400 GBPL Electrical Objective Kaleidoscope: Reach, Loss, Cutoff, Noise, and COM

Richard Mellitz (Samtec)

Brandon Gore (Samtec), Adam Gregory(Samtec), Tim Wig (Samtec)

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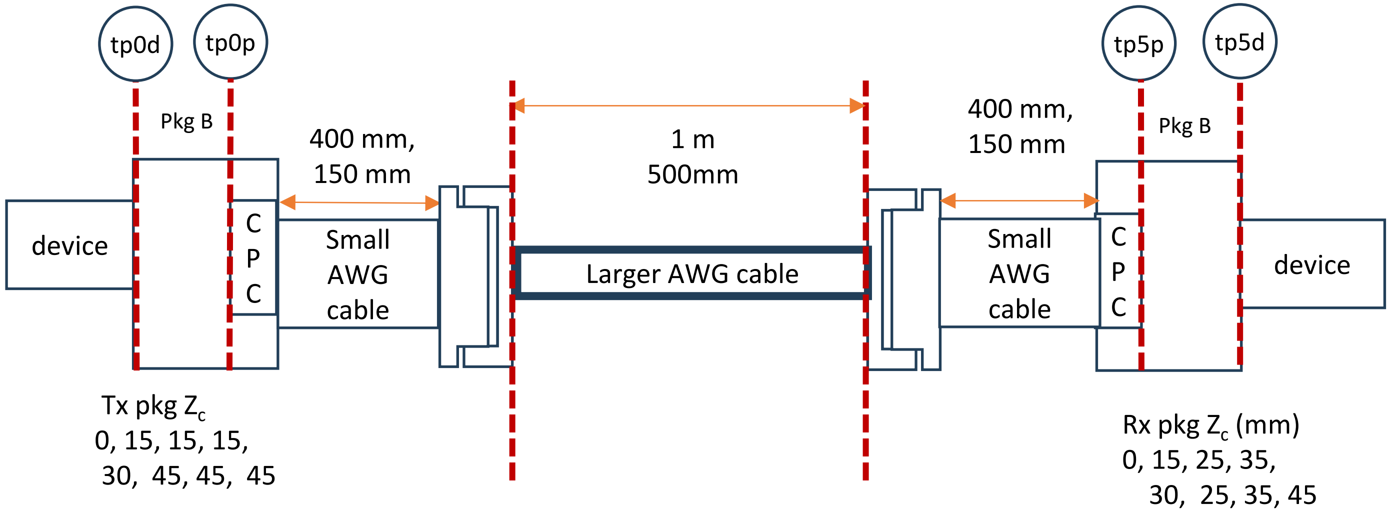
Contents

Abstract

- Explore the electrical landing-zone options and conundrums for DAC reach up to 1 meter.
- Quantify PAM6 COM sensitivity to baud rate, channel loss, and device noise for hypothetical channels exhibiting a steep high-frequency loss transition near Nyquist.
- Define apparent channel bandwidth for such channels.
- Assess what die-to-die loss objectives may be practical for 400 Gb/lane electrical channels.

Channel Architecture and Test Points



References to test points TP0d, TP0p, TP5p, and TP5d are used in following slides

Process

- ❑ Sweep DAC length, host cable length, and package loading.
- ❑ Produces a population of hypothetical channels spanning a broad die-to-die loss range.
- ❑ Use that population for COM sensitivity analysis.

COM Parameter Sweeps

- Sweep receiver noise using η_0 $(3\text{e}9\ \text{v}^2/\text{GHz}$ to $5\text{e}9\ \text{v}^2/\text{GHz})$
- Sweep transmitter noise using SNR_{TX} (33 dB to 40 dB)
- Evaluate PAM6 COM sensitivity to device noise

