212.5 Gbps PAM4 Link Simulations and Analyses for CR and KR Channels: Using COM 4.50 Beta3 MMSE

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212.5 CR/KR (end-to-end) COM Investigation with MMSE-based Equalization Determination/Optimization

- Background / Goals
  - MMSE-based equalization optimization scheme was proposed[1], adopted, and "prototyped" in COM v4.30 and updated in COM v4.5B3
  - Using updated reference transmitter/receiver configurations and 802.3dj CR /KR channels (end-to-end), we performed COM analysis with updated EQ determination/optimization method
    - The COM configurations were updated from the modified COM Config Set 2[2]
  - Goals are:
    - Identify 802.3dj CR /KR (end-to-end) solution space with new MMSE method for RX FFE/EQ determination with COM v4.4 B3
    - Use the simulation results to support the proposed comments against 802.3dj D1.0 spec accordingly/appropriately

Test Channels

Ch id	Channel Type	Channel Source
1	CR	https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_04_230629.zip
2	CR	https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_03_230629.zip
3~7	CR	https://www.ieee802.org/3/dj/public/tools/CR/kocsis_3dj_02_2305.zip
8~34	KR	https://www.ieee802.org/3/dj/public/tools/KR/mellitz_3dj_02_elec_230504.zip
35~40	CR	https://www.ieee802.org/3/dj/public/tools/CR/shanbhag_3dj_01_2305.zip
41~44	KR	https://www.ieee802.org/3/dj/public/tools/KR/shanbhag_3dj_02_2305.zip
45~80	KR	https://www.ieee802.org/3/dj/public/tools/KR/weaver_3dj_02_2305.zip
81~88	KR	https://www.ieee802.org/3/dj/public/tools/KR/weaver_3dj_elec_01_230622.zip

COM Reference TX/RX Configuration Highlights

- TX
  - Package: Class A reference package with TLine length 33+1.8mm
  - TX FFE: 2 pre-taps and 1 post-tap
- RX
  - Package: Class A reference package with TLine length 31+1.8mm
  - CTLE
    - [fp1, fp2, fz, f_HP_PZ] = fb / [1.8973, 2.6562, 4.223, 80] Hz
    - g_DC = [-15:1:0]
    - g_DC_HP = [-5:1:0]
  - FFE:
    - 31 fixed taps (6 pre-taps and 24 post-taps)
    - 20 floating taps (4 groups of 5 consecutive taps) up to 60 UI
    - Coefficient Range: Main tap fixed to 1, abs(Max) = 0.7 for fixed taps, abs(Max) = 0.05 for floating taps
  - MLSE:
    - 1 tap with max coefficient b_max = 0.85
  - EQ tuning methods
    - FFE_OPT_METHOD = MMSE
  - CDR Phase (ts_anchor)
    - ts_anchor=1 with range [-16, 16]
    - TS_SRCH_METHOD=middle

Changes, from Modified COM Config Set 2 as in [2], were marked in red.
Used COM v4.50B3 for this study.

COM Configuration (Set 3 with no floating tap shown)

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		[min:step:max]
c(-4)	0		[min:step:max]
c(-5)	0		[min:step:max]
c(-6)	0		[min:step:max]
c(1)	[-0.2:0.02:0]		[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	[-15:1:0]	dB	[min:step:max]
f_z	25.16	GHz	
f_p1	40.00	GHz	
f_p2	56.00	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	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		

sample_adjustment	[-16, 16]		
ts_anchor	1		
RXFFE FLOAT CTL	Taps		
FFE_OPT_METHOD	MMSE		'MMSE', 'FV-LMS'
TS_SRCH_METHOD	middle		
num_ui_RXFF_noise	2048		

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	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	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

