Backplane Reference Receiver Analysis

July 2019

Howard Heck (Intel), Phil Sun (Credo Semiconductor)

Backplane Consensus Group

Contributors

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- Upen Kareti, Cisco
- Adam Healey, Broadcom
- Clint Walker, Alphawave IP
- Phil Sun, Credo Semiconductor
- Mau-lin Wu, Mediatek
- Matt Brown
- Mike Li, Intel
- Beth Kochuparambil, Cisco
- Kent Lusted, Intel

Supporters

- Clint Walker, AlphaWave IP
- Rich Mellitz, Samtec
- Upen Kareti, Cisco Systems
- Adam Healey, Broadcom

Objectives & Recommendations

Provide analysis & recommendations for

- Reference receiver (# taps, # banks, span)
  - $\Rightarrow$ Group recommendation: 12 fixed taps, 3 banks of 3 or 4 floating taps with 40UI span
- Termination model
  - $\Rightarrow$ Group recommendation: Adopt the termination model described in http://www.ieee802.org/3/ck/public/adhoc/jun12_19/healey_3ck_adhoc_01_061219.pdf.
- Rx noise figure (η_0)
  - $\Rightarrow$ Group recommendation: Adopt the baseline value (8.2×10^{-9} V^2/GHz) that we have been using.

Contents

- COM Worksheets
- Channels
- Reference Rx Analysis
  - Initial
  - Final
- Termination Model Analysis
- Rx Noise Impact Analysis

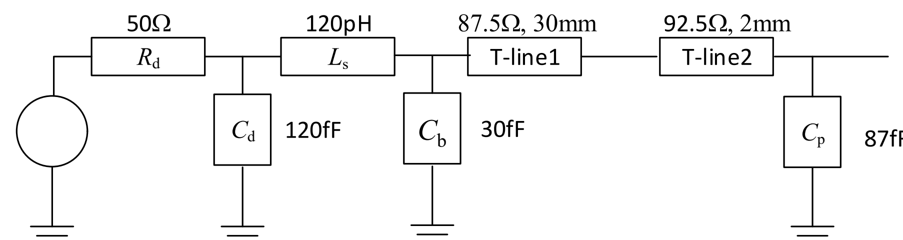
COM Worksheet – Proposed Termination

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	53.125	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1.2e-4 , 1.2e-4]	nF	[TX RX]
L_s	[0.12, 0.12]	nH	[TX RX]
C_b	[0.3e-4 0.3e-4]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 31; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 30; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 30; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 29; 1.8 1.8]	mm	[test cases]
C_p	[0.87e-4 0.87e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50, 50]	Ohm	[TX RX]
A_v	0.412	V	vp/vf=.694
A_fe	0.412	V	vp/vf=.694
A_ne	0.608	V	
L	4		
M	32		
filter and Eq			
f_r	0.75	*fb	
c(0)	0.54		min
c(-1)	[-0.34:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.12]		[min:step:max]
c(-3)	[-0.06:0.02:0]		[min:step:max]
c(1)	[-0.1:0.05:0]		[min:step:max]
N_b	20	UI	
b_max(1)	0.85		
b_max(2..N_b)	0.3		
g_DC	[-20:1:0]	dB	[min:step:max]
f_z	21.25	GHz	
f_p1	21.25	GHz	
f_p2	53.125	GHz	
g_DC_HP	[-6:1:0]		[min:step:max]
f_HP_PZ	0.6640625	GHz	
ffe_pre_tap_len	0	UI	
ffe_post_tap_len	0	UI	
ffe_tap_step_size	0.02		
ffe_main_cursor_min	0.7		
ffe_pre_tap1_max	0.3		
ffe_post_tap1_max	0.3		
ffe_tapn_max	0.125		
ffe_backoff	0		
Floating Tap Control			
N_bg	1		0 1 2 or 3 groups
N_bf	4		taps per group
N_f	40		UI span for floating taps
bmaxg	0.3		max DFE value for floating taps

I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	1	logical
RESULT_DIR	.\TestCaseFloatingBank\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	New_15	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10.5	dB
DER_0	1.00E-04	
T_r	6.16E-03	ns
FORCE_TR	1	logical
Include PCB	0	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	3000	
TDR_Butterworth	1	logical
beta_x	2.28E+09	
rho_x	**0.25**	
fixture delay time	0	enter sec
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	8.20E-09	V^2/GHz
SNR_TX	33	dB
R_LM	0.95	

