

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 02 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 operating point
5. Run COM on the full set of channels

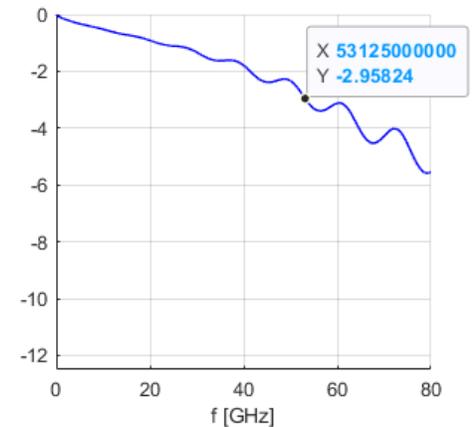
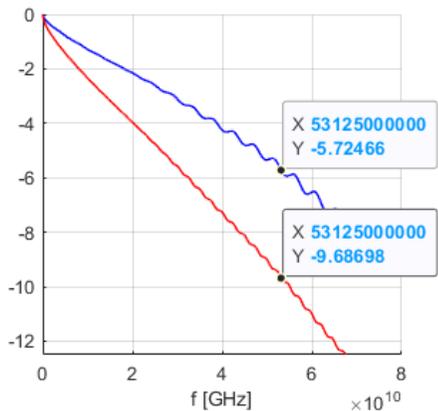
Channel construction



From [mli 3df 02a 220316](#)

From [benartsi 3df 01b 2207](#)
 z_{p1} (trace) = 15 mm / 30 mm

From [benartsi 3df 01b 2207](#),
 z_{p1} (trace) = 6 mm
 z_{p2} (pkg via) = 0.5 mm
 z_{p4} (PCB via) = 0.4 mm



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

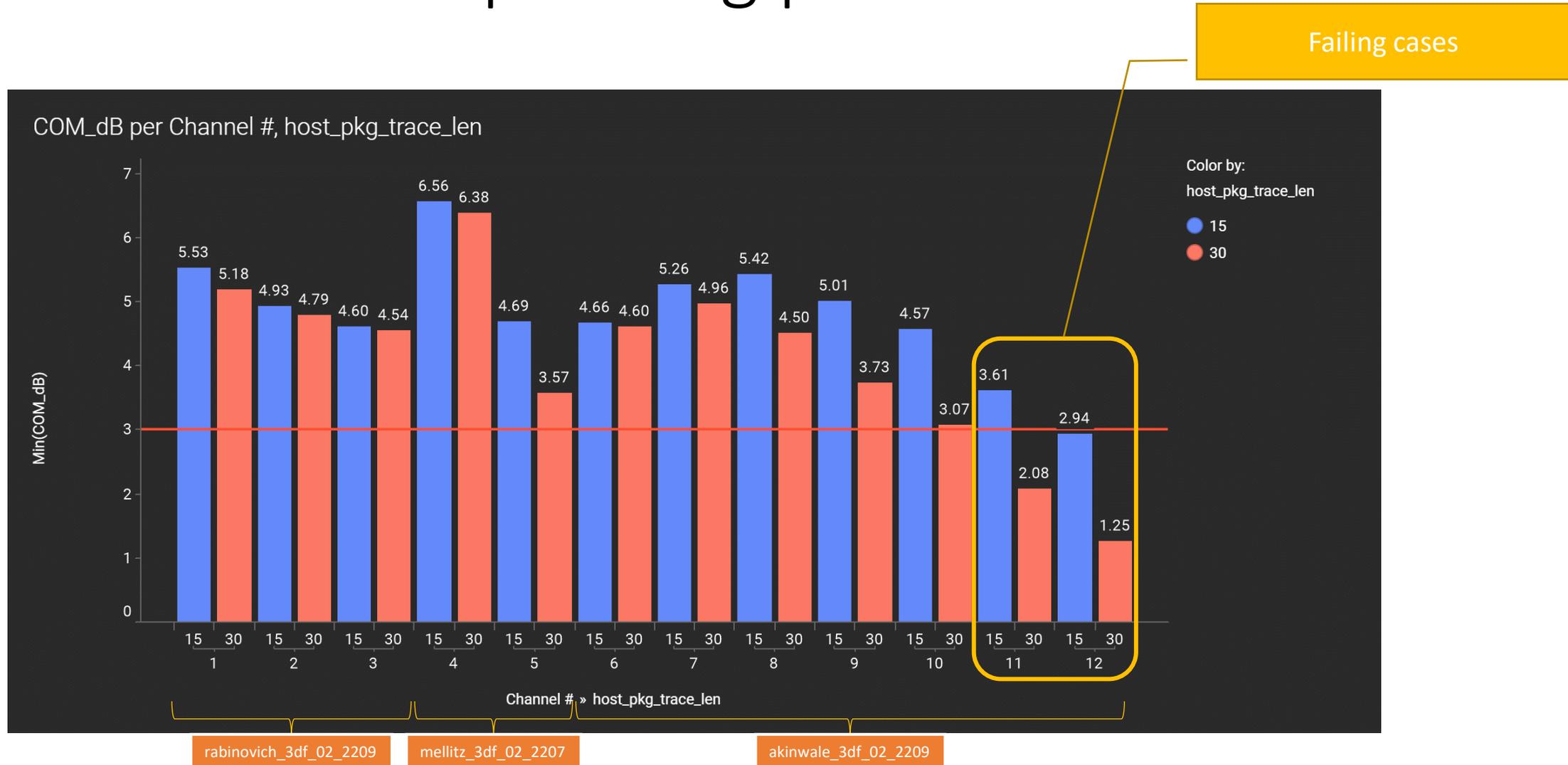
(other parameters that may also have a large effect, but are considered hard to change, were not included in the analysis)
- A set of values for these parameters, which makes two challenging channels have $COM \approx 3$ dB, was defined as the “operating point”
 - Channel # 5 (37.3 dB die-to-die)
 -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

