Choosing an Optimum Reference Receiver for 200Gbps/Lane KR and CR

Tobey P.-R. Li, Mau-Lin Wu

MediaTek

IEEE P802.3dj Task Force

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Outline

- ☐ Investigation Highlights
- ☐ Update to CR and KR Link Simulation based on COM 4.5beta3
- ☐ Reference Receiver Parameters Study
- ☐ Proposed Changes to Table 178–13 and Table 179-16

Investigation Highlights

- A wide range of reference receiver parameters were used for CR & KR analysis
  - Contributions used reference receiver framework of RxFFE + 1-tap DFE and MMSE methodology

	COM	f_r	eta_0	b_max (1)	d_w	N_fix	N_g	N_f	MLSE	Note
lim_3dj_02_2403	4.3	0.5	5e-9	0.85	6	67	0	-	1	
healey_3dj_01_2401	4.2beta	0.58	6e-9	0.85	5	10	[0, 1]	4	0	• No guarantee 40 dB loss budget • Short PKG effect haven't been studied
lit_3dj_01a_2403	4.4beta	0.58	6e-9	0.75	5	10	1	4	0	• No guarantee 40 dB loss budget

- This presentation will investigate the effect on reference receiver parameters
  - Number of Rx FFE fixed-position taps: [16:4:24 30 40:20:120]
  - Requirement of Rx FFE floating taps: [2:2:10] groups* 4 taps per group
  - Requirement of MLSE

Channel Test Cases

- Channel source: Tools & Channels

CR/KR Channel Source	Test Cases
shanbhag_3dj_01_2305	6
kocsis_3dj_02_2305	5
lim_3dj_03_230629	1
lim_3dj_04_230629	1
lim_3dj_07_2309	1
akinwale_3dj_02_2311	4
weaver_3dj_02_2311	12
mellitz_3dj_02_elec_230504	27
weaver_3dj_02_2305	36
shanbhag_3dj_02_2305	4
weaver_3dj_elec_01_230622	4
akinwale_3dj_01_2310	7
Total	**108**

- Package model follows 802.3dj D1.0 Table 179–15

Table 179–15—Device, package, and PCB model parameters

Parameter	Symbol	Value	Units
Device model			
Single-ended device capacitance for stage 1	$C_d^{(1)}$	40×10^{-6}	nF
Single-ended device capacitance for stage 2	$C_d^{(2)}$	90×10^{-6}	nF
Single-ended device capacitance for stage 3	$C_d^{(3)}$	110×10^{-6}	nF
Single-ended device series inductance for stage 1	$L_s^{(1)}$	0.13	nH
Single-ended device series inductance for stage 2	$L_s^{(2)}$	0.15	nH
Single-ended device series inductance for stage 3	$L_s^{(3)}$	0.14	nH
Single-ended bump capacitance	C_b	30×10^{-6}	nF
Class A package model			
Transmission line parameter γ_0	γ_0	5×10^{-4}	1/mm
Transmission line parameter a_1	a_1	8.9×10^{-4}	$ns^{1/2}$/mm
Transmission line parameter a_2	a_2	2×10^{-4}	ns/mm
Transmission line parameter τ	τ	~~6.141×10^{-4}~~ 6.141e-3	
Transmission line 1 length, Test 1	$z_p^{(1)}$	33	mm
Transmission line 1 length, Test 2	$z_p^{(1)}$	12	mm
Transmission line 1 characteristic impedance	$Z_c^{(1)}$	87.5	Ω
Transmission line 2 length	$z_p^{(2)}$	1.8	mm
Transmission line 2 characteristic impedance	$Z_c^{(2)}$	92.5	Ω
Single-ended package capacitance at package-to-board interface	C_p	40×10^{-6}	nF
Class B package model			
Transmission line parameter γ_0	γ_0	5×10^{-4}	1/mm
Transmission line parameter a_1	a_1	6.5×10^{-4}	$ns^{1/2}$/mm
Transmission line parameter a_2	a_2	2.93×10^{-4}	ns/mm
Transmission line parameter τ	τ	~~6.141×10^{-4}~~ 6.141e-3	
Transmission line 1 length, Test 1, Tx / Rx	$z_p^{(1)}$	45 / 44	mm
Transmission line 1 length, Test 2, Tx / Rx	$z_p^{(1)}$	30 / 29	mm
Transmission line 1 characteristic impedance	$Z_c^{(1)}$	87.5	Ω
Transmission line 2 length	$z_p^{(2)}$	2	mm
Transmission line 2 characteristic impedance	$Z_c^{(2)}$	95	Ω
Transmission line 3 length	$z_p^{(3)}$	1.3	mm
Transmission line 3 characteristic impedance	$Z_c^{(3)}$	100	Ω
Transmission line 4 length	$z_p^{(4)}$	1.5	mm
Transmission line 4 characteristic impedance	$Z_c^{(4)}$	78	Ω
Single-ended package capacitance at package-to-board interface	C_p	40×10^{-6}	nF

