

212.5 Gbps PAM4 COM Link Simulations and Analyses for CR and KR Channels: COM FFE Determined with MMSE

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

- Background / Goals
 - MMSE-based equalization optimization scheme was proposed[1], adopted, and “prototyped” in COM v4.30
 - Using updated reference transmitter/receiver configurations and 802.3dj CR (end-to-end)/KR channels, we performed COM analysis with updated EQ determination/optimization method
 - The COM configurations were updated from the modified COM Config Set 2[2]
 - Per [3], floating taps were not used in this study
 - Goals are:
 - Identify 802.3dj CR (end-to-end)/KR solution space with new MMSE method for RX FFE/EQ determination

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:
 - 67 fixed taps (6 pre-taps and 60 post-taps) per “COM Reference RX Progress Update –29 February 2024” suggestion
 - vs. the target FFE configuration (to be investigated in the future)
 - » 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 other 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]

Changes, from Modified COM Config Set 2 as in [2], were marked in red.

COM Configuration

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	60		
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'
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	

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	0	0 1 2 or 3 groups
N_bf	0	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:

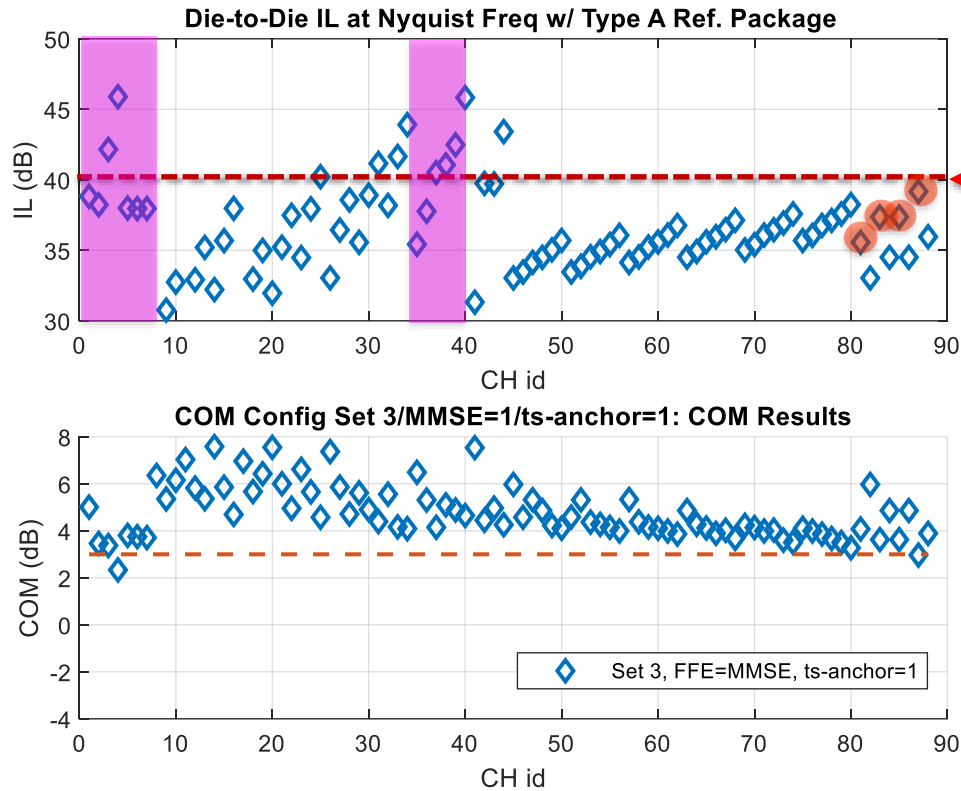
- Parameter changes from Modified COM Config Set 2 as in [2] are marked in yellow
- COM v4.30 was used in this study