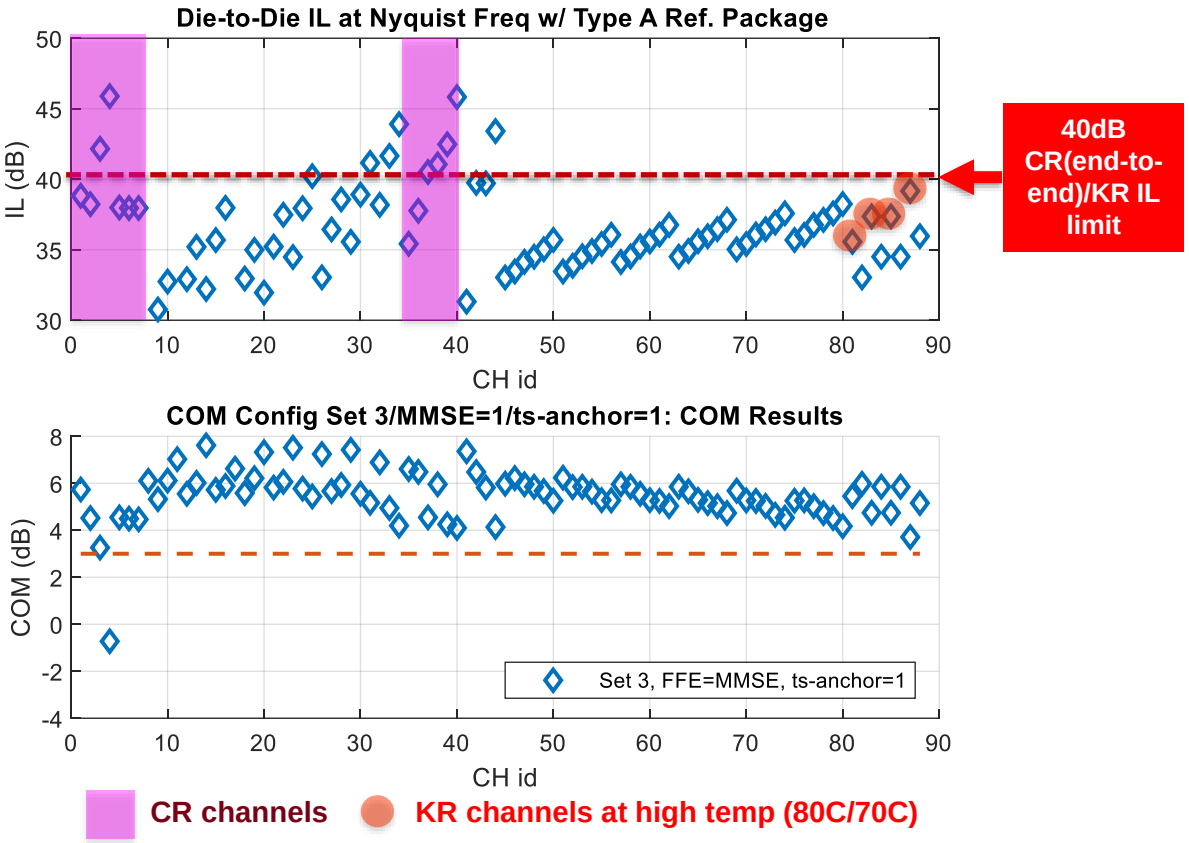
Notes:

- ***Parameter changes from Modified COM Config Set 2 as in [2] are marked in yellow***
- ***COM v4.50B3 was used in this study***

IEEE 802.3dj CR/KR Test Channels IL and COM

FFE_OPT_METHOD = MMSE, ts_anchor = 1 w/ range [-16, 16]