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 0.0009909 0.0002772]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	*[0 3.8206e-04 9.5909e-05]*	
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	90	Ohm
z_bp (TX)	*119*	mm
z_bp (NEXT)	*119*	mm
z_bp (FEXT)	*119*	mm
z_bp (RX)	*119*	mm



COM Worksheet – Simple Termination

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	53.125	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[0.9e-4 , 0.9e-4]	nF	[TX RX]
L_s	[0, 0]	nH	[TX RX]
C_b	[0 0]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 31; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 30; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 30; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 29; 1.8 1.8]	mm	[test cases]
C_p	[0.87e-4 0.87e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50, 50]	Ohm	[TX RX]
A_v	0.412	V	vp/vf=.694
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c(-3)	[-0.06:0.02:0]		[min:step:max]
c(1)	[-0.1:0.05:0]		[min:step:max]
N_b	20	UI	
b_max(1)	0.85		
b_max(2..N_b)	0.3		
g_DC	[-20:1:0]	dB	[min:step:max]
f_z	21.25	GHz	
f_p1	21.25	GHz	
f_p2	53.125	GHz	
g_DC_HP	[-6:1:0]		[min:step:max]
f_HP_PZ	0.6640625	GHz	
ffe_pre_tap_len	0	UI	
ffe_post_tap_len	0	UI	
ffe_tap_step_size	0.02		
ffe_main_cursor_min	0.7		
ffe_pre_tap1_max	0.3		
ffe_post_tap1_max	0.3		
ffe_tapn_max	0.125		
ffe_backoff	0		
Floating Tap Control			
N_bg	1		0 1 2 or 3 groups
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N_f	40		UI span for floating taps
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DIAGNOSTICS	0	logical
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RESULT_DIR	.\TestCaseFloatingBank\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	New_15_SimpleTerm	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10.5	dB
DER_0	1.00E-04	
T_r	6.16E-03	ns
FORCE_TR	1	logical
Include PCB	0	logical
TDR and ERL options		
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ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	3000	
TDR_Butterworth	1	logical
beta_x	2.28E+09	
rho_x	**0.25**	
fixture delay time	0	enter sec
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
Noise, jitter		
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Table 93A–3 parameters		
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Table 92–12 parameters		
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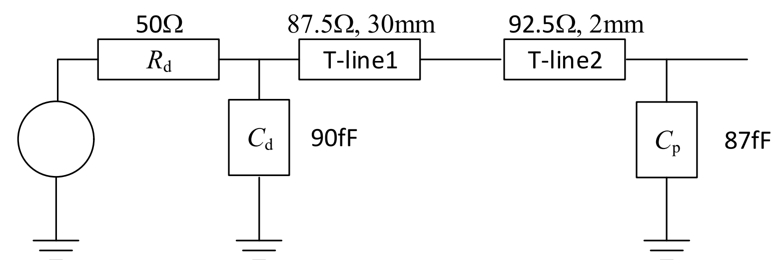
board_Z_c	90	Ohm
z_bp (TX)	*119*	mm
z_bp (NEXT)	*119*	mm
z_bp (FEXT)	*119*	mm
z_bp (RX)	*119*	mm