IEEE 802.3dj CR/KR Test Channels IL and COM

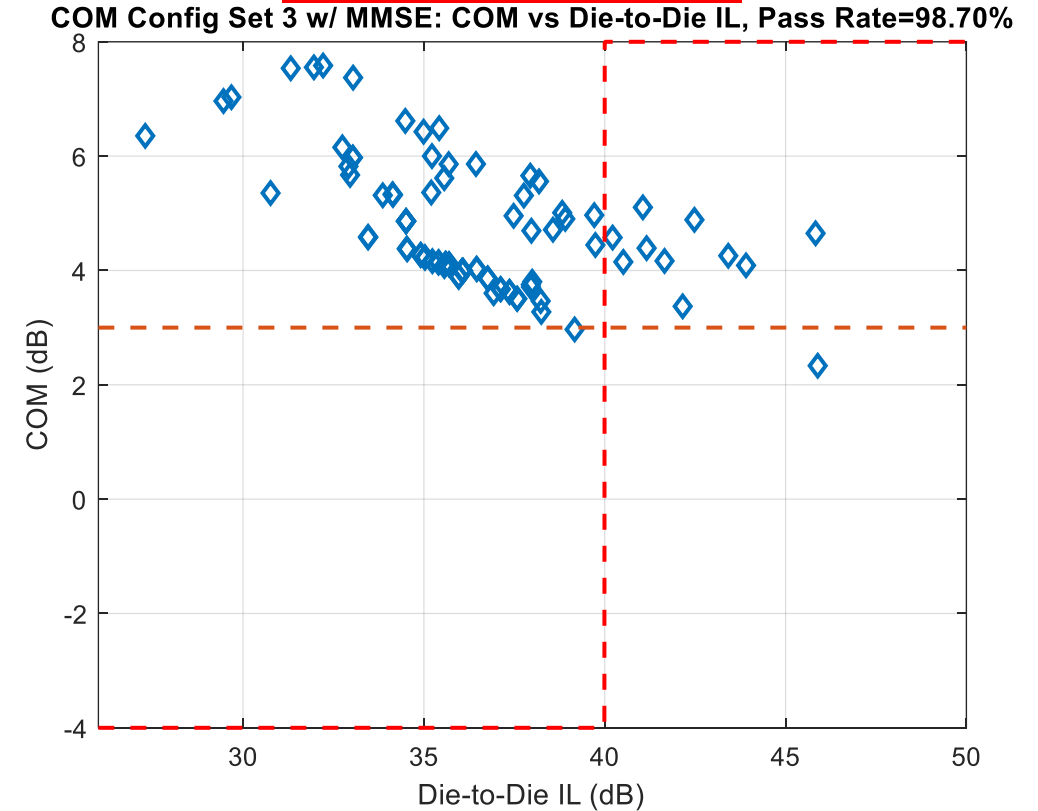
FFE_OPT_METHOD = MMSE, ts_anchor = 1 w/ range [-16, 16]