COM Configuration

- **Simulator: COM 4.50beta3**

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	[0.13 0.15 0.14; 0.13 0.15 0.14]	nH	[TX RX]
C_b	[0.3e-4 0.3e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50 50]	Ohm	[TX RX]
PKG_NAME	PKG_LowR_CLASSA PKG_LowR_CLASSA		TX RX
A_v	0.413	V	
A_fe	0.413	V	
A_ne	0.608 *	V	
z_p select	[1 2]		
L	4		
M	32		
filter and Eq			
f_r	0.58	*fb	
c(0)	0.5		min
c(-1)	-0.34:0.02:0		[min:step:max]
c(-2)	0:0.02:0.12		[min:step:max]
c(-3)	0		[min:step:max]
c(1)	-0.2:0.02:0		[min:step:max]
N_b	1	UI	
b_max(1)	0.75		As/dffe1
b_max(2..N_b)	0		As/dfe2..N_b
b_min(1)	0		As/dffe1
b_min(2..N_b)	0	S	As/dfe2..N_b
g_DC	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	1.328125	GHz	
Butterworth	1	logical	include in fr

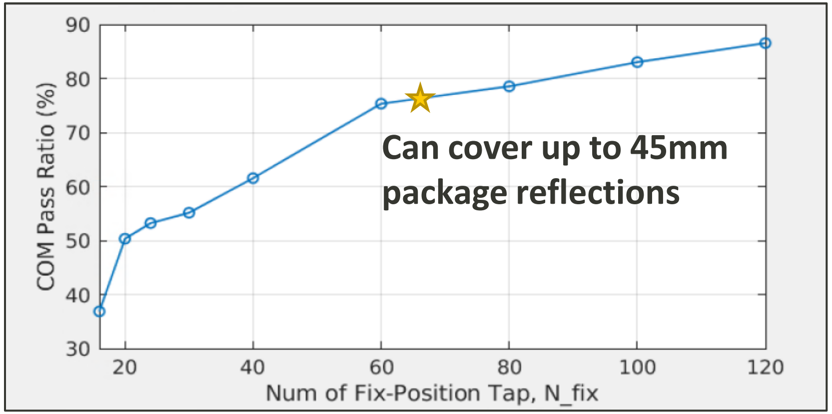
I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	0	logical
RESULT_DIR	.\results\CRKR_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	KR_set1_eval_	
COM_CONTRIBUTION	1	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	ns
TR_TDR	0.01	
N	7000	logical
TDR_Butterworth	1	
beta_x	0	
rho_x	0.618	
TDR_W_TXPKG	0	UI
N_bx	0	
fixture delay time	[0 0]	
Tukey_Window	1	
Noise, jitter		UI
sigma_RJ	0.01	UI
A_DD	0.02	V^2/GHz
eta_0	6.00E-09	dB
SNR_TX	33	
R_LM	0.95	

Operational		
ERL Pass threshold	10	dB
COM Pass threshold	3	db
DER_0	2.00E-04	
T_r	0.004	ns
FORCE_TR	1	logical
PMD_type	C2C	
EW	1	
MLSE	0	logical
ts_anchor	1	
sample_adjustment	[-16 16]	
Local Search	0	
Filter: Rx FFE		
ffe_pre_tap_len	6	UI
ffe_post_tap_len	24	UI
ffe_pre_tap1_max	1	
ffe_post_tap1_max	1	
ffe_tapn_max	1	
FFE_OPT_METHOD	MMSE	
num_ui_RXFF_noise	4096	
Floating Tap Control		
N_bg	0	0 1 2 or 3 groups
N_bf	4	taps per group
N_f	80	UI span for floating taps
bmaxg	1	max DFE value for floating taps
B_float_RSS_MAX	1	rss tail tap limit
N_tail_start	25	(UI) start of tail taps limit
RXFFE FLOAT CTL	FOM	

