COM analysis of contributed C2M channels – towards a 200 Gb/s per lane AUI proposal

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Intro

- For a C2M baseline proposal we need to agree on channels and endpoint assumptions
- Effects on the architecture should also be considered
- This presentation addresses
  - What channels are feasible
  - What error statistics can be expected
  - What would it take

Previous work

- Several sets of AUI channels have been contributed
  - akinwale_3df_01_2209, akinwale_3df_02_2209, akinwale_3df_03_2209 (chip to module, range of losses)
  - mellitz_3df_02_2207 (chip to chip)
  - rabinovich_3df_01_2209, rabinovich_3df_01_2209 (chip to module)

  (+some earlier contributions)
- mli_3df_02a_220316 proposes die termination and package model
- benartsi_3df_01b_2207 proposes model and parameters for large-scale switch package
- kareti_3df_01a_2207 suggests large-scale switch applications may need 36-38 dB die to die

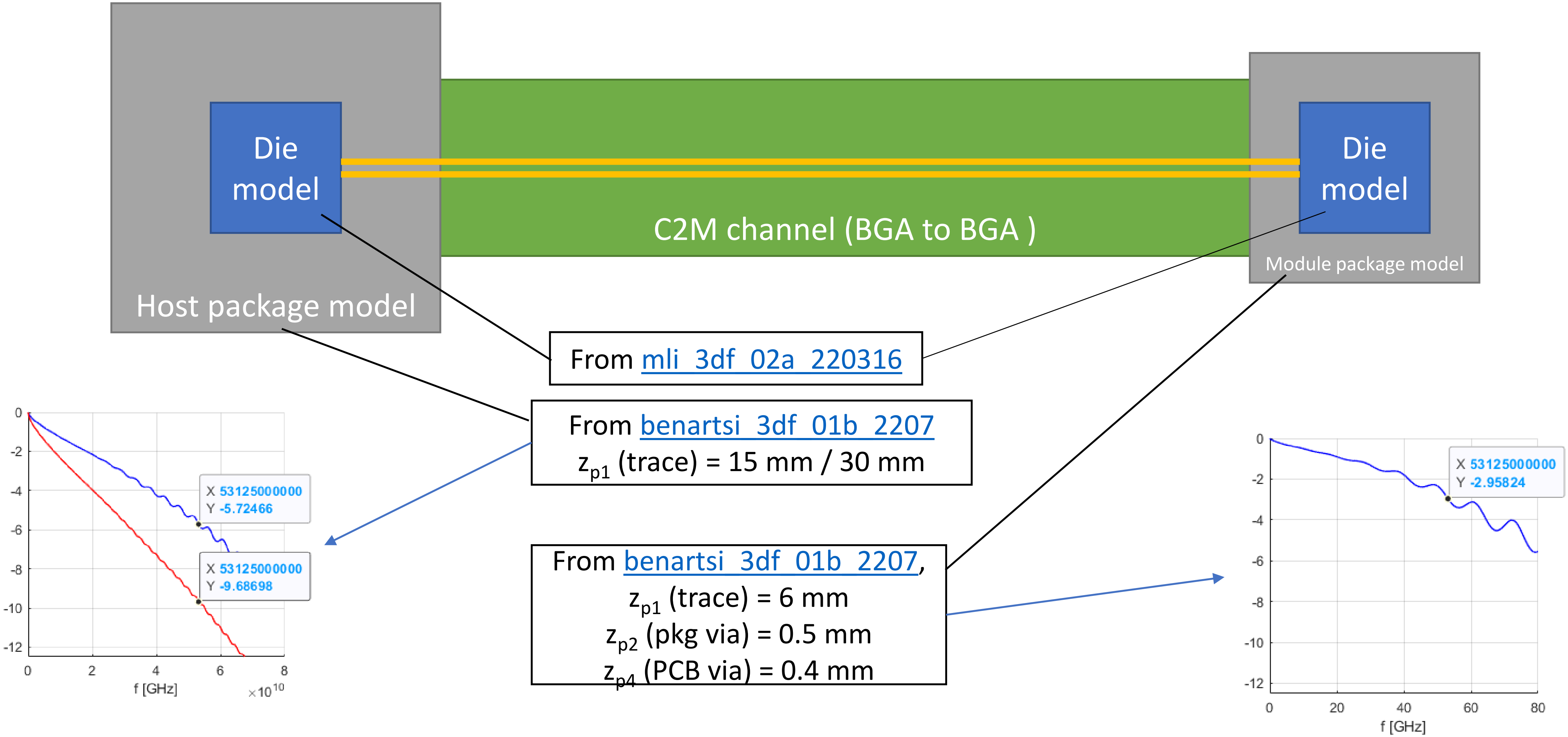
Goals of this presentation

- Propose a set of COM parameters (and a configuration spreadsheet) for 200 Gb/s AUI application
- Propose a loss budget for C2M
- Highlight effects on the 802.3dj architecture beyond electrical specifications

Method

1. Define channel construction for C2M simulation
2. Identify the key COM parameters for a selected subset of C2M channels
3. Propose a set of values for these parameters (operating point)
4. Examine sensitivity around the working point
5. Run COM on the full set of channels

Channel construction



Channel set for operating point selection

Channel #	Source	File/folder Name(s)	IL [dB] @ 56.125 GHz (Thru, BGA to BGA)	IL [dB] including packages (min, max)
1-3	rabinovich_3df_02_2209	Rabinovich_C2M_200G_Paral_*mil_092122 [19, 67, 93]	12.3, 13.3, 13.4	21.3 – 26.4
4-5	mellitz_3df_02_2207	TA_6002_6003 TA_6002_6003_tp0_tp5	13.9 24.3	22.9 – 37.3
6-12	akinwale_3df_02_2209	C2M_PCB_93ohms_*dB_202208016_v2 [10, 15, 20, 22, 24, 26, 28]	8.8, 13, 18.1, 20.6, 22.3, 24.9, 26.6	17.8 – 39.9

15 mm / 30 mm host packages and module package add 9 / 13 dB to each channel (without die models)

Key parameters

- Initial analysis identified the following parameters as having a large effect on COM:
  - η_0 (receiver input noise spectral density)
  - T_r (transmitter bandwidth)
  - f_r (receiver bandwidth)
  - Max b(1)
  - DER_0