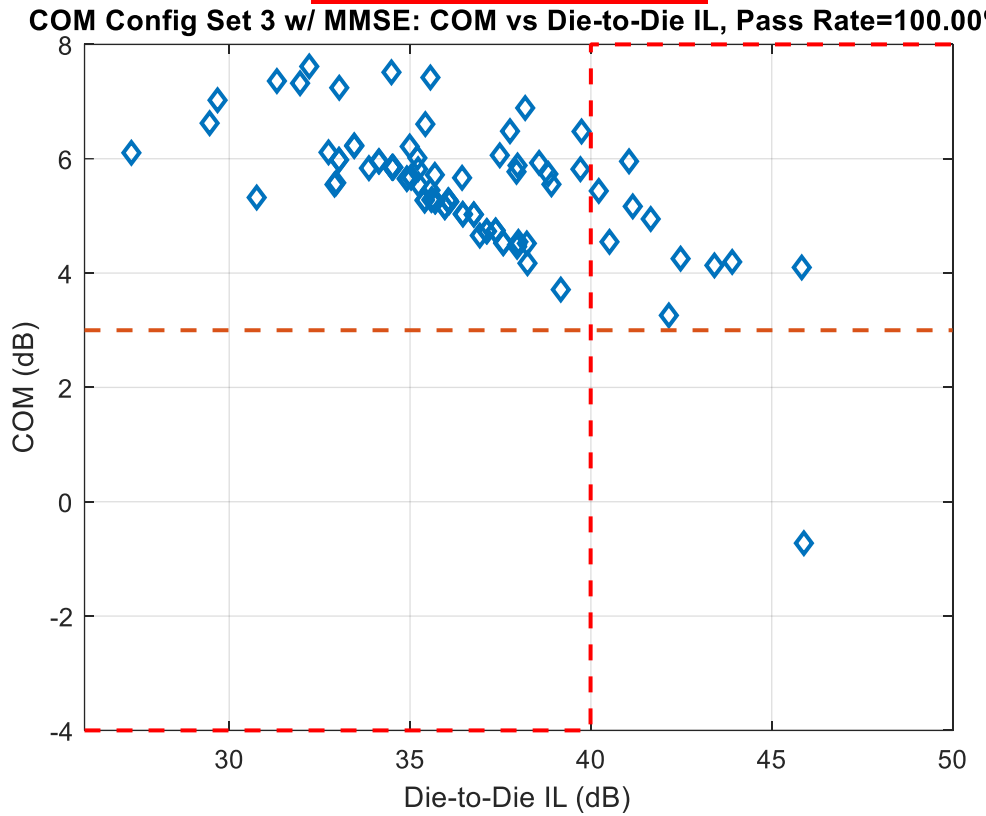
Die-to-Die IL and COM



40dB CR(end-to-end)/KR IL limit

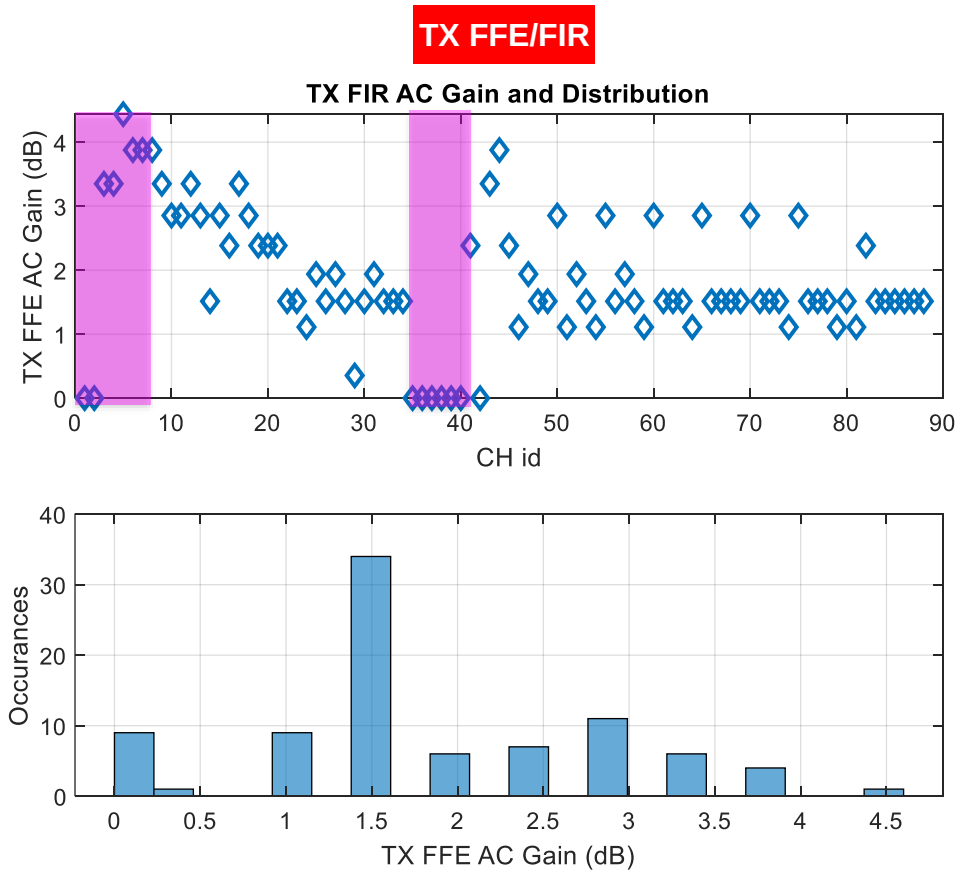
- Among 88 channels, 87 passed 3dB COM
  - Pass rate: 98.86%
  - Better than the pass rate as Modified COM Config Set 2 in [2]