Die-to-Die IL and COM



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

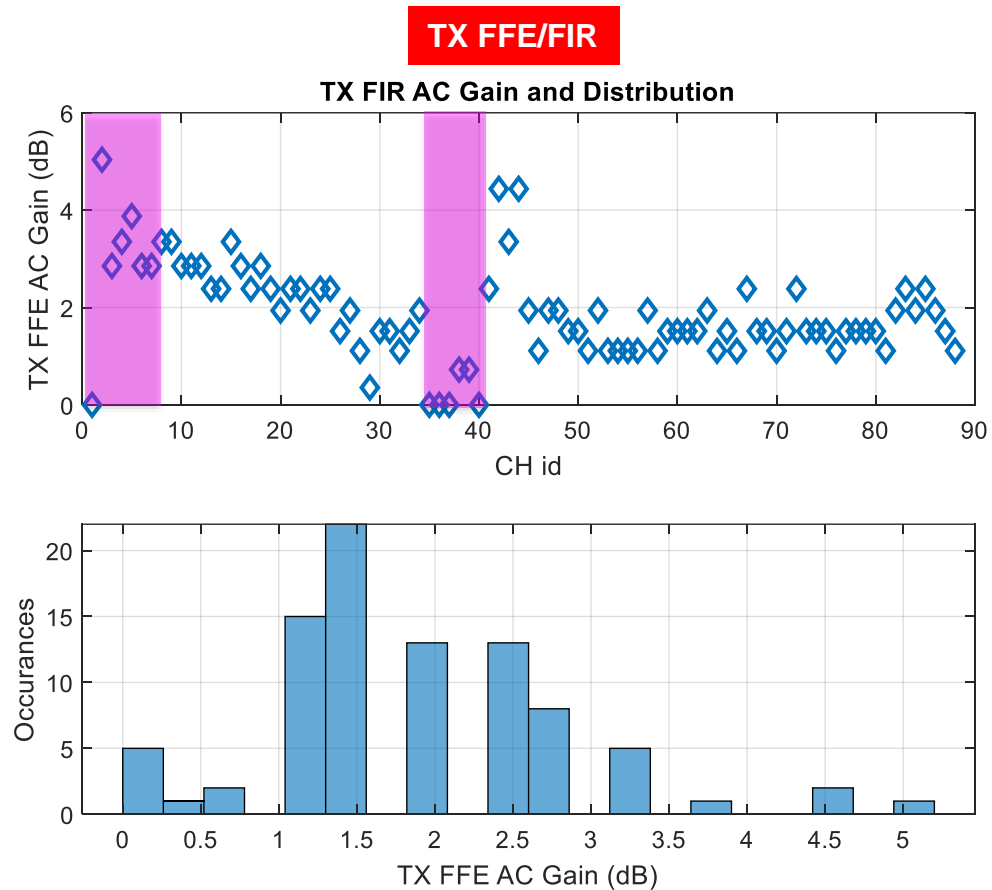
40dB IL Target vs 3dB COM



- Among 88 channels, only 2 failed 3dB COM
 - Pass rate: 97.73%
 - Same pass rate as Modified COM Config Set 2 in [2]

- With 802.3dj's 40dB channel IL limit target
 - 77 channels met 40dB IL target
 - 76 channels met both 40dB IL and 3dB COM
 - Pass rate: 98.70%
 - Same pass rate as Modified COM Config Set 2 in [2]

TX FFE/FIR Usage and Observations

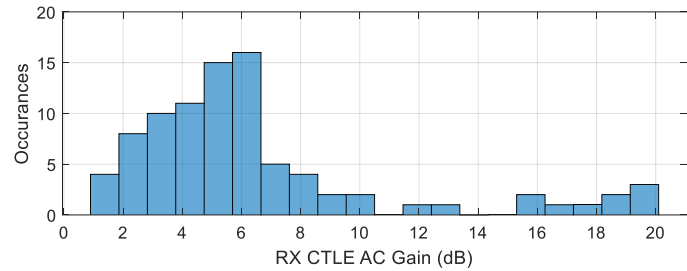
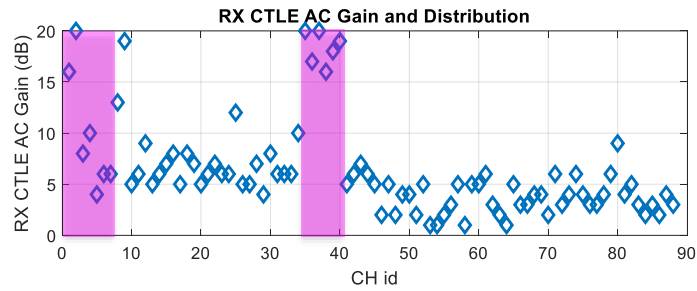


- TX FFE taps usage
 - Pre-tap 2: 3 cases, mean = 0.02
 - Pre-tap 1: 81 cases, mean = -0.102
 - Main tap: 88 cases, mean = 0.9045
 - Post-tap 1: 2 cases, mean = -0.04
- Observations
 - Much reduced TX FFE usage than previous COM revisions
 - Possible to further reduce TX FFE/FIR length
 - 2 Pre-taps + Main tap, or
 - 1 Pre-tap + Main tap

 CR channels

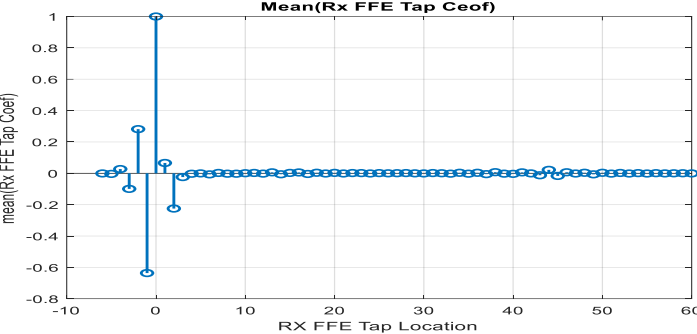
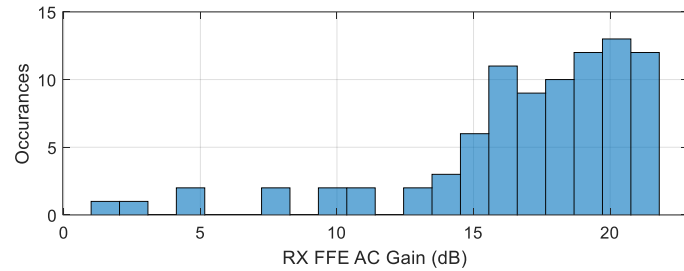
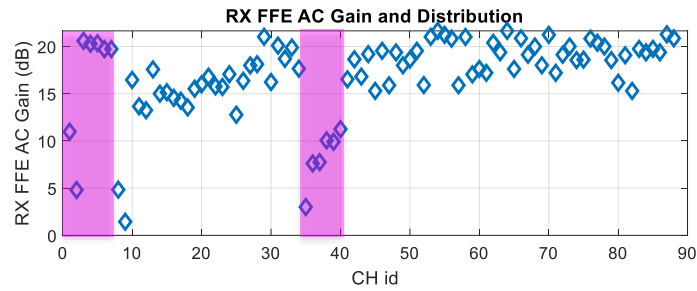
RX EQ Usage and Observations

