212.5 Gbps PAM4 COM Link Simulations and Analyses for CR and KR Channels

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July 2023

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Background

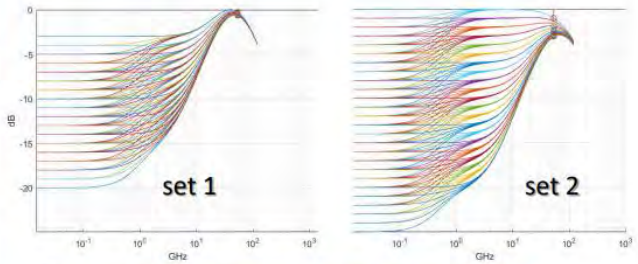
- "200 Gb/s per lane KR Backplane Objective Proposal"[1] shows two example COM configurations Set 1 and Set 2, with 5 example KR channels
- Some preliminary COM analysis were performed with those 5 channels with
  - COM Config Set 1 w/ 31mm TX Pkg and 29mm RX Pkg, however with worse PKG IL/overall perf
  - COM Config Set 2 w/ 42mm TX Pkg and 40mm RX pkg, however with better PKG IL/overall perf

Example parameters sets which suggest > 3 dB COM feasibility for "X" = 40 dB

THIS IS NOT A PARAMETER PROPOSAL

parameter	Used for this work set 1	Used for this work set 2
η_0 [V²/GHz]	4e-9	5e-9
SNR_Tx	33	33
t_r [ps]	4	4
f_r	0.58	0.5
b_{max}	0.75	0.85
DFE equivalent [Taps]	1	1
Tx FFE Pre/Post	4/1	4/1
Rx FFE pre/post cursor	6/60	6/24
FFE floating groups/ floating taps per group*	NA	4/5
DER_0	1e-4	1e-4
MLSE used	yes	yes

* RX FFE floating taps estimated in COM 4.0 with RX DFE floating taps in the presentation



parameter	Used for this work set 1	Used for this work Set 2
fz	fb/4.223	fb/2.5
fp1	fb/2.6562	fb/2.5
fp2	Fb/1.8973	Fb
fLF	Fb/80	Fb/160
Gdc	-15 to 0-3 (step 1)	-20 to 0 (step 1)
Gdc2	-5 to 0 (step 1)	-6 to 0 (step 1)

IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force

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Motivation, Objective, and New Investigations

- Motivation
  - New CR and KR channels had become available, and deserve new COM investigations
- Objective
  - Study COM Config Set1 and Set2 with the same PKG trace length and the latest/more channels, which is a needed/timely investigation
- New Investigations
  - COM analysis performed with
    - Latest CR channels (13)
    - Latest KR channels (75)
    - Same/common package length for modified PKG trace length for Set 1 and Set 2: TX 33mm and RX 31mm

Test Channels: A total of 88

Ch #	Channel Source
1	*A 212.5 Gbps-PAM4 1 Meter DAC Long Reach Channel and Its Characteristics: Design B (https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_04_230629.zip)*
2	*A 212.5 Gbps-PAM4 1 Meter DAC Long Reach Channel and Its Characteristics: Design A (https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_03_230629.zip)*
3~7	*https://www.ieee802.org/3/dj/public/tools/CR/kocsis_3dj_02_2305.zip*
8~34	*https://www.ieee802.org/3/dj/public/tools/KR/mellitz_3dj_02_elec_230504.zip*
35~40	*https://www.ieee802.org/3/dj/public/tools/CR/shanbhag_3dj_01_2305.zip*
41~44	*https://www.ieee802.org/3/dj/public/tools/KR/shanbhag_3dj_02_2305.zip*
45~80	*https://www.ieee802.org/3/dj/public/tools/KR/weaver_3dj_02_2305.zip*
81~88	*https://www.ieee802.org/3/dj/public/tools/KR/weaver_3dj_elec_01_230622.zip*