Other noise and jitter parameters

sigma_RJ	0.008
A_DD	0.0015
eta_0	
SNR_TX	
R_LM	0.93

170 Gbaud and 180 Gbaud PAM6 COM Filters

Table 93A-1 parameters		
Parameter	Setting	Units
data rate	425	Gbit
PAM N levels selector	6 (26-05-11)	selector
L	6	use selector
f_b	170.00	GBd
f_min	0.05	GHz
Delta_f	Setting	GHz
R_0	46.25	s
PKG_NAME	PKG_CPC PKG_CPC	
z_p select	[1 2 3 4 5 6 7 8]	
M	32	
C_d	[0.4e-4 0.9e-4 1.1e-4 ;0.4e-4 0.9e-4 1.1e-4]/1.4	nF
L_s	[0.13 0.15 0.14; 0.13 0.15 0.14]/1.4	nH
C_b	[0.3e-4 0.3e-4]/1.4	nF
filter and Eq		
f_r	0.55	*fb
c(0)	0.55	
c(-1)	0	[-0.34:0.02:0
c(-2)	0	0:0.02:0.14
c(1)	0	[-0.2:0.02:0]
N_b	1	UI
b_max(1)	0.85	
b_max(2..N_b)	0	
b_min(1)	0	
b_min(2..N_b)	0	
g_DC	[-20:1:-15]	[-20:1:-0]
f_z	68.00	GHz
f_p1	68.00	GHz
f_p2	170.00	GHz
g_DC_HP	[-6:1:-0]	
f_HP_PZ	1.0625	GHz

Parameter	Setting	Units
data rate	425	Gbit
PAM N levels selector	6 (26-05-11)	selector
L	6	use selector
f_b	180.00	GBd
f_min	0.05	GHz
Delta_f	Setting	GHz
R_0	46.25	s
PKG_NAME	PKG_CPC PKG_CPC	
z_p select	[1 2 3 4 5 6 7 8]	
M	32	
C_d	[0.4e-4 0.9e-4 1.1e-4 ;0.4e-4 0.9e-4 1.1e-4]/1.4	nF
L_s	[0.13 0.15 0.14; 0.13 0.15 0.14]/1.4	nH
C_b	[0.3e-4 0.3e-4]/1.4	nF
filter and Eq		
f_r	0.55	*fb
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N_b	1	UI
b_max(1)	0.85	
b_max(2..N_b)	0	
b_min(1)	0	
b_min(2..N_b)	0	
g_DC	[-20:1:-15]	[-20:1:-0]
f_z	72.00	GHz
f_p1	72.00	GHz
f_p2	180.00	GHz
g_DC_HP	[-6:1:-0]	
f_HP_PZ	1.125	GHz

COM Package Cases

.START	PKG_CPC	[2.8 5.6 6.7 9.4] d	tp0p or Tp5p
Parameter	**Setting**	**Units**	
R_d	[46.25 46.25]	Ohm	[TX RX]
package_tl_gamma0_a1_a2	[0.0005 0.00065 0.000293]		
package_tl_tau	0.006141	ns/mm	
package_Z_c	[87.5 87.5 ; 95 95 ; 100 100; 78 78]	Ohm	[TX RX]
z_p (TX)	15 30 45 45 45 ;0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ;0 0 0 0	mm	[test cases]
z_p (NEXT)	35 30 25 35 45 ;0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ;0 0 0	mm	[test cases]
z_p (FEXT)	15 30 45 45 45 ;0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ;0 0 0 0	mm	[test cases]
z_p (RX)	35 30 25 35 45 ;0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ;0 0 0	mm	[test cases]
C_p	[0 0]	nF	[TX RX]
A_v	0.385	V	Vf=0.400
A_fe	0.385	V	Vf=0.399
A_ne	0.481	V	Vf=0.400
.END			

