MLSE Sequence Truncation Implementation Penalty

Hossein Shakiba
Huawei Technologies Canada
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Supporter(s)

- Upen Reddy Kareti (Cisco Systems Inc.)

Outline

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Motivation

- MLSE implementation penalty is still TBD in Draft 1.1 (Q in Equation 178A-36)
- It is one of the open "Big Ticket Items" after comment resolutions in June Electronic Interim (lusted_3dj_elec_01_240620.pdf)
- In shakiba_3dj_01a_2403.pdf the following implementation issues were listed and analyzed:
  - Pre-screening
  - Sequence Truncation
  - α Mismatch
  - Quantization Noise
- This contribution highlights sequence truncation as the primary implementation constraint specific to MLSE and proposes an analytic approach to quantify it
- Presented data is based on COM version "com_ieee8023_93a_460beta3_hs1p0"
  - Customization is to include implementation penalty due to truncation

Introduction

- Pre-screening provides a means of removing the MLSE ΔCOM improvement if the pre-MLSE signal quality is not suitable for clock recovery
  - ❖ It's been implemented in the COM code by ignoring MLSE and setting $\Delta COM = 0$ if DER before MLSE is higher than a set threshold (defaulted to 1E-2)
- Contributions shakiba_3dj_01a_2403.pdf and shakiba_3dj_02_2405.pdf demonstrated that quantization noise impact goes well beyond MLSE and suggested a direct method to include it as a new noise component at the COM and system modeling levels
- Contribution healey_3dj_01b_2405.pdf also recognized the importance of quantization noise and discussed the above and another approach to account for it
  - ❖ This contribution appears to favour the other approach that uses eta_0 as a knob to mimic the effect
- Currently, α mismatch is not recognized as a critical concern

Sequence Truncation

- One of the practical simplifications to MLSE is to limit length of the sequence
- There are several ways this can be implemented, but they all share a similar concept
- The case considered here for analysis is the case where the sequence processing and trace-back are both limited to a truncated length
- As a result:

1) Error events shorter than $trunc$ will still be entirely processed and Equation U1.c directly applies
   - Equation U1.c executes to its first $trunc - 1$ terms
2) Longer error events will be partially processed and in Equation U1.c:
   - The MLSE sequence noise will have $trunc$ terms
   - The PDF convolution expression iterates $trunc - 1$ times
   - The correlation matrix $\rho_{noise,jEE}$ truncates to a $\rho_{noise,truncEE}(trunc \times trunc)$ sub-matrix

Sequence Truncation in Equation U1.c*

$$PDF_{noise,jEE}(x) = \begin{cases} PDF_{noise}(x) * \mathrm{conv}_{i=2}^{j} \frac{1}{1-\alpha} PDF_{noise}\left(\frac{x}{1-\alpha}\right) * \frac{1}{\alpha} PDF_{noise}\left(\frac{x}{\alpha}\right) & , j < trunc \\ PDF_{noise,truncEE}(x) = PDF_{noise}\ (x) * \mathrm{conv}_{i=2}^{trunc} \frac{1}{1-\alpha} PDF_{noise}\left(\frac{x}{1-\alpha}\right) & j \geq trunc \end{cases}$$

$$\rho_{noise,jEE} = \begin{cases} \rho_{noise,jEE}\big((j+1) \times (j+1)\big) & , j < trunc \\ \rho_{noise,truncEE} = \rho_{noise,jEE}\big((1{:}\,trunc) \times (1{:}\,trunc)\big) & j \geq trunc \end{cases}$$

$$DER_{MLSE,trunc} \approx \sum_{j=1}^{trunc-1} \left(\frac{L-1}{L}\right)^{j-1} \left(CDF_{noise,jEE}\left(-A_s \frac{\left(\mathrm{trace}(\rho_{noise,jEE})\right)^{\frac{3}{2}}}{\sqrt{\sum_{vertical} \sum_{horizental}(\rho_{noise,jEE})}} \right) \right) + L \left(\frac{L-1}{L}\right)^{trunc-1} \left(CDF_{noise,truncEE}\left(-A_s \frac{\left(\mathrm{trace}(\rho_{noise,truncEE})\right)^{\frac{3}{2}}}{\sqrt{\sum_{vertical} \sum_{horizental}(\rho_{noise,truncEE})}} \right) \right)$$

* Rewritten format based on the Draft 1.0 comments (Annex 178A)