Channels – Full Set

#	Main File	Folder	Files	Documentation
1		Cable_BKP_16dB_0p575m.zip	Cable_BKP_16dB_0p575m_*.s4p	
2	cable_CKP_16dB.zip	Cable_BKP_16dB_0p575m_more_isi.zip	Cable_BKP_16dB_0p575m_more_isi_*.s4p	
3		Cable_BKP_16dB_0p995m_updated.zip	Cable_BKP_16dB_0p995m_updated_*.s4p	
4		Cable_BKP_16dB_0p0p995m_more_isi_updated.zip	Cable_BKP_16dB_0p0p995m_more_isi_updated_*.s4p	
5		Cable_BKP_20dB_0p575m.zip	Cable_BKP_20dB_0p575m_*.s4p	
6	cable_CKP_20dB.zip	Cable_BKP_20dB_0p575m_more_isi.zip	Cable_BKP_20dB_0p575m_more_isi_*.s4p	
7		Cable_BKP_20dB_0p995m_updated.zip	Cable_BKP_20dB_0p995m_updated_*.s4p	
8		Cable_BKP_20dB_0p0p995m_more_isi_updated.zip	Cable_BKP_20dB_0p0p995m_more_isi_updated_*.s4p	heck_3ck_02_0119.pdf
9		Cable_BKP_24dB_0p575m.zip	Cable_BKP_24dB_0p575m_*.s4p	
10	cable_CKP_24dB.zip	Cable_BKP_24dB_0p575m_more_isi.zip	Cable_BKP_24dB_0p575m_more_isi_*.s4p	
11		Cable_BKP_24dB_0p995m_updated.zip	Cable_BKP_24dB_0p995m_updated_*.s4p	
12		Cable_BKP_24dB_0p0p995m_more_isi_updated.zip	Cable_BKP_24dB_0p0p995m_more_isi_updated_*.s4p	
13		Cable_BKP_28dB_0p575m.zip	Cable_BKP_28dB_0p575m_*.s4p	
14	cable_CKP_28dB.zip	Cable_BKP_28dB_0p575m_more_isi.zip	Cable_BKP_28dB_0p575m_more_isi_*.s4p	
15		Cable_BKP_28dB_0p995m_updated.zip	Cable_BKP_28dB_0p995m_updated_*.s4p	
16		Cable_BKP_28dB_0p0p995m_more_isi_updated.zip	Cable_BKP_28dB_0p0p995m_more_isi_updated_*.s4p	
17		DPO_IL_12dB	DPO_4in_Meg7_*.s4p	
18	tracy_3ck_02_0119_orthoBP.zip	DPO_IL_24dB	DPO_10in_Meg7_*.s4p	
19		DPO_IL_28dB	DPO_12in_Meg7_*.s4p	tracy_3ck_01b_0119.pdf
20		DPO_IL_32dB	DPO_14in_Meg7_*.s4p	
21	tracy_3ck_03_0119_tradBP.zip	-	Std_BP_12inch_Meg7_*.s4p	
22		Link_1		
23		Link_2		
24		Link_3		
25		Link_4		
26	zambell_3ck_01_1118_links01to09.zip	Link_5		
27		Link_6		
28		Link_7		
29		Link_8		
30		Link_9		
31		Link_10		
32		Link_11		
33		Link_12		
34		Link_13		
35	zambell_3ck_01_1118_links10to18.zip	Link_14	See the folder	zambell_3ck_01_1118.pdf
36		Link_15		
37		Link_16		
38		Link_17		
39		Link_18		
40		Link_19		
41		Link_20		
42		Link_21		
43		Link_22		
44	zambell_3ck_01_1118_links19to278.zip	Link_23		
45		Link_24		
46		Link_25		
47		Link_26		
48		Link_27		
49		CaBP_BGAVia_Opt1_24dB.zip	CaBP_BGAVia_Opt1_24dB_*.s4p	
50		CaBP_BGAVia_Opt1_28dB.zip	CaBP_BGAVia_Opt1_28dB_*.s4p	
51	mellitz_3ck_adhoc_02_081518_cabledbackplane.zip	CaBP_BGAVia_Opt1_32dB.zip	CaBP_BGAVia_Opt1_32dB_*.s4p	mellitz_3ck_adhoc_02_081518.pdf
52		CaBP_BGAVia_Opt2_24dB.zip	CaBP_BGAVia_Opt2_24dB_*.s4p	
53		CaBP_BGAVia_Opt2_28dB.zip	CaBP_BGAVia_Opt2_28dB_*.s4p	
54		CaBP_BGAVia_Opt2_32dB.zip	CaBP_BGAVia_Opt2_32dB_*.s4p	

