COM Simulation and Analysis for 200Gbps/Lane CR

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IEEE P802.3df Task Force

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Outline

- ☐ Overview
- ☐ Link Budget Analysis for 200G/L PAM4 CR
- ☐ Channel Feasibility: Key Challenges
- ☐ SerDes Feasibility: COM Sensitivity to Key Parameters
- ☐ Modulation Type for 200G/L CR: PAM4 vs PAM6
- ☐ Conclusion

Motivation and Methodology

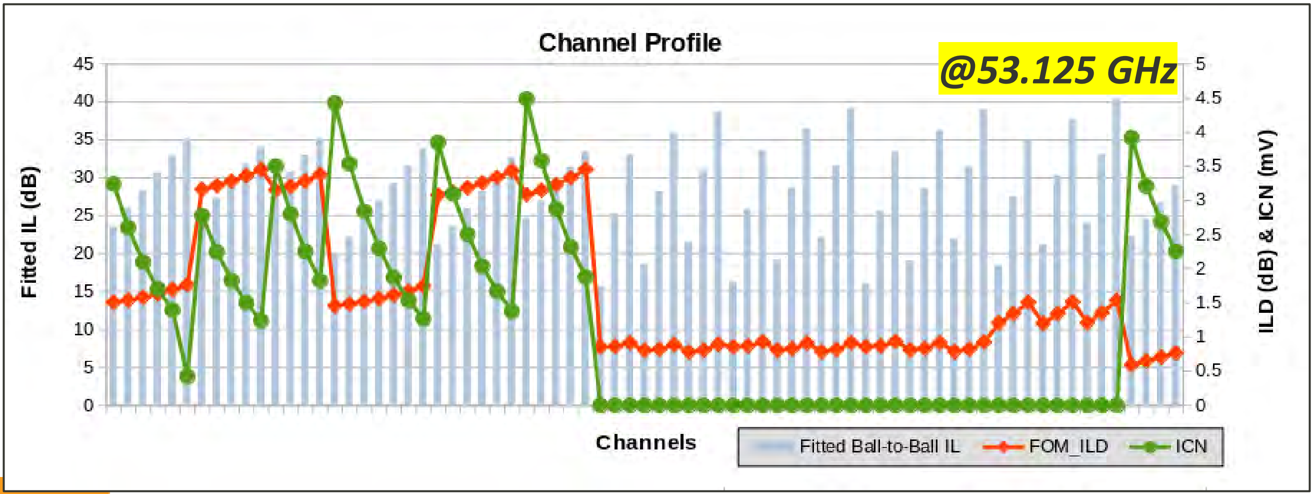
- **Explore feasibility of 200G/L PAM4 CR**
  - Channel & SerDes requirements?
- **Analyze channel requirements – based on COM v3.70 simulation**
  - All available 200G CR channels from IEEE, OIF, & OSFP (total 73x)
  - Based on baseline SerDes
- **Assess SerDes feasibility – starting from COM sensitivity check with sweeping key SerDes parameters**
  - Provide the directions to make good trade-off between performance & power/cost of SerDes
  - Allow the interoperability between channel & SerDes improvements
- **Investigate modulation format for 200G/L CR – comparing PAM4 & PAM6 under the assumption of identical transceiver capability**

Objectives

- **Do**
  - Leverage published channel materials to represent potential 200Gbase channel characteristics and evaluate their corresponding performance
  - Analyze 200G/L CR feasibility from the system's point of view
  - Point out key challenges of channel: roll-off characterizing impairments, reflection, & crosstalk
  - Provide direction of next generation SerDes: COM sensitivity of key parameters
  - Provide the baseline performance for candidate modulation formats
- **Don't**
  - Offer the SerDes or channel solutions
  - Draw conclusions on modulation type for 200G/L CR

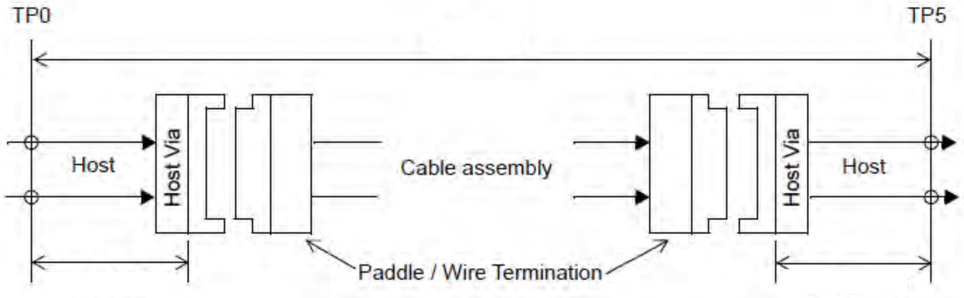
CR Channel Profile

- **Channel variations mainly come from**
  - Host PCB length
  - Cable length, impedance, & AWG
  - Verticals (connector & BGA breakout region)
  - Crosstalk
- **Total of 73 channels**



Source	Contributor	LR Channels
1. OSFP 200GEL	Amphenol Amphenol Keysight	• 0.5/1m 27AWG CA • 1”-7” PCB at each side (92 Ohm, 1.3dB/in @56GHz) • BGA breakout: parallel/orthogonal (no skew)/orthogonal • **Crosstalk mainly comes from connector via**
2. mellitz_3df_01_220502	Samtec	• 0.5/1m/1.5 27AWG CA (100Ohm target) • 2”/5”/7.45” PCB at each side (1.6dB/in @53.125GHz) • Termination: T-line (ideal)/SMA 1.0mm/SMA 1.85mm/via 28mm • **No crosstalk**
3. oif2022.194.00	Samtec	• 1/1.5m 28AWG CA (92.5 Ohm) • Cable backplane with connector direct to package: 100/250 mm 34 AWG (92.5 Ohm) • **Direct to package connector (Cp and Zp2 set to zero)** • **Crosstalk mainly comes from connector via**

BGA breakout included in channel group 1 & 2



The objective is to explore diverse channels to assess LR technology feasibility

- **Channel IL: 16~42 dB**
- **FOM_ILD: 0.93~4.23 dB**

COM Simulation Consideration: 200G Baseline

Table 93A-1 parameters				
Parameter	Setting	Units	Information	
f_b	106.25	GBd		
f_min	0.05	GHz		
Delta_f	0.01	GHz		
C_d	[0.7e-4 0.7e-4]	nF	[TX RX]	
L_s	[0.12 0.12]	nH	[TX RX]	
C_b	[0.3e-4 0.3e-4]	nF	[TX RX]	
z_p select	[1 2]		[test cases to run]	
z_p (TX)	[12 31; 1.8 1.8]	mm	[test cases]	
z_p (NEXT)	[12 29 ; 1.8 1.8]	mm	[test cases]	
z_p (FEXT)	[12 31; 1.8 1.8]	mm	[test cases]	
z_p (RX)	[12 29 ; 1.8 1.8]	mm	[test cases]	
C_p	[0.87e-4 0.87e-4]	nF	[TX RX]	
R_0	50	Ohm		
R_d	[50 50]	Ohm	[TX RX]	
A_v	0.413	V		
A_fe	0.413	V		
A_ne	0.608	V		
L	4			
M	32	amp/UI		
samples_for_C2M	32	amp/UI		
T_O	0	mUI		
AC_CM_RMS	0	V	[test cases]	0.0235 0.0256
filter and Eq				
f_r	0.75	*fb		
c(0)	0.5		min	
c(-1)	[-0.4:0.02:0.04]		[min:step:max]	
c(-2)	[-0.1:0.02:0.2]		[min:step:max]	
c(-3)	[-0.1:0.02:0.1]		[min:step:max]	
c(1)	[-0.2:0.02:0.1]		[min:step:max]	
N_b	24	UI		
b_max(1)	0.85		As/dffe1	
b_max(2..N_b)	[0.5 0.3 0.3 0.2*ones(1,20)]		As/dfe2..N_b	
b_min(1)	0.3		As/dffe1	
b_min(2..N_b)	0.2 0.05 0.05 -0.03*ones(1,20)]		As/dfe2..N_b	
g_DC	[-20:1:-2]	dB	[min:step:max]	
f_z	42.5	GHz		
f_p1	42.5	GHz		
f_p2	106.25	GHz		
g_DC_HP	[-6:1:0]		[min:step:max]	
f_HP_PZ	1.328125	GHz		
G_Qual	[-2 -20 ;-2 -20; -2 -20;-2 -20]	dB	ranges	
G2_Qual	[0 -1 -2 -6]	dB	ranges	

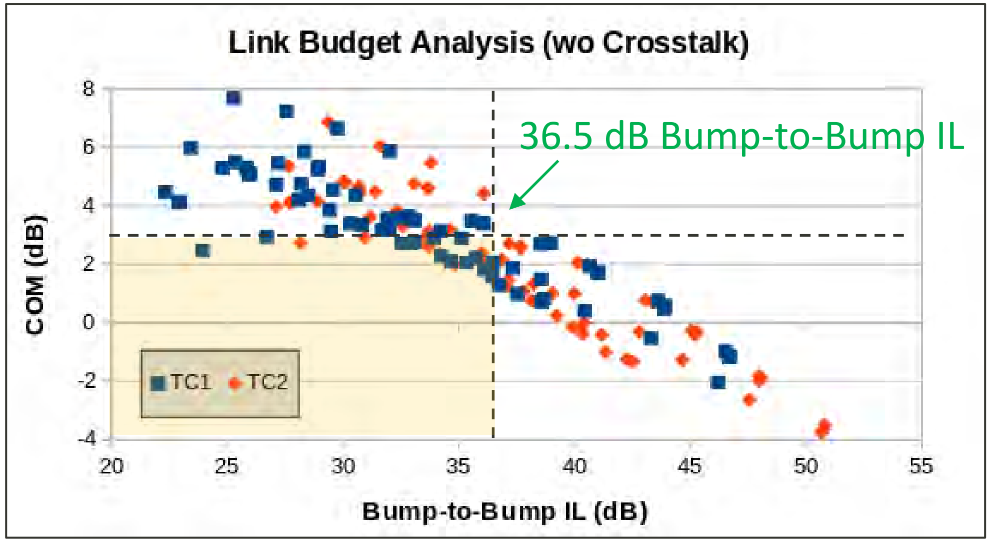
I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	0	logical
RESULT_DIR	.\results\100GEL_C2M_host_{da	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	CR_eval_	
COM_CONTRIBUTION	0	logical
Local Search	2	
Operational		
VEC Pass threshold	12	db
EH_min	10	mV
ERL Pass threshold	9.5	dB
Min_VEO_Test	0	mV
DER_0	0.0001	
T_r	0.0037496470588	ns
FORCE_TR	1	logical
Sigma BBN step	5.00E-03	V
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	4.10E-09	V^2/GHz
SNR_TX	33	dB
R_LM	0.95	

