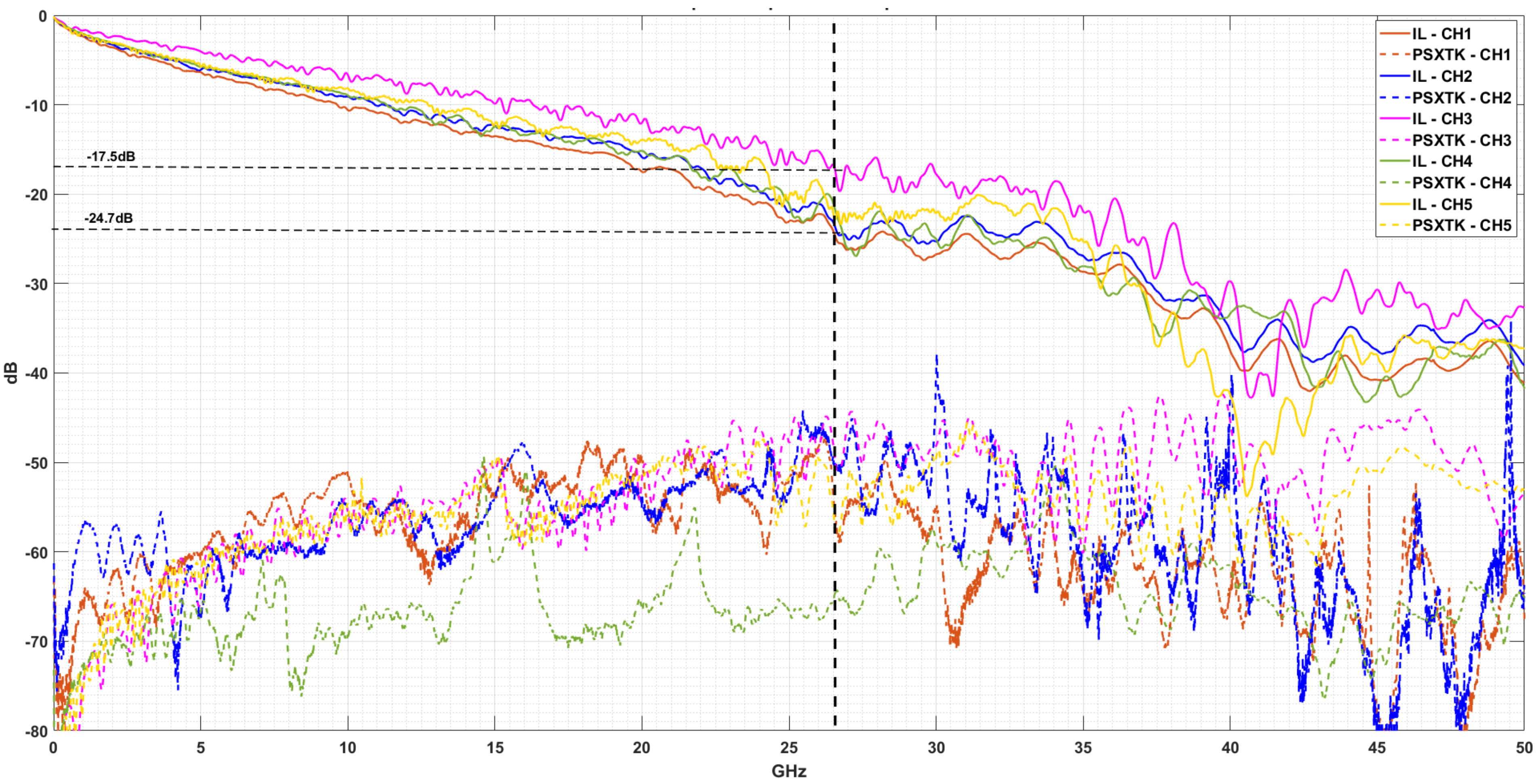
Tx and Rx FFE optimization

- Rx FFE is optimized using Minimum Mean Square Error (MMSE) criteria for any given Tx FIR, channel, xtalk etc.
- The Tx FIR is brute force optimized based on the link SNR.