#	Main File	Folder	Files	Documentation
55			Bch1_3p5	
56			Bch2_7	
57			Bch2_a0_7	
58			Bch2_a10_7	
59			Bch2_a12p5_7	
60			Bch2_a15_7	
61			Bch2_a2p5_7	
62			Bch2_a5_7	
63			Bch2_a7p5_7	
64	kareti_3ck_01_1118_backplane.zip	-	Bch2_b10_7	
65			Bch2_b15_7	
66			Bch2_b2p5_7	
67			Bch2_b2_7	
68			Bch2_b4_7	
69			Bch2_b6_7	
70			Bch2_b7p5_7	
71			Bch2_b8_7	
72			Bch3_14	
73			Bch4_30	
74			CAch1_b2	
75			CAch1	
76			CAch2_a0	
77			CAch2_a10	
78			CAch2_a2p5	
79			CAch2_a5	
80			CAch2_a7p5	
81			CAch2_b10	kareti_3ck_01a_1118.pdf
82			CAch2_b2p5	
83	kareti_3ck_01_1118_cabledBP.zip	-	CAch2_b2	
84			CAch2_b4	
85			CAch2_b6	
86			CAch2_b7p5	
87			CAch2_b8	
88			CAch2	
89			CAch3_b2	
90			CAch3	
91			CAch4_b2	
92			CAch4	
93			OAch1	
94			OAch2	
95			OAch3	
96			OAch4	
97			OAch5	
98			OAch6	
99			OAch7	
100	kareti_3ck_01_1118_orthoBP.zip	-	Och1	
101			Och2	
102			Och3	
103			Och4	
104			Och5	
105			Och6	
106			Och7	
107			Och8	

107 channels pulled from the p802.3ck repository.

As in the past, we analyzed two subsets:

- <29dB
- <28dB

Updated P802.3ck Critical Channels

Contribution	Channel	#	Name	IL (dB)
heck_3ck_01_1118	~~28dB Cabled Backplane/Cable_BKP_28dB_0p575m_more_isi~~	~~14~~	~~Heck1~~	~~28.8~~
	16dB Cabled Backplane/Cable_BKP_16dB_0p575m_more_isi	2	Heck2	15.2
mellitz_3ck_adhoc_02_081518	24,28,30dB including BGA Via/CaBP_BGAVia_Opt2_28dB	53	Mellitz1	26.3
tracy_3ck_01_0119	Traditional Backplane Channels/Std_BP_12inch_Meg7	21	Tracy1	15.7
	Orthogonal Backplane Channels/DPO_IL_12dB	17	Tracy2	12.2
(Modified to fix non-physical response)	Measured Orthogonal Backplane Channels/OAch4	96	Kareti1	27.7
kareti_3ck_01a_1118	~~Measured Orthogonal Backplane Channels/Och4~~	~~103~~	~~Kareti2~~	~~28.1~~
	Measured Cabled Backplane Channels/CAch3_b2	89	Kareti3	28.5
	~~Measured Traditional Backplane Channels/Bch2_a7p5_7~~	~~63~~	~~Kareti4~~	~~28.4~~
	Measured_Traditional_Backplane_Channels/Bch2_b7p5_7	70	Kareti5	28.9
(Replacement for Heck1)	28dB_Cabled_Backplane/Cable_BKP_28dB_0p575	13	Heck3	29.0

Notes:

- Kareti1 channel model was modified to remove non-physical artifacts from the pulse response.
- Heck3 replaced Heck1 in final analysis.