CTLE



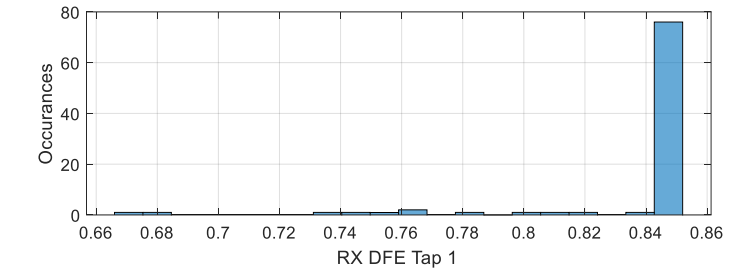
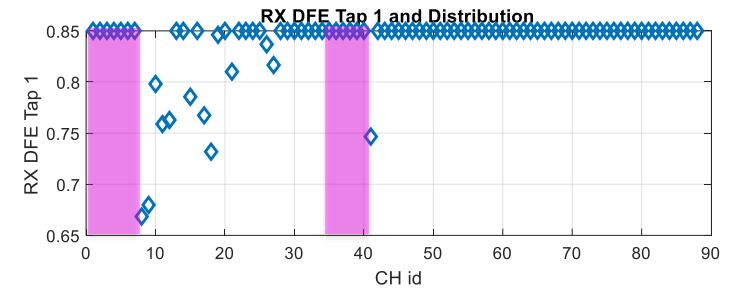
- RX CTLE usage
 - CR channels tend to have higher CTLE usage
- Observations
 - Extend CTLE gain range?