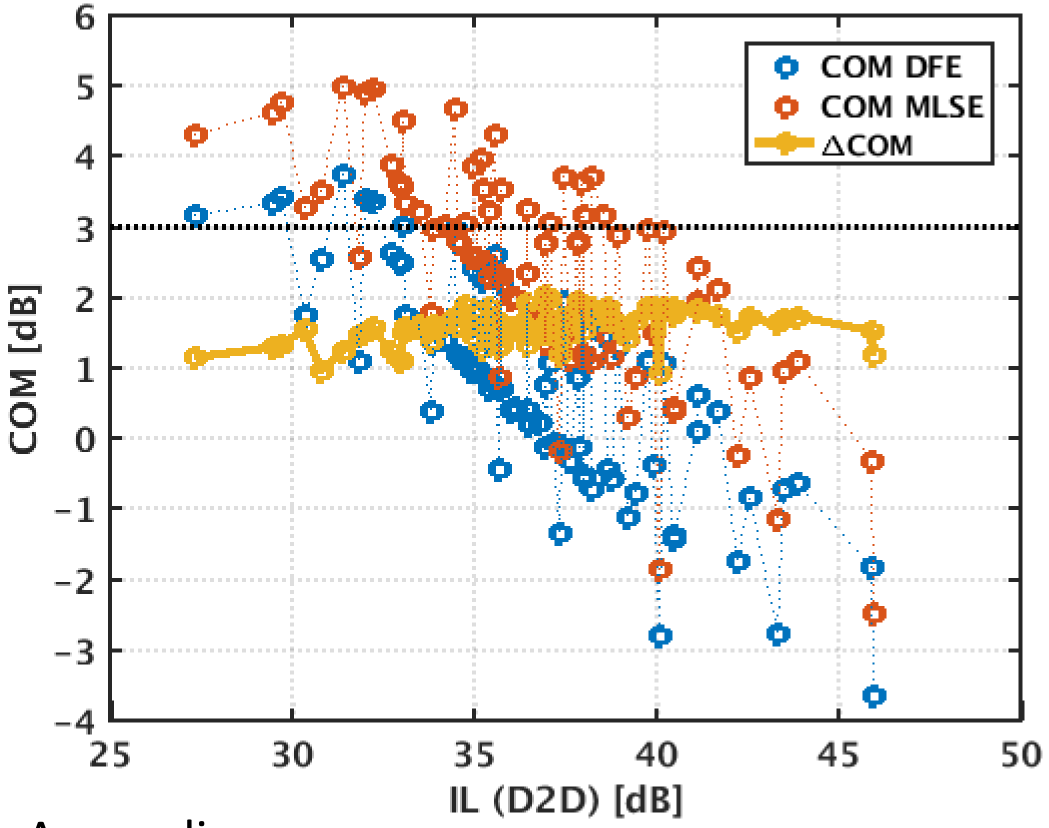
- This leads to a sequence truncation penalty of:

$$Q_{trunc} \approx 20 \log_{10}\left(\frac{CDF_{noise}^{-1}(DER_{MLSE})}{CDF_{noise}^{-1}(DER_{MLSE,trunc})} \right)$$

- Which is basically the reduction in SNR due to truncation

Test Results* – Without Truncation

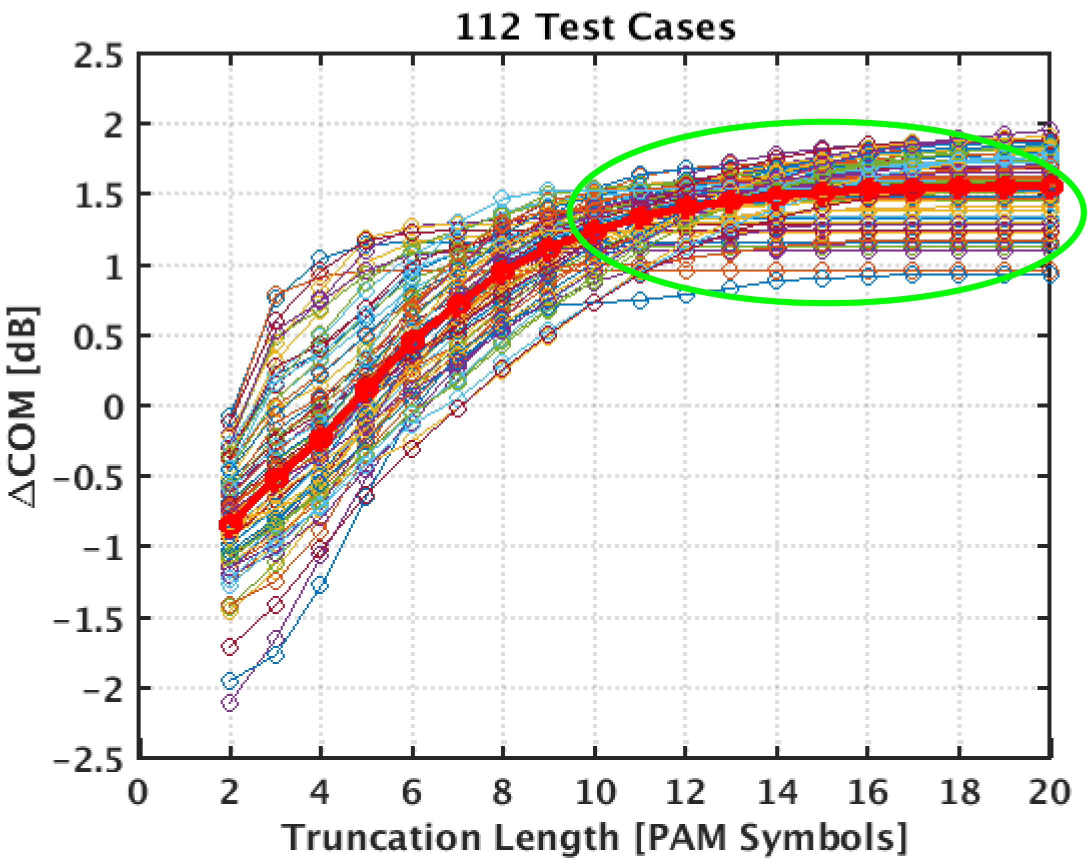
- With the latest COM version (mostly MMSE RxFFE changes and MLSE updates), for the test cases equation U1.c results in an MLSE ΔCOM with Min = 0.93dB, Max = 2.04dB, and Ave = 1.56dB (still no MLSE implementation penalty, $Q = 0$)