Modified COM Config Set 1

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	[0.4e-4 0.9e-4 1.1e-4 ; 0.4e-4 0.9e-4 1.1e-4]	nF	[TX RX]
L_s	[.13 .15 .14; .13 .15 .14]	nH	[TX RX]
C_b	[0.3e-4, 0.3e-4]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 33; 1 1; 1 1; 0.5 0.5]	mm	[test cases]
z_p (NEXT)	[12 31; 1 1; 1 1; 0.5 0.5]	mm	[test cases]
z_p (FEXT)	[12 33; 1 1; 1 1; 0.5 0.5]	mm	[test cases]
z_p (RX)	[12 31; 1 1; 1 1; 0.5 0.5]	mm	[test cases]
C_p	[0.5e-4 0.5e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[45 45]	Ohm	[TX RX]
A_v	0.386	V	
A_fe	0.386	V	
A_ne	0.6	V	
AC_CM_RMS	0	V	[test cases]
L	4		
M	32		
filter and Eq			
f_r	0.58	*fb	
c(0)	0.55		min
c(-1)	[-0.4:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.1]		[min:step:max]
c(-3)	0		[min:step:max]
c(-4)	0		[min:step:max]
c(-5)	0		[min:step:max]
c(-6)	0		[min:step:max]
c(1)	[-0.2:0.05:0]		[min:step:max]
N_b	1	UI	
b_max(1)	0.75		
b_max(2..N_b)	0.15		
b_min(1)	0		
b_min(2..N_b)	-0.15		
g_DC	[-15:1:-3]	dB	[min:step:max]
f_z	25.15983898	GHz	
f_p1	40.00075296	GHz	
f_p2	56.00063248	GHz	
g_DC_HP	[-5:1:0]		[min:step:max]
f_HP_PZ	1.328125	GHz	
MLSE	1		
ffe_pre_tap_len	6		
ffe_post_tap_len	60		
ffe_tap_step_size	0		
ffe_main_cursor_min	1		
ffe_pre_tap1_max	1		
ffe_post_tap1_max	1		
ffe_tapn_max	1		
ffe_backoff	0		

I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\100GEL_KR_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	KR_eval_	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10	dB
DER_0	0.0001	
T_r	0.004	ns
FORCE_TR	1	logical
Local Search	2	
BREAD_CRUMBS	1	logical
SAVE_CONFIG2MAT	1	logical
PLOT_CM	0	
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	1000	
beta_x	0	
rho_x	0.618	
fixture delay time	[0 0]	[port1 port2]
TDR_W_TXPKG	0	
N_bx	20	UI
Tukey_Window	1	logical
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	4.00E-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 0.0008455 0.000340225]	
package_tl_tau	0.00644805	ns/mm
package_Z_c	[92 92; 70 70; 80 80; 100 100]	Ohm
Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	*[0 3.8206e-04 9.5909e-05]*	
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	*110.3*	mm
z_bp (NEXT)	*110.3*	mm
z_bp (FEXT)	*110.3*	mm
z_bp (RX)	*110.3*	mm
C_0	[0.29e-4]	nF
C_1	[0.19e-4]	nF
Include PCB	**0**	**logical**
Floating Tap Control		
N_bg	0	0 1 2 or 3 groups
N_bf	3	taps per group
N_f	80	UI span for floating taps
bmaxg	0.2	max DFE value for floating taps
B_float_RSS_MAX	0.1	rss tail tap limit
N_tail_start	25	(UI) start of tail taps limit
ICN & FOM_ILD parameters		
f_v	0.556	*Fb
f_f	0.556	*Fb
f_n	0.556	*Fb
f_2	80.000	GHz
A_ft	0.600	V
A_nt	**0.600**	V

Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V

Notes:

- ***Changes/modifications are marked in green***
- ***Differences are marked in yellow between Set 1 and Set 2***
- ***PKG models and parameters same as [2]***
- ***COM v4.0 was used in this study***