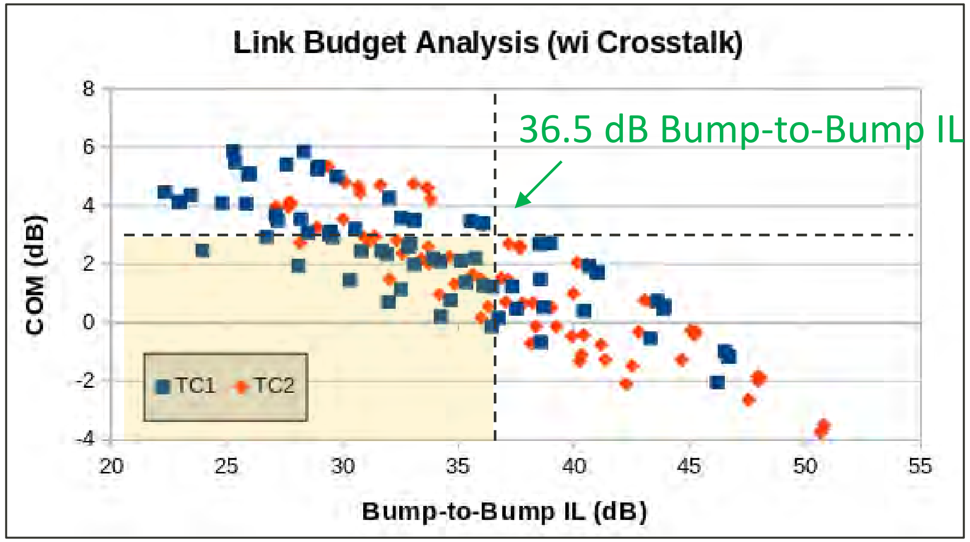
Table 93A-3 parameters		
Parameter	Setting	Units
package_tl_gamma0_a1_a2	[0 0.000644085 0.00018018]	
package_tl_tau	5.700E-03	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm
ICN & FOM_ILD parameters		
f_v	0.594	*Fb
f_f	0.594	Hz f_r specified in first column
f_n	0.594	GHz
f_2	80	GHz
A_ft	0.600	V
A_nt	0.600	V
Histogram_Window_Weight	gaussian	Seletions (rectangle, gaussian,
COM Pass threshold	3	

- **Die model** : keep the similar IL as 100G (parameters need further investigation)
- **PKG model**: 25% trace loss improvement from 100G, follows the values proposed in oif2021.596.01 (parameters need further investigation)
- **RXEQ length/rise time/jitter/RX noise PSD** scaled with 2x baud rate
- **DER/TX swing/TX SNR/Nonlinearity/TXEQ length** kept the same as 100G
- COM version: 3.70
- Test case (TC) 1 (short package): [z_p (TX) z_p (RX)] = [12 12] mm
- TC 2 (long package) : [z_p (TX) z_p (RX)] = [31 29] mm

Link Budget Analysis for 200G/L PAM4 CR

- **Whole link budget analysis**
  - To allow the interoperability among channel components & point out the design challenges
    - Currently the group don't have consensus in package model → bump-to-bump IL target is evaluated instead of ball-to-ball IL target
  - Analyze performance from the system's point of view
- **Whether 200G/L PAM4 CR works?**
  - If keep the same IL target from 100G to 200G: bump-to-bump IL ~ 36.5 dB (28.5dB ball-to-ball + 8 dB PKG in 802.3ck)
  - If make SerDes capability aligned from 100G to 200G





Channel Feasibility: ILD

**wo crosstalk*

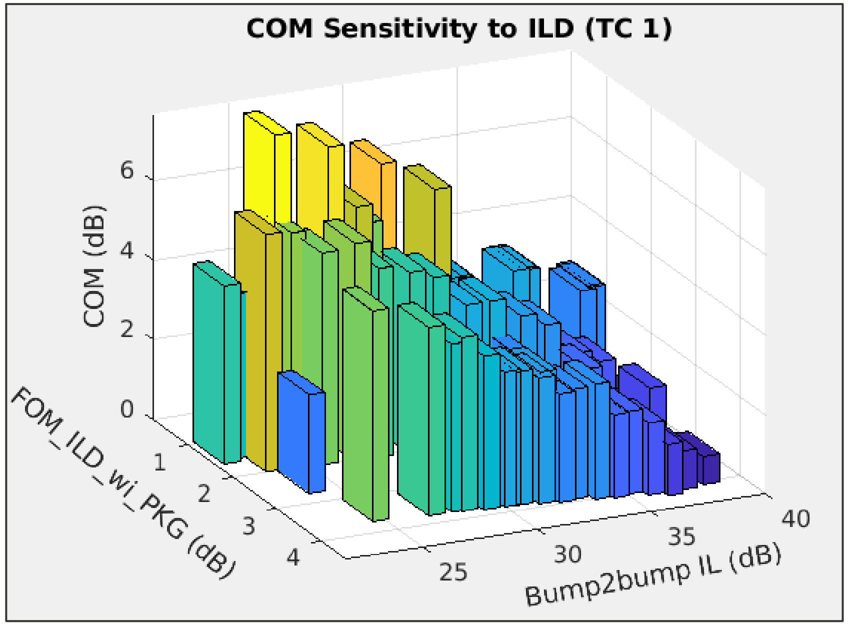
- **Resonances characterizing impairments in next generation have been discussed in** noujeim_3df_01_220224
- **Vertical transition**
  - Connector footprint
  - BGA breakout region

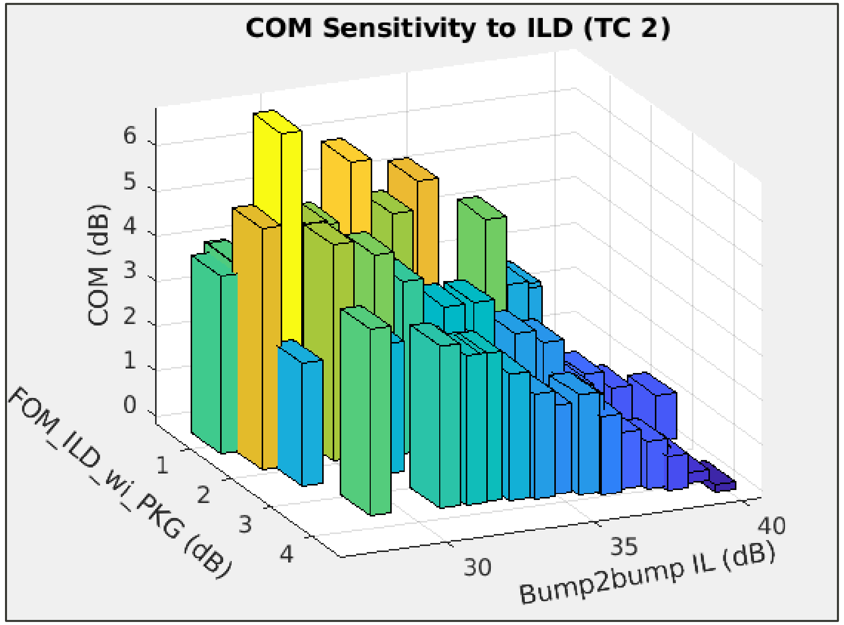
  → Can cause multiple reflections

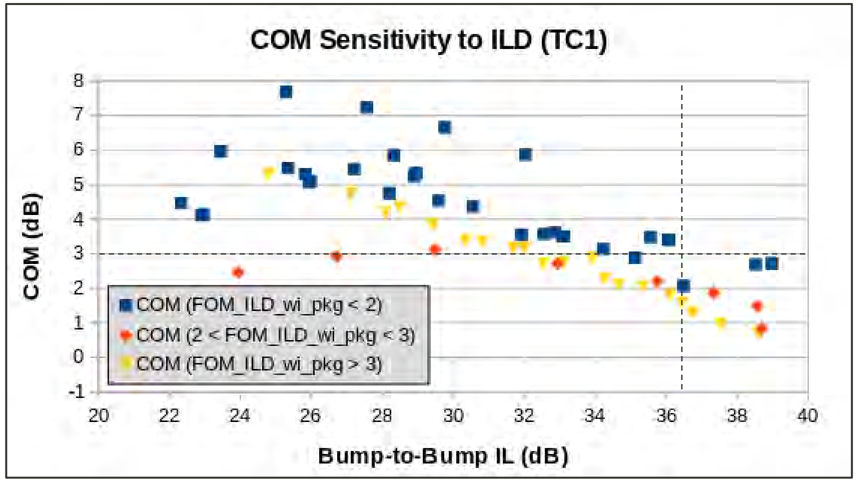
  → Need more banks of floating taps
- **Impedance mismatch**
  - Connector-BGA breakout
  - Channel-package

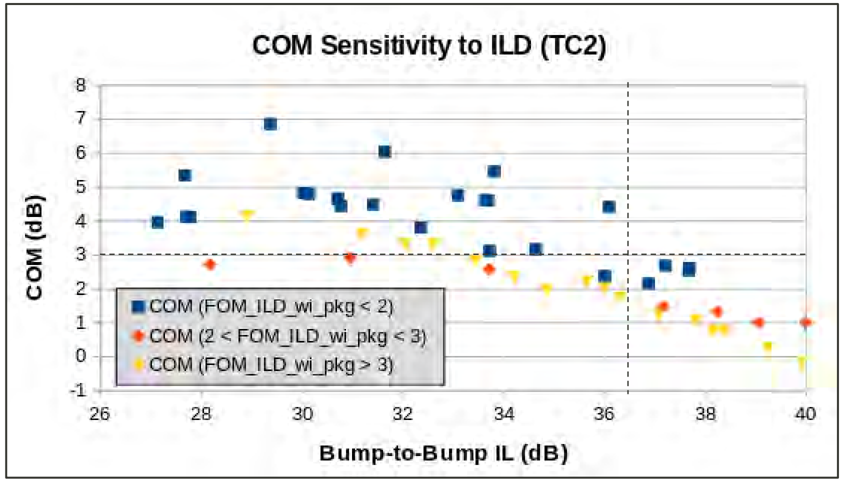
  → Reflection issue have been investigated in 802.3ck

  → Length of DFE/floating tab used to compensate reflections is twice of that for 100G/L CR





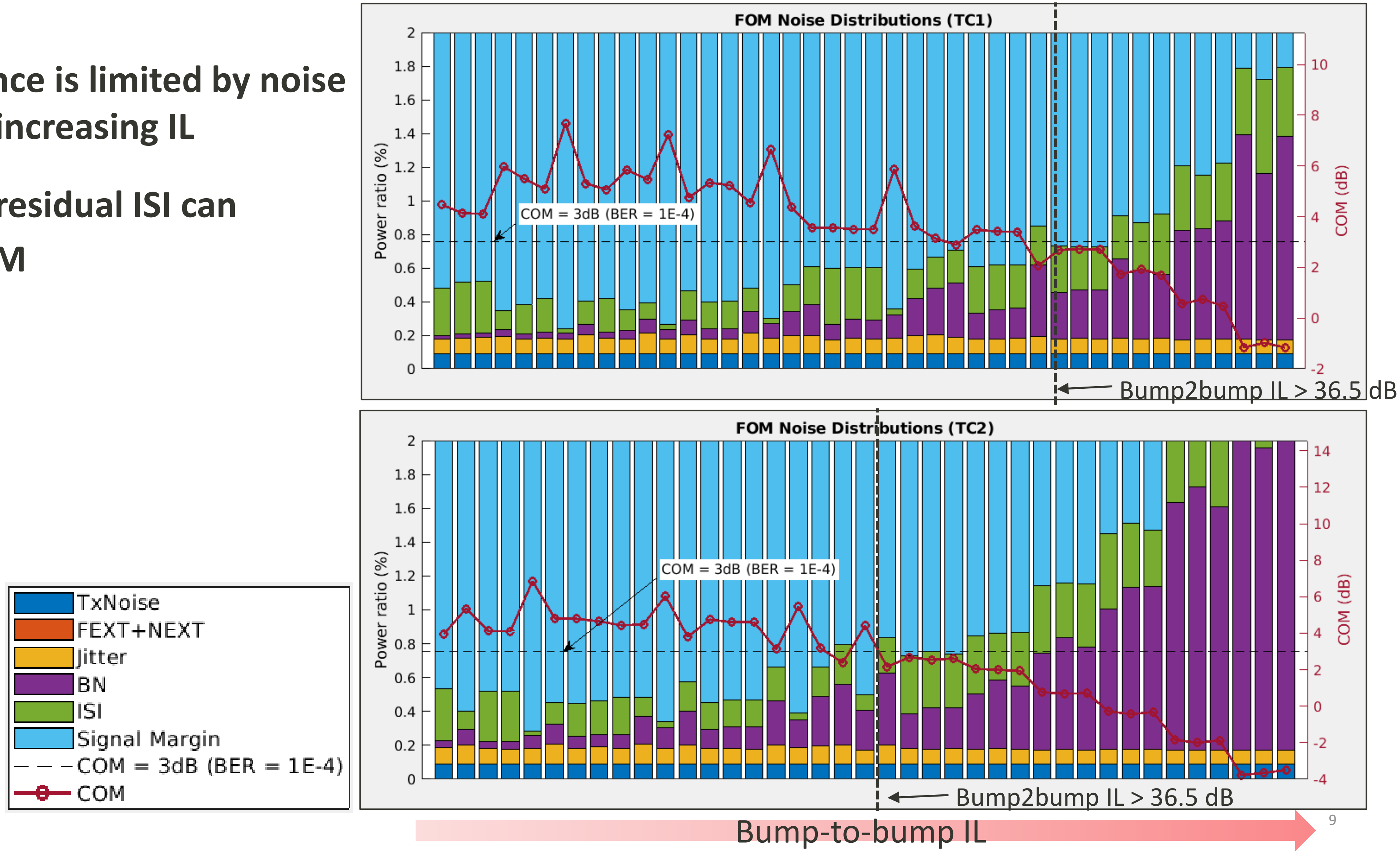




Noise Distribution (wo Crosstalk)