- ❑ Using .3dj package class B parameters
- ❑ Just for building loss range

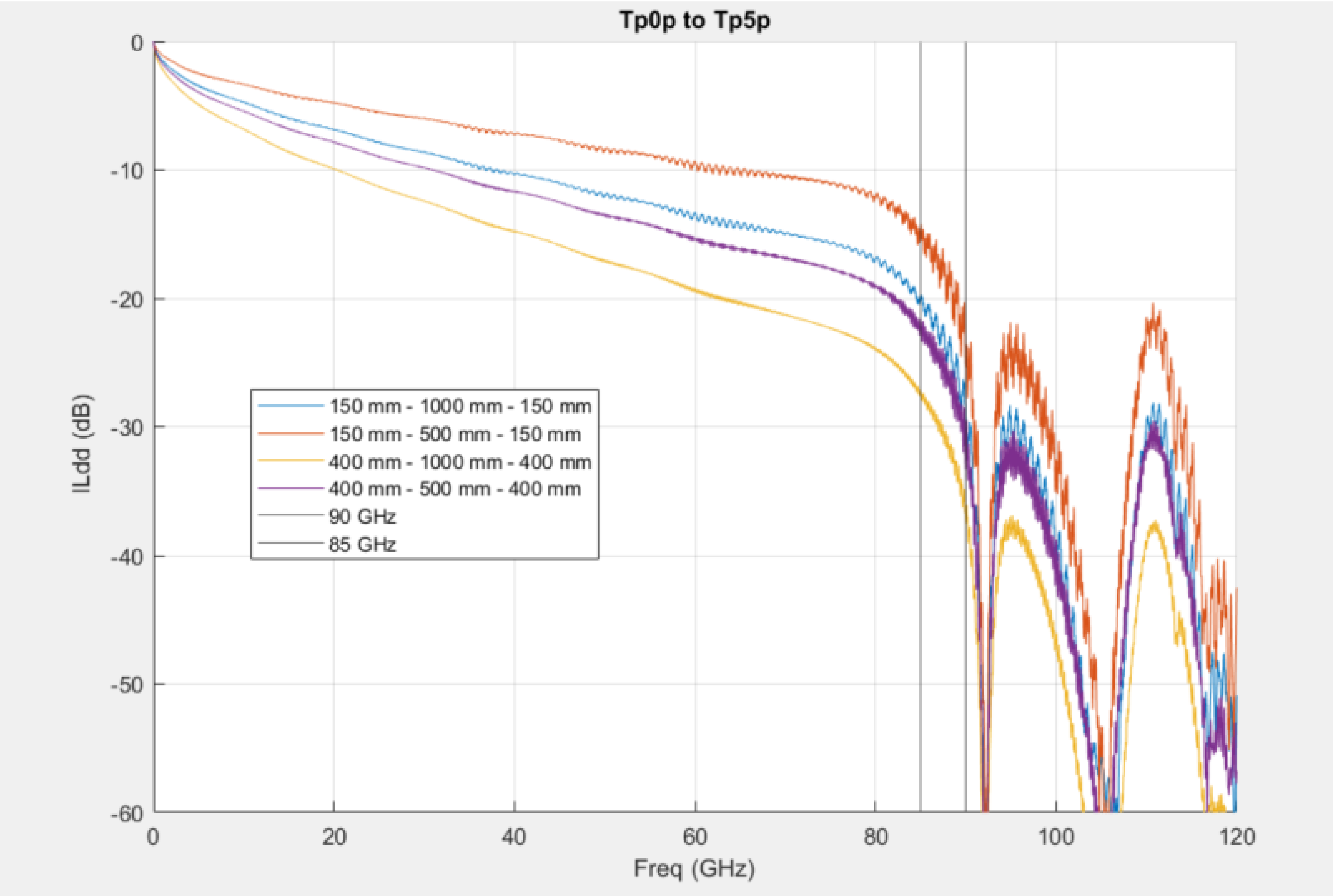
Other operational parameters include MLSD for this work COM dB is at DER0 of 2e-4 (which is expected to change with FEC)

Rx FFE parameters

Floating Tap Control		
N_bg	3	0 1 2 or 3 groups
N_bf	5	taps per group
N_f	124	UI span for floating taps
bmaxg	0.05	max DFE value for floating taps
B_float_RSS_MAX	0.1	rss tail tap limit (not used)
N_tail_start	17	(UI) start of tail taps limit
Filter: Rx FFE		
ffe_pre_tap_len	6	UI
ffe_post_tap_len	16	UI
ffe_main_cursor_min	1	
ffe_pre_tap1_max	0.7	
ffe_post_tap1_max	0.7	
ffe_tapn_max	0.7	
N_qb	6	like enob