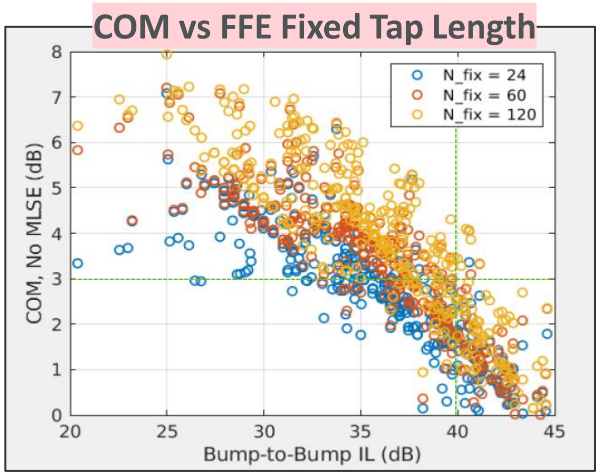
** Was 0.45 in lit_3dj_01a_2403*

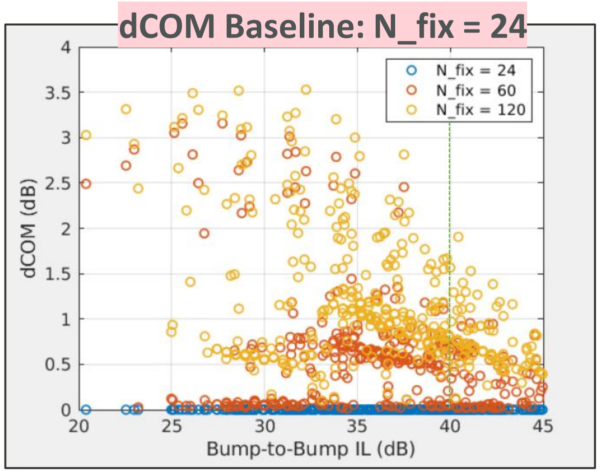
COM vs RX FFE Fixed-Tap Length

- **For this set of data, d_w = 6 and MLSE = 0**
- **Short/reflective channels can comfortably exceed COM of 3dB with increasing number of taps**
- **Increasing N_fix to 60 or 120 doesn't make 40dB loss channels pass**



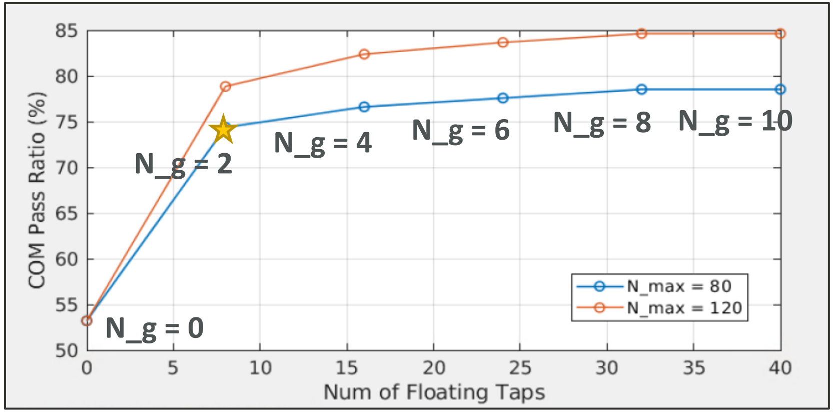
** Pass criteria: COM >= 3dB & Channel bump-to-bump IL <= 40dB*