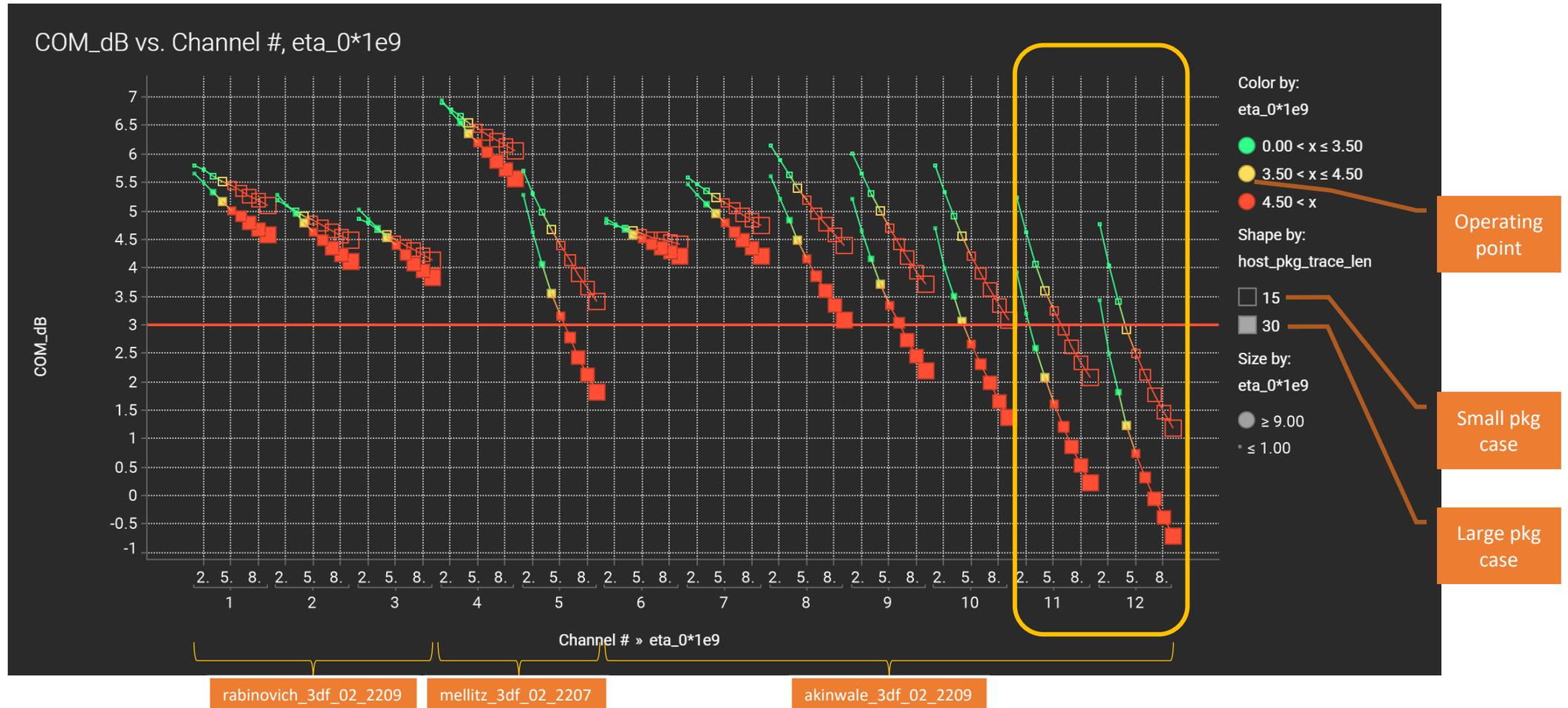


Implications

- $DER_0=1e-4$ 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**

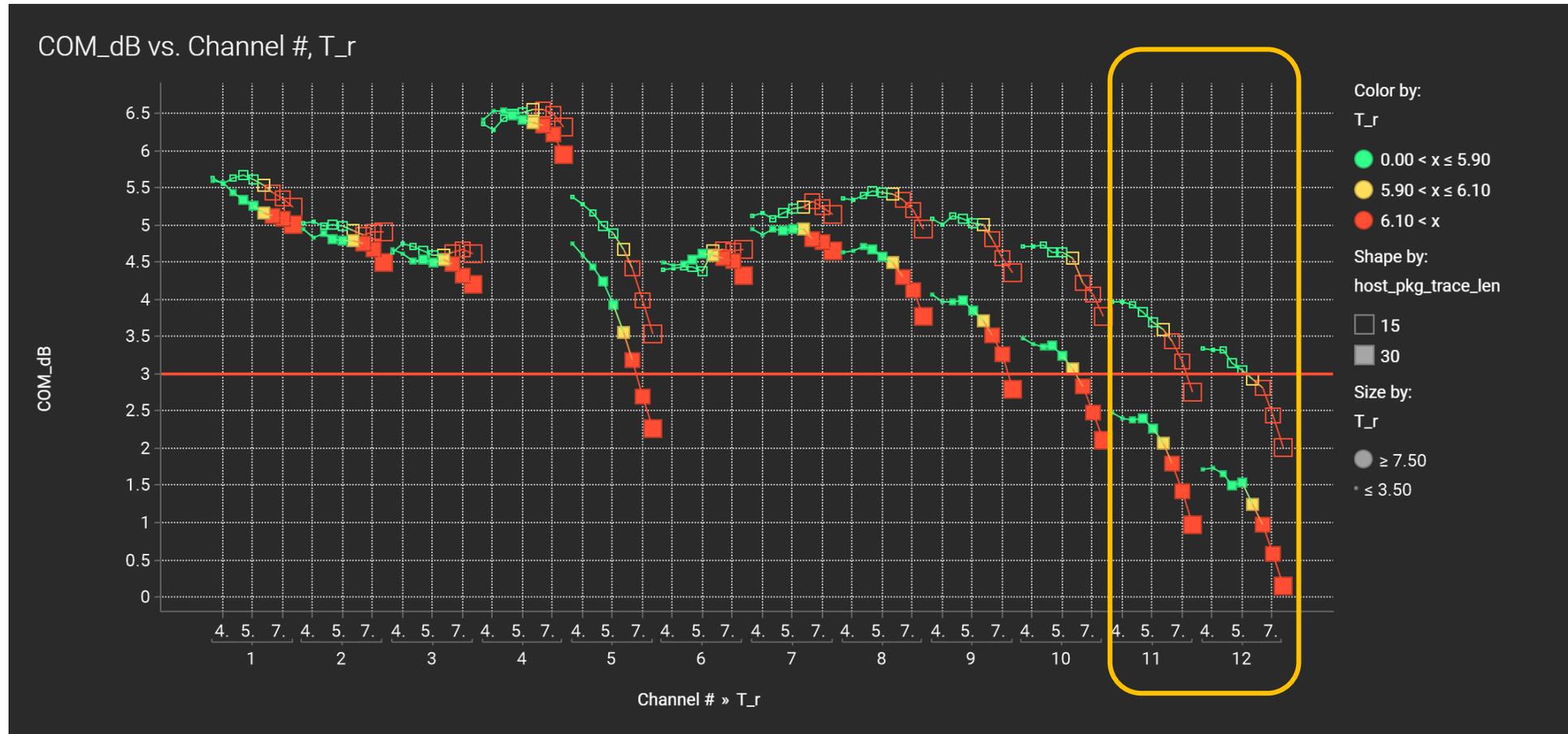
Effect of η_0

η_0 [V²/GHz] sweep from 1e-9 to 9e-9 in 1e-9 step