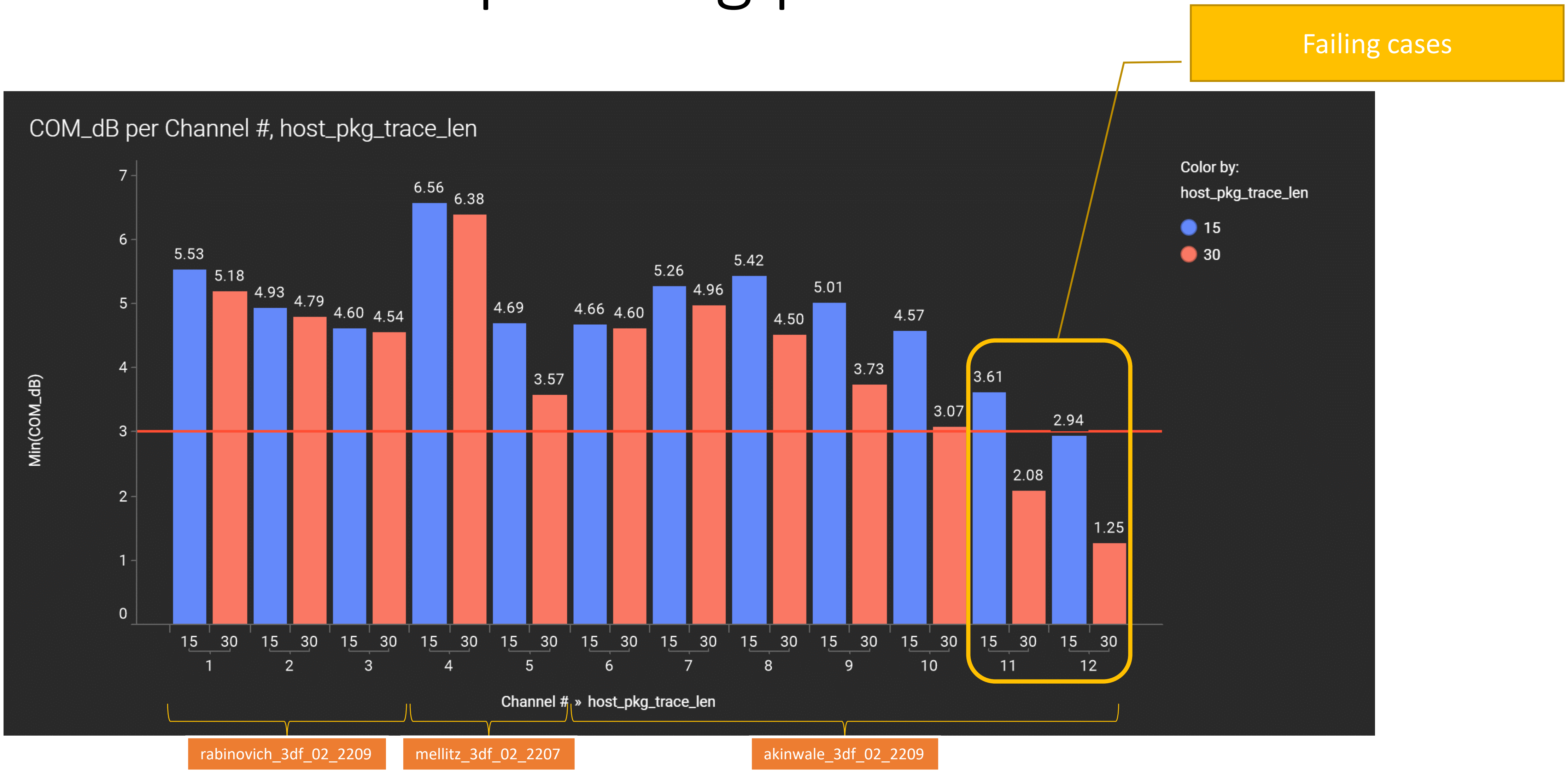
  (other parameters that may also have a large effect, but are considered hard to change, were not included in the analysis)
- A set of values for these parameters, which makes two challenging channels have COM≈3 dB, was defined as the “operating point”
  - Channel # 5 (37.3 dB die-to-die)
  - Channel #10 (35.3 dB die-to-die)

Proposed values for key parameters

Parameter	In 100GBASE-CR (Clause 162)	In 100GAUI-1 C2C (Annex 120F)	Proposed Value for 200GAUI	Rationale
η_0 [V^2/GHz]	9e-9	2e-8	**4e-9**	About the same RMS with doubled bandwidth. Related to package xtalk, thermal and device noise; Challenging but achievable
T_r [ps]	7.5	7.5	**6**	Silicon switching speed does not scale; improved only by process
f_r	0.75*f_b (≈40 GHz)	0.75*f_b (≈40 GHz)	**0.55*f_b (≈58 GHz)**	High bandwidth is challenging; lower BW improves COM results
$bb_{max}(1)$	0.85	0.65	**1**	High value required for high loss channels; error propagation can be addressed
SNR_{TX}	32.5	33	**32.5**	Increasing would burden design and has diminishing return on high loss channels
DER_0	1e-4	1e-5	**1e-4**	RS544 with uncorrelated errors needs DER=4e-4 for FLR=1e-12 BER budgeting with a low portion for AUIs does not seem feasible (may be split between 2 AUIs)
N_b	12	6	**24**	Scale with UI
N_f	40	0	**80**	Scale with UI
Tx FFE length	5 (3 pre)	5 (3 pre)	**6 (4 pre)**	Compensate better for pulse rise time; relatively cheap to implement