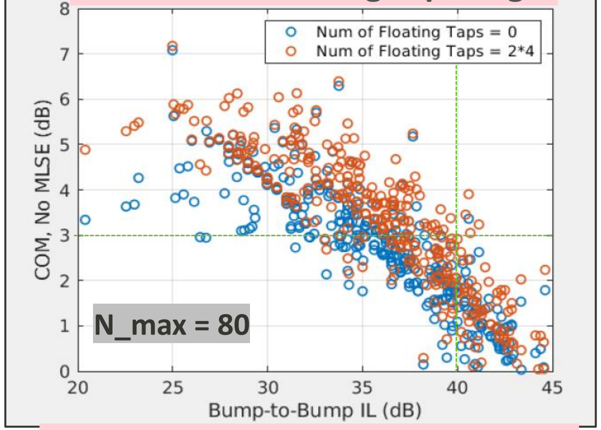
COM vs RX FFE Floating-Tap Length

- For this set of data, d_w = 6, N_fix = 24, N_f = 4, and MLSE = 0
- Floating taps can provide higher flexibility and can use a fewer taps to achieve comparable performance as long FFE fixed taps

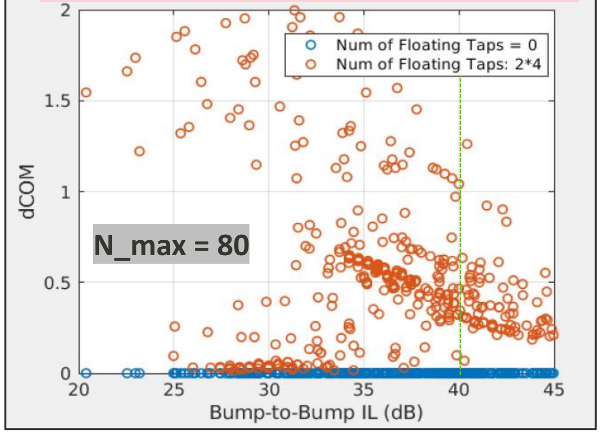


** Pass criteria: COM >= 3dB & Channel bump-to-bump IL <= 40dB*

COM vs FFE Floating Tap Length

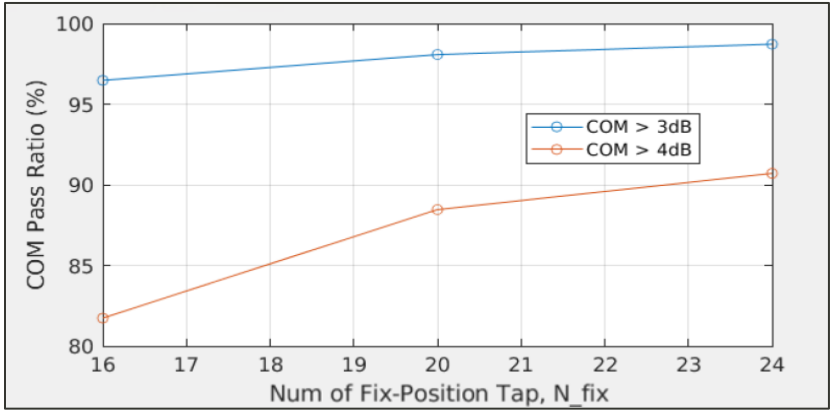


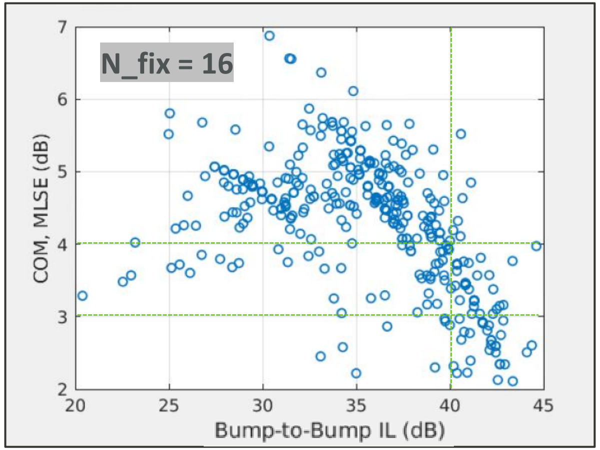
dCOM Baseline: FFE Fixed Tap Only



COM with MLSE Enabled

- **For this set of data, d_w = 6, N_g = 0, and MLSE = 1**
- **Most of the channels can meet 3 dB COM by using MLSE + short FFE fixed taps**
  - **MLSE has proven to be successful in compensating additional loss due to higher Nyquist frequency**
  - **In real world, MLSE gain for 40dB channels is a little over 1dB → MLSE penalty ~1dB**