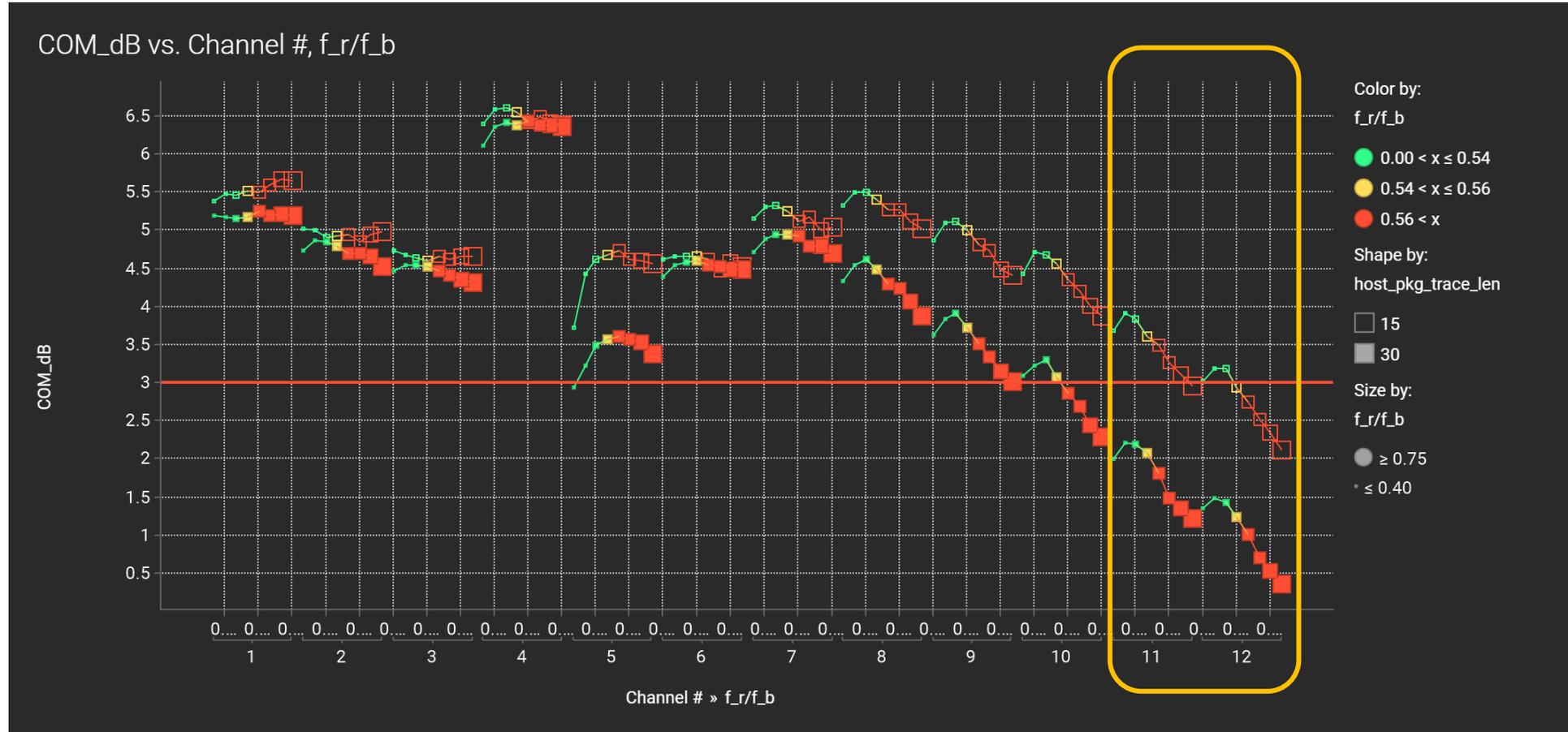
Effect of T_r

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



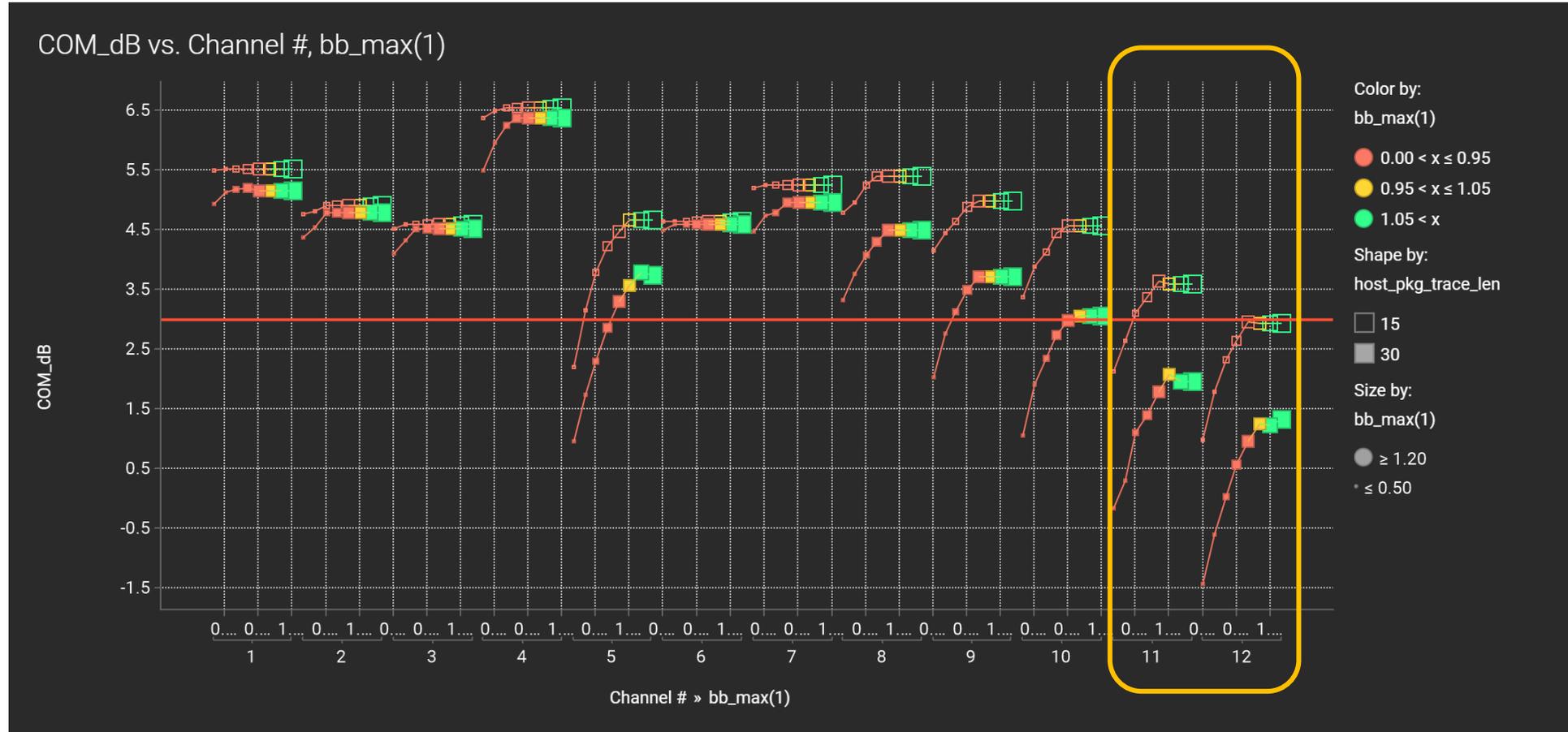
Effect of f_r