Note: full proposed parameter table in the final slide

COM results at operating point

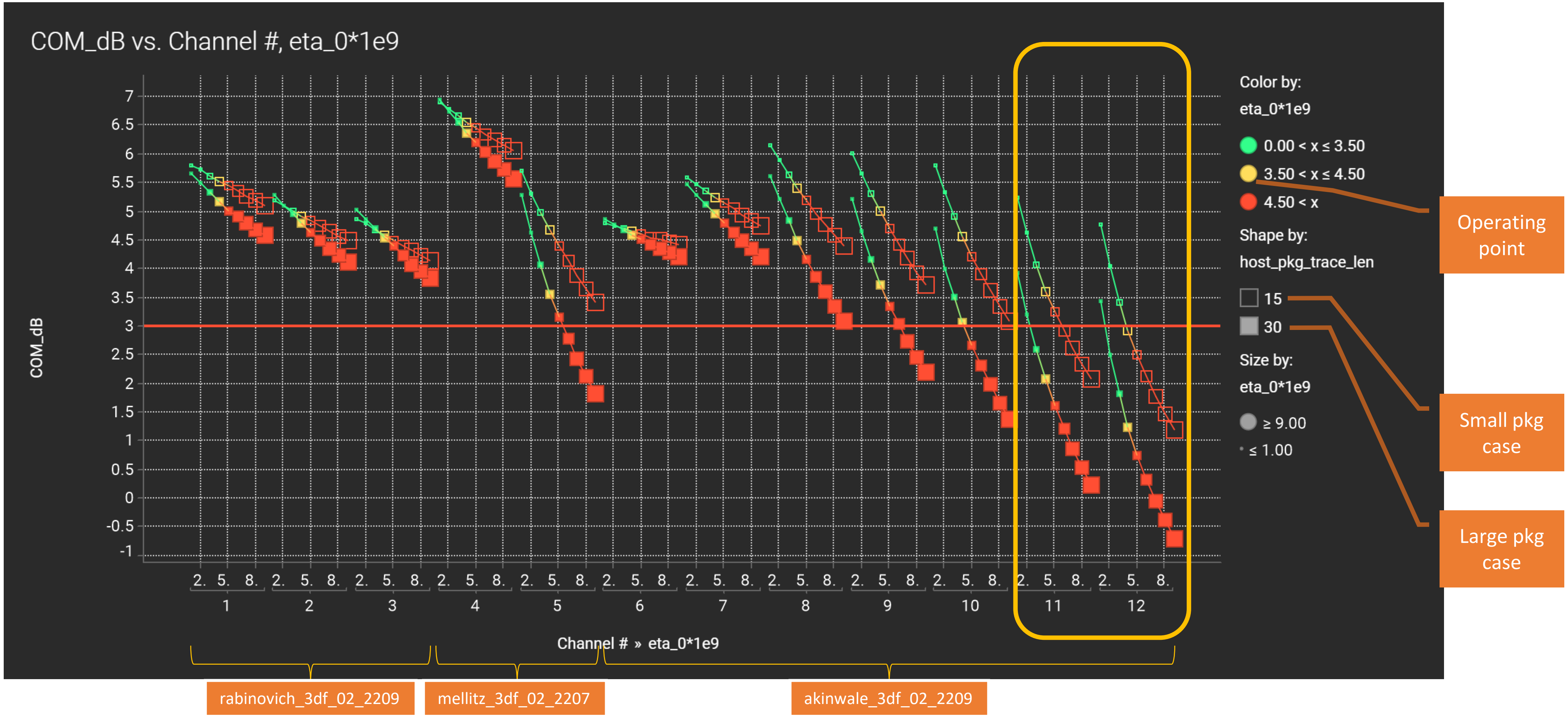


Implications

- DER0=1e-4 is close to the full RS544 correction capability
  - We need to enable error correction for the electrical segment alone
  - Operating with 1e-5 may be possible with lower loss channels – in these cases it may be possible to bypass error correction
  - Possible solution: **Flexible segmented / concatenated architecture**
- Large value of $b_{max}(1) \Rightarrow$ correlated errors are possible
  - If bit muxing is used, the actual BER will need to be much lower than $DER_0/2$ to get equivalent FEC performance
  - Possible solution: **Symbol muxing PMA**
- Tx FFE values have a large variation over the channels considered (see backup)
  - This is for a specific reference receiver; real receivers may vary further
  - Tx parameters may need to be optimized per AUI channel/receiver
    - Module output too
  - Possible solution: **Link training over the AUI segment**