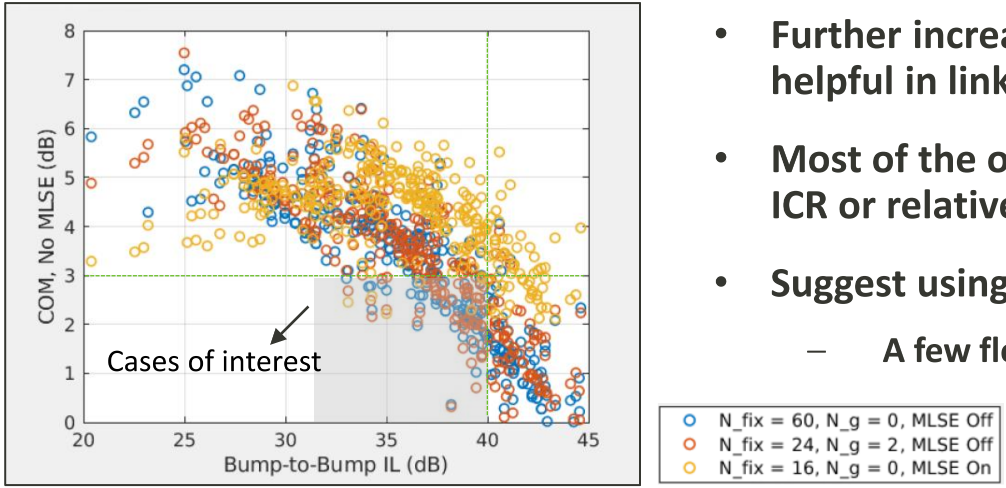




- *Pass criteria: COM >= 3dB (or 4dB) & Channel bump-to-bump IL <= 40dB*

Choosing An Optimum Reference Receiver

	d_w	N_fix	N_g*N_f	N_max	MLSE	COM Pass Ratio	EQ Power
~~FFE Fixed Tap Only~~	6	60	0	-	0	75%	High
FFE Fixed Taps + Floating Taps	6	24	2*4	80	0	74%	Low (If small N_g)
FFE Fixed Taps + MLSE	6	16	0	-	1	96% for COM >= 3dB 82% for COM >= 4dB	Low



- Further increasing number of taps seems less helpful in link budget expansion
- Most of the outlier channels are with either lower ICR or relatively low channel ERL, see Appendix
- Suggest using short FFE fixed taps together with
  - A few floating groups or MLSE

Proposal: Option A

- **Ref RX: RxFFE fixed taps + MLSE**
- **Proposed COM parameter values to Table 178–13 and Table 179-16**

Parameter	Symbol	Value	Units
Random jitter, RMS	σ_{RJ}	TBD	UI
Dual-Dirac jitter, peak	A_{DD}	TBD	UI
Level separation mismatch ratio	R_{LM}	0.95	—
Number of samples per unit interval	M	32	—
Receiver discrete-time equalizer parameters			
Number of pre-cursor taps	d_w	6	—
Number of fixed-position taps	N_{fix}	16	—
Number of floating tap groups	N_g	0	—
Number of taps per floating tap group	N_f	TBD	—
Highest allowed tap index	N_{max}	TBD	—
Normalized upper limit on feed-forward coefficient w(j)	$w_{max}(j)$	TBD	—
Normalized lower limit on feed-forward coefficient w(j)	$w_{min}(j)$	TBD	—
Number of feedback taps	N_b	1	—
Normalized upper limit on feedback coefficient b(j)	$b_{max}(j)$	0.75	—
Normalized lower limit on feedback coefficient b(j)	$b_{min}(j)$	0	—
Target detector error ratio	DER_0	2×10^{-4}	—