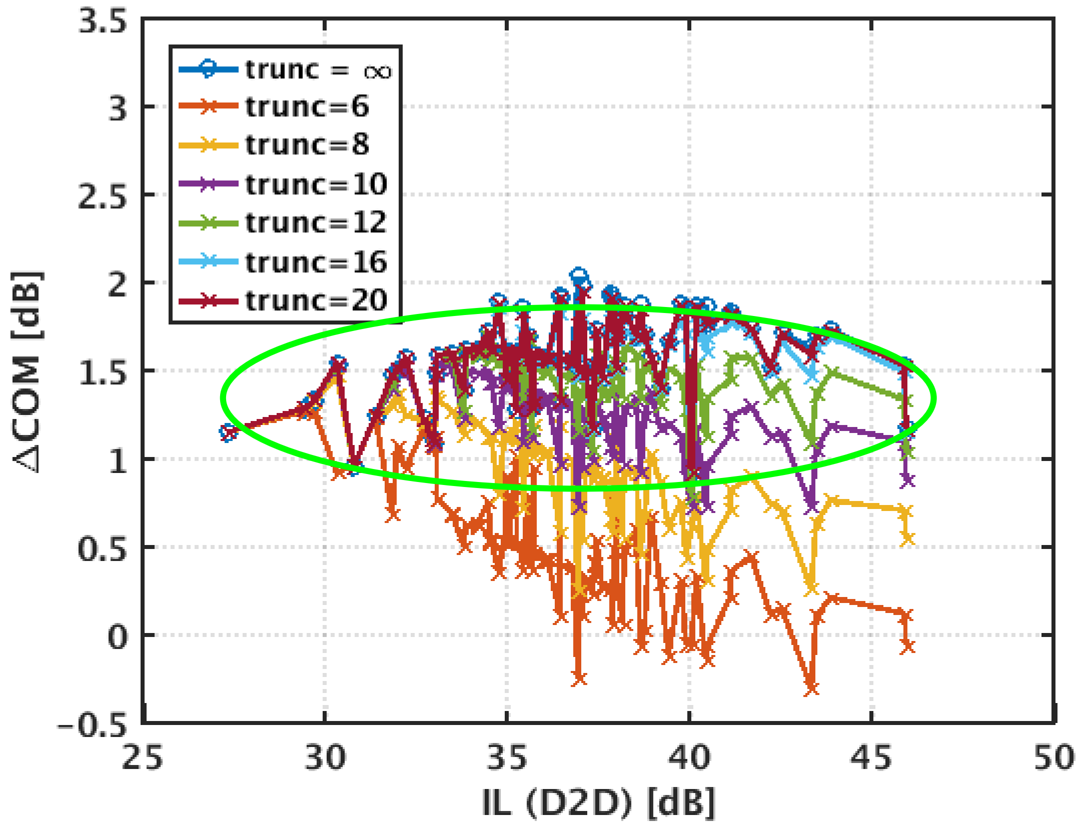
* For the test channels see the Appendix