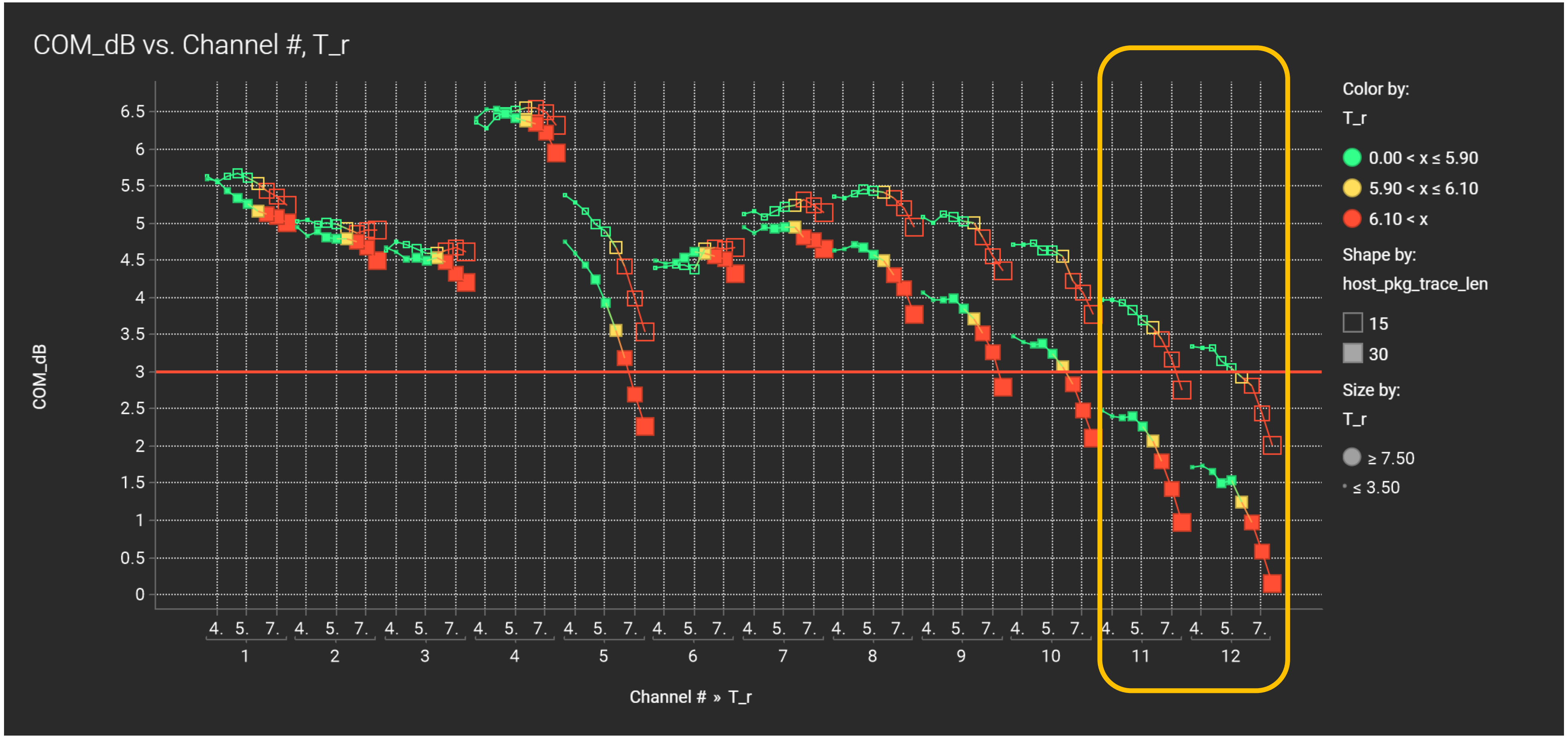
Effect of η_0

η_0 [V^2/GHz] sweep from 1e-9 to 9e-9 in 1e-9 step



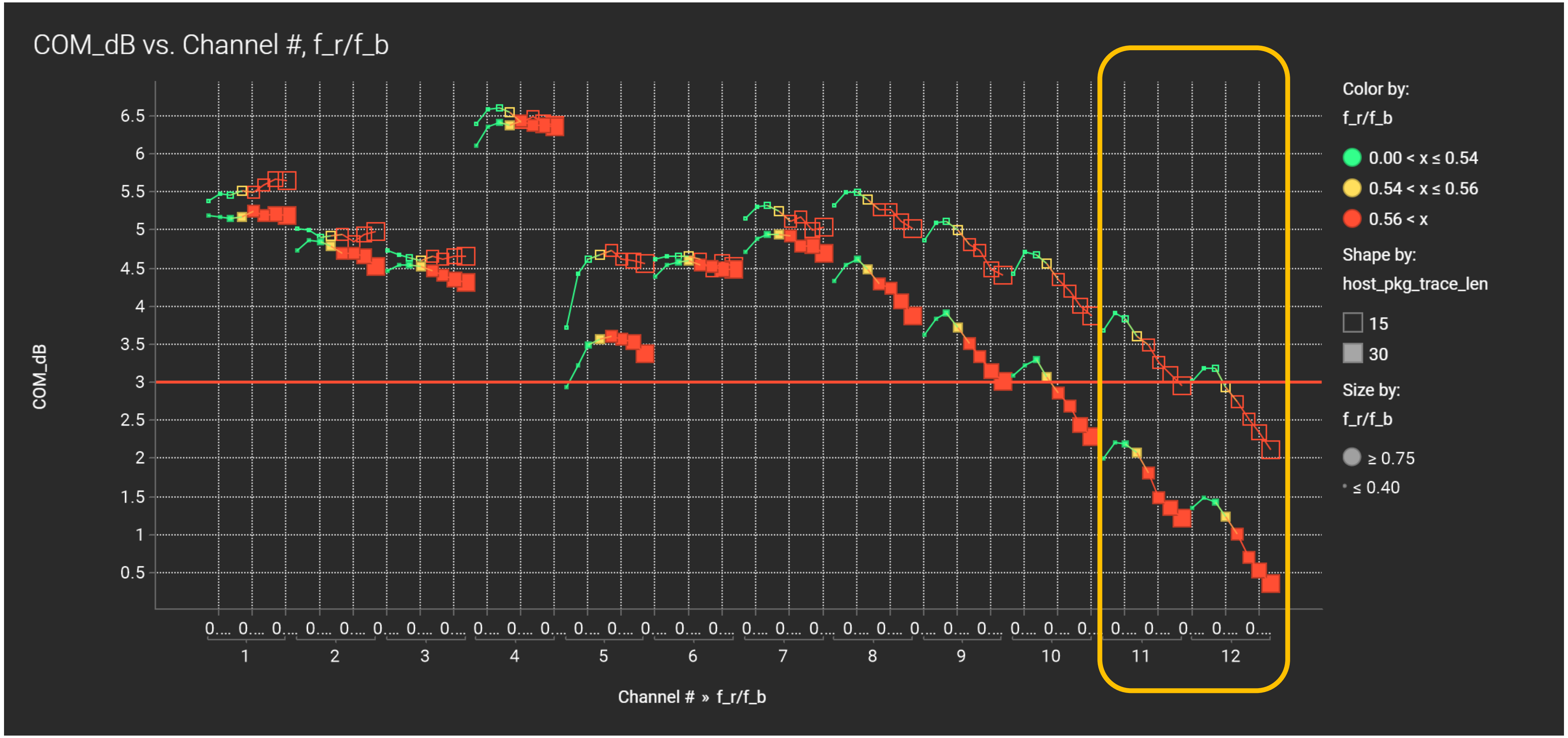
Effect of T_r

T_r [ps] sweep from 3.5 to 7.5 in 0.5 step



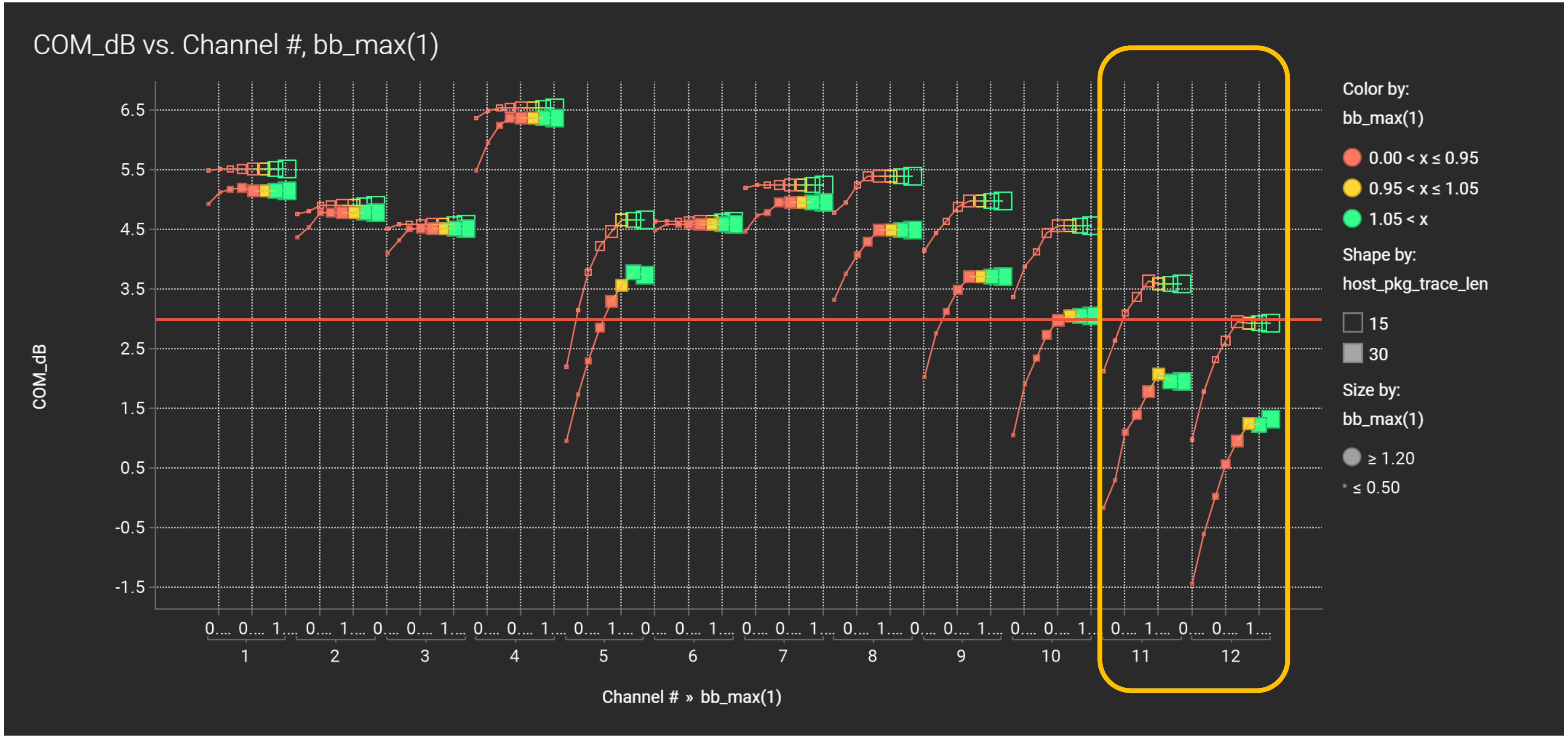
Effect of f_r

f_r/f_b sweep from 0.4 to 0.75 in 0.05 step



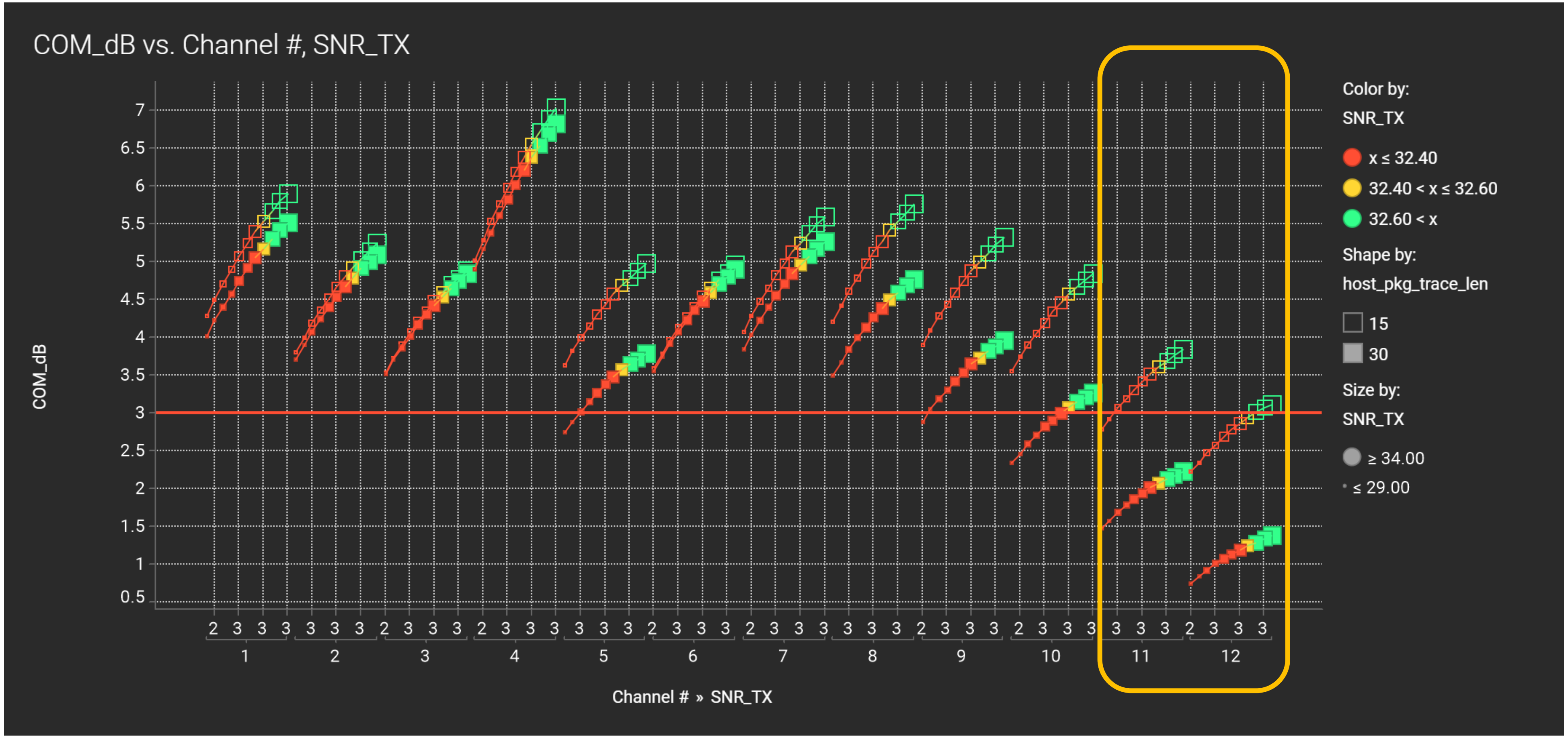
Effect of $bb_{max}(1)$

$bb_{max}(1)$ sweep from 0.5 to 1 in 0.1 step



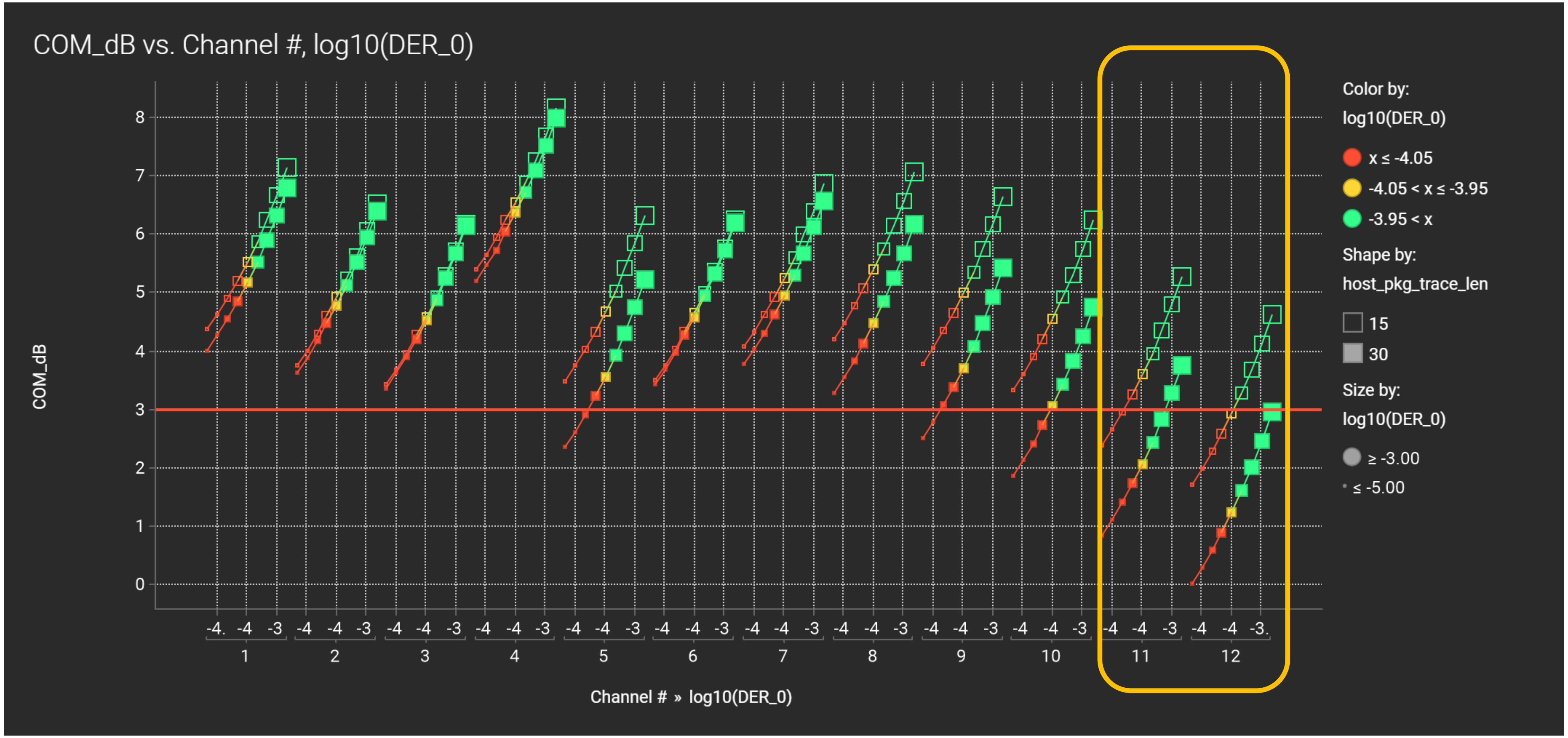
Effect of SNR_{TX}

SNR_{TX} sweep from 29 to 34 in 0.5 step



Effect of DER_0

DER_0 sweep from 1e-5 to 1e-3, 4 steps per decade



Future work

- Fine-tune parameters with more channels
- Analyze the effect of bit/symbol muxing on FLR with given DER
- Consider electrical specification method for C2M
  - What should be similar to C2C / backplane
  - What should be different
- Address functional aspects
  - Symbol muxing
  - Link training on AUIs within a segmented link (optical/electrical)

Summary

- Feasibility of contributed C2M channels with die-to-die IL from 18 dB to 37 dB has been demonstrated by COM analysis
- An operating point for key parameters is proposed