**Channels with FOM_ILD_wi_PKG <= 2*

- **Basically, performance is limited by noise enhancement with increasing IL**
- **Reflection-induced residual ISI can further degrade COM**



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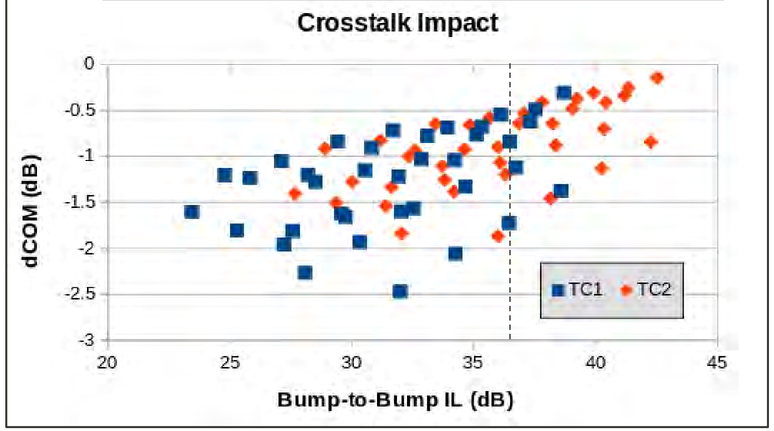
Channel Feasibility: Crosstalk

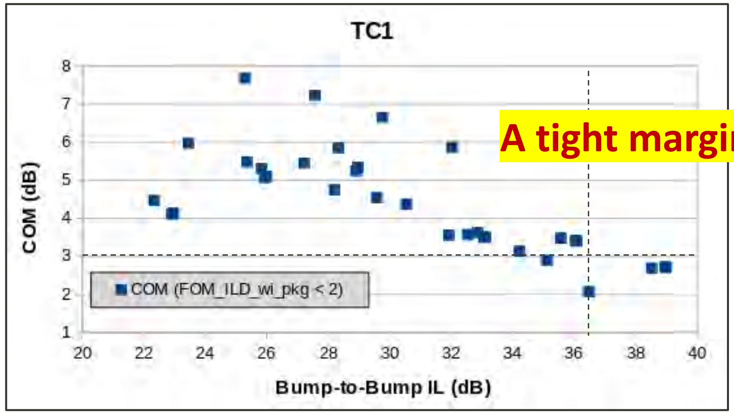
- **Crosstalk Impact**
  - Crosstalk can degrade COM up to ~2dB at IL of interest

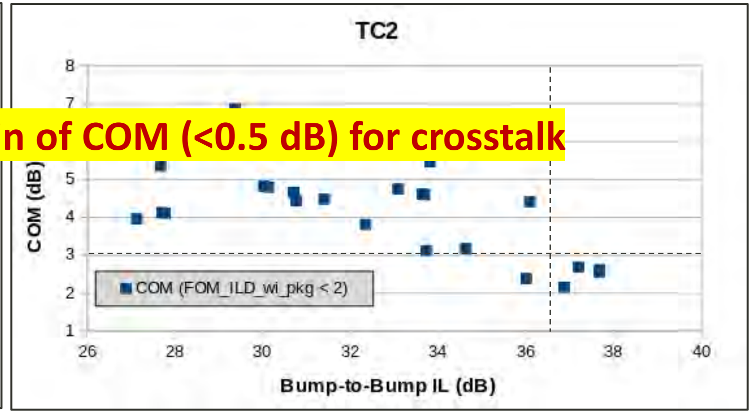
dCOM = COM (wi Xtalk) - COM (wo Xtalk)



- **Insertion-loss-to-crosstalk ratio (ICR) of test channels: 10.5 dB ~ 22 dB**

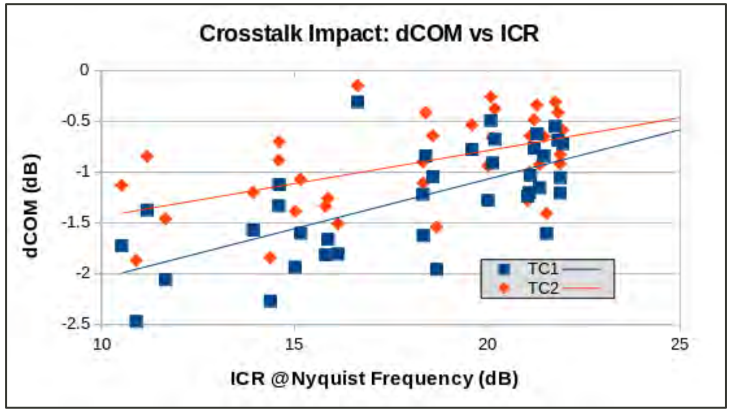
- **Link budget analysis (wo crosstalk)**





A tight margin of COM (<0.5 dB) for crosstalk

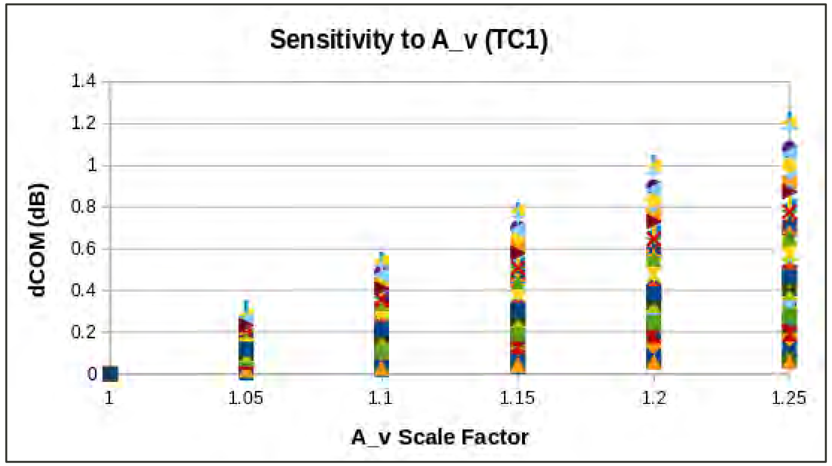
- **Crosstalk limit: ICR >= 25 dB?**

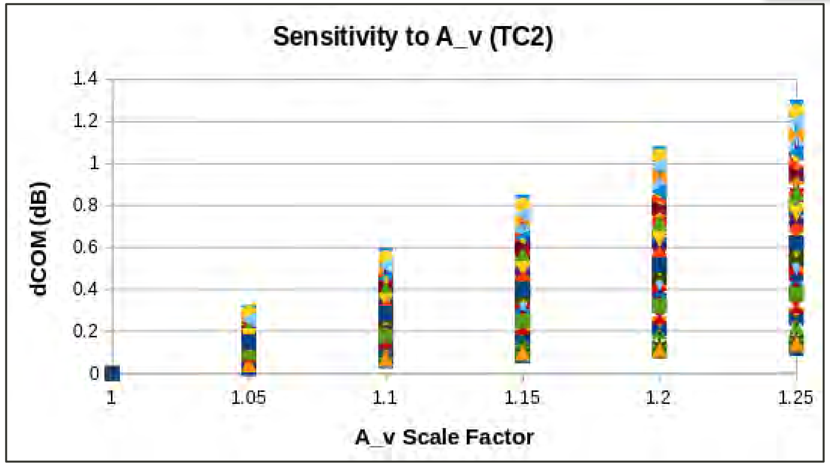


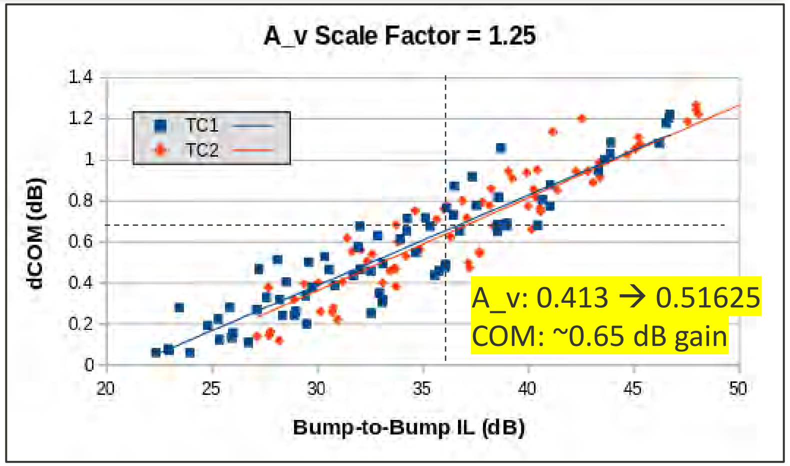
Sensitivity to Transceiver Capability: A_v & SNR_TX

- Increased A_v can help to enlarge signal margin
- Concern: Linearity & power consumption