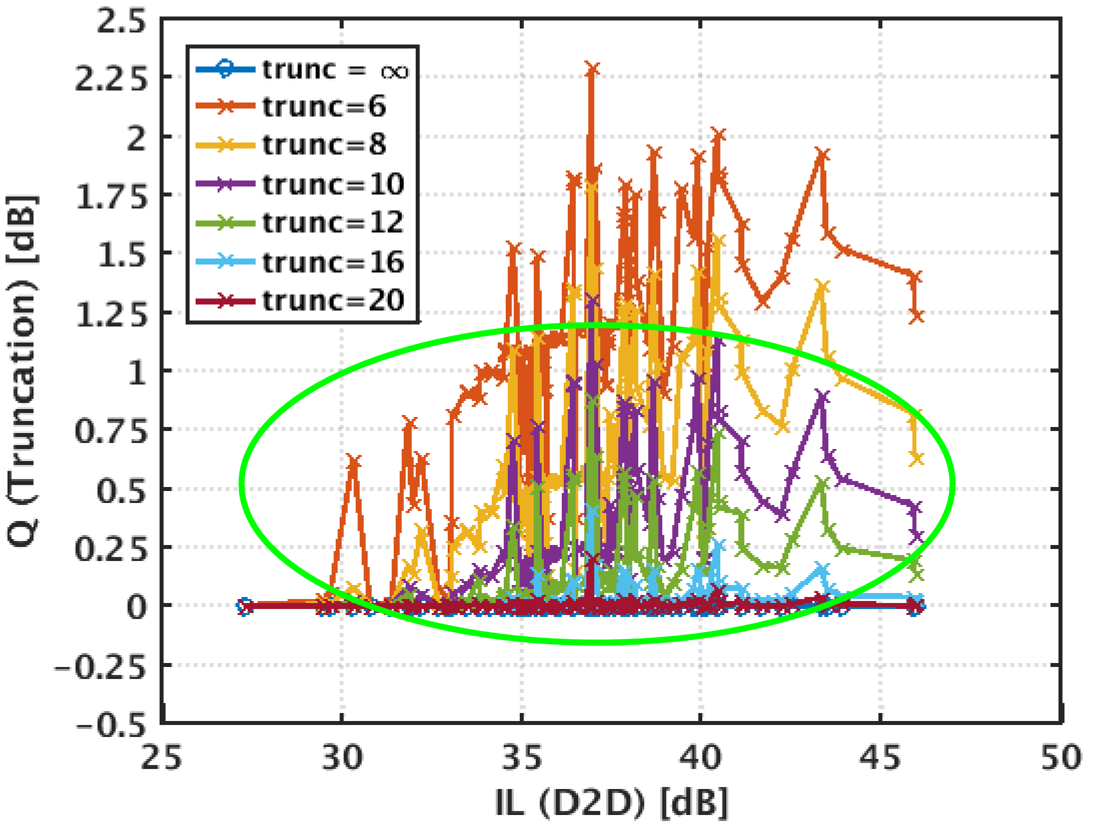
Test Results – With Truncation, Overall Picture

- There is a trade off between performance vs. complexity and latency (reasons for truncation)
- Data supports why implementations have usually chosen truncating to no less than 10
- Some implementations have chosen around 20
- Truncating in the range of 10-20 seems to be a reasonable choice
- For our purpose, with some pessimism, the lower end of the range (~ 10-15) may be considered



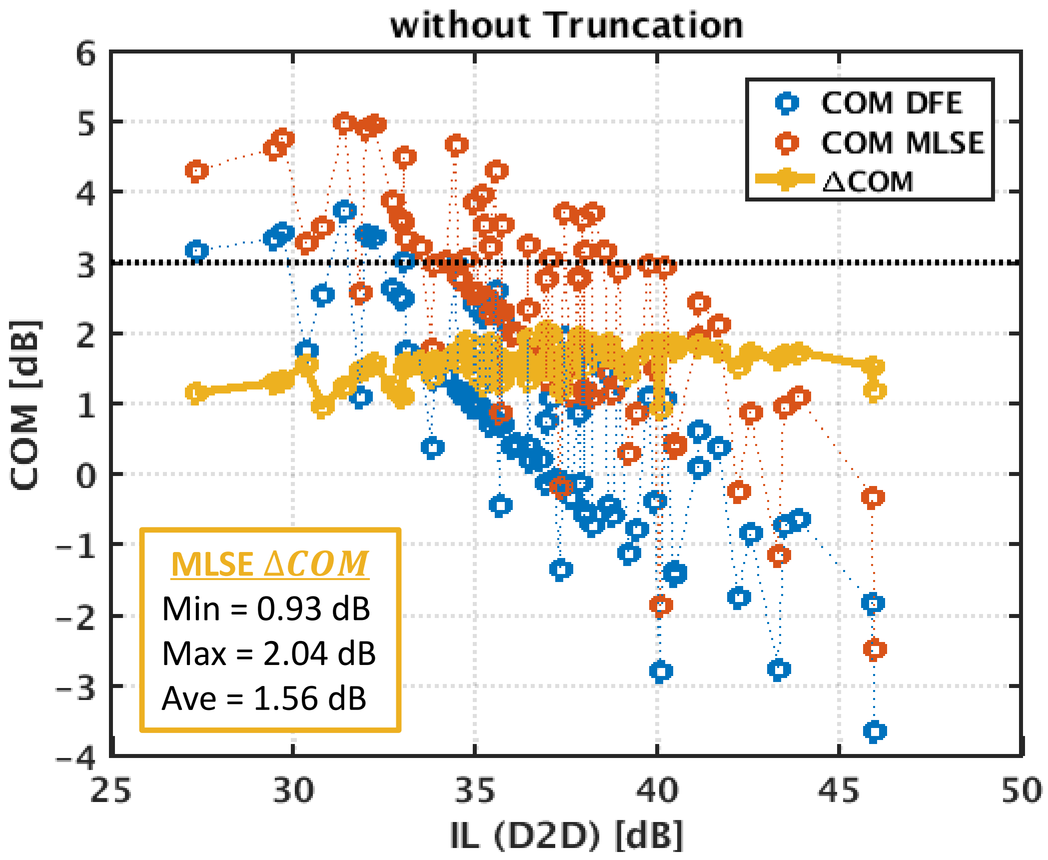
Test Results – With Truncation, Versus IL