- Implications beyond electrical specifications must be considered
  - FEC scheme
  - Symbol muxing
  - Link training on AUI

Proposed COM spreadsheet (operating point)

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	106.25	GBd	
f_min	0.02	GHz	
Delta_f	0.02	GHz	
C_d	[40 90 110; 40 90 110]*1e-6	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]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[15 30; 2 2; 0.18 0.18; 0.5 0.5]	mm	[test cases]
z_p (NEXT)	[6 6 ; 0.5 0.5; 0.18 0.18; 0.4 0.4]	mm	[test cases]
z_p (FEXT)	[15 30; 2 2; 0.18 0.18; 0.5 0.5]	mm	[test cases]
z_p (RX)	[6 6 ; 0.5 0.5; 0.18 0.18; 0.4 0.4]	mm	[test cases]
C_p	[8e-6 0]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50 50]	Ohm	[TX RX]
A_v	0.413	V	
A_fe	0.413	V	
A_ne	0.608	V	
L	4		
M	32	Samp/UI	
samples_for_C2M	100	Samp/UI	
T_O	50	mUI	
AC_CM_RMS	0	V	[test cases]
filter and Eq			
f_r	0.55	*fb	
c(0)	0.5		min
c(-1)	[-0.34:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.14]		[min:step:max]
c(-3)	[-0.06:0.02:0]		[min:step:max]
c(-4)	[0:0.01:0.03]		[min:step:max]
c(1)	[-0.1:0.02:0]		[min:step:max]
N_b	24	UI	
b_max(1)	1		As/dffe1
b_max(2..N_b)	0.3		As/dfe2..N_b
b_min(1)	0.3		As/dffe1
b_min(2..N_b)	-0.15		As/dfe2..N_b