Reference Receiver

Analysis Cases – Round 1

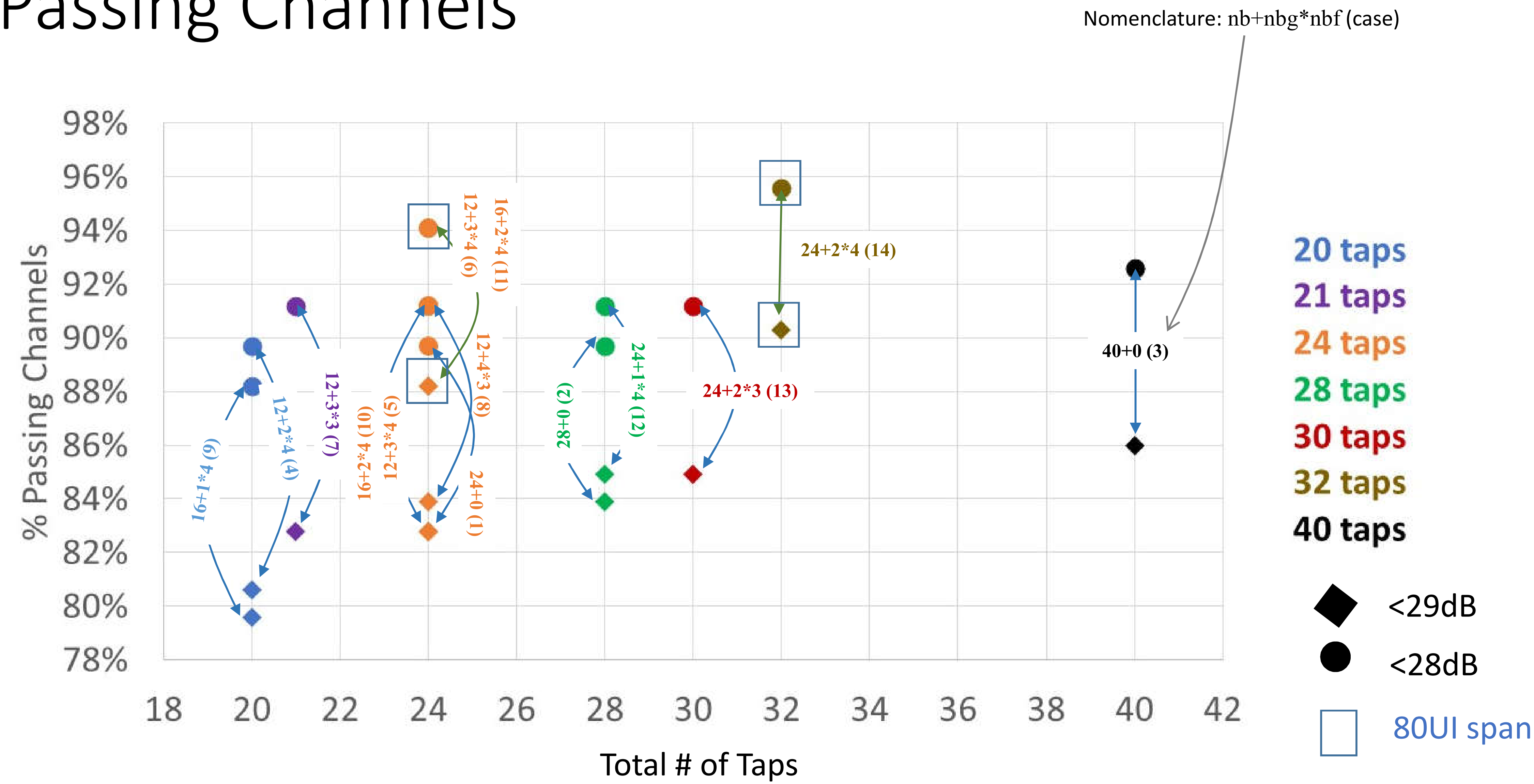
Case	Total # Taps	# Fixed Taps	# Banks	# Taps per Bank	Span
1	24	24	-	-	-
2	28	28	-	-	-
3	40	40	-	-	-
4	20	12	2	4	40UI
5	24	12	3	4	40UI
6	24	12	3	4	80UI
7	21	12	3	3	40UI
8	23	12	4	3	40UI
9	20	16	1	4	40UI
10	24	16	2	4	40UI
11	24	16	2	4	80UI
12	28	24	1	4	40UI
13	30	24	2	3	40UI
14	32	24	2	4	80UI

Conditions:

- η_0=0.82×10^{-8} V^2/GHz
- z_p = 31mm (Tx), 29mm (Rx)
- COM version = 2.70* w/ new termination model:
  - R_d=50 ohms
  - C_d=120 fF
  - L_s=120 pH
  - C_b=30 fF
  - C_p=87 fF
- Channels with <29dB IL (93), <28dB IL (77)

*http://www.ieee802.org/3/ck/public/tools/tools/mellitz_3ck_adhoc_01_061219_COM2p70.zip