40dB IL Target vs 3dB COM



- With 802.3dj's 40dB channel IL limit target
  - 77 channels met 40dB IL target
  - 77 channels met both 40dB IL and 3dB COM
  - Pass rate: 100%
  - Better than the pass rate as Modified COM Config Set 2 in [2]

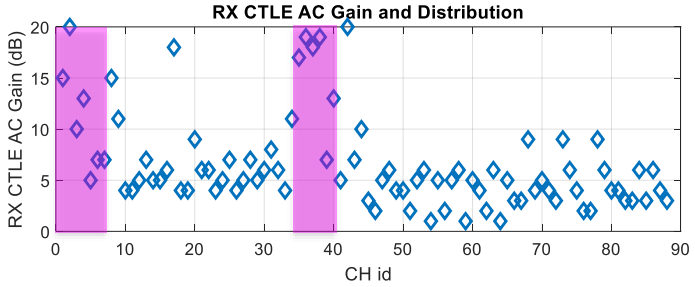
TX FFE/FIR Usage and Observations

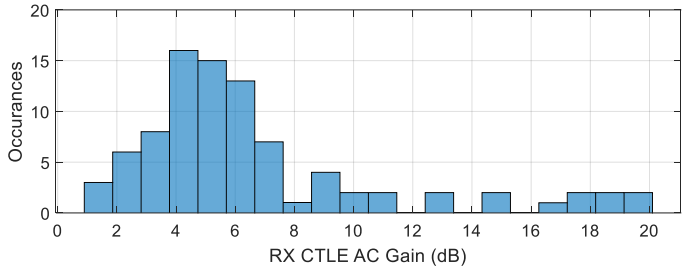


- TX FFE taps usage
  - Pre-tap 2: 1 cases, mean = 0.10
  - Pre-tap 1: 79 cases, mean = -0.1030
  - Main tap: 88 cases, mean = 0.9064
  - Post-tap 1: 0 cases, mean = 0
- Observations
  - Much reduced TX FFE usage than previous COM revisions
  - Possible to further reduce TX FFE/FIR length
    - 2 Pre-taps + Main tap, or
    - 1 Pre-tap + Main tap

RX EQ Usage and Observations

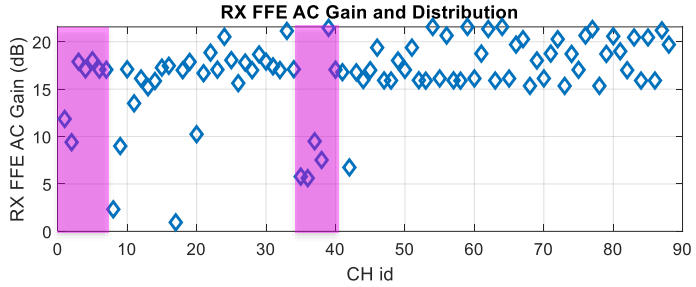
CTLE

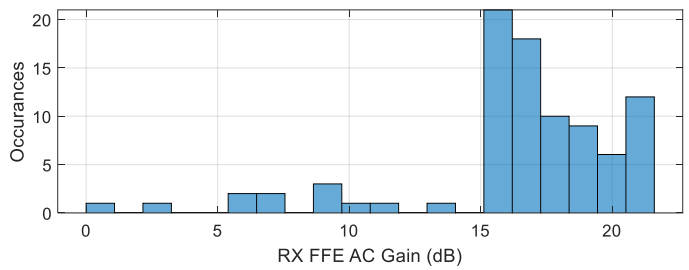


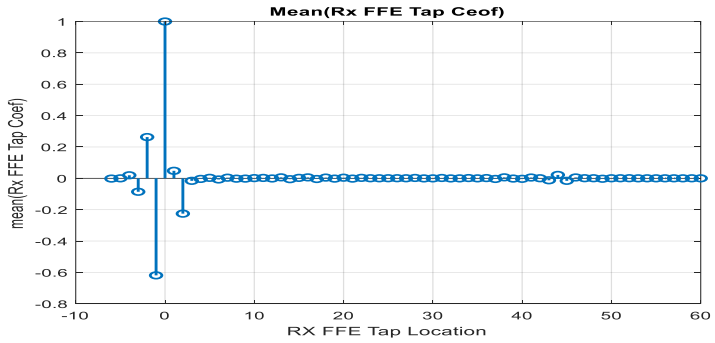


- RX CTLE usage
  - CR channels tend to have higher CTLE usage
- Observations
  - Extend CTLE gain range?