** Baseline: A_v scale factor = 1 (A_v = 0.413 V)*

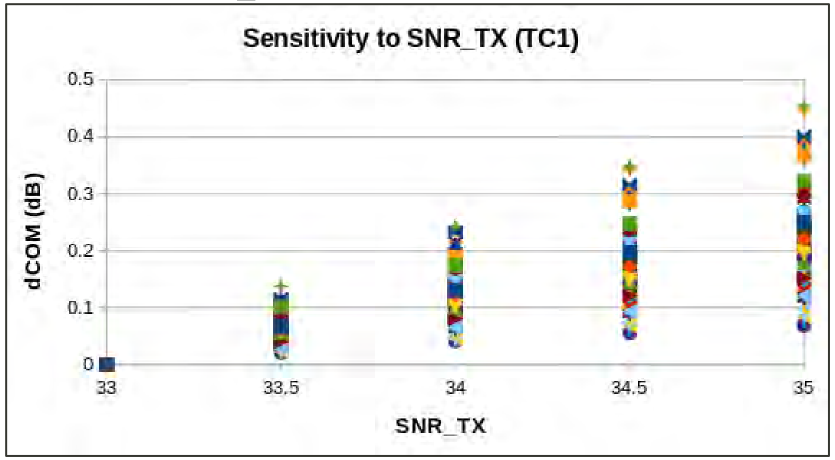


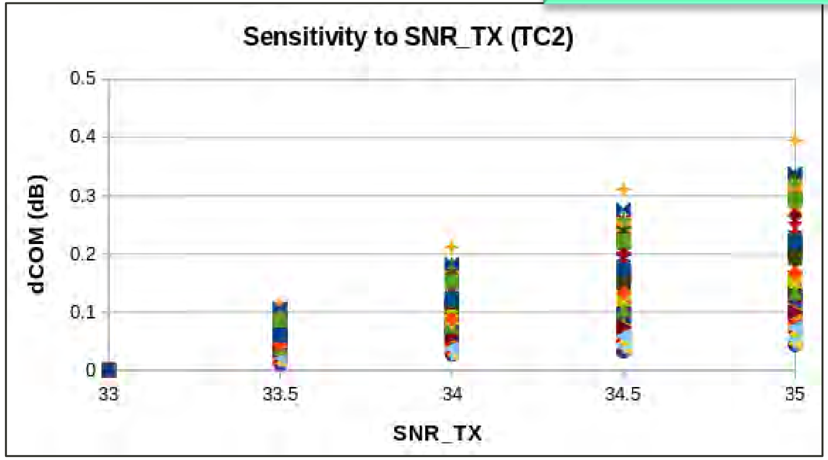


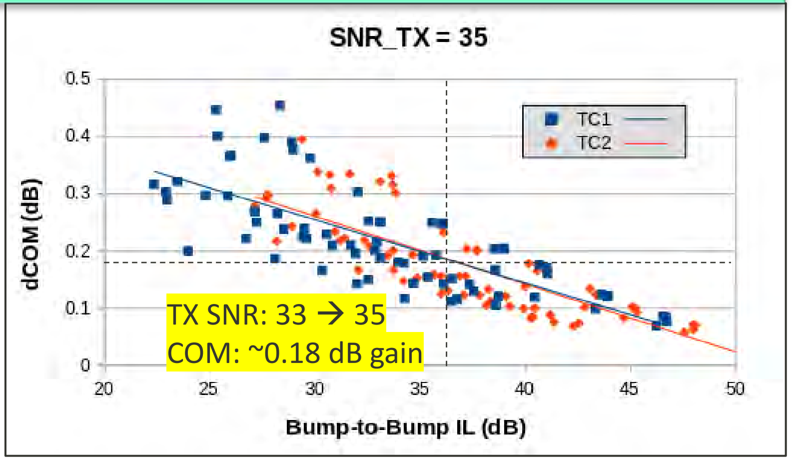


- TX noise is less significant since ISI dominates the noise budget

** Baseline: SNR_TX = 33 dB*







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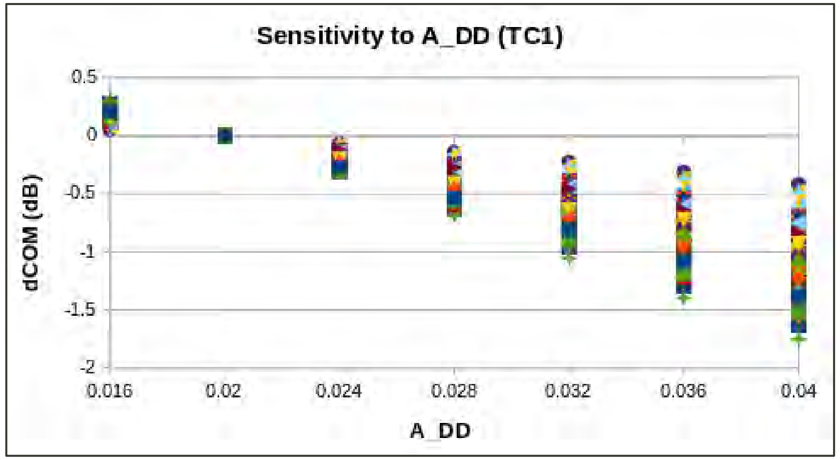
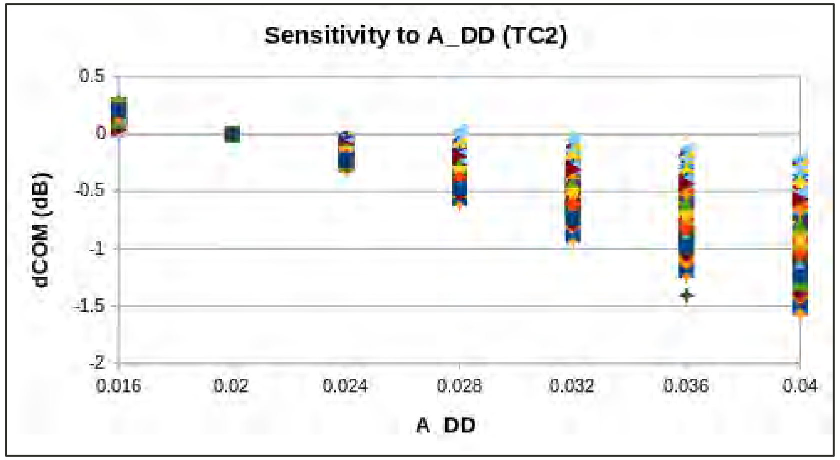
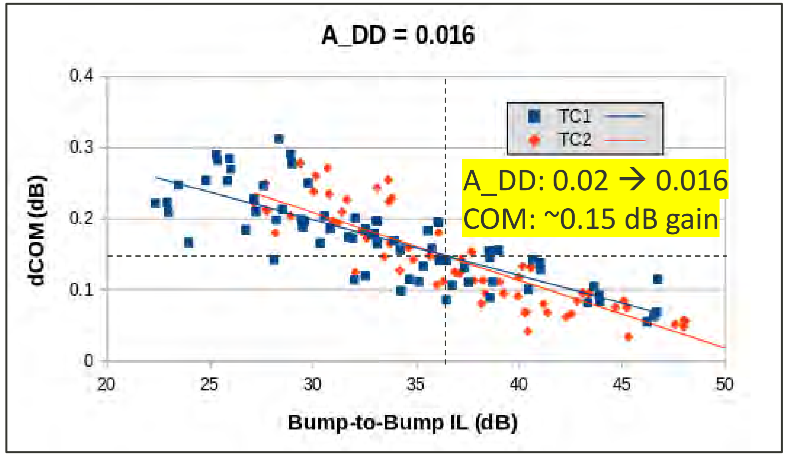
Sensitivity to Transceiver Capability: Jitter

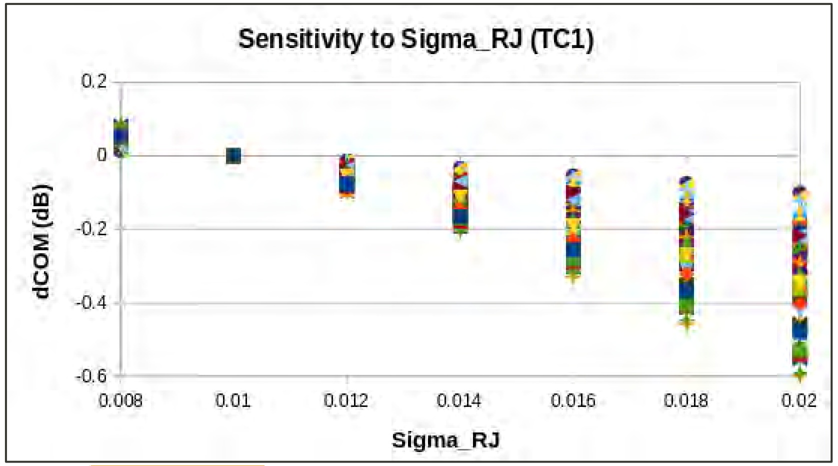
** Baseline: A_DD = 0.02*

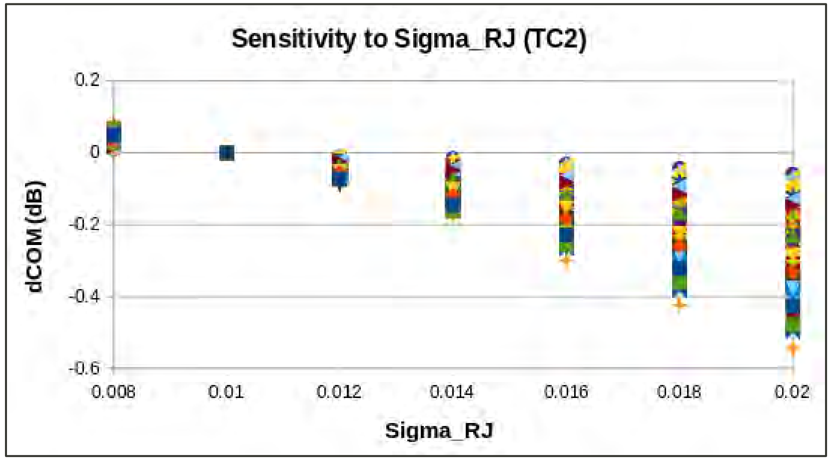


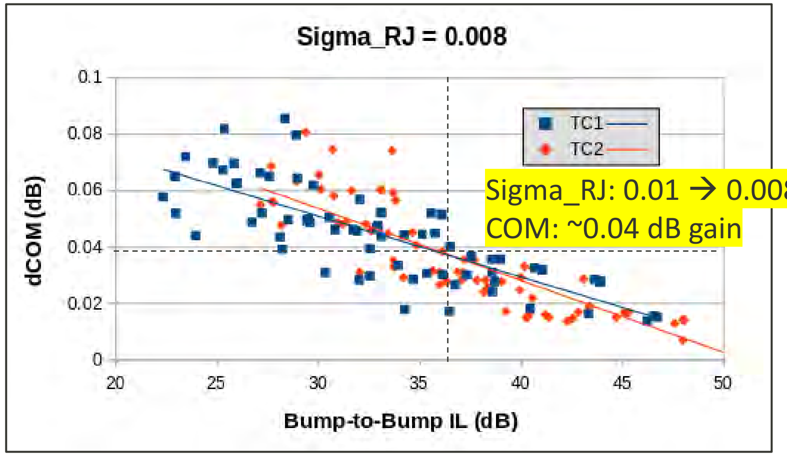




** Baseline: Sigma_RJ = 0.01*







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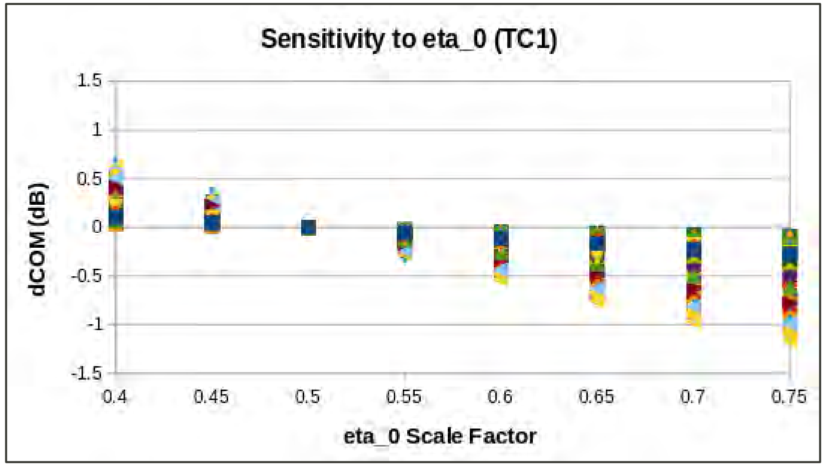
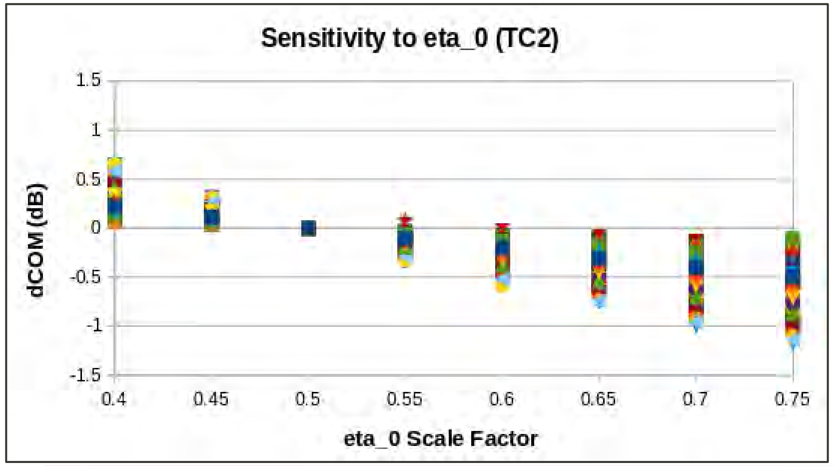
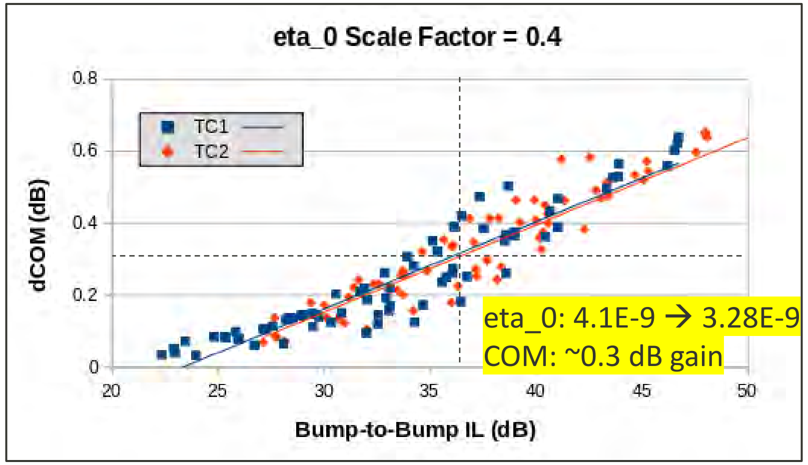
Sensitivity to Transceiver Capability: eta_0 & f_r