Modified COM Config Set 2

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	[0.4e-4 0.9e-4 1.1e-4 ; 0.4e-4 0.9e-4 1.1e-4]	nF	[TX RX]
L_s	[.13 .15 .14; .13 .15 .14]	nH	[TX RX]
C_b	[0.3e-4, 0.3e-4]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 33; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 31; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 33; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 31; 1.8 1.8]	mm	[test cases]
C_p	[0.4e-4 0.4e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[46.25 46.25]	Ohm	[TX RX]
A_v	0.413	V	
A_fe	0.413	V	
A_ne	0.608	V	
AC_CM_RMS	0	V	[test cases]
L	4		
M	32		
filter and Eq			
f_r	0.5	*fb	
c(0)	0.54		min
c(-1)	[-0.4:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.16]		[min:step:max]
c(-3)	[-0.1:0.02: 0]		[min:step:max]
c(-4)	[0:0.02:0.1]		[min:step:max]
c(-5)	0		[min:step:max]
c(-6)	0		[min:step:max]
c(1)	[-0.2:0.02:0]		[min:step:max]
N_b	1	UI	
b_max(1)	0.85		
b_max(2..N_b)	[0.3 0.2*ones(1,22)]		
b_min(1)	0.3		
b_min(2..N_b)	[-0.3 -0.2*ones(1,22)]		
g_DC	[-20:1:0]	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	0.6640625	GHz	
MLSE	1		
ffe_pre_tap_len	6		
ffe_post_tap_len	24		
ffe_tap_step_size	0		
ffe_main_cursor_min	0.7		
ffe_pre_tap1_max	0.7		
ffe_post_tap1_max	0.7		
ffe_tapn_max	0.7		
ffe_backoff	0		

I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\100GEL_KR_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	KR_eval_	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	8	dB
DER_0	0.0001	
T_r	0.004	ns
FORCE_TR	1	logical
Local Search	2	
BREAD_CRUMBS	1	logical
SAVE_CONFIG2MAT	1	logical
PLOT_CM	0	
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	3500	
beta_x	0	
rho_x	0.618	
fixture delay time	[0 0]	[port1 port2]
TDR_W_TXPKG	0	
N_bx	21	UI
Tukey_Window	1	logical
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	5.00E-09	V^2/GHz
SNR_TX	33	dB
R_LM	0.95	

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0.0005 0.00089 0.0002]	
package_tl_tau	0.006141	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm
Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	*[0 3.8206e-04 9.5909e-05]*	
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	*110.3*	mm
z_bp (NEXT)	*110.3*	mm
z_bp (FEXT)	*110.3*	mm
z_bp (RX)	*110.3*	mm
C_0	[0.29e-4]	nF
C_1	[0.19e-4]	nF
Include PCB	**0**	**logical**
Floating Tap Control		
N_bg	4	0 1 2 or 3 groups
N_bf	5	taps per group
N_f	60	UI span for floating taps
bmaxg	0.05	max DFE value for floating taps
B_float_RSS_MAX	0.02	rss tail tap limit
N_tail_start	50	(UI) start of tail taps limit
ICN & FOM_ILD parameters		
f_v	0.556	*Fb
f_f	0.556	*Fb
f_n	0.556	*Fb
f_2	80.000	GHz
A_ft	0.600	V
A_nt	**0.600**	V