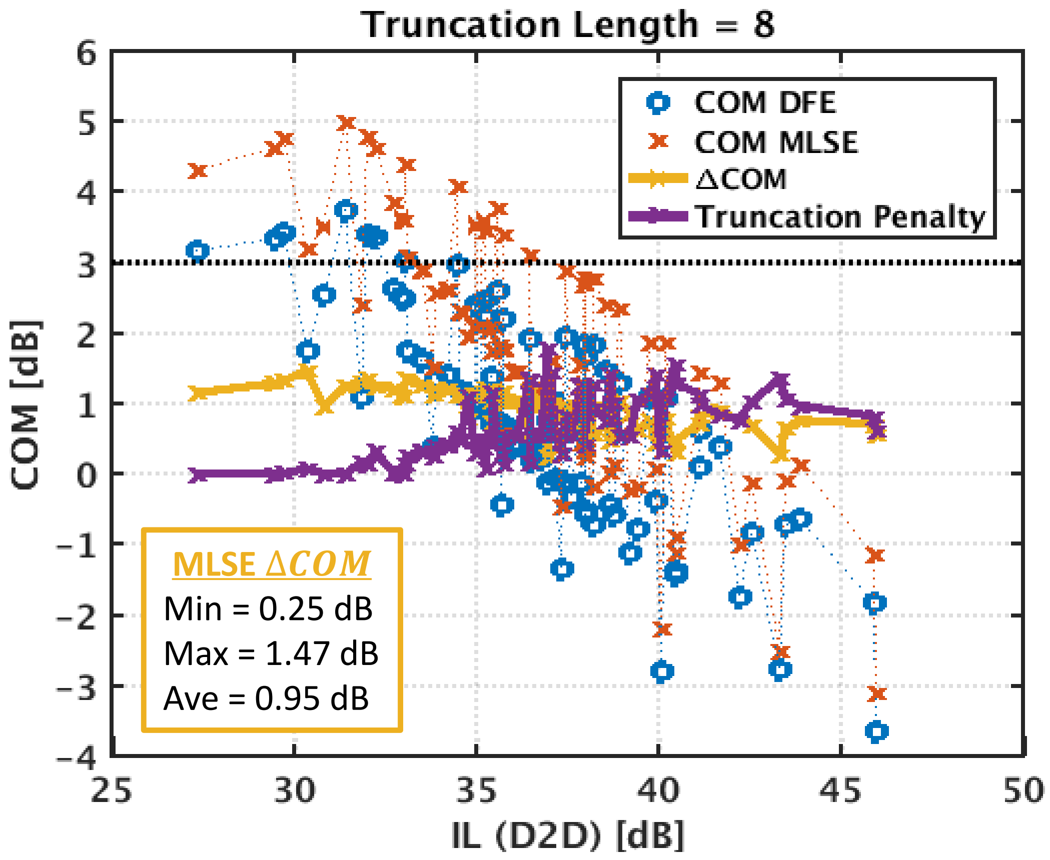




- Generally speaking, truncation penalty increases with insertion loss
- The slight drops at the high loss end are from cases that most likely fail anyway
- This is a trend that many people may expect and may like ☺