** Baseline: eta_0 scale factor = 0.5 (eta_0 = 4.1E-9)*

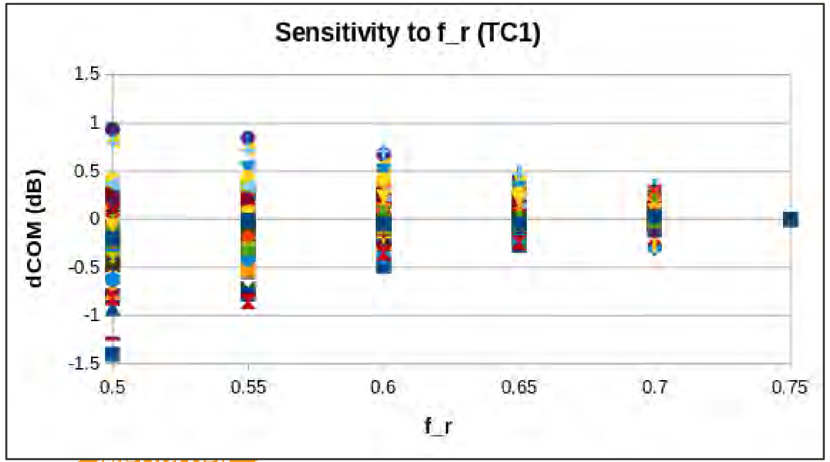


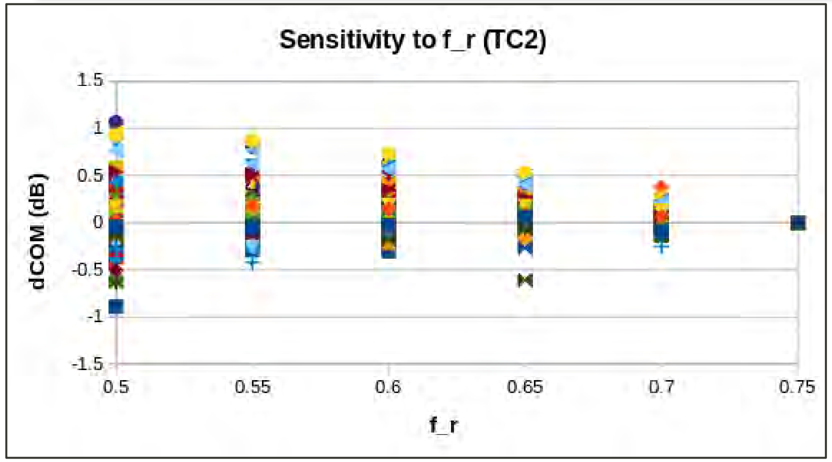


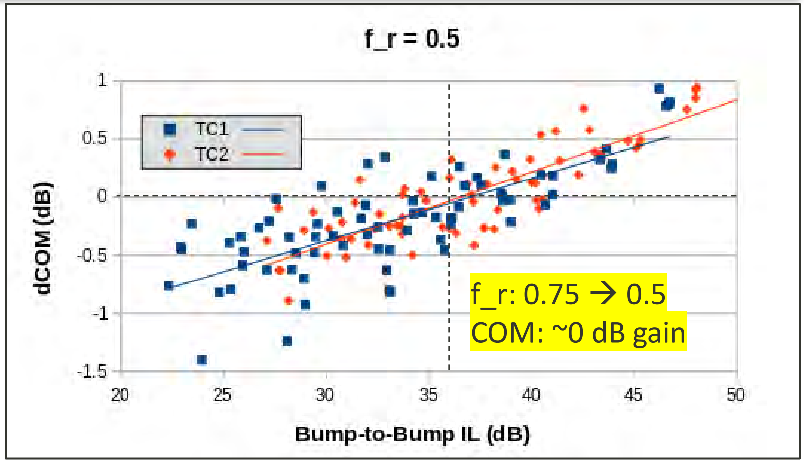


- A proper design of RX filter can achieve a better tradeoff between peaking gain & noise reduction
- Higher loss channels enjoy higher performance gain as reducing f_r

** Baseline: f_r = 0.75*

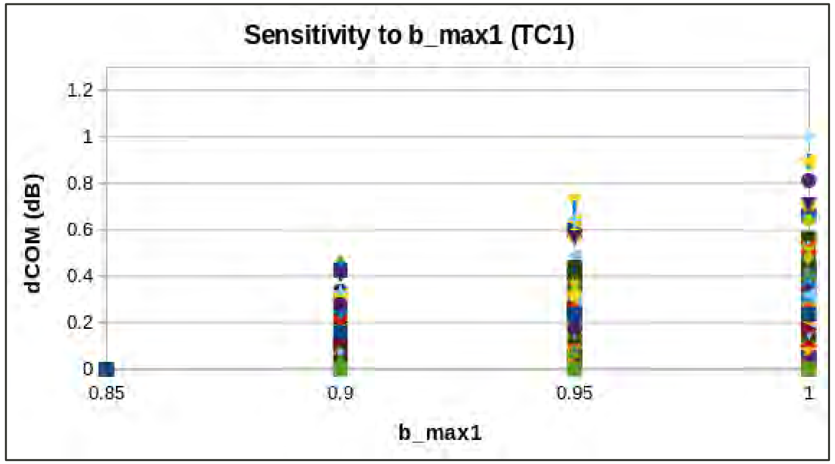


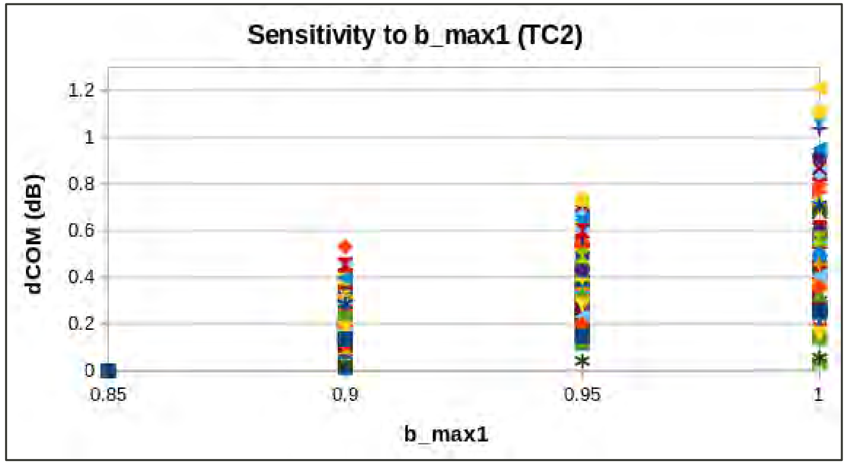


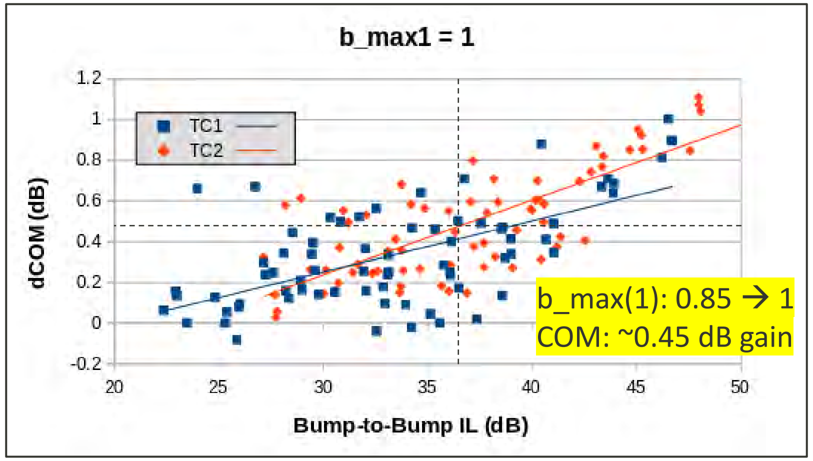


Sensitivity to Transceiver Capability: b_max (1)

**Baseline: b_max (1) = 0.85*







- **More flexible DFE coefficient range**
  - Beneficial for longer channels due to less noise enhancement induced by CTLE
  - Can help near-main cursor reflections (induced by roll-off)
- **Concern: error propagation**

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Summary: Sensitivity to Transceiver Capability

- **Average COM gain obtained by SerDes enhancement**
  - Based on TC2 & target bump-to-bump IL = 36.5 dB

	Changes from Baseline	Improvement	COM Gain
A_v	0.413 → 0.51625	25% increased	0.65 dB
SNR_TX	33 → 35	25% increased	0.18 dB
A_DD	0.02 → 0.016	20 % decreased	0.15 dB
Sigma_RJ	0.01 → 0.008	20 % decreased	0.04 dB
eta_0	4.1E-9 → 3.28E-9	20 % decreased	0.30 dB
f_r	0.75 → 0.5		0.00 dB
b_max (1)	0.85 → 1	17% increased	0.45 dB