f_r/f_b sweep from 0.4 to 0.75 in 0.05 step



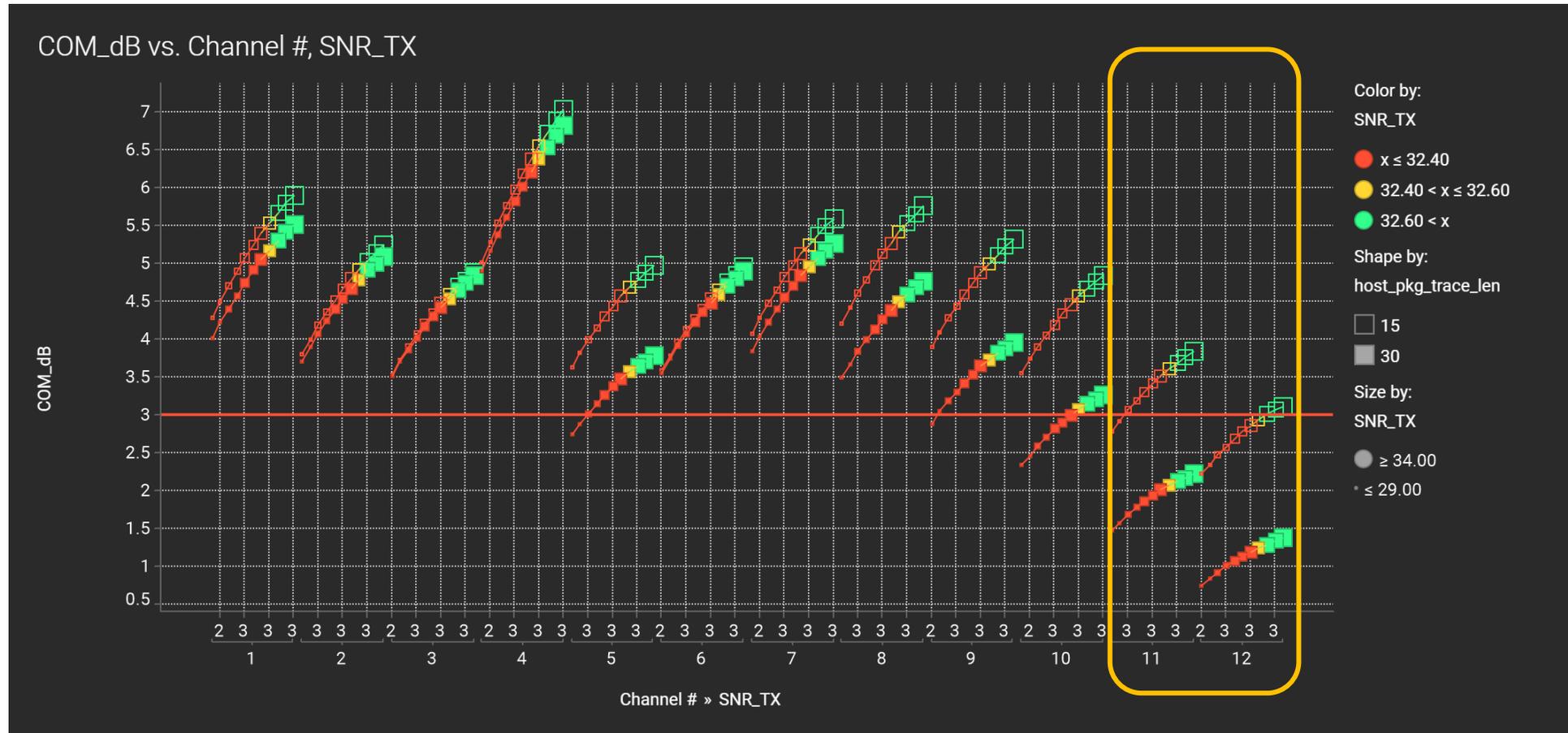
Effect of $bb_{max}(1)$

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



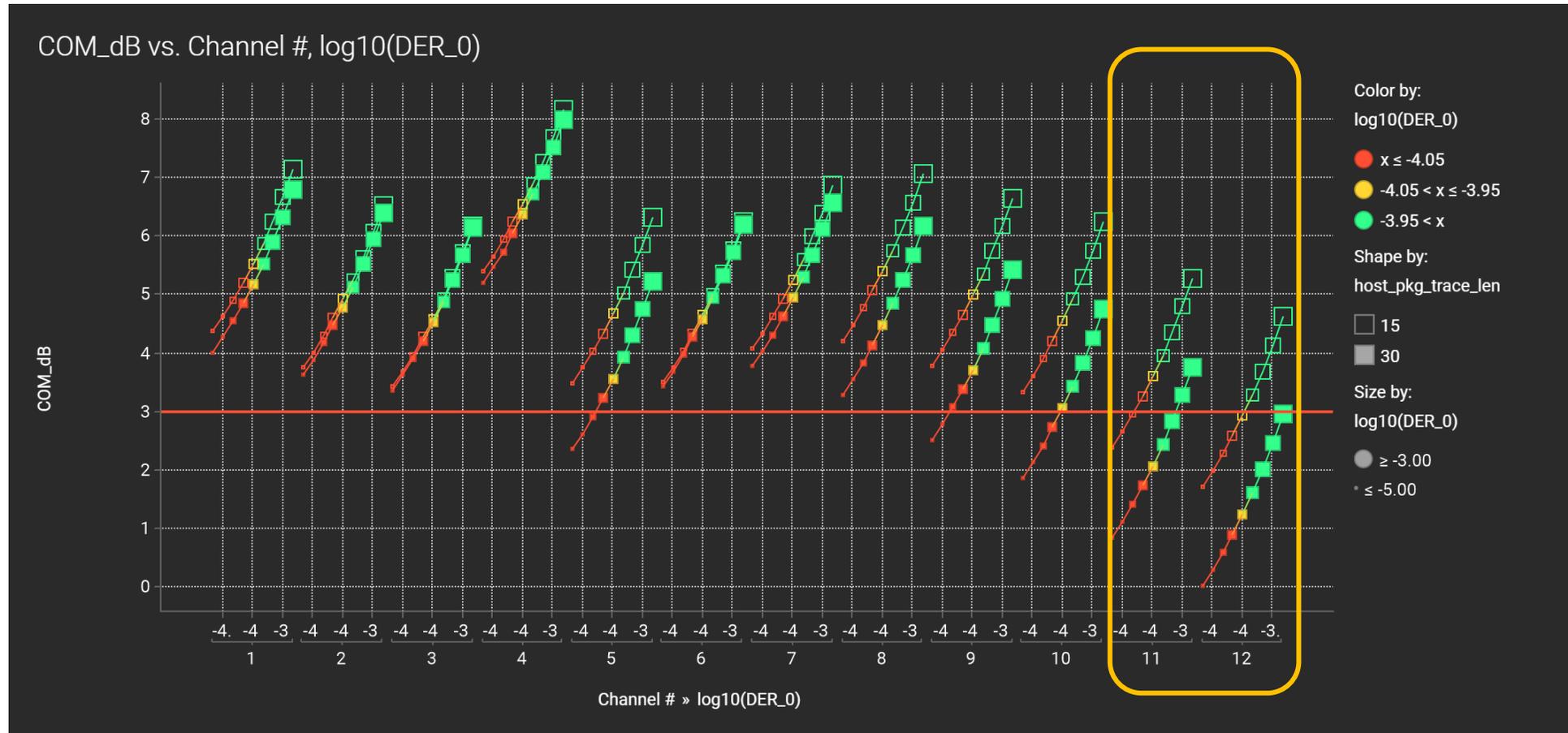
Effect of SNR_{TX}

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	

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		
sigma_r	Gaussian	gaussian, triangle, rectangle
	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