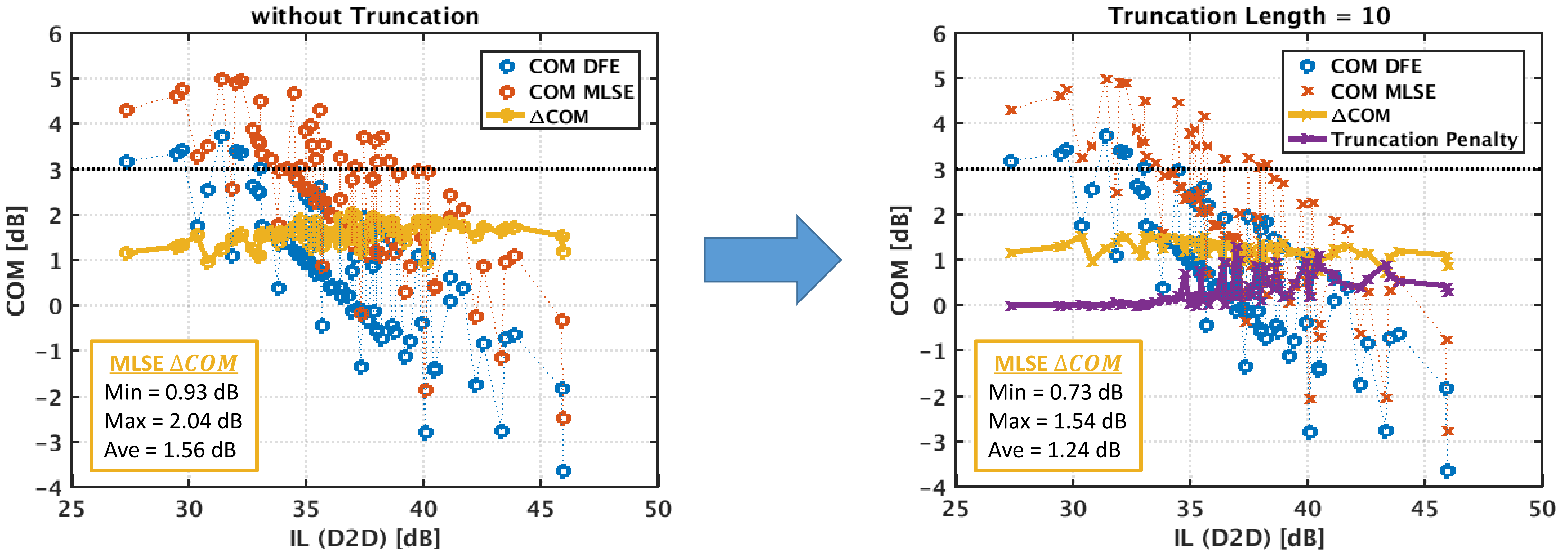
Test Results – With Truncation, $trunc = 8$





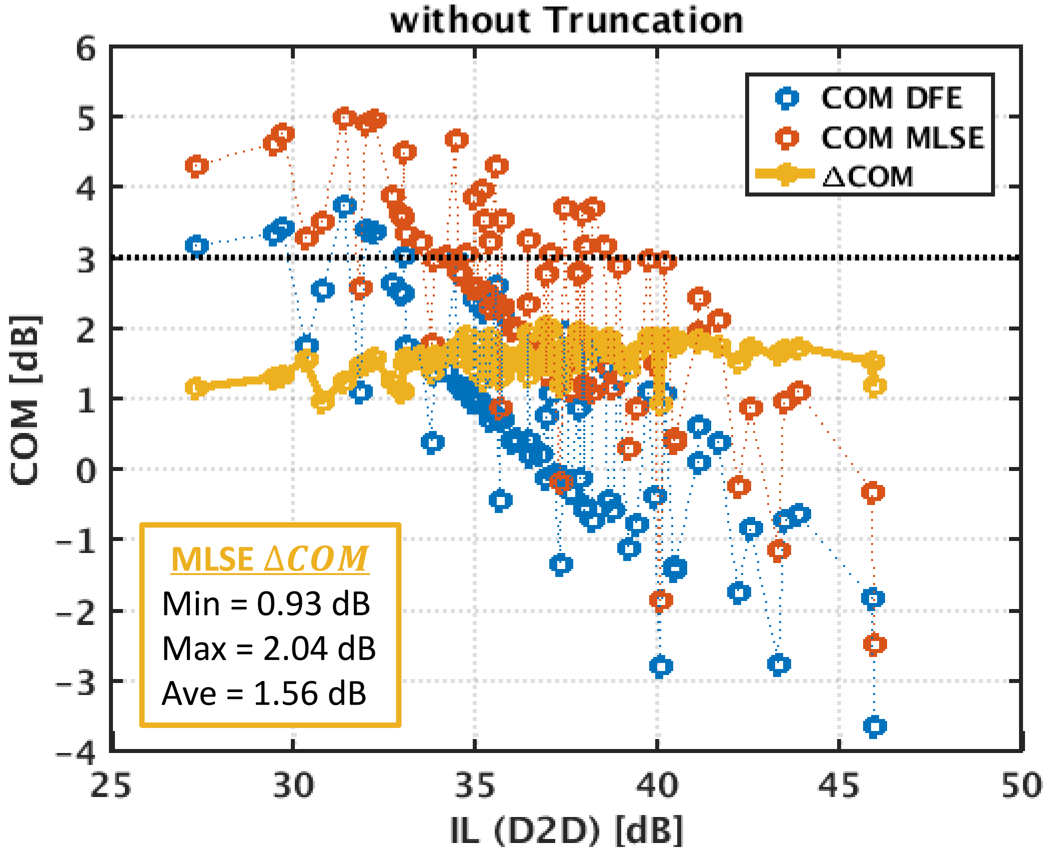
- A truncation length of 8 penalizes MLSE by an average of 0.61dB
- The resulting ΔCOM averages to 0.95dB, concentrated around 30-40dB IL, which is a critical range where MLSE has the most impact