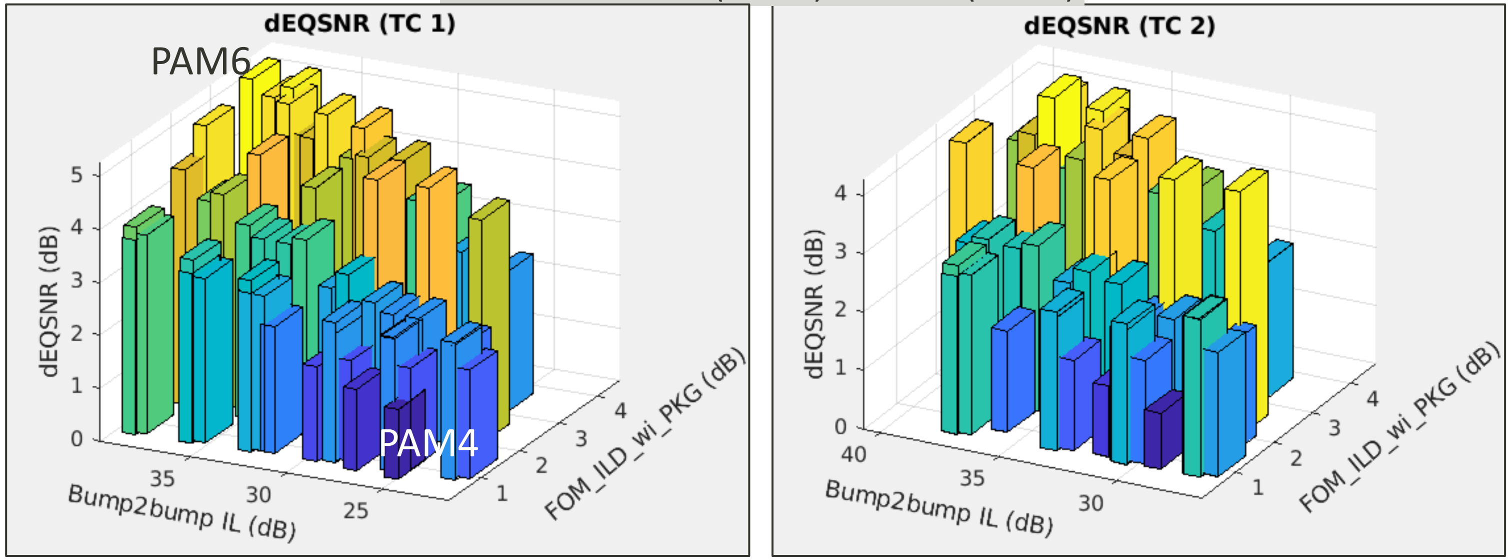
- **Potential ways to improve the reach of 200G/L CR**
  - Increase A_v → Further investigation in linearity & power consumption required
  - Increase b_max (1) → Advanced RX technology can help the problem of error propagation?
  - Enhance eta_0 → It's very challenging to further improve RX noise

PAM4 vs PAM6 (wo Crosstalk)

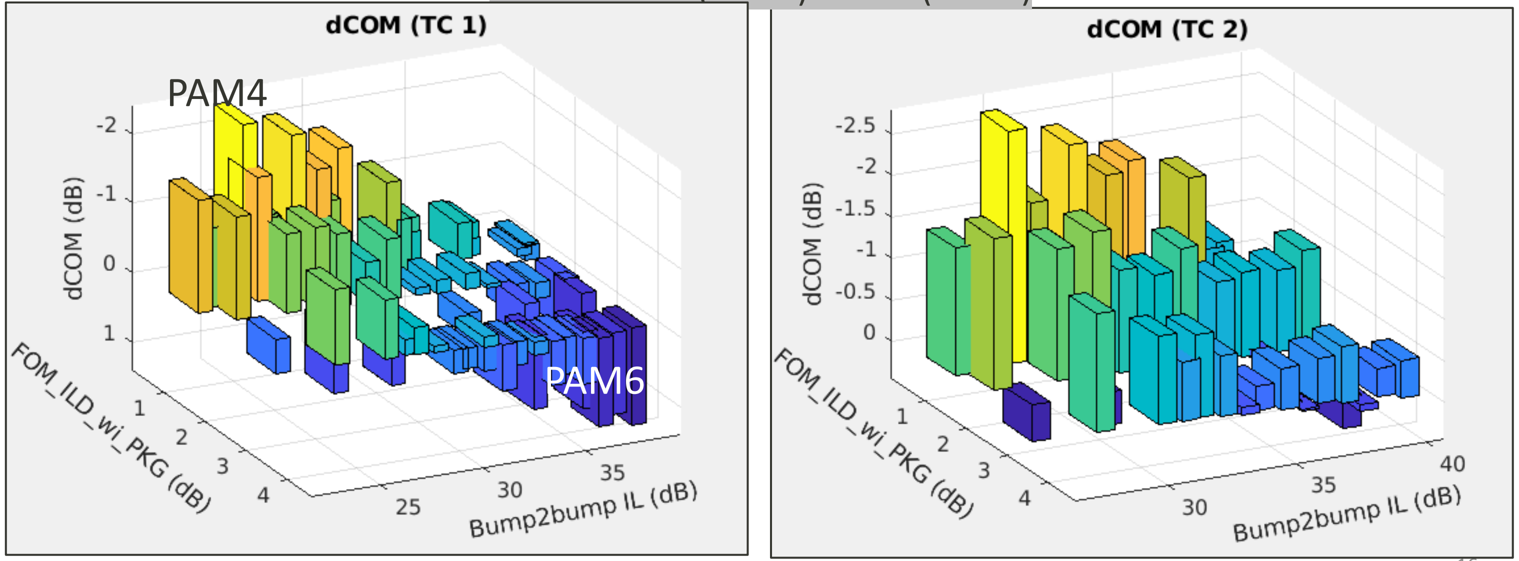
- **Assumptions: Identical transceiver capability for both PAM4 & PAM6**
  - Identical impairments (absolute values of rise time, jitter, & RX noise)
  - Identical equalizer length

SNR penalty (PAM4 → PAM6)	1E-4	1E-5	1E-6
PAM4	18.23	19.46	20.42
PAM6	21.81	23.06	24.04
SNR Penalty (dB)	**3.58**	**3.6**	**3.62**

dEQSNR = EQSNR(PAM6) – EQSNR(PAM4)

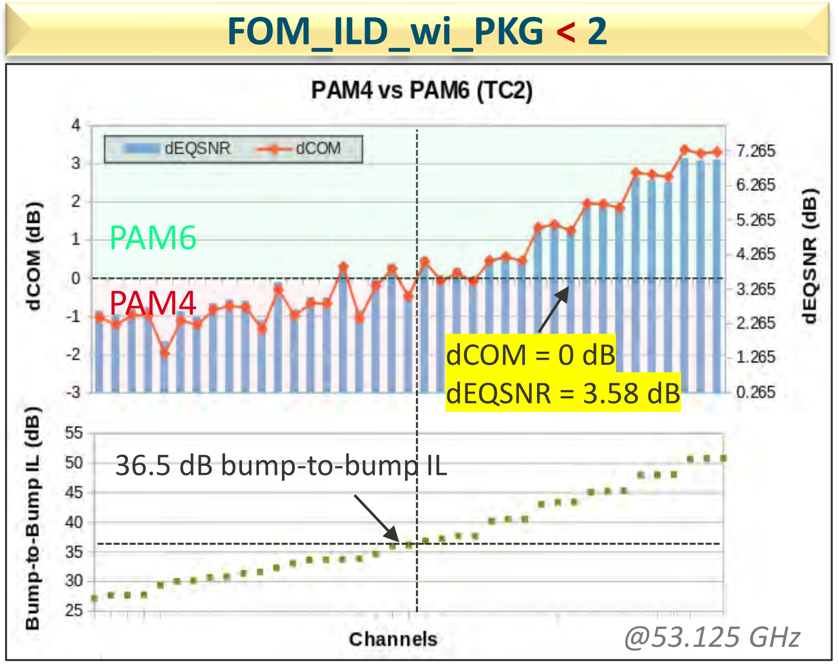


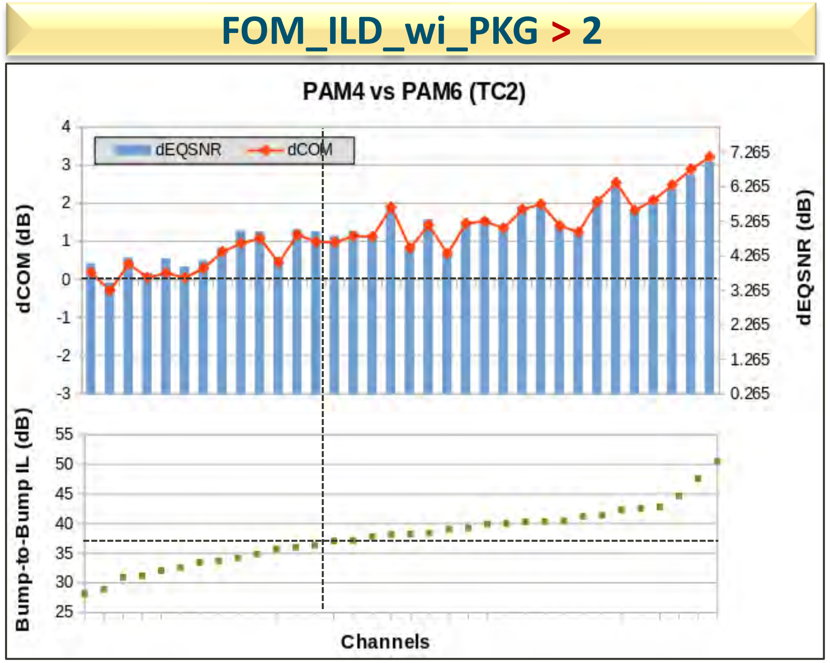
dCOM = COM(PAM6) – COM(PAM4)



PAM4 vs PAM6 (wo Crosstalk)

- **PAM4 shows the better overall performance under**
  - Bump-to-bump IL @ 53.125 GHz <= 36.5 dB
  - Channel bandwidth is sufficient (FOM_ILD_wi_PKG <= 2)
- **PAM6 outperform PAM4 when channel loss increases**
- **Channels with limit bandwidth enjoy higher performance gain when moving from PAM4 to PAM6**





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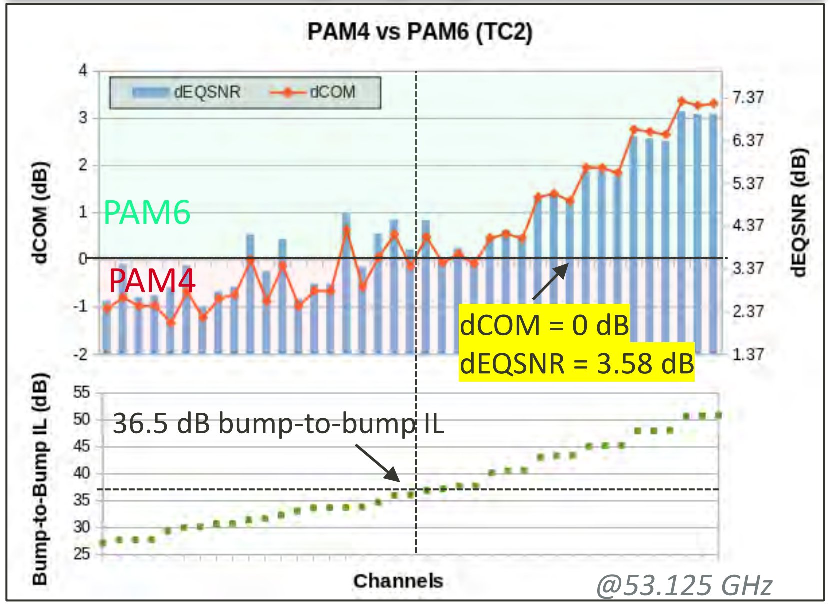
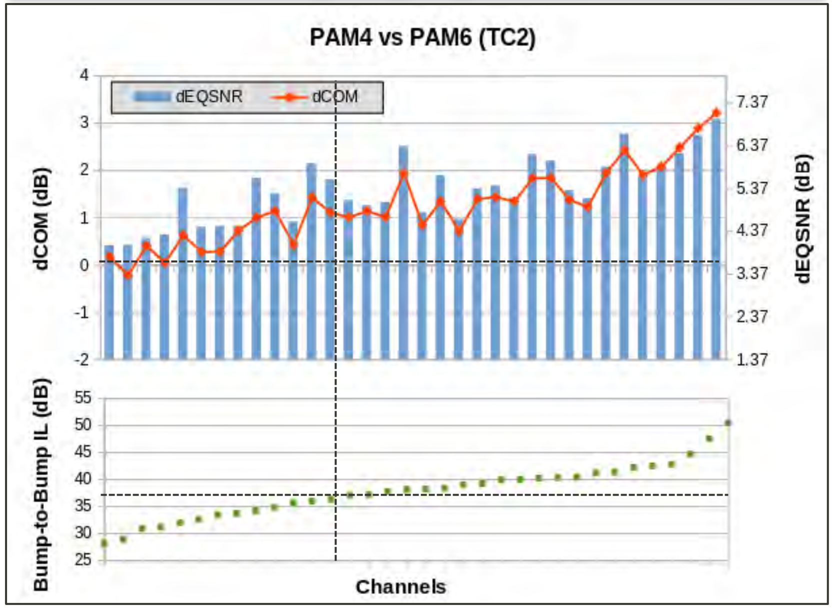
PAM4 vs PAM6 (wi Crosstalk)

- **Crosstalk has a high-pass frequency response in general**
- **If signals can no longer maintain sufficient isolation, PAM6 gains a competitive advantage**
- **Required channel specifications as considering backward compatibility with 100G/L modulation format**
  - BW/Reflection-related requirement: ILD <= 2dB?
  - Crosstalk requirement: ICR >= 25 dB?