g_DC	[-18:1:-8]	dB	[min:step:max]
f_z	42.5	GHz	
f_p1	42.5	GHz	
f_p2	106.25	GHz	
g_DC_HP	[-3:0.5:0]		[min:step:max]
f_HP_PZ	0.6	GHz	

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\{date}\	Path
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	C2M_eval_	
COM_CONTRIBUTION	0	logical
Local Search	2	
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	7.3	dB
DER_0	1.00E-04	
T_r	6.00E-03	ns
FORCE_TR	1	5
PMD_type	C2C	
BREAD_CRUMBS	0	logical
SAVE_CONFIG2MAT	1	logical
PLOT_CM	0	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	1200	
beta_x	0	
rho_x	0.618	
fixture delay time	[0 0]	[port1 port2]
TDR_W_TXPKG	0	
N_bx	0	UI
Tukey_Window	1	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	4.00E-09	V^2/GHz
SNR_TX	32.5	dB
R_LM	0.95	

different for each test fixture

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 1.33e-3 3.9525e-4]	
package_tl_tau	6.420E-03	ns/mm
package_Z_c	[94 94; 90 90; 200 200; 70 70]	Ohm
ICN & FOM_ILD parameters		
f_v	0.371	*Fb
f_f	0.371	GHz f_r specified in first column
f_n	0.371	GHz
f_2	58.4375	GHz
A_ft	0.600	V
A_nt	0.600	V
Histogram_Window_Weight	Gaussian	gaussian. triangle, rectangle
sigma_r	0.02	sigma in UI fo or gaus.. Wind