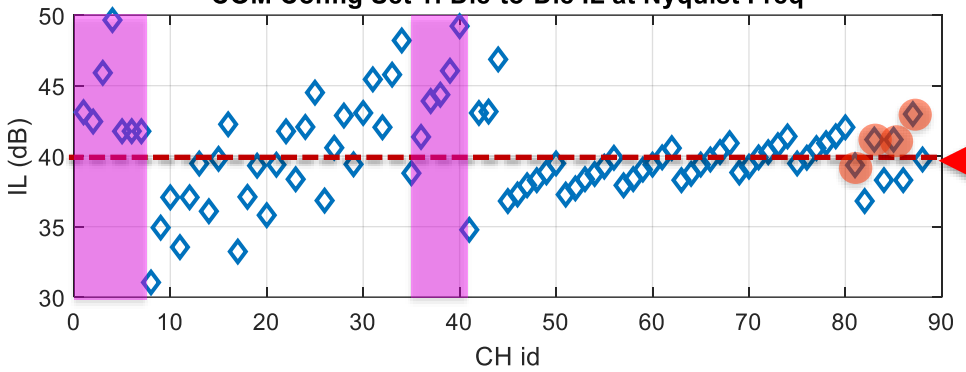
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V

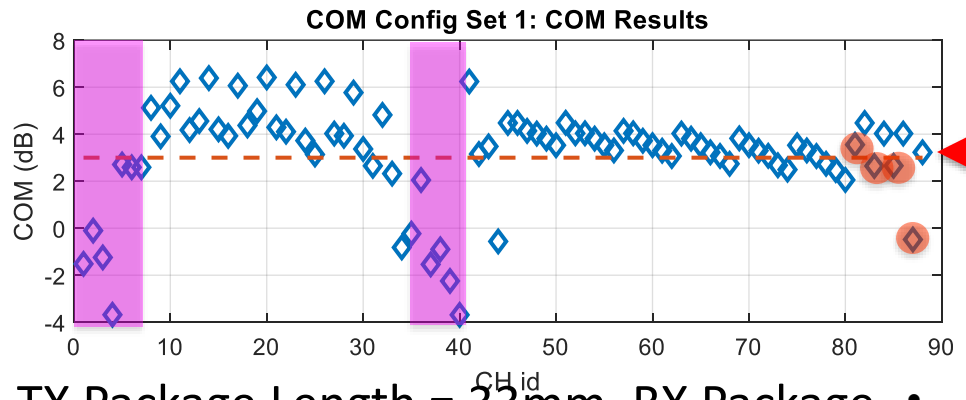
Notes:

- ***Changes/modifications are marked in green***
- ***Differences are marked in yellow between Set 1 and Set 2***
- ***PKG model and parameters same as in[3]***
- ***COM v4.0 was used in this study***