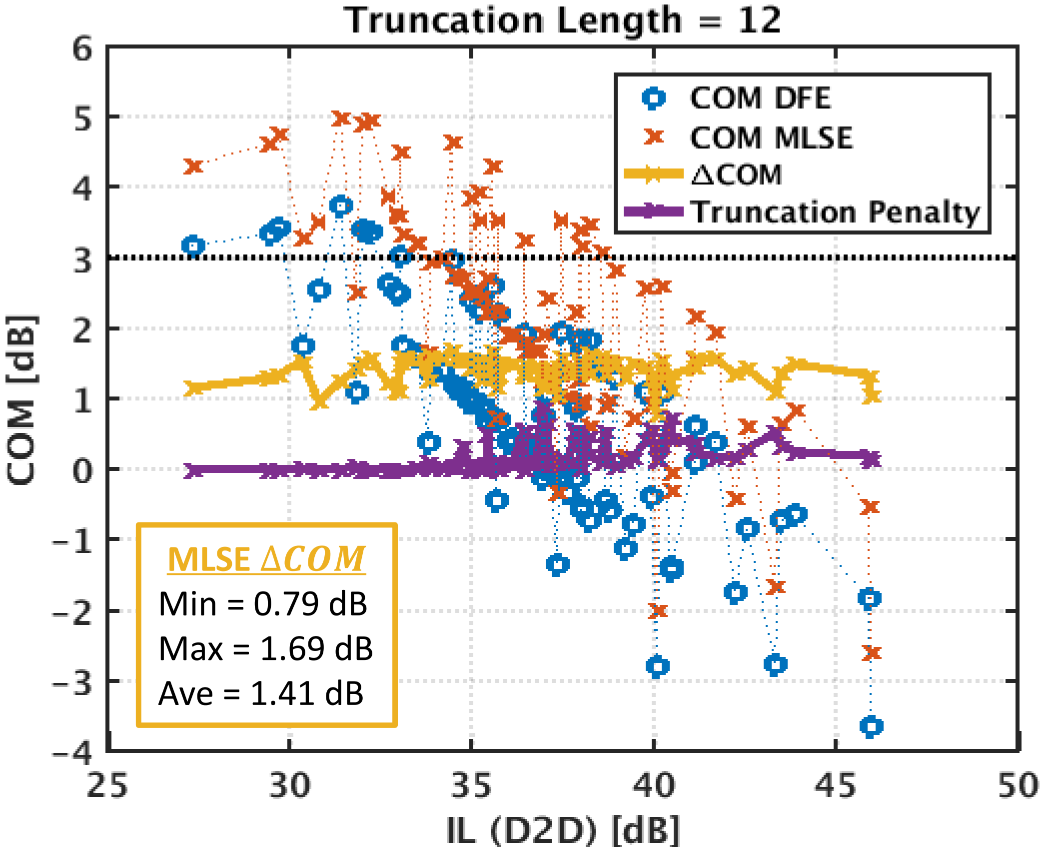
Test Results – With Truncation, $trunc = 10$



- A truncation length of 10 penalizes MLSE by an average of 0.32dB
- The resulting ΔCOM averages to 1.24dB, concentrated around 30-40dB IL, which is a critical range where MLSE has the most impact

Test Results – With Truncation, $trunc = 12$





- A truncation length of 12 penalizes MLSE by an average of 0.16dB
- The resulting ΔCOM averages to 1.41dB, concentrated around 30-40dB IL, which is a critical range where MLSE has the most impact

Options

- The following options have been discussed for including the MLSE implementation penalty (Q in equation 178A-36):

1) Subtract an agreed upon fix amount (Q_{cte}) from ΔCOM ($Q = Q_{cte}$)

   ☹ Difficult to justify and partially defeating the prospect of calculating ΔCOM using U1.c on a case basis

2) Limit ΔCOM to an agreed upon maximum value (ΔCOM_{max})

   $$\left(Q = \begin{cases} 0 & ,\Delta COM \leq \Delta COM_{max} \\ \Delta COM - \Delta COM_{max} & ,\Delta COM > \Delta COM_{max} \end{cases}\right)$$

   ☹ Difficult to justify and partially defeating the prospect of calculating ΔCOM using U1.c on a case basis

3) Derate ΔCOM by an agreed upon factor ($Q \propto \Delta COM$)

   ☹ Difficult to justify and partially defeating the prospect of using U1.c to calculate ΔCOM

4) Use the proposed method in this contribution and use the truncation SNR penalty (Q_{trunc} in slide 7) as Q with an agreed upon value for $trunc$

   ☺ Same justification and inline with the prospect and methodology of calculating ΔCOM using U1.c

Summary and Conclusion

- MLSE implementation penalty is still TBD (Q in Equation 178A-36)
- This contribution extended the same analysis approach of calculating MLSE ΔCOM using U1.c to calculating the MLSE sequence truncation penalty, Q_{trunc}
- With the view of truncation being the primary reason for MLSE implementation constraint, Q_{trunc} can represent Q in equation 178A-36
- This option is preferred over the other options of using a constant penalty, limiting ΔCOM to a maximum value, or derating ΔCOM
- The option is inline with the method and analysis used to calculate MLSE ΔCOM using U1.c
- Contributions are encouraged to agree upon the method and parameters

Backup Slides

Test Channels (KR/CR)