FOM_ILD_wi_PKG < 2



FOM_ILD_wi_PKG > 2



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Conclusions of 200G/L CR

- **Feasibility of 200G/L PAM4 CR requires both channel and SerDes technology enablement**
  - Based on potential reach: bump2bump IL ~36.5 dB
- **Channel feasibility and the potential directions for channel design were explored**
  - FOM_ILD_wi_PKG <= 2dB
  - ICR >= 25 dB
- **SerDes feasibility started with the sensitivity check of key parameters, and the potential solutions to achieve 200G/L PAM4 CR were observed**
  - Increased TX swing under proper assessment of linearity & power consumption
  - More flexible DFE coefficient range with advanced RX technology
- **Baseline performance of PAM4 & PAM6 was compared under the assumption of identical transceiver capability**
  - PAM4 can outperform PAM6 under the well-qualified channel conditions

Further discussion

- **Whether 36.5 dB bump-to-bump IL target can meet the 200G/L CR objective with 1 m cable reach?**
- **Potential approaches to extend bump-to-bump IL target**
  - Further SerDes enhancement, e.g., increased A_v & b_max(1)
  - Advanced RX technology, e.g., MLSD
  - PAM6

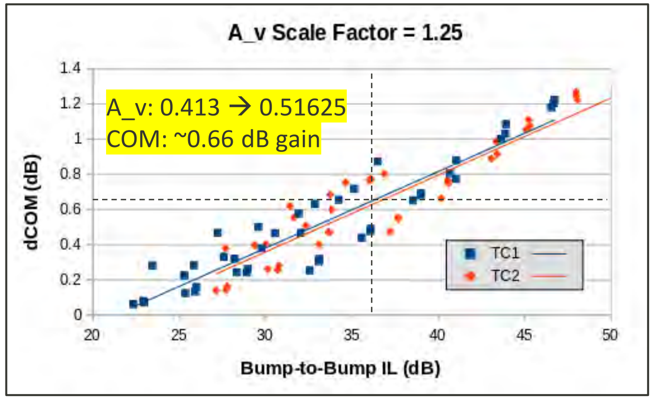
APPENDIX

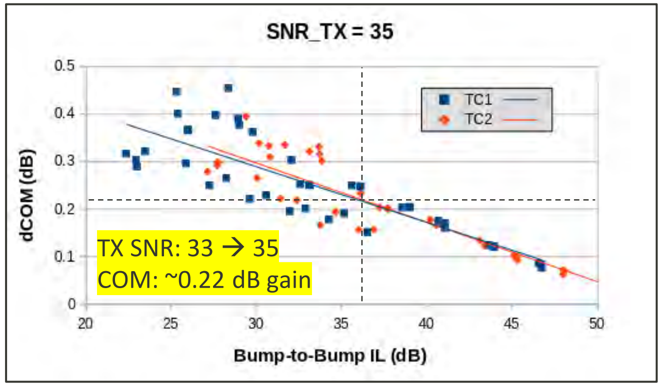
Sensitivity to Transceiver Capability

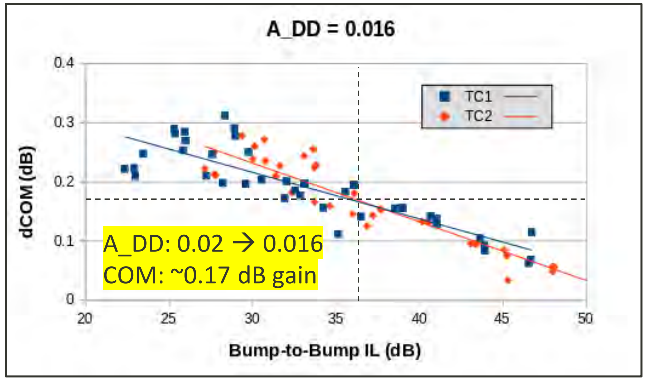
Remove channels with ILD > 2

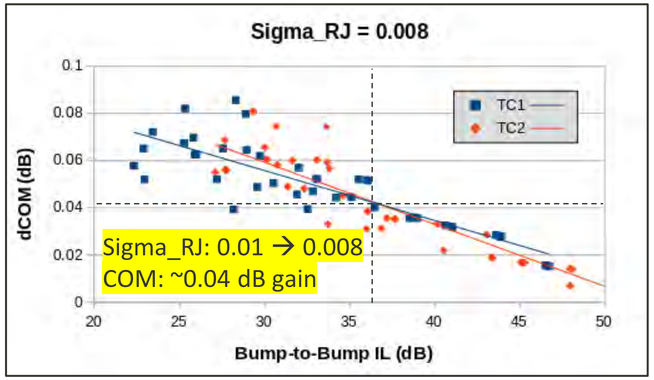
- **Minor changes in performance trend and the resulting values when removing channels with FOM_ILD_wi_PKG > 2**

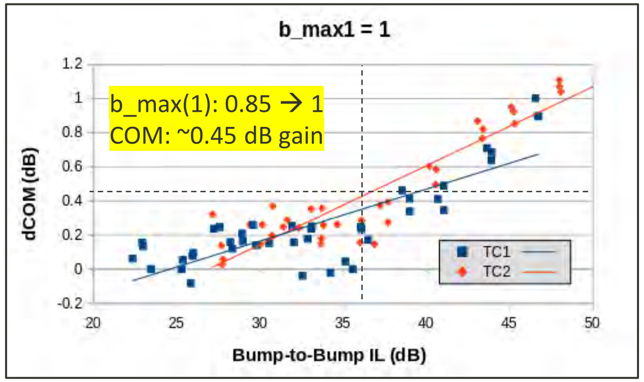
	Changes from Baseline	Improvement	COM Gain
A_v	0.413 → 0.51625	25% increased	0.66 dB
SNR_TX	33 → 35	25% increased	0.22 dB
A_DD	0.02 → 0.016	20 % decreased	0.17 dB
Sigma_RJ	0.01 → 0.008	20 % decreased	0.04 dB
eta_0	4.1E-9 → 3.28E-9	20 % decreased	0.32 dB
f_r	0.75 → 0.5		0.04 dB
b_max (1)	0.85 → 1	17% increased	0.45 dB