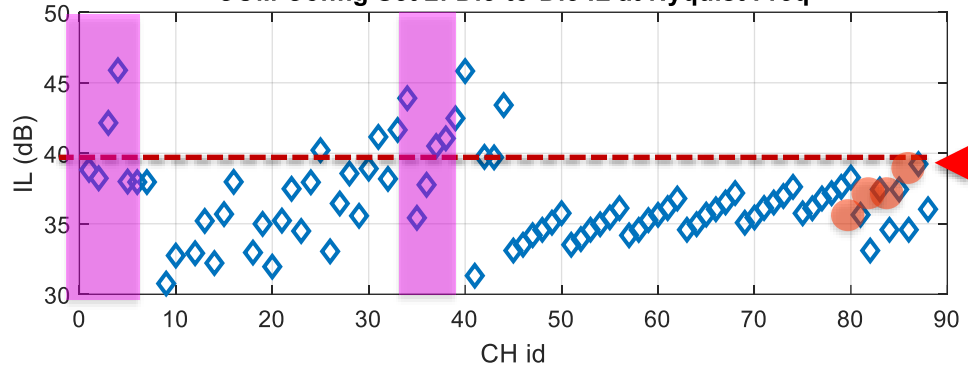
COM Performance Comparison

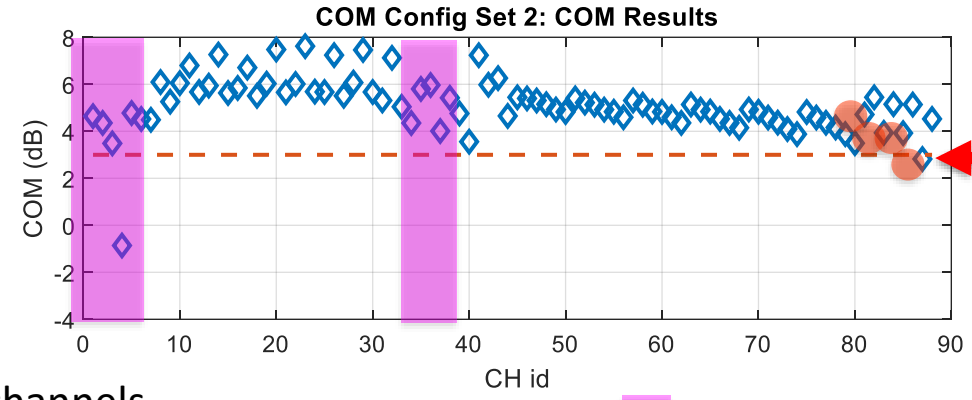
COM Config Set 1





COM Config Set 2





40dB IL

3dB COM

- TX Package Length = 33mm, RX Package Length = 31mm
- 3dB COM passing rate
  - COM Config Set 1: 62 out of 88 (70.5%)
  - COM Config Set 2: 86 out of 88 (97.7%)
  - Set 2 has large solution space vs set1

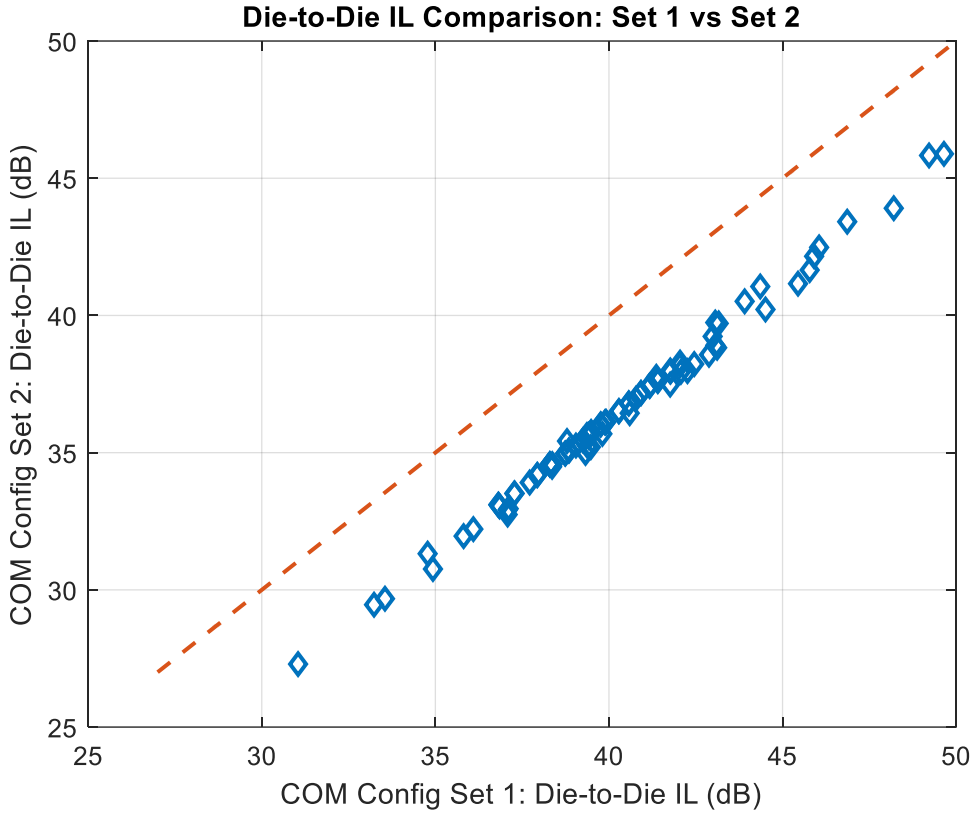
- For 13 CR channels
  - 3dB COM passing rate
    - COM Config Set 1: 0 out of 13 (0%)
    - COM Config Set 2: 12 out of 13 (92.3%)
  - Set 2 has large solution space vs Set1