RX FFE

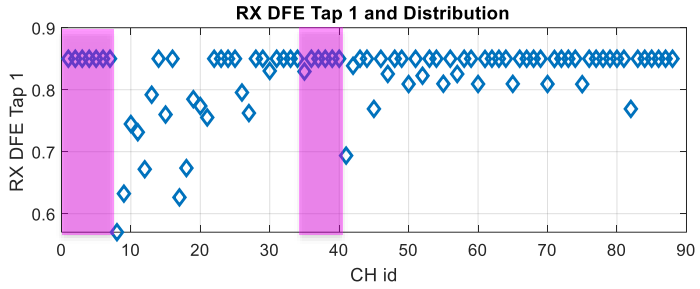


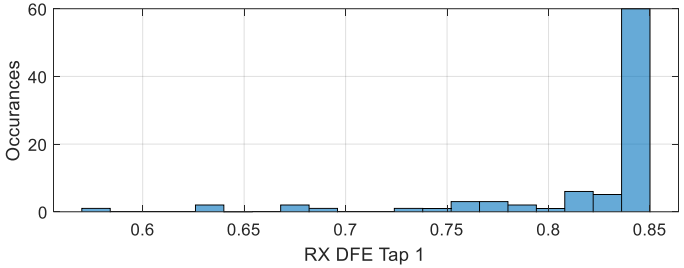




- RX FFE usage
  - KR channels tend to have higher RX FFE usage

RX DFE

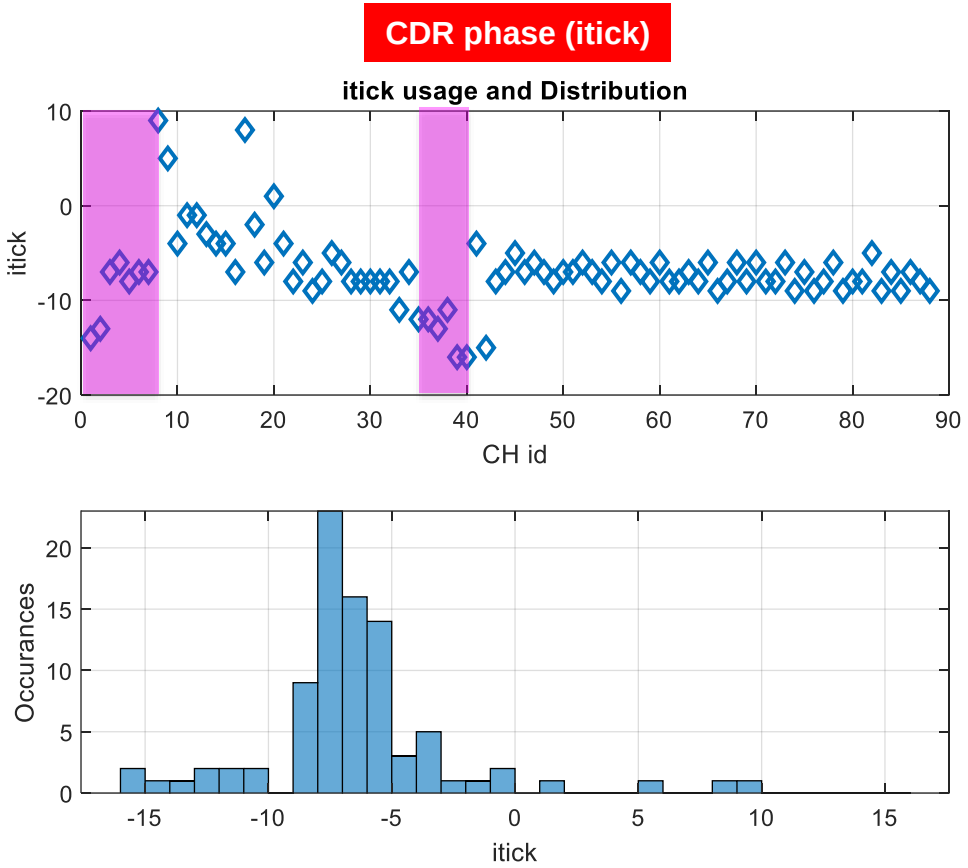




- RX DFE usage
  - Maxed out at 0.85 (per COM configuration) for most cases

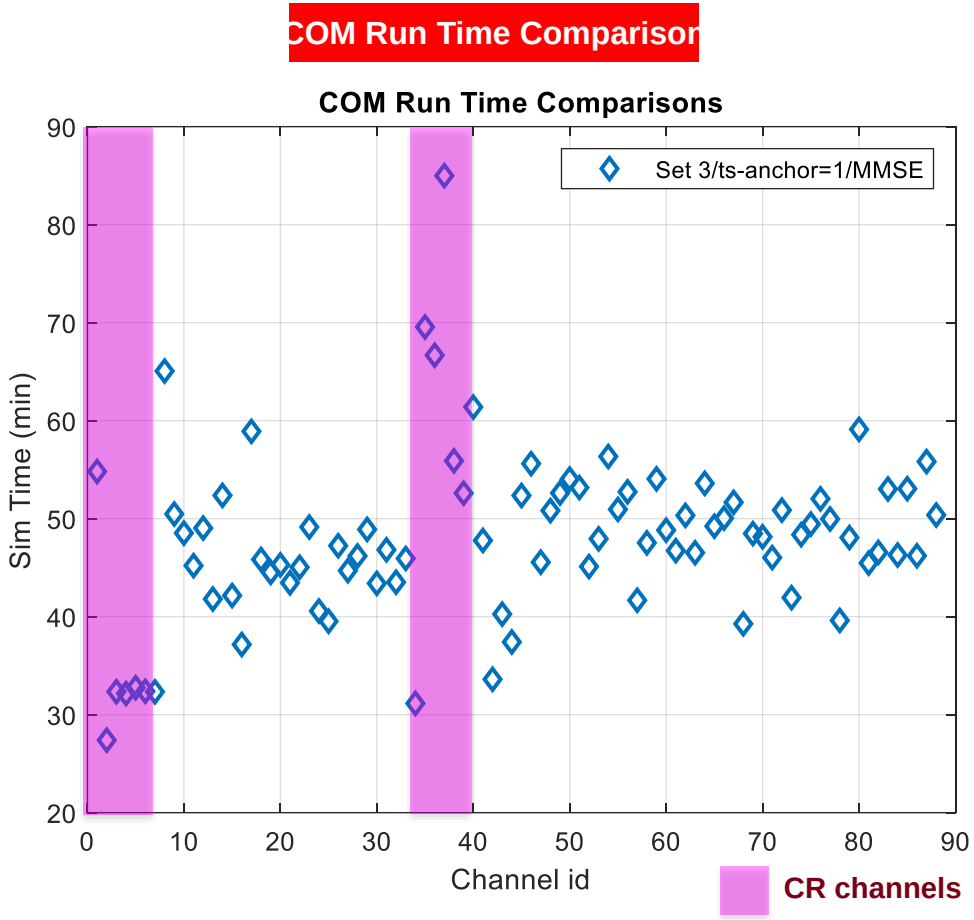
CR channels

CDR Phase Range Observations



- CDR phase range
  - Min = -16
  - Max = 9
- Observations
  - Recommend setting sample_adjustment to [-16:16]

COM Run Time



- Slow COM run time with MMSE method
  - Take ~3 days to run 88 COM analysis with MMSE method
  - Avg: ~48 min per run, max = 85 min.
- Used TS_SRCH_METHOD = middle for this study
  - TS_SRCH_METHOD = full-sweep is suggested/recommended for optimal results but it takes too much time for COM analysis
    - Saw > 4 hours for each single case (per package/channel combination)

Summary

- COM with MMSE EQ optimization method analysis indicated that:
  - Ref TX and RX/MMSE EQ can support most (87) of the 802.3dj CR /KR channels (end-to-end) with Class A reference package
- Results obtained from those simulation results will be used to support the proposed comments against 802.3dj 1.0 spec accordingly/appropriately
- Further potential improvements
  - Increase CTLE gain range for better perf
  - Reduce the long run time, yet keep the same accuracy

References

[1] https://www.ieee802.org/3/dj/public/24_01/healey_3dj_01_2401.pdf

[2] https://www.ieee802.org/3/dj/public/23_07/lim_3dj_03a_2307.pdf

Thank You!