Additionally, set MLSE = 1
MLSE penalty shall be considered

** Proposed for COM parameters only, not for TX training*

Parameter	Symbol	Value	Units
Signaling rate	f_b	106.25	GBd
Maximum start frequency	f_{min}	0.05	GHz
Maximum frequency step	Δf	0.01	GHz
Receiver 3 dB bandwidth	f_r	0.58*fb ~62GHz	
Transmitter equalizer, coefficient –3 Minimum value Maximum value Step size	$c(-3)$	Remove it*	—
Transmitter equalizer, coefficient –2 Minimum value Maximum value Step size	$c(-2)$	0:0.02:0.12	—
Transmitter equalizer, coefficient –1 Minimum value Maximum value Step size	$c(-1)$	-0.34:0.02:0	—
Transmitter equalizer, coefficient 0 Minimum value	$c(0)$	0.5	—
Transmitter equalizer, coefficient 1 Minimum value Maximum value Step size	$c(1)$	-0.2:0.02:0	—
Continuous time filter, gain 1 Minimum value Maximum value Step size	g_1	–20 0 1	dB dB dB
Continuous time filter, gain 2 Minimum value Maximum value Step size	g_2	–6 0 1	dB dB dB
Continuous time filter, zero 1 frequency for g_1=0 Continuous time filter, zero 1 frequency for g_2=0	f_{z1} f_{z2}	f_b / 2.5 f_b / 80	GHz GHz
Continuous time filter, pole 1 frequency Continuous time filter, pole 2 frequency Continuous time filter, pole 3 frequency	f_{p1} f_{p2} f_{p3}	f_b / 2.5 f_b f_b / 80	GHz GHz GHz
Transmitter differential peak output voltage Victim Far-end aggressor Near-end aggressor	A_v A_{fe} A_{ne}	0.413 0.413 0.608	V V V
Transmitter transition time	T_r	0.004	ns
Number of signal levels	L	4	—
One-sided noise spectral density	η_0	6e-9	V^2/GHz
Transmitter signal-to-noise ratio	SNR_{TX}	33	dB

Proposal: Option B

- Ref RX: RxFFE fixed taps + floating taps
- Proposed COM parameter values to Table 178–13 and Table 179-16

Parameter	Symbol	Value	Units
Random jitter, RMS	σ_{RJ}	TBD	UI
Dual-Dirac jitter, peak	A_{DD}	TBD	UI
Level separation mismatch ratio	R_{LM}	0.95	—
Number of samples per unit interval	M	32	—
Receiver discrete-time equalizer parameters Number of pre-cursor taps Number of fixed-position taps Number of floating tap groups Number of taps per floating tap group Highest allowed tap index Normalized upper limit on feed-forward coefficient $w(j)$ Normalized lower limit on feed-forward coefficient $w(j)$ Number of feedback taps Normalized upper limit on feedback coefficient b(j) Normalized lower limit on feedback coefficient b(j)	d_w N_{fix} N_g N_f N_{max} $w_{max}(j)$ $w_{min}(j)$ N_b $b_{max}(j)$ $b_{min}(j)$	6 24 2 4 65 TBD TBD 1 0.75 0	— — — — — — — — — —
Target detector error ratio	DER_0	2×10^{-4}	—

Additionally, set MLSE = 0

Parameter	Symbol	Value	Units
Signaling rate	f_b	106.25	GBd
Maximum start frequency	f_{min}	0.05	GHz
Maximum frequency step	Δf	0.01	GHz
Receiver 3 dB bandwidth	f_r	0.58*fb ~62GHz	
Transmitter equalizer, coefficient –3 Minimum value Maximum value Step size	$c(-3)$	Remove it*	—
Transmitter equalizer, coefficient –2 Minimum value Maximum value Step size	$c(-2)$	0:0.02:0.12	—
Transmitter equalizer, coefficient –1 Minimum value Maximum value Step size	$c(-1)$	-0.34:0.02:0	—
Transmitter equalizer, coefficient 0 Minimum value	$c(0)$	0.5	—
Transmitter equalizer, coefficient 1 Minimum value Maximum value Step size	$c(1)$	-0.2:0.02:0	—
Continuous time filter, gain 1 Minimum value Maximum value Step size	g_1	–20 0 1	dB dB dB
Continuous time filter, gain 2 Minimum value Maximum value Step size	g_2	–6 0 1	dB dB dB
Continuous time filter, zero 1 frequency for g_1=0 Continuous time filter, zero 1 frequency for g_2=0	f_{z1} f_{z2}	f_b / 2.5 f_b / 80	GHz GHz
Continuous time filter, pole 1 frequency Continuous time filter, pole 2 frequency Continuous time filter, pole 3 frequency	f_{p1} f_{p2} f_{p3}	f_b / 2.5 f_b f_b / 80	GHz GHz GHz
Transmitter differential peak output voltage Victim Far-end aggressor Near-end aggressor	A_v A_{fe} A_{ne}	0.413 0.413 0.608	V V V
Transmitter transition time	T_r	0.004	ns
Number of signal levels	L	4	—
One-sided noise spectral density	η_0	6e-9	V^2/GHz
Transmitter signal-to-noise ratio	SNR_{TX}	33	dB