Operational		
ERL Pass threshold	7.3	dB
COM Pass threshold	3	db
DER_0	2.00E-04	
T_r	0.00300	ns
FORCE_TR	1	logical
PMD_type	C2C	
EW	0	
MLSD	1	logical
ts_anchor	1	
sample_adjustment	[-24 24]	
num_ui_RXFF_noise	2000	need enough UI to capture pulse c
zero_pad	1	recommended
flim	110.0E+9	Hz
zero_pad_tukey_window_in_fb	0.2	fb
Local Search	0	use to get a handle on where the t
TS_SRCH_MODE	middle	not used if local search = 0
P_peak	1.00E-07	SCMR CDF probability

Channel Population and Loss Characteristics



Channels exhibit a broad range of loss and high-frequency behavior while sharing a similar apparent bandwidth near 88 GHz.

Die-to-die loss spans a wide range across the channel configurations:

- 14 dB to 52 dB @ 85 GHz
- 25 dB to 62 dB @ 90 GHz

Describing Channels with a Steep High-Loss Onset

Motivation

- Classical bandwidth definitions become ambiguous for channels with a steep high-loss onset.
- 3 dB bandwidth, $F_b/2$, and "3 dB beyond a steep spectral high-loss onset " often produce different answers.
- A better way is needed to describe the frequency where channel behavior fundamentally changes.
- A cumulative inverse-channel penalty metric can provide a convenient way to identify the frequency region where channel inversion and equalization burden begin to increase rapidly.
  - Not intended as a direct measure of channel capacity.
- Inspired by the inverse-channel weighting that appears in optimum equalization and Salz-style[1] SNR analyses.
- Maybe used to simply channel identification.

[1]J Salz, "Optimum Mean-Square Decision Feedback Equalization" The Bell System Technical Journal Vol. 52, No. 8, October, 1973

Method: First Persistent CICP Deviation

Define cumulative inverse-channel penalty (CICP):

$$CICP(f) = \frac{\int_0^f |H(\nu)|^{-2}\, d\nu}{\int_0^{F_{max}} |H(\nu)|^{-2}\, d\nu}$$

CICP : a fraction of total inverse-channel penalty accumulated below *f*

f : evaluation frequency

F_{max}: Upper analysis frequency used for normalization, typically the maximum frequency of the available S-parameter data

H (f): the insertion loss

Inspired by inverse-channel weighting used in Salz-style equalization analysis.

Fit the smooth-channel region

$$CICP_{fit} = a_0 + a_1\sqrt{f} + a_2 f + a_3 f^2$$

using user-selected frequency limits.