CR channels

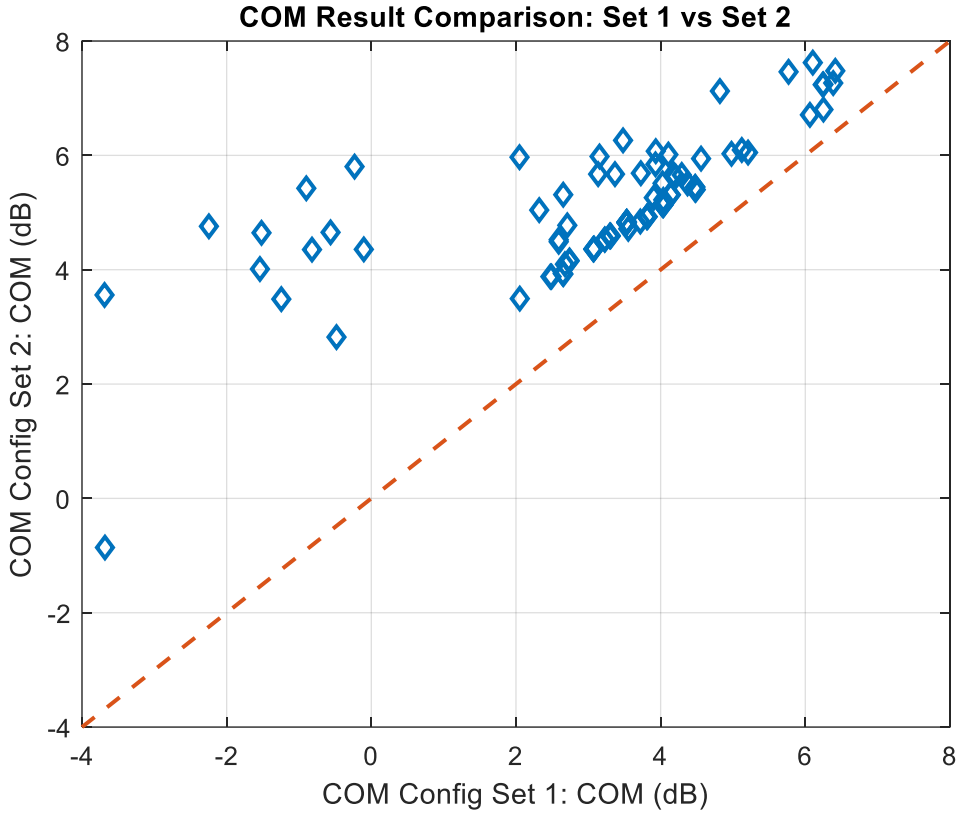
KR channels at high temp (80C/70C

COM Performance Comparison *(cont.)*

Die-to-Die IL: Set 1 vs Set 2



COM: Set 1 vs Set 2