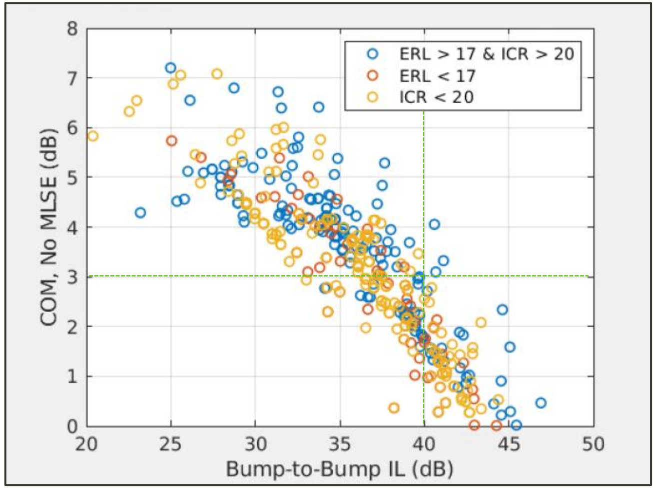
* Proposed for COM parameters only, not for TX training

Appendix

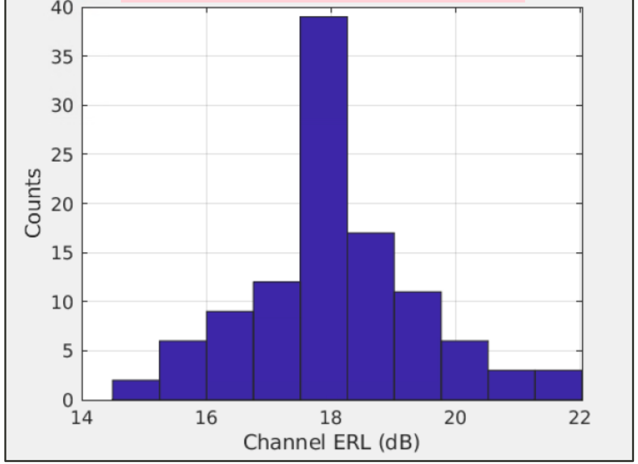
Channel Characteristics vs COM

- Ref RX: RxFFE fixed taps only
- ERL and ICR are used for relative comparison, not a baseline proposal

	d_w	N_fix	N_g*N_f	N_max	MLSE	COM Pass Ratio
FFE Fixed Tap Only	6	60	0	-	0	75%



The 20% to last ERL ~17dB

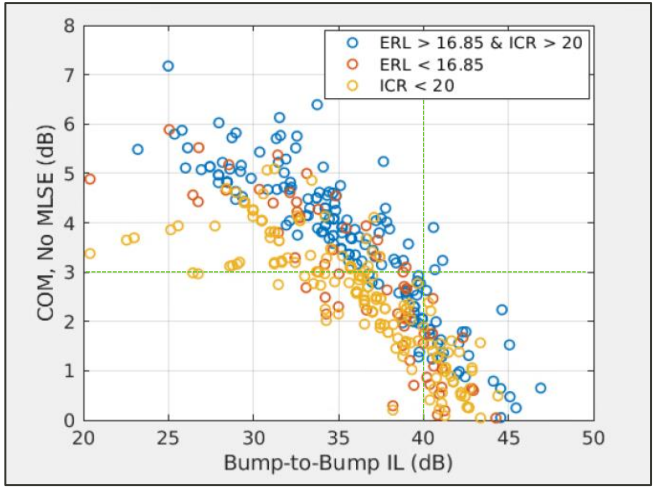


Symbol	Value	Units
T_r	0.01	ns
β_x	0	GHz
ρ_x	0.618	—
N	7000	UI
N_{bx}	60	UI
T_{fx}	0	ns
tw	1	—