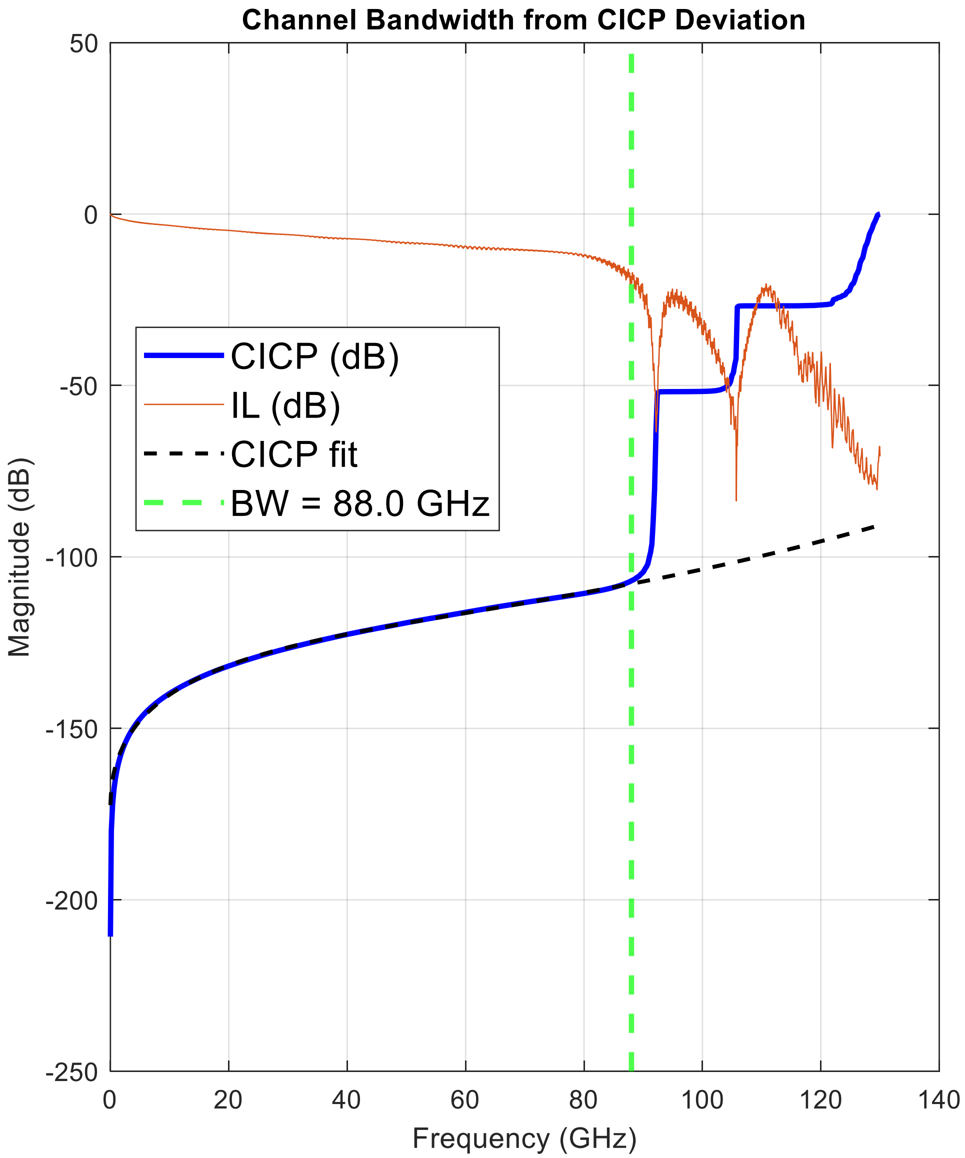
Identify the first persistent departure

$$B_w = min\{f : RMSE(f) > T\}$$

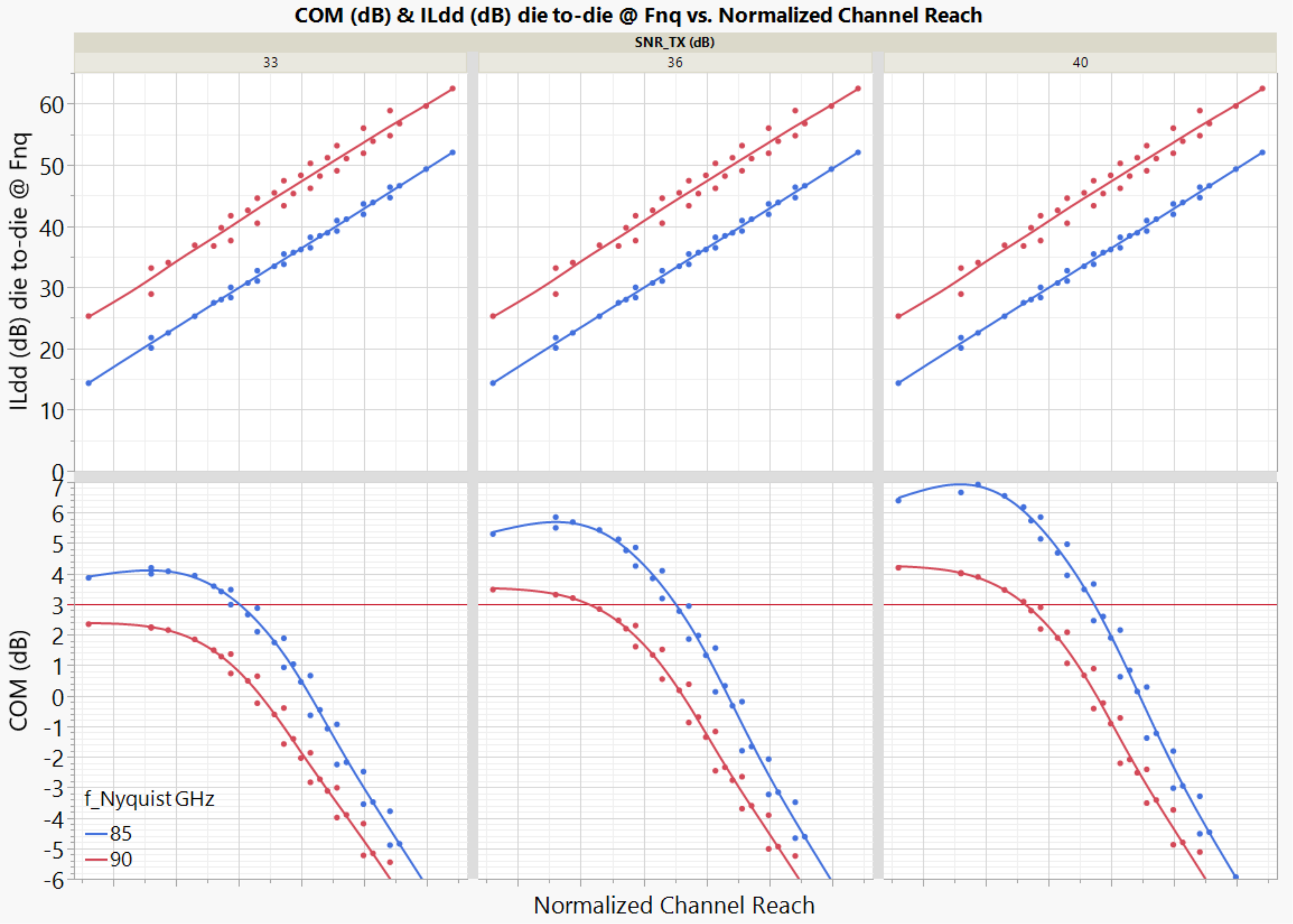
for N consecutive frequency samples

RMSE(f): square root of moving residual mean-square error (dB)

T: residual threshold (dB) (or n σ of RMSE mode dB)