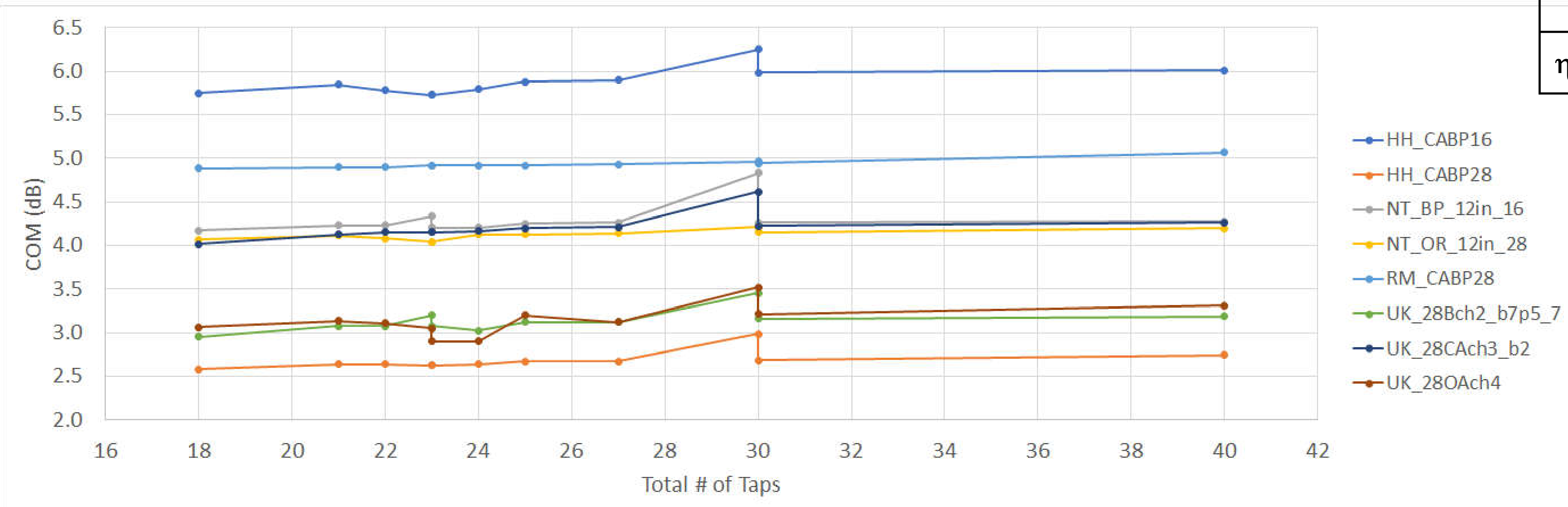
% Passing Channels



Critical Channels

	18	21	22	23	23	24	25	27	30	30	40	Total Taps
	12	12	16	20	20	24	16	24	24	24	40	# Fixed Taps
	2	3	2	1	1	0	3	1	2	2	0	# Banks
	40	40	40	80	40	-	40	40	80	40	40	Float Span (UI)
Heck2	5.747	5.8486	5.7807	5.7302	5.7302	5.7977	5.8827	5.8998	6.2494	5.9808	6.0119	HH_CABP16
Heck1	2.5802	2.6389	2.6389	2.6271	2.6271	2.6389	2.6743	2.6743	2.9871	2.6861	2.7454	HH_CABP28
Tracy2	4.1681	4.2273	4.2273	4.3349	4.2035	4.2035	4.2511	4.263	4.8299	4.263	4.2749	NT_BP_12in_16
Tracy1	4.0685	4.1102	4.0824	4.0408	4.0408	4.1242	4.1242	4.1382	4.2084	4.1522	4.1943	NT_OR_12in_28
Mellitz1	4.8825	4.8978	4.8978	4.913	4.913	4.913	4.913	4.9283	4.959	4.9437	5.0673	RM_CABP28
Kareti5	2.9504	3.0733	3.0733	3.1979	3.0733	3.0239	3.1229	3.1229	3.4526	3.1603	3.1853	UK_28Bch2_b7p5_7
Kareti3	4.0132	4.1242	4.1522	4.1522	4.1522	4.1662	4.1943	4.2084	4.6125	4.2225	4.265	UK_28CAch3_b2
Kareti1	3.0609	3.1353	3.1105	3.0485	2.9017	2.9017	3.1979	3.1229	3.5175	3.2104	3.3116	UK_28OAch4
	×	?	×	×	×	×	✓	×	✓✓	✓	✓✓	