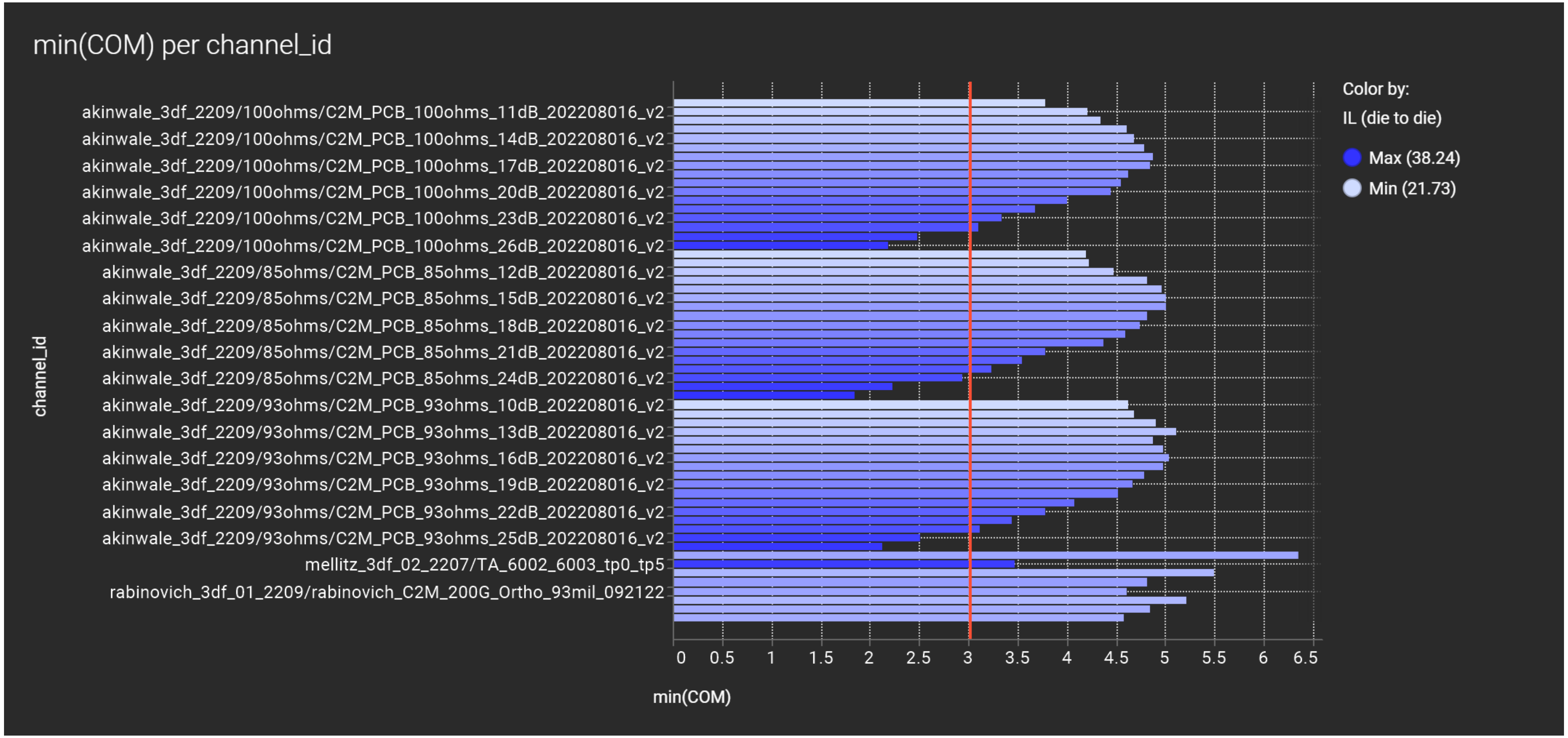
Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	[0 3.8206e-04 9.5909e-05]	
board_tl_tau	0.00579	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	407	mm
z_bp (NEXT)	407	mm
z_bp (FEXT)	407	mm
z_bp (RX)	407	mm
C_0	0	nF
C_1	0	nF
Include PCB	0	logical

updated for 802.3df/dj C2M

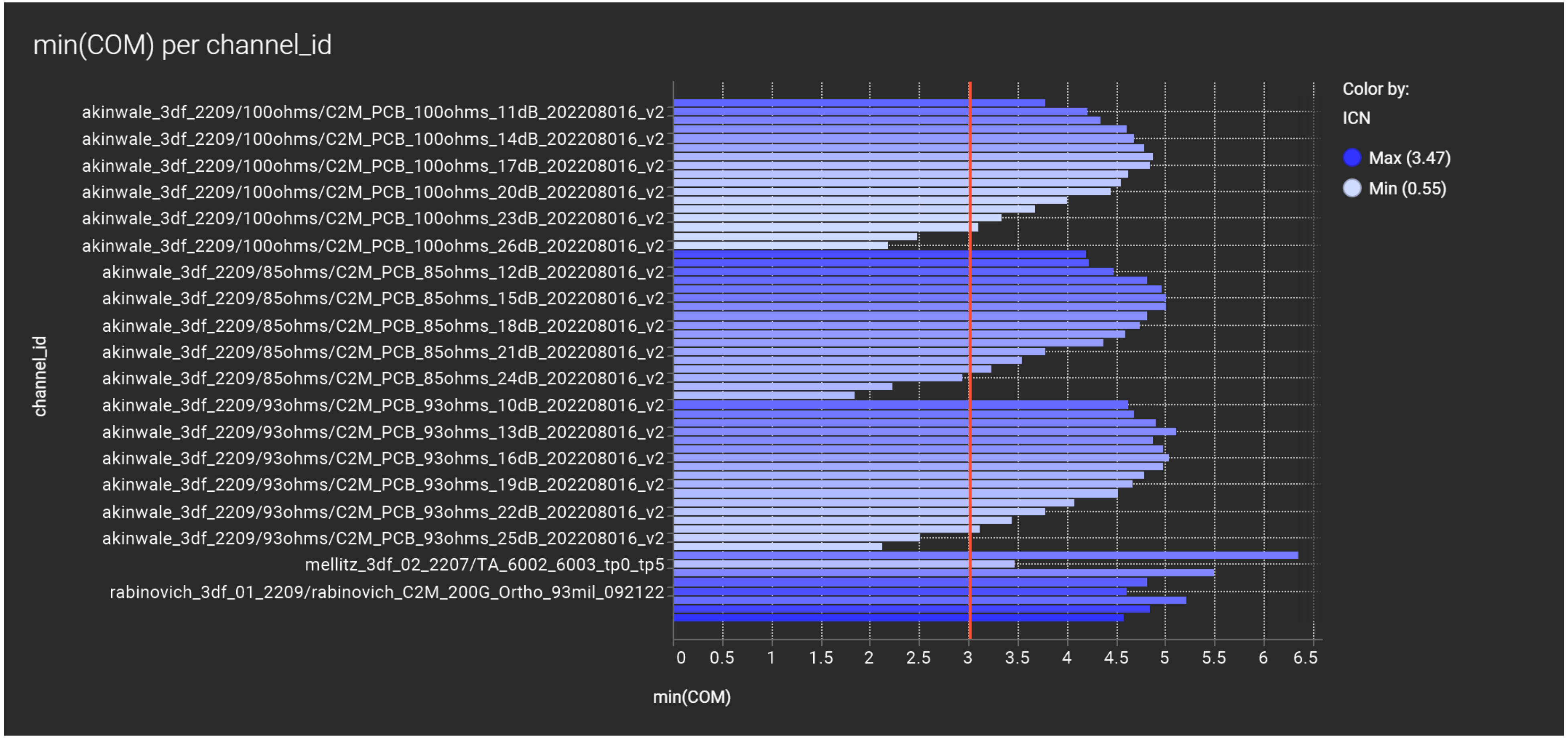
Floating Tap Control		
N_bg	3	0 1 2 or 3 groups
N_bf	3	taps per group
N_f	80	UI span for floating taps
bmaxg	0.2	max DFE value for floating taps
N_tail_start	24	
B_float_RSS_MAX	0.1	