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	

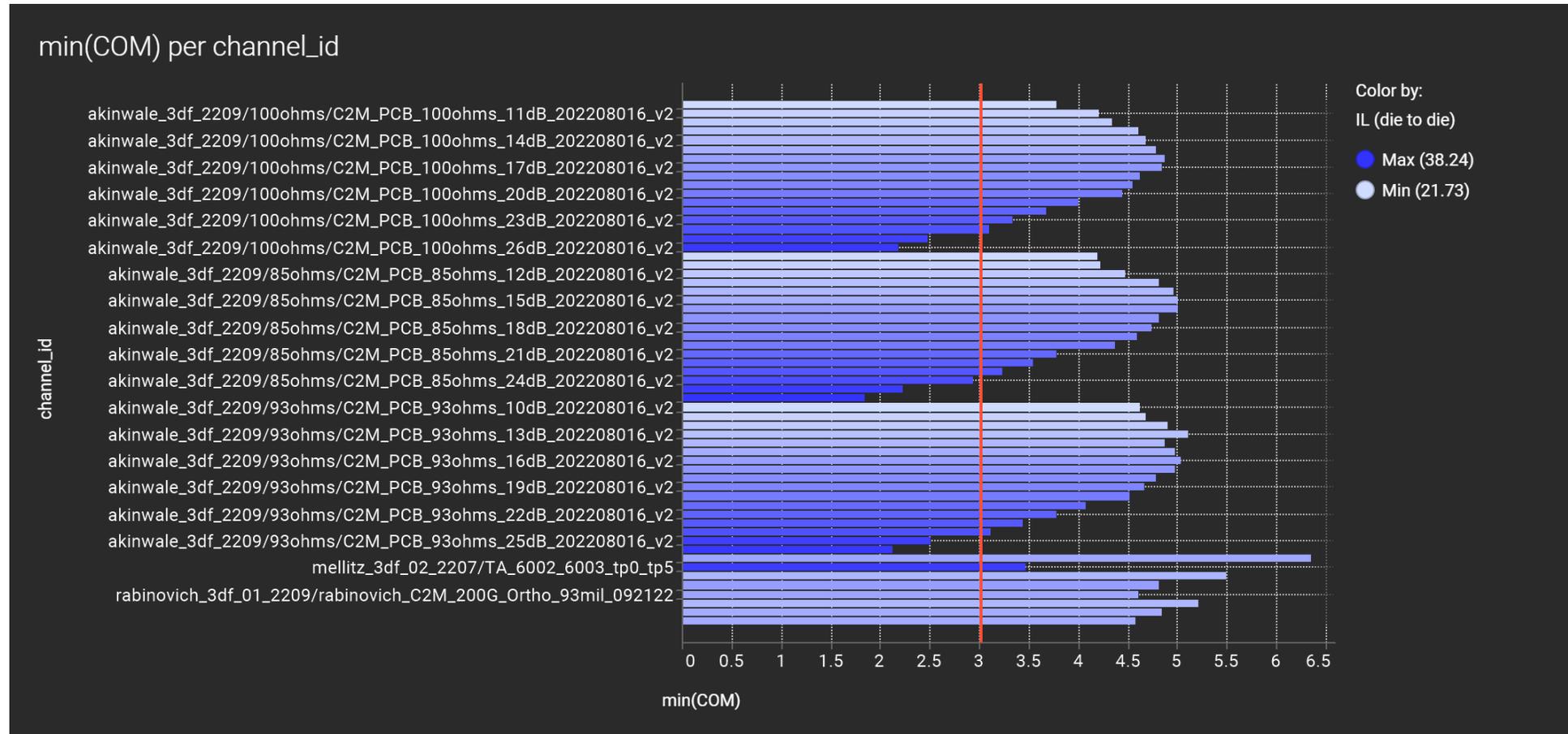
different for each test fixture

updated for 802.3df/dj C2M

Backup

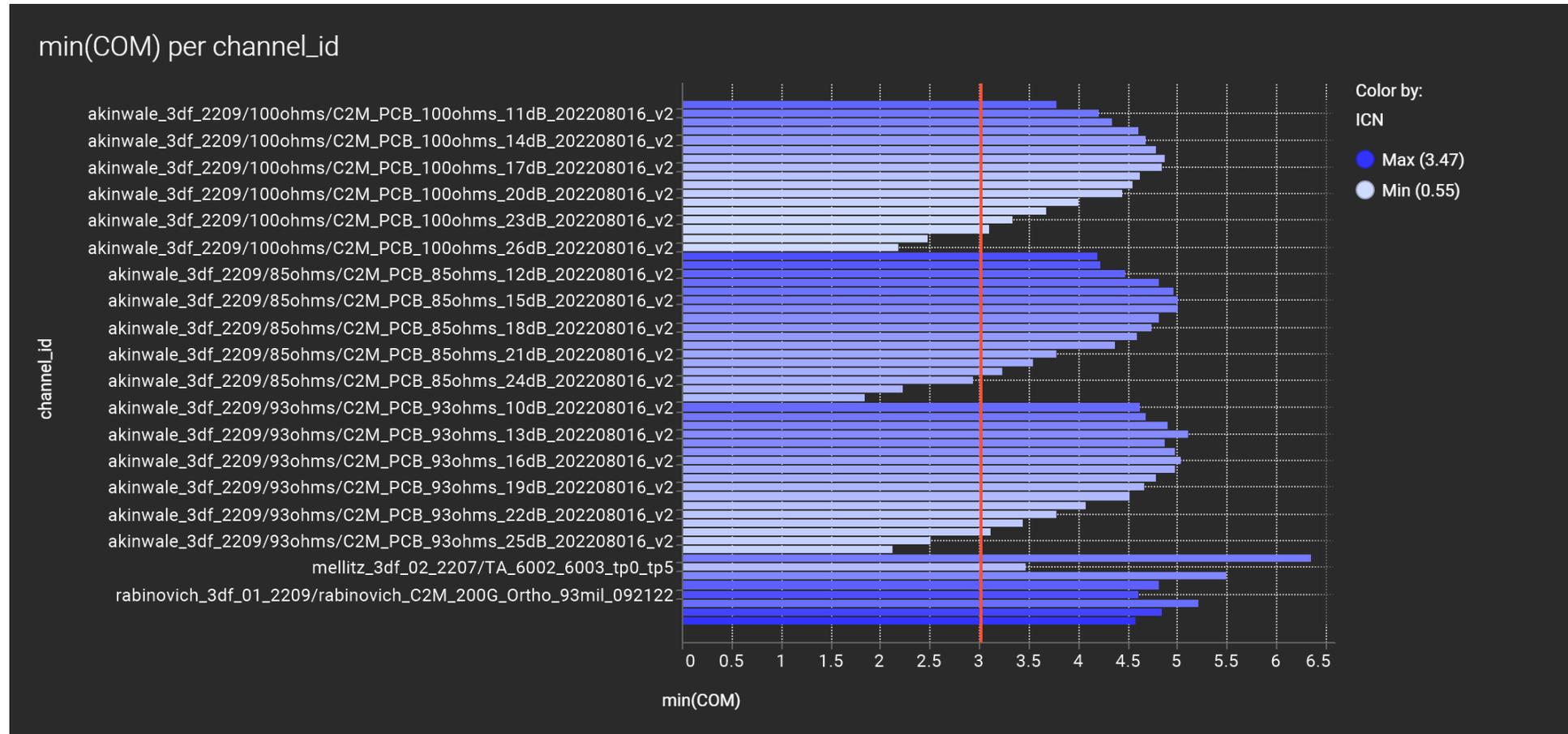
All contributed channels at operating point