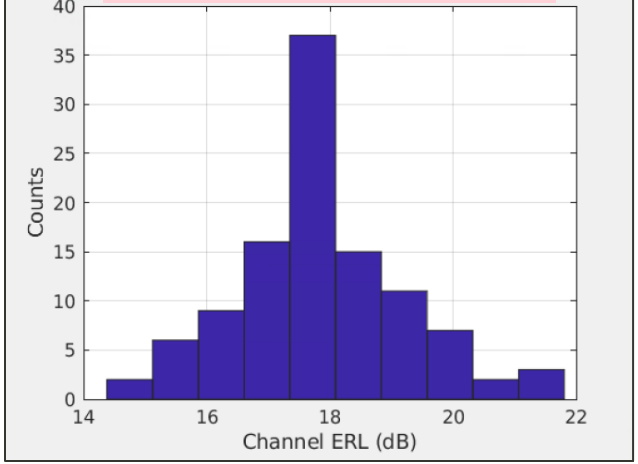
Channel Characteristics vs COM

- Ref RX: RxFFE fixed taps + floating taps
- ERL and ICR are used for relative comparison, not a baseline proposal

	d_w	N_fix	N_g*N_f	N_max	MLSE	COM Pass Ratio
FFE Fixed Tap + Floating Tap	6	24	2*4	80	0	74%



The 20% to last ERL ~16.85dB

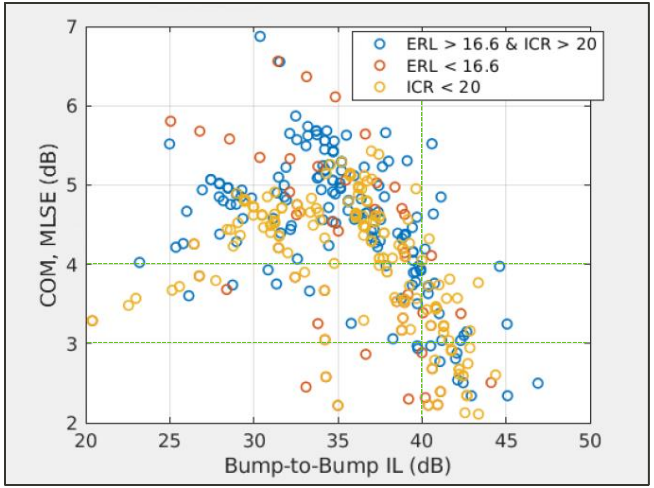


Symbol	Value	Units
T_r	0.01	ns
β_x	0	GHz
ρ_x	0.618	—
N	7000	UI
N_{bx}	32	UI
T_{fx}	0	ns
t_w	1	—

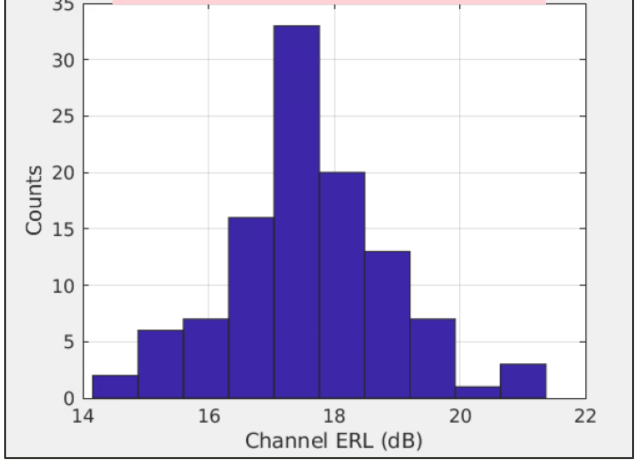
Channel Characteristics vs COM

- **Ref RX: RxFFE fixed taps + MLSE**
- **ERL and ICR are used for relative comparison, not a baseline proposal**

	d_w	N_fix	N_g*N_f	N_max	MLSE	COM Pass Ratio
FFE Fixed Tap + MLSE	6	16	0	-	1	96% for COM >= 3dB 82% for COM >= 4dB



The 20% to last ERL ~16.6dB



- **ERL Parameters**

Symbol	Value	Units
T_r	0.01	ns
β_x	0	GHz
ρ_x	0.618	—
N	7000	UI
N_{bx}	16	UI
T_{fx}	0	ns
t_w	1	—

Thank you

Questions and Discussions