Taps/Bank		3
Termination	C_d	120fF
	L_s	120pH
	C_b	30fF
Package trace	Tx	31mm
	Rx	29mm
η_0	0.82×10^{-8} V²/GHz	



Analysis Cases – Final Experiment

Objective: Finalize the reference DFE details (see the blue table)

- Want to minimize complexity (min # of banks, min span)

Metrics:

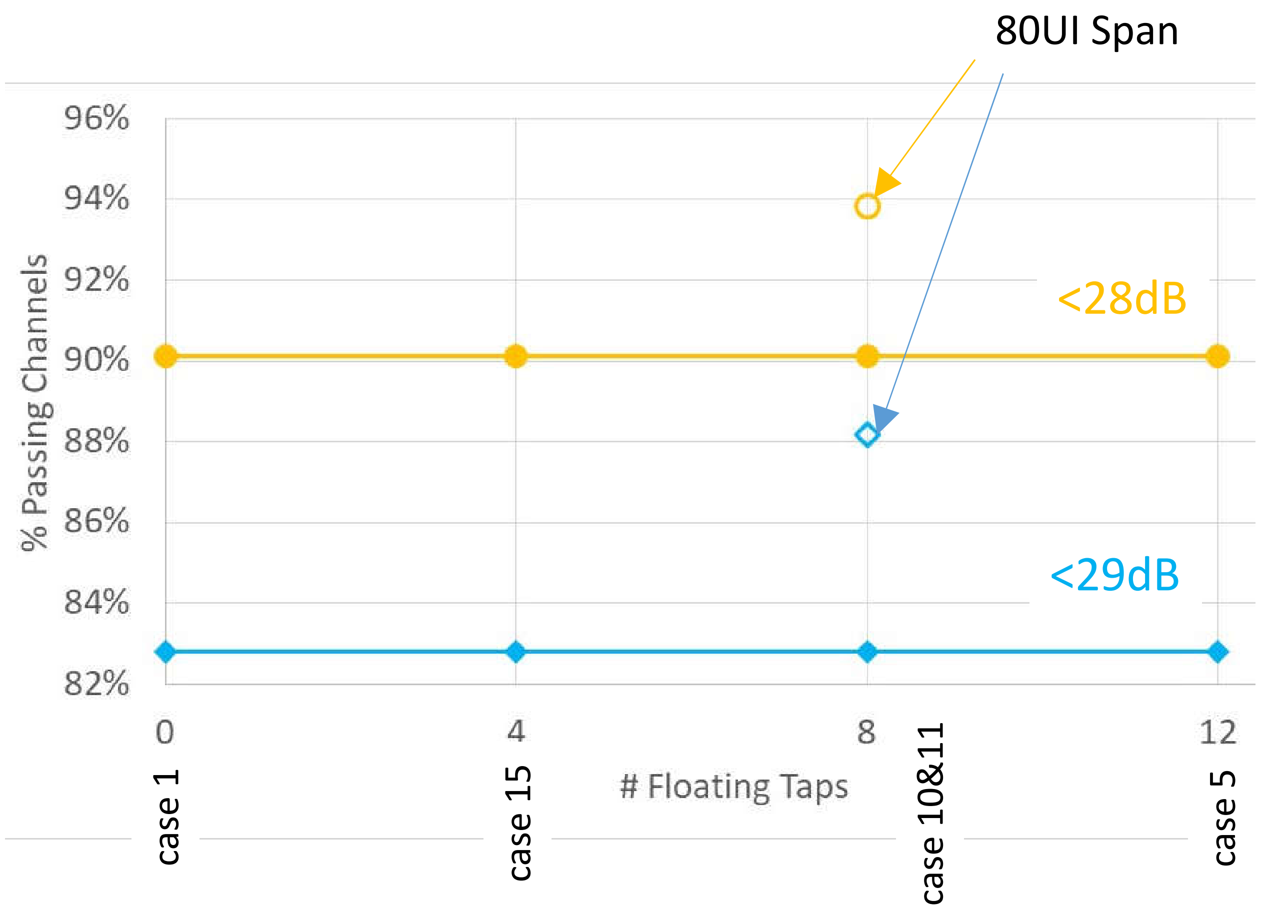
- % passing channels & mean COM for sub-29dB, sub-28dB
- COM results for critical channels