(Color scale: IL D2D)

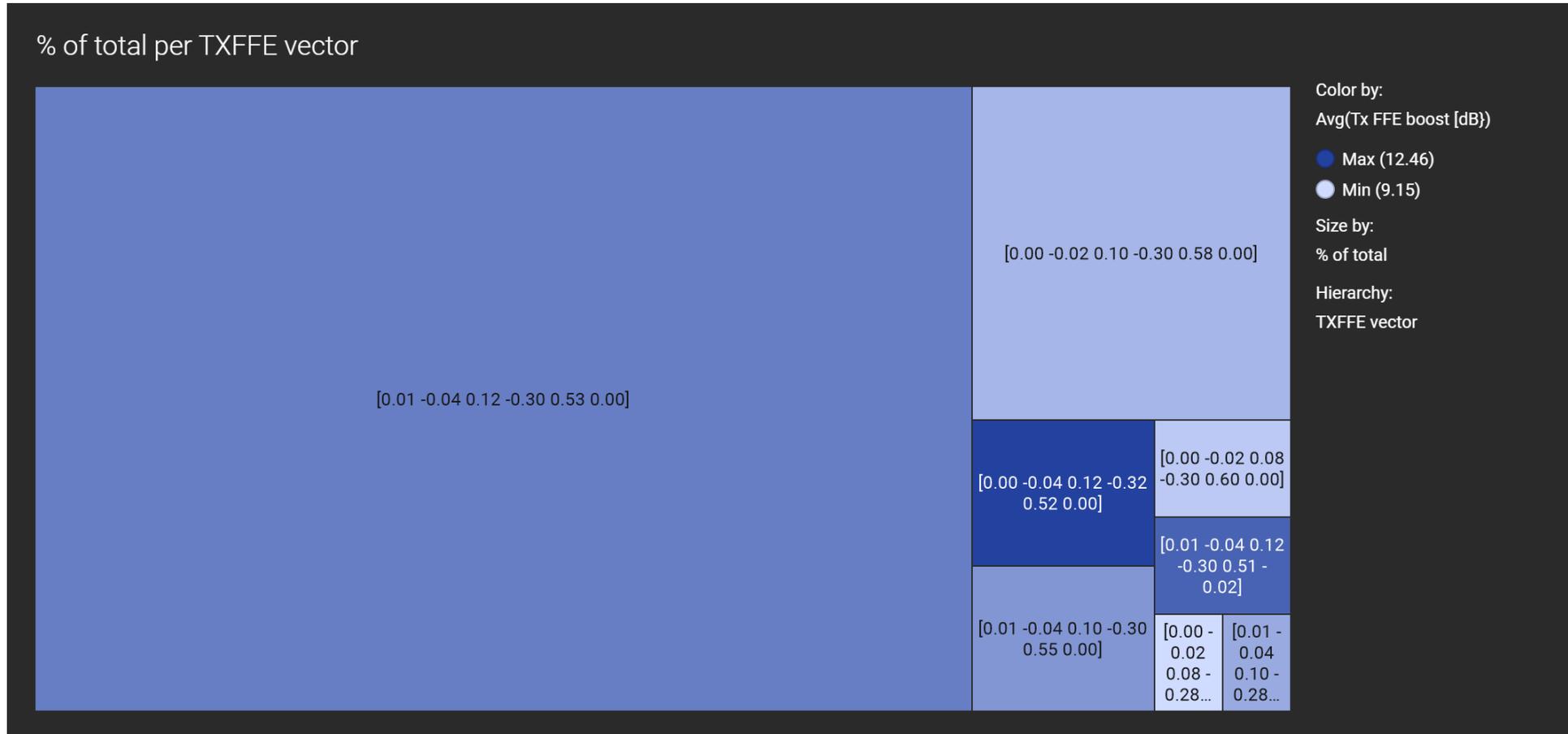


All contributed channels at operating point

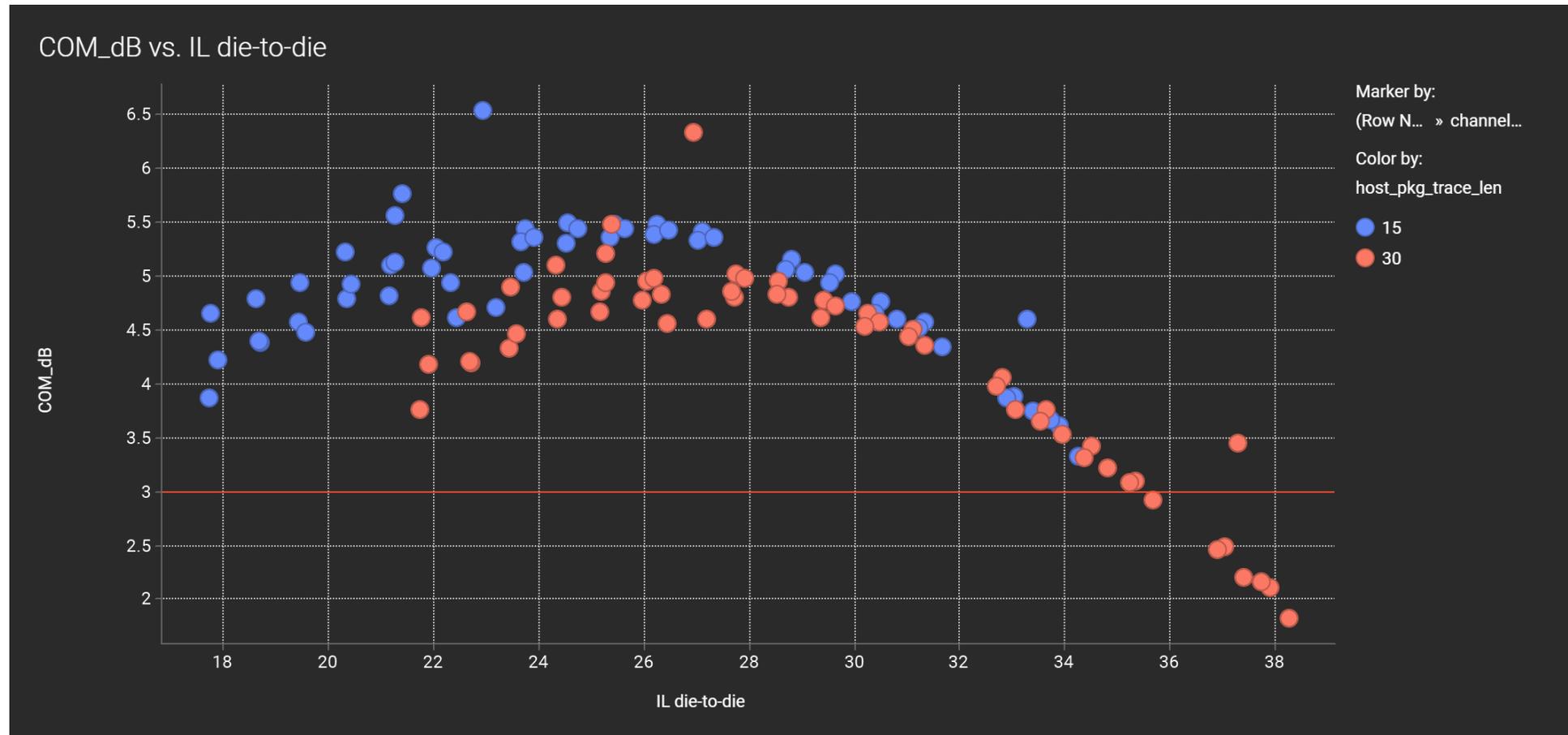
(Color scale: ICN)



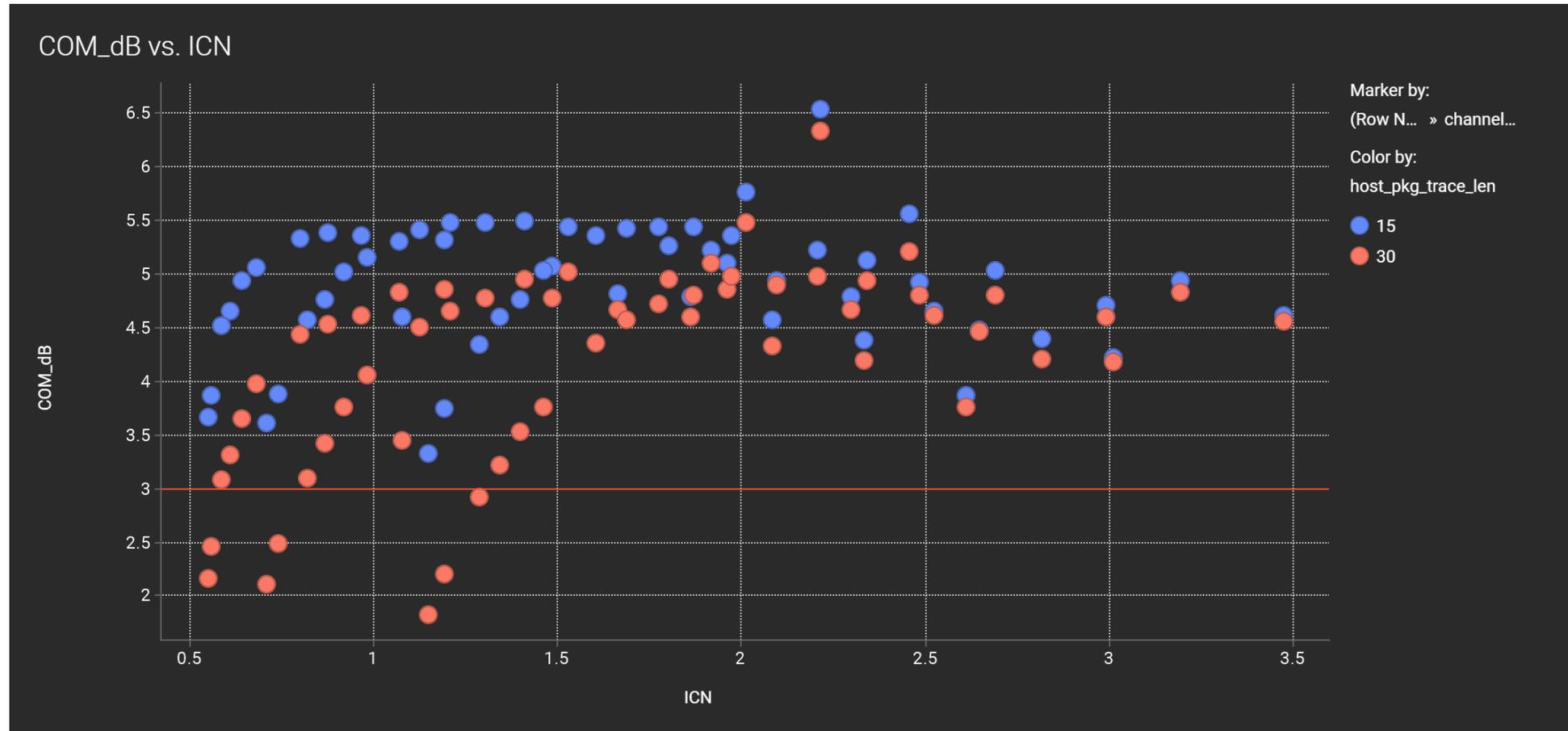
Tx FFE coefficients



COM/IL scatter plot



COM/ICN scatter plot



Raised cosine effect is similar to a choice of f_r with the existing Butterworth filter

(Raised cosine filter is an option in beta version 3.85 of COM, provided by Rich Mellitz)