RX FFE



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

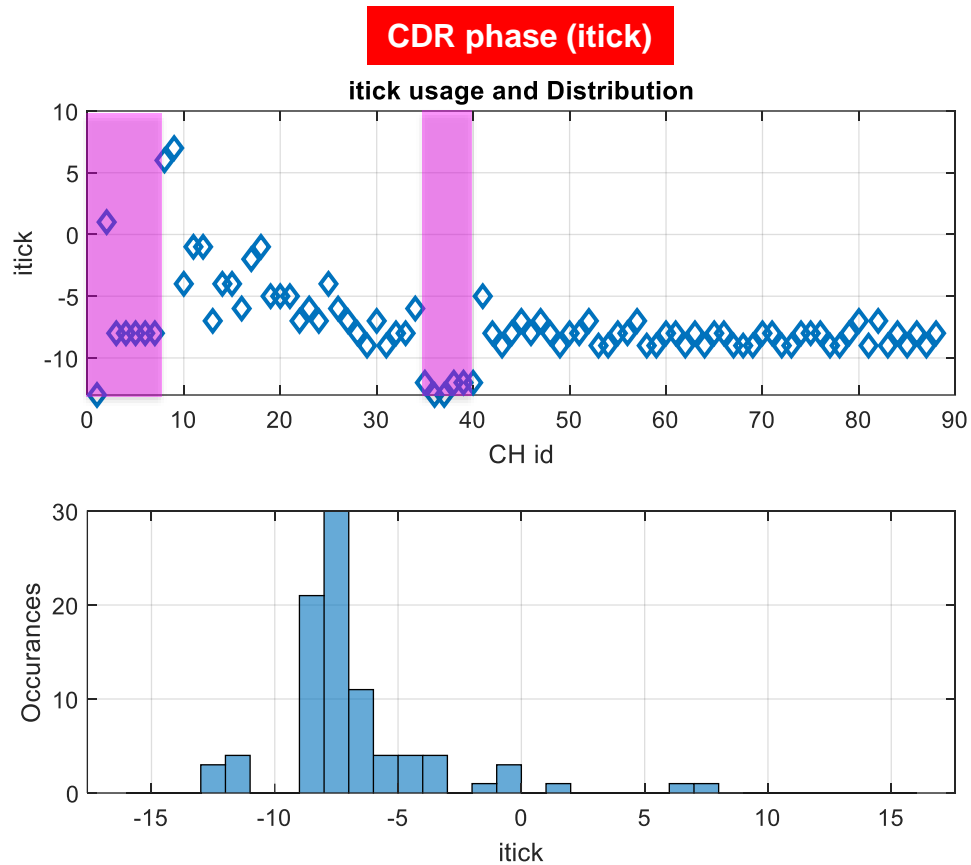
RX DFE



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

 CR channels

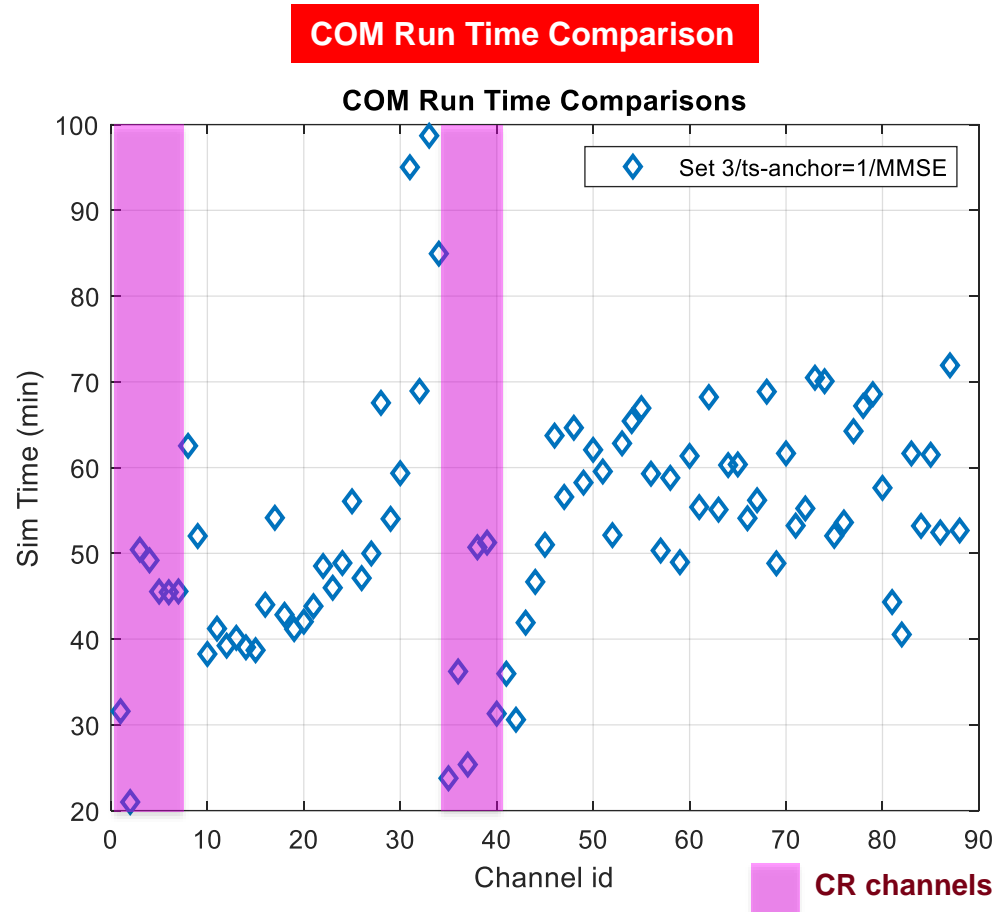
CDR Phase Range Observations



- CDR phase range
 - Min = -13
 - Max = 7
- Observations
 - Recommend setting `sample_adjustment` to [-16:16]

 CR channels

COM Run Time



- Slow COM run time with MMSE method
 - Take ~3.5 days to run 88 COM analysis with MMSE method
 - Avg: ~52 min per run, max = 98 min.

Summary

- COM with MMSE EQ optimization method analysis indicated that:
 - Ref TX and RX/MMSE EQ can support most of the 802.3dj CR (end-to-end)/KR channels with Class A reference package
- Discussions and future investigations
 - Room to further reduce/optimize the number of TX FFE/FIR taps
 - Increase CTLE gain range for better perf
 - Recommend setting `sample_adjustment` to `[-16:16]` 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
- [3] https://www.ieee802.org/3/dj/public/adhoc/electrical/24_0229/lusted_3dj_elec_01a_240229.pdf

Thank You!