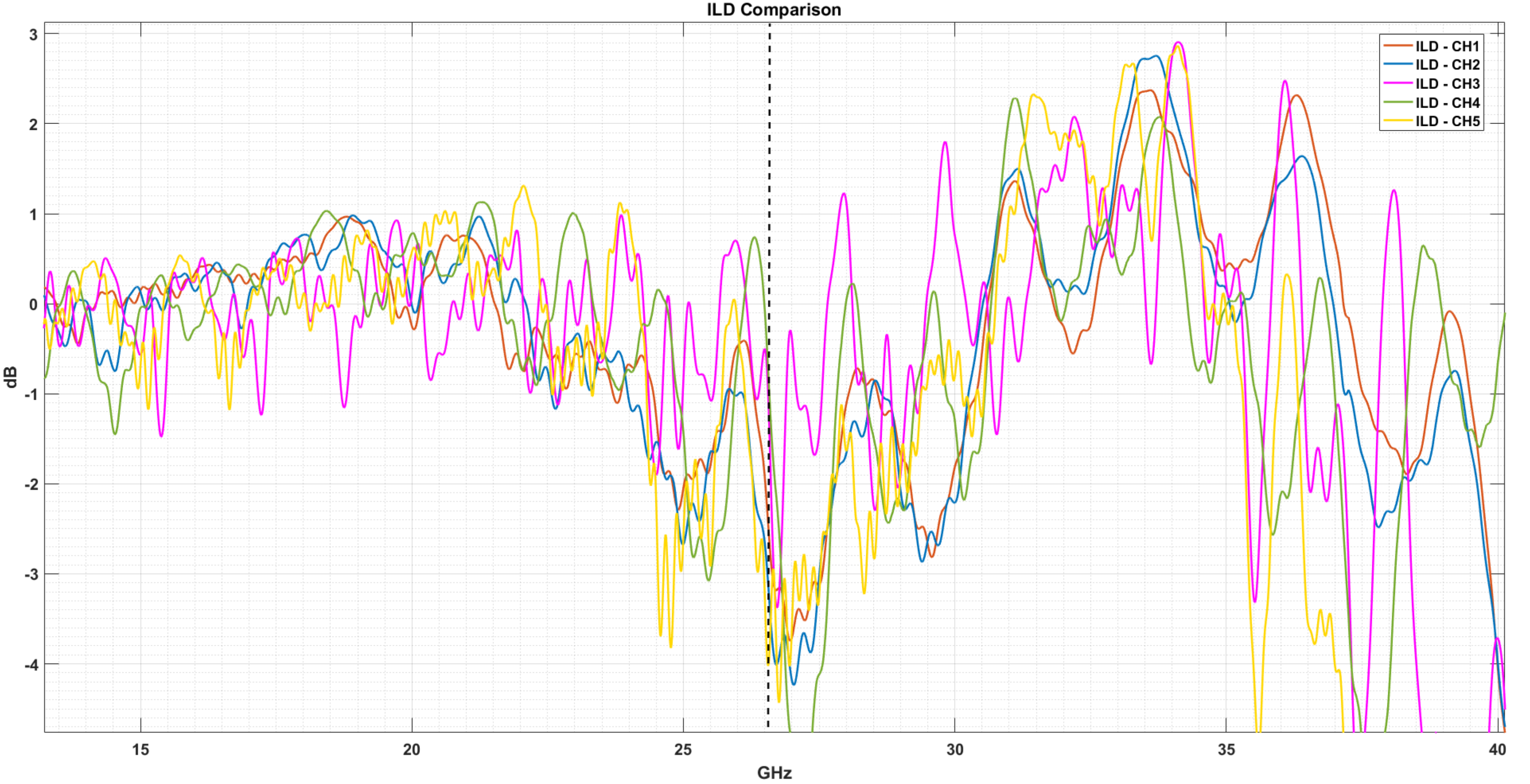
Channels

- 5 channels were selected for the analysis
  - 16dB C2M channel contribution from lim_3ck_01_0918 (referred to CH1)
    - Spokane contribution
  - 14dB C2M channel contribution from lim_3ck_01b_0718 (referred to as CH2)
  - Customer proprietary channel (referred to as CH3)
  - Channel contribution from tracy_100GEL_06_0118 (referred to CH4)
    - OIF Micro-via case
  - Channel contribution from mellitz_3ck_02_0518 (referred to CH5)
    - 14dB BC-BOR-N-N-N
- Package models and die models
  - Channel above include cascade of both PKG and Die models for Thru and Xtalk channels
  - No PKG cross-talk is included in the simulations
  - Uses a 30mm host package design from current customer
  - Uses a 4mm package design from current product indicative of 100G devices
  - Uses a ~130fF equivalent load for the die

Bump to bump channel frequency response



ILD Comparison



SNR Simulation Results

				Channel - 1	Channel - 2	Channel - 3	Channel - 4	Channel - 5
	IL @ Nyq (dB)			24.7	23.4	17.2	21.4	22.9
	ILDMax (upto Nyq) dB			4.8	5.2	4.2	4.7	5.5
Architecture	Configuration		SNR (dB)					
11T TX FFE (2Pre) → RX CTLE/VGA → Tail DFE	#Tail DFE	0		19.3	19.8	19.3	18.8	18.7
	#Tail DFE	16		19.7	20.8	21.1	19.5	19.2
4T TX FFE (2Pre) → RX CTLE/VGA → 6T RX FFE (2 Pre) → Tail DFE	#Tail DFE	0		19.4	19.4	21.8	20.5	20.2
	#Tail DFE	16		22.4	23.5	23.8	21.6	22.5

- Note:
  - Rx FFE without DFE has shorter span in the simulations (covers upto 3 post + CTLE), compared to TX FFE case which has upto 8 post taps + CTLE

Summary

- TX FFE heavy architecture shows worse SNR compared to RX FFE
  - The noise at various input blocks of the receiver was included based on analog simulations
  - 19.5dB SNR is not sufficient to close system budgets to account for tolerances, and yield
  - A brute force search on TX FFE is not a practical solution and does not address background adaptation
- Rx FFE based architecture is more robust under the various channels studied (lossy, reflective, etc)
- A detailed implementation of the RX FFE based architecture and TX FFE based architecture shows only a 10% power delta between the 2 cases in 7nm process
  - Assumes a Tail DFE is present in the receiver