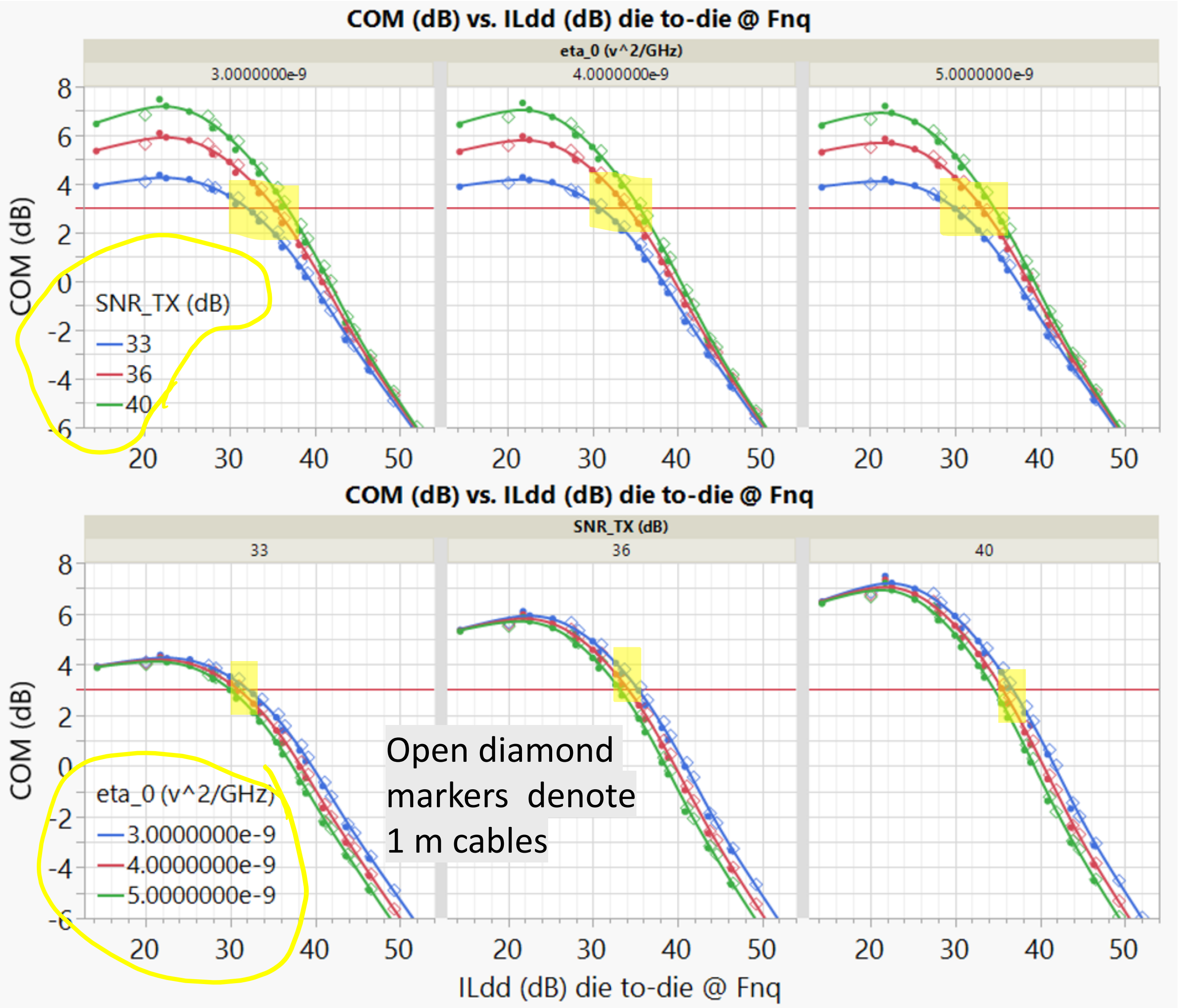


Impact of Nyquist Frequency on COM Margin



- Settings
  - Rx noise (η_0) fixed at 5e-9 V^2/GHz
  - Channel bandwidth fixed at 88 GHz
- Loss specified at 90 GHz, e.g. beyond the 88 GHz channel bandwidth, may not be representative.
  - Given the COM shift between PAM6 Nyquist of 85 GHz and 90 GHz
- For a given normalized reach (i.e. the same channel), COM appears strongly sensitive to a Nyquist frequency change of only 5 GHz
  - Channel bandwidth sweeps are really needed to verify this

COM vs IL_{dd} Loss at 85 GHz Nyquist Frequency



- ❑ IL_{dd} falls between 30 and 40 dB at Nyquist
- ❑ ~35 dB marks a practical upper bound at Nyquist
- ❑ Channel reach (loss at 3 dB COM, yellow highlight) degrades sharply with device noise: ~5 dB Δ loss from Tx and ~2 dB Δ loss from Rx

Summary

- 1 m DAC is feasible only with low noise and a low-loss host, and depends on the actual channel design
- IL_{dd} ≈ 35 dB at Nyquist is a practical upper bound
  - 40 dB IL_{dd} would require revisiting channel and device assumptions
- Using loss as an objective requires channel bandwidth beyond Nyquist qualification
- Device noise strongly influences achievable IL_{dd} and DAC reach
- Next steps:
  - Extend to channels with a wider range of bandwidths
  - Examine PAM4 behavior more closely
  - Refine the apparent-bandwidth method and propose adding it to the COM code
- Considering all this, there does appear to be a kaleidoscope of channel and device interactions

Thank You!