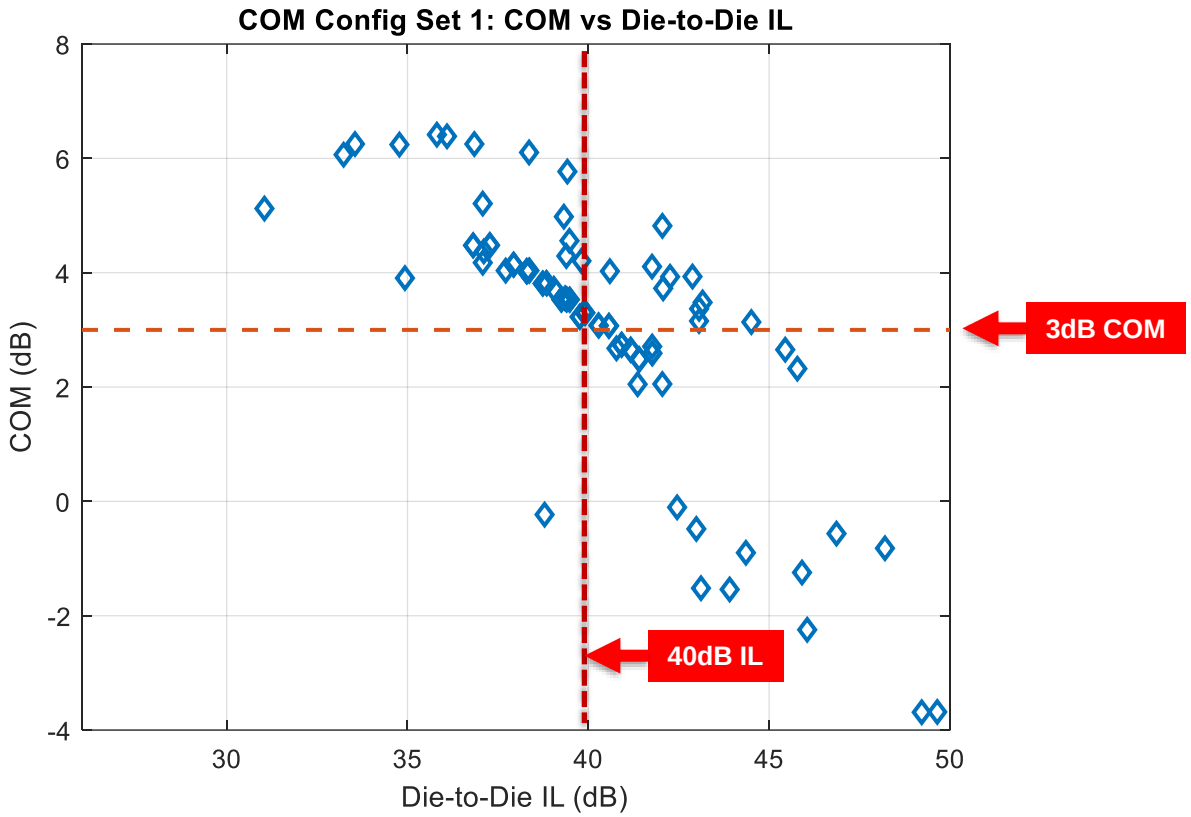


- Mean die-to-die IL difference ~ 3.84dB between Set 1 vs Set 2
  - Caused by reference package (in TX and RX) differences between Set1 and Set2 (see li_3dj_02_0723)