Backup

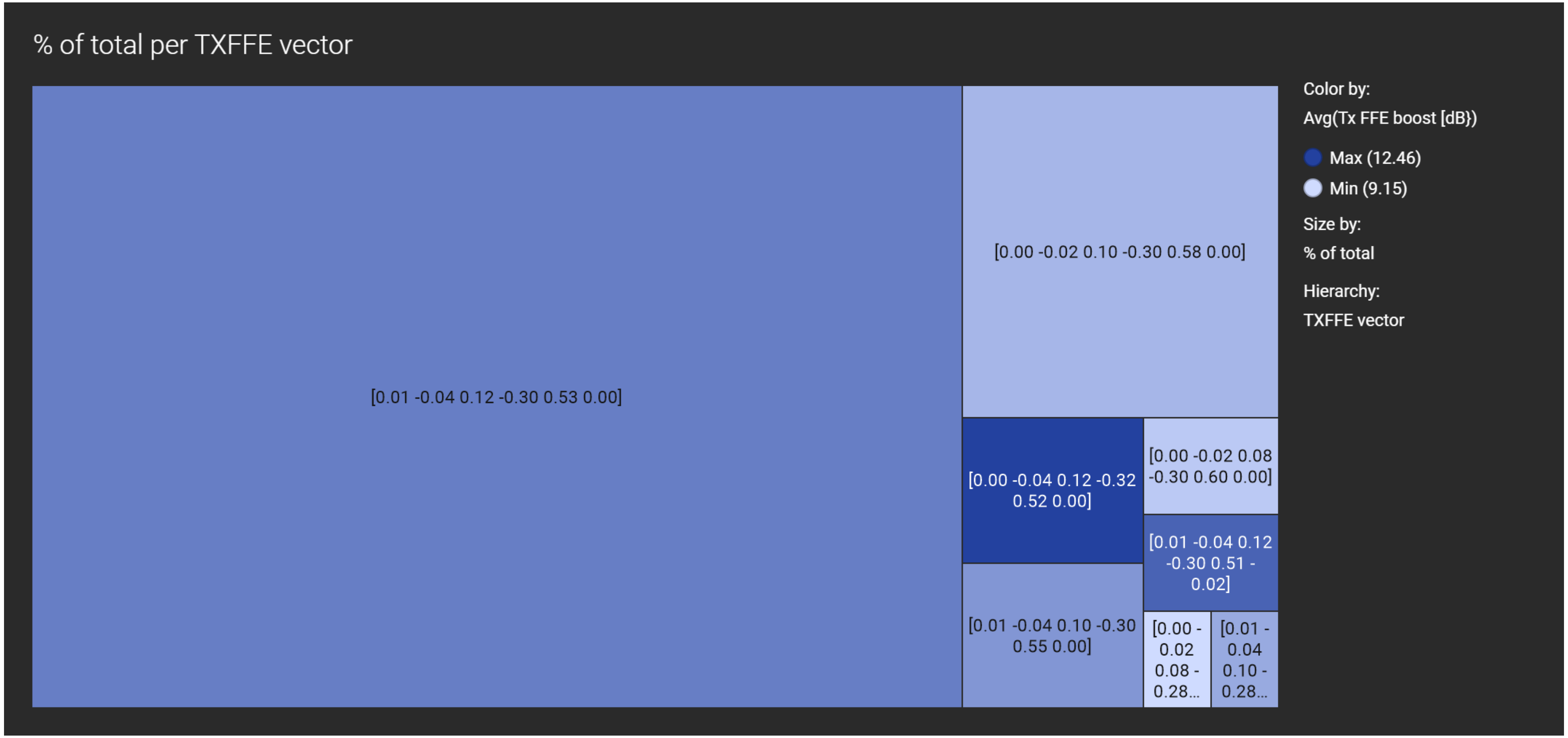
All contributed channels at operating point
(Color scale: IL D2D)



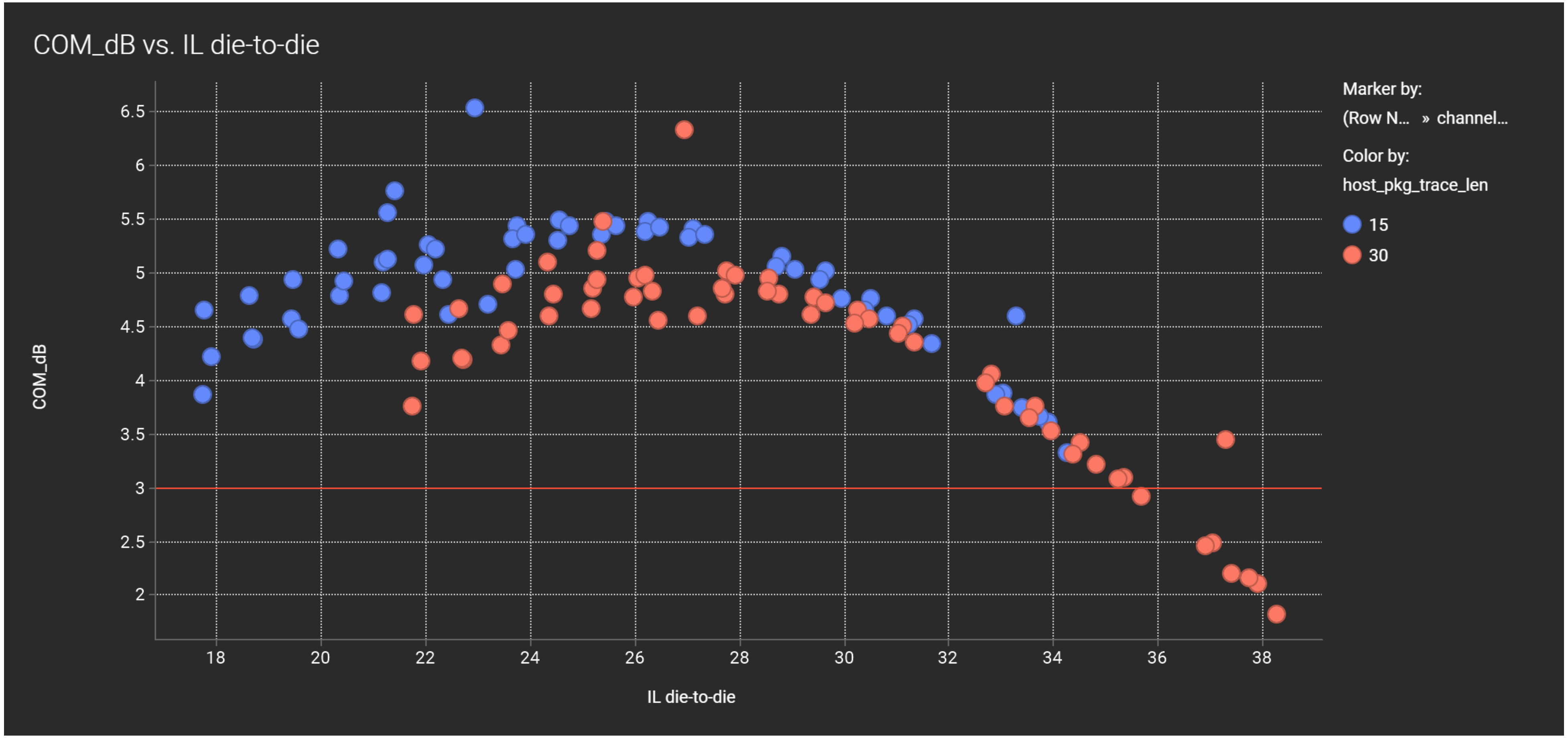
All contributed channels at operating point
(Color scale: ICN)



Tx FFE coefficients



COM/IL scatter plot



COM/ICN scatter plot