Channel #	Channel Source
1	https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_03_230629.zip
2	https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_04_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
89	https://www.ieee802.org/3/dj/public/tools/CR/lim_3dj_07_2309.zip
90 – 96	https://www.ieee802.org/3/dj/public/tools/KR/akinwale_3dj_01_2310.zip
97 – 100	https://www.ieee802.org/3/dj/public/tools/CR/akinwale_3dj_02_2311.zip
101 – 112	https://www.ieee802.org/3/dj/public/tools/CR/weaver_3dj_02_2311.zip

COM Config

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	5.00E+01	Ohm	
R_d	[50 50]	Ohm	[TX RX]
PKG_NAME	PKG_HiR_CLASSB PKG_Module		TX RX
A_v	0.413	V	
A_fe	0.413	V	
A_ne	0.608	V	
z_p select	[4]		
L	4		
M	32		
filter and Eq			
f_r	0.58	*fb	
c(0)	0.55		min
c(-1)	0		[min:step:max]
c(-2)	0		[min:step:max]
c(-3)	0		[min:step:max]
c(-4)	0		[min:step:max]
c(1)	0		[min:step:max]
N_b	1	UI	
b_max(1)	0.85		As/dfe1
b_max(2..N_b)	0.3		As/dfe2..N_b
b_min(1)	0		As/dfe1
b_min(2..N_b)	-0.15	S	As/dfe2..N_b
g_DC	-1	dB	[min:step:max]
f_z	42.50	GHz	
f_p1	42.50	GHz	
f_p2	106.25	GHz	
g_DC_HP	-4		[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\C2M_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	C2M TP1a_COM_model	
COM_CONTRIBUTION	1	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	ns
TR_TDR	0.01	
N	4000	logical
TDR_Butterworth	1	
beta_x	0	
rho_x	0.618	
TDR_W_TXPKG	0	UI
N_bx	20	
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	1.25E-08	dB
SNR_TX	33	
R_LM	0.95	
DER_CDR	1.00E-02	
ENOB	32	
trunc	128	
BREAD_CRUMBS	1	logical

Legend
baseline
new
relevant for RxFFE
adjusted in experiment

Table 93A-3 parameters			
Parameter	Setting	Units	Information
package_tl_gamma0_a1_a2	[5e-4 0.00065 0.0003]		
package_tl_tau	0.006141	ns/mm	
package_Z_c	92 ; 70 70; 80 80; 100	Ohm	
z_p (TX)	1 1 1 1; 1 1 1 1 ; 0.5	mm	[test cases to run]
z_p (NEXT)	1 1 1 1; 1 1 1 1 ; 0.5	mm	[test cases]
z_p (FEXT)	1 1 1 1; 1 1 1 1 ; 0.5	mm	[test cases]
z_p (RX)	1 1 1 1; 1 1 1 1 ; 0.5	mm	[test cases]
C_p	[0.4e-4 0.4e-4]	nF	[test cases]
Operational			
ERL Pass threshold	10	dB	
COM Pass threshold	3	db	
DER_0	2.50E-05		
T_r	4.00E-03	ns	
FORCE_TR	1	logical	
PMD_type	C2C		
T_O	0	mUI	
samples_for_C2M	100	samples/UI	
EW	0		
MLSE	3	logical	
ts_anchor	1		
sample_adjustment	[-32 32]		
Local Search	0		
Filter: RxFFE			
ffe_pre_tap_len	5	UI	
ffe_post_tap_len	12	UI	
ffe_pre_tap1_max	1	(normalized)	
ffe_post_tap1_max	1	(normalized)	
ffe_tapn_max	1	(normalized)	FV-LMS or MMSE
FFE_OPT_METHOD	MMSE		
num_ui_RXFF_noise	1024		FOM or ISI
RXFFE FLOAT CTL	FOM		
Floating Tap Control			
N_bg	2	0 1 2 or 3 groups	
N_bf	4	taps per group	
N_f	50	UI span for floating taps	
bmaxg	0.2	max DFE value for floating taps	
B_float_RSS_MAX	1	rss tail tap limit	
N_tail_start	13	(UI) start of tail taps limit	

SAVE_CONFIG2MAT	0	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
ICN parameters		
f_v	0.278	Fb
f_f	0.278	Fb
f_n	0.278	Fb
f_2	61.625	GHz
A_ft	0.450	V
A_nt	0.450	V
Parameter	**Setting**	
board_tl_gamma0_a1_a2	*[0 6.44084e-4 3.6036e-05]*	1.4 db/in @ 53.125G
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	*32*	mm
z_bp (NEXT)	*32*	mm
z_bp (FEXT)	*32*	mm
z_bp (RX)	*32*	mm
C_0	[0.2e-4 0]	nF
C_1	[0.2e-4 0]	nF
Include PCB	**0**	**logical**
Seletions (rectangle, gaussian,dual_rayleigh,triangle		
Histogram_Window_Weight	gaussian	selection
Qr	*0.02*	UI