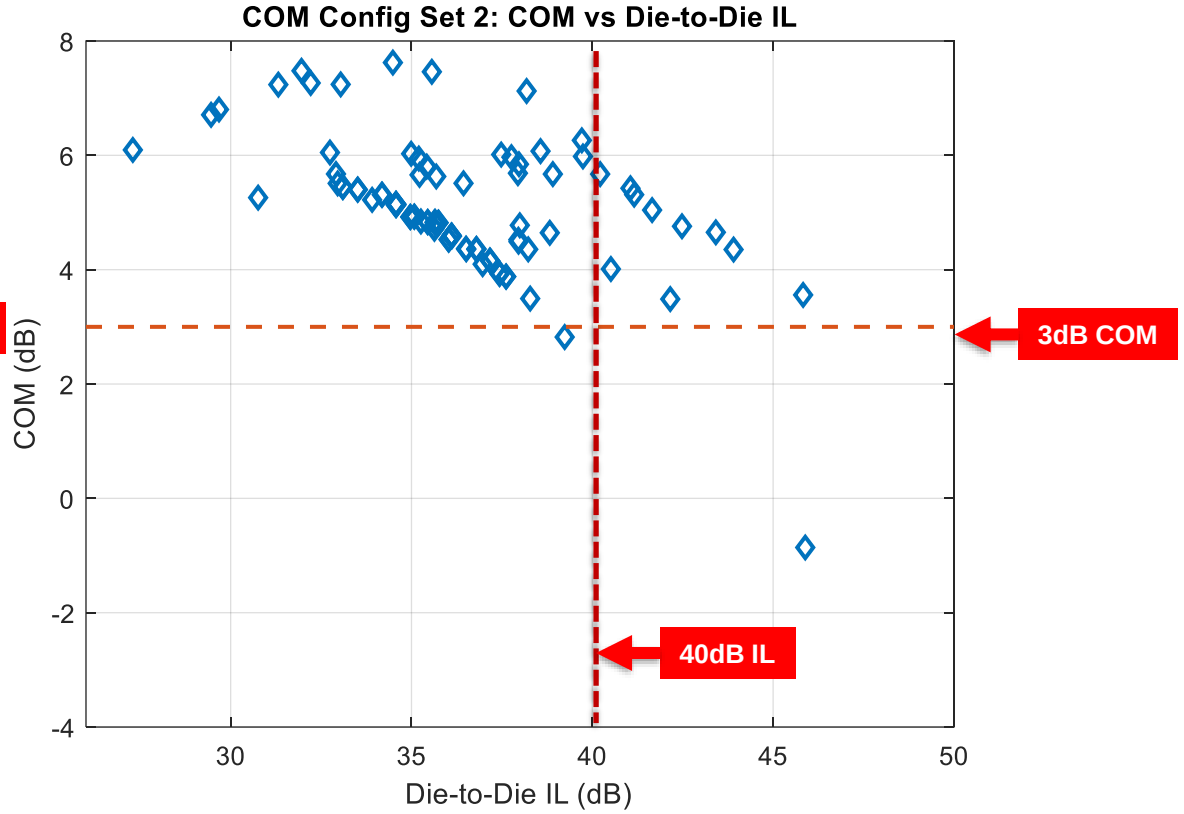
- Mean COM difference ~- 1.97dB between Set 1 and Set 2

COM Performance Comparison *(cont.)*

COM Config Set 1: Die-to-Die IL vs. COM



COM Config Set 2: Die-to-Die IL vs. COM



- Die-to-Die IL <= 40dB & >= 3dB COM passing rate
  - COM Config Set 1: 48/49
  - COM Config Set 2: 76/77
  - Set 1 has smaller channel solution space than Set 2

Summary and Conclusions

- For all 88 KR (75)/CR(13) channels,
  - COM Config Set 1: 62 out of 88 passing 3dB COM
  - COM Config Set 2: 86 out of 88 passing 3dB COM
  - Set 1 has worse reference package IL which results in higher die-to-die IL (~3.84dB avg) compared to Set 2's
  - Set 1 results in worse COM (~1.97dB avg) compared to Set 2's
- All CR channels (**13**) failed with Set 1
  - Set 2 failed 1 out of 13
- 3 out of 4 KR channels at high temperature failed with Set 1
  - Set 2 failed 1 out of 4
- Set 2 provides larger solution than set 1 using <= 40 dB bump-to-bump and/or >=3 dB COM criteria
- More works are needed to converge Set 1 and Set 2 COM config to provide acceptable solution space for needed KR/CR channels

References

[1] R. Mellitz et al. : https://www.ieee802.org/3/dj/public/23_05/mellitz_3dj_01a_2305.pdf , May, 2023

[2] R. Mellitz, A. Ran, L. Ben-Artsi: https://www.ieee802.org/3/df/public/22_11/benartsi_3df_01a_2211.pdf , Jul, 2022

[3] M. Li et al. : https://www.ieee802.org/3/dj/public/23_05/li_3dj_02_2305.pdf , May, 2023

Thank You!