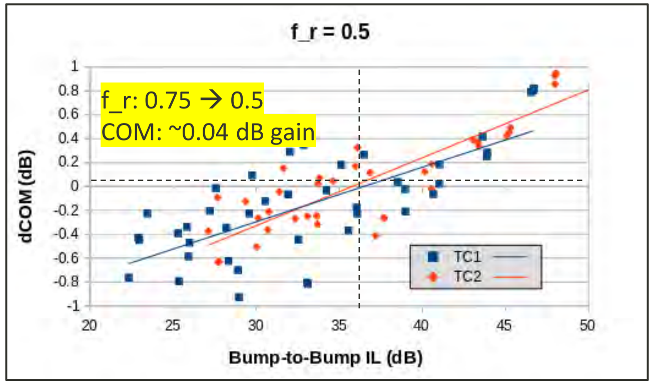


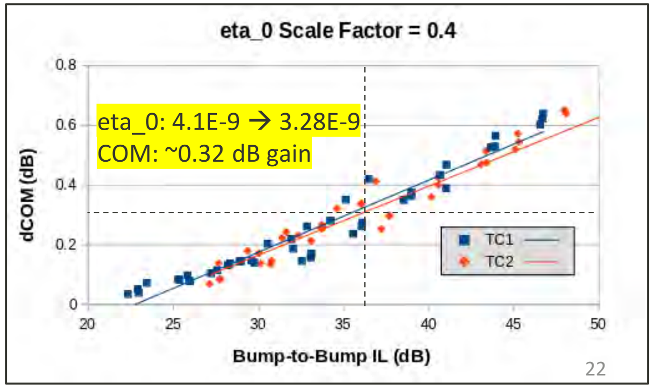












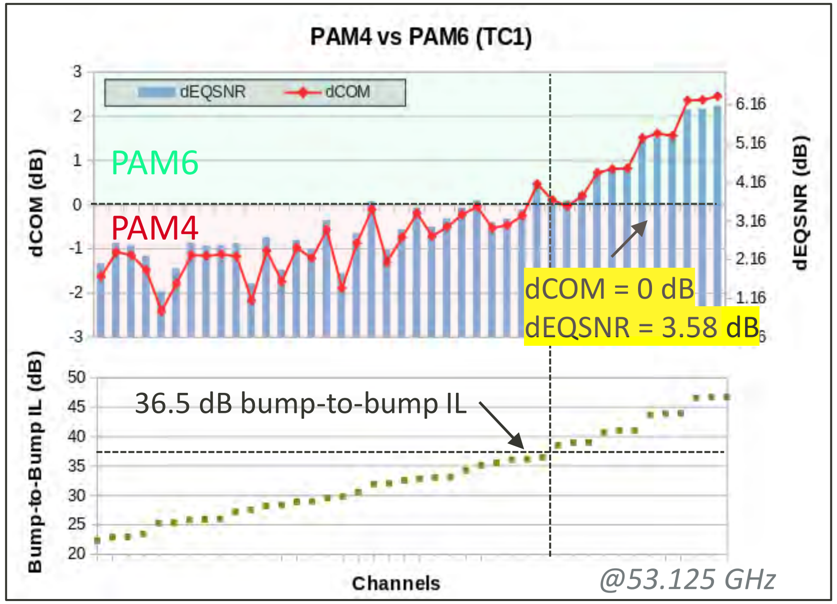
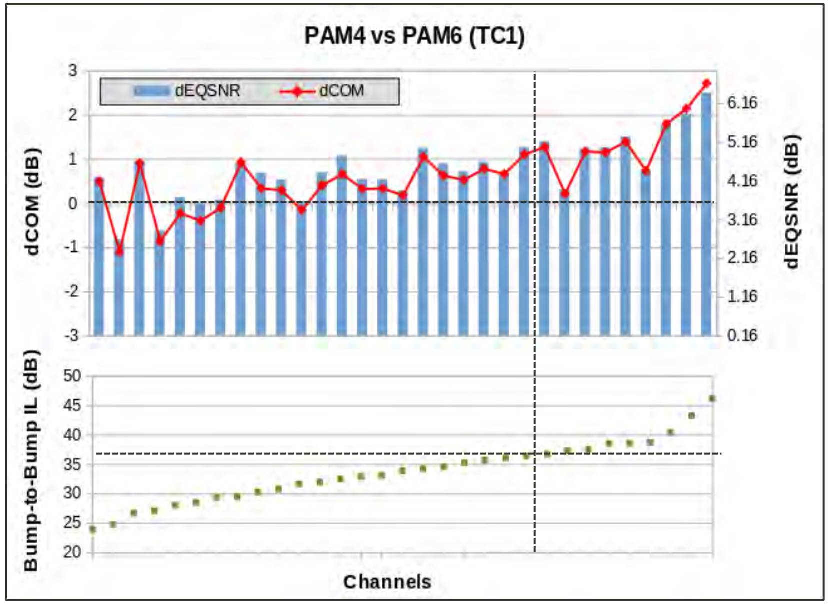
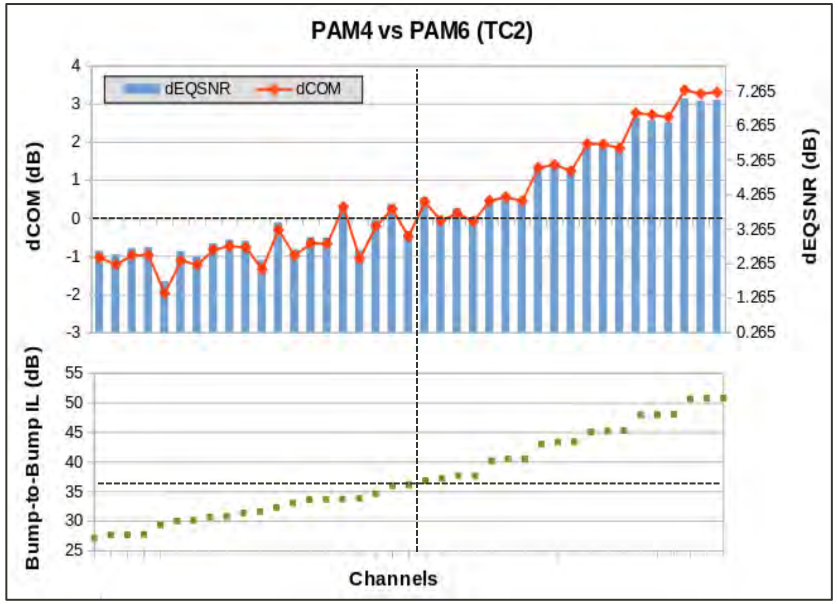
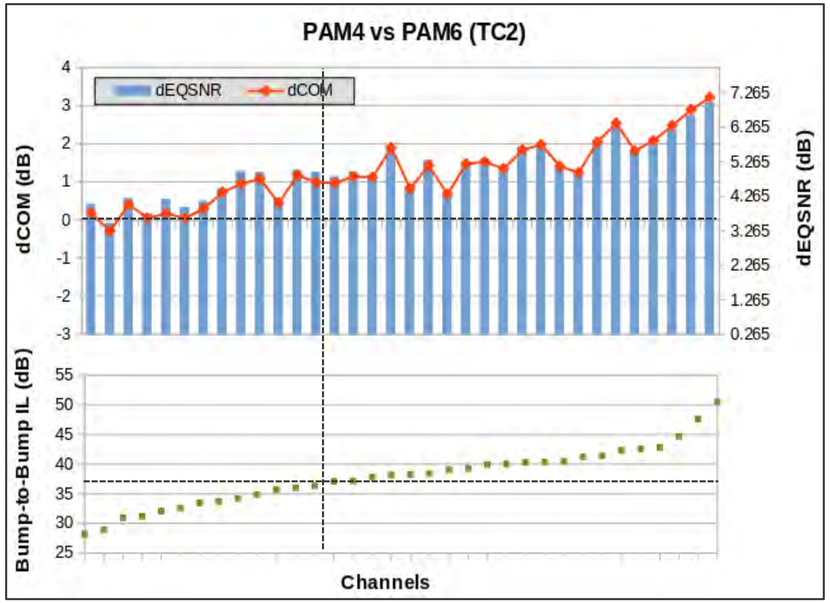
COM Spreadsheet: PAM6

Table 93A-1 parameters				
Parameter	Setting	Units	Information	
f_b	82.2062215373401	GBd		
f_min	0.05	GHz		
Delta_f	0.01	GHz		
C_d	[0.7e-4 0.7e-4]	nF	[TX RX]	
L_s	[0.12 0.12]	nH	[TX RX]	
C_b	[0.3e-4 0.3e-4]	nF	[TX RX]	
z_p select	[1 2]		[test cases to run]	
z_p (TX)	[12 31; 1.8 1.8]	mm	[test cases]	
z_p (NEXT)	[12 29 ; 1.8 1.8]	mm	[test cases]	
z_p (FEXT)	[12 31; 1.8 1.8]	mm	[test cases]	
z_p (RX)	[12 29 ; 1.8 1.8]	mm	[test cases]	
C_p	[0.87e-4 0.87e-4]	nF	[TX RX]	
R_0	50	Ohm		
R_d	[50 50]	Ohm	[TX RX]	
A_v	0.413	V		
A_fe	0.413	V		
A_ne	0.608	V		
L	6			
M	32	Samp/UI		
samples_for_C2M	32	Samp/UI		
T_O	0	mUI		
AC_CM_RMS	0	V	[test cases]	[0.0235 0.0256]
Filter and Eq				
f_r	0.75	*fb		
c(0)	0.5		min	
c(-1)	[-0.4:0.02:0.04]		[min:step:max]	
c(-2)	[-0.1:0.02:0.2]		[min:step:max]	
c(-3)	[-0.1:0.02:0.1]		[min:step:max]	
c(1)	[-0.2:0.02:0.1]		[min:step:max]	
N_b	24	UI		
b_max(1)	0.85		As/dffe1	
b_max(2..N_b)	[0.5 0.3 0.3 0.2* ones(1,20)]		As/dfe2..N_b	
b_min(1)	0.3		As/dffe1	
b_min(2..N_b)	[0.2 0.05 0.05 -0.03 * ones(1,20)]		As/dfe2..N_b	
g_DC	[-20:1:-2]	dB	[min:step:max]	
f_z	32.882488614936	GHz		
f_p1	32.882488614936	GHz		
f_p2	82.2062215373401	GHz		
g_DC_HP	[-6:1:0]		[min:step:max]	
f_HP_PZ	1.02757776921675	GHz		

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	0	logical
RESULT_DIR	.\results\100GEL_C2M_host_{date}	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	CR_eval_	
COM_CONTRIBUTION	0	logical
Local Search	2	
Operational		
VEC Pass threshold	12	db
EH_min	10	mV
ERL Pass threshold	9.5	dB
Min_VEO_Test	0	mV
DER_0	0.0001	
T_r	0.00374964705882	ns
FORCE_TR	1	logical
PMD_type	CR	
BREAD_CRUMBS	0	logical
SAVE_CONFIG2MAT	1	logical
PLOT_CM	0	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.00645936511945	ns
N	3500	
beta_x	0	
rho_x	0.618	
fixture delay time	[0 0]	[port1 port2]
TDR_W_TXPKG	0	
N_bx	0	UI
Tukey_Window	1	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
Noise, jitter		
sigma_RJ	0.00773705614469	UI
A_DD	0.01547411228938	UI
eta_0	5.30E-09	V^2/GHz
SNR_TX	33	dB
R_LM	0.95	

Table 93A-3 parameters		
Parameter	Setting	Units
package_tl_gamma0_a1_a2	[0 0.000644085 0.00018018]	
package_tl_tau	5.700E-03	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm
ICN & FOM_ILD parameters		
f_v	0.767	*Fb
f_f	0.767	GHz f_r specified in first column
f_n	0.767	GHz
f_2	80	GHz
A_ft	0.600	V
A_nt	0.600	V
Histogram_Window_Weight	gaussian	Seletions (rectangle, gaussian,dual
COM Pass threshold	3	
Floating Tap Control		
N_bg	3	0 1 2 or 3 groups
N_bf	6	taps per group
N_f	80	UI span for floating taps
bmaxg	0.2	max DFE value for floating taps

PAM4 vs PAM6 (wo Crosstalk)

	FOM_ILD_wi_PKG < 2	FOM_ILD_wi_PKG > 2
TC 1		
TC 2		

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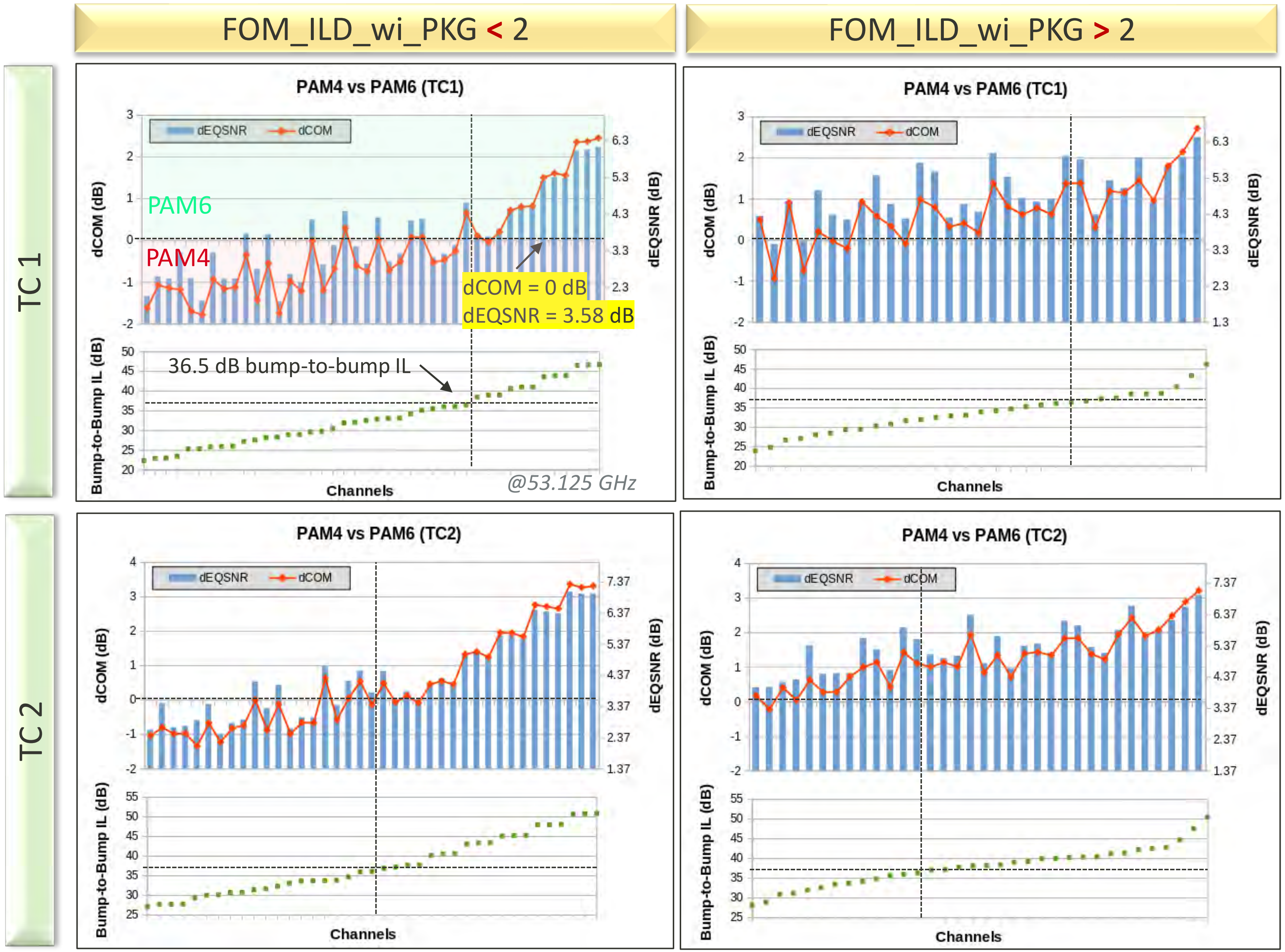
PAM4 vs PAM6 (wi Crosstalk)



THANK YOU