Analysis Features:

- 24 taps total in each case
- η_0=0.82×10^{-8} V^2/GHz
- Termination model: C_d=120fF, L_s=120pH, C_b=30fF

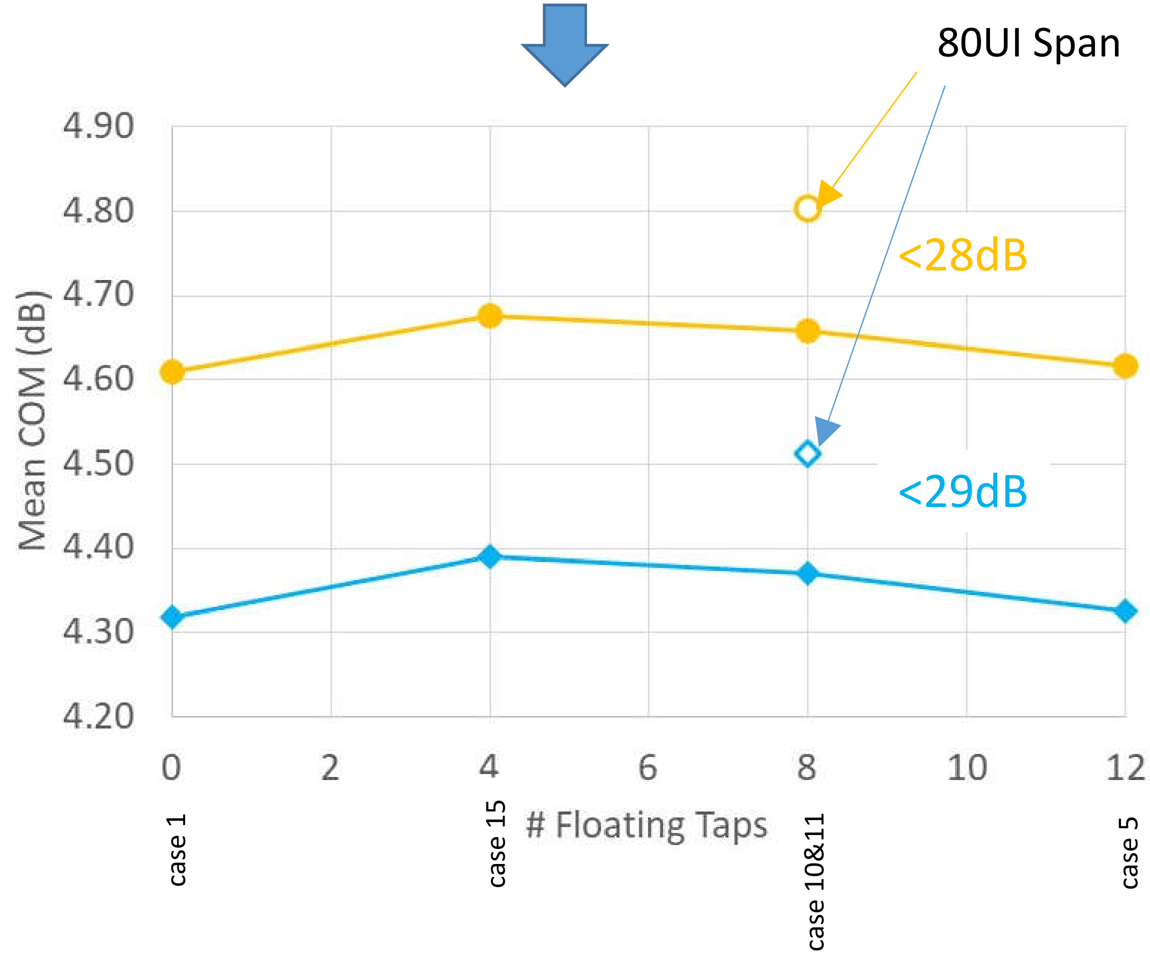
Case	# Fixed Taps	# Banks	# Taps per Bank	Span
1	24	0	-	-
15	20	1	4	40
10	16	2	4	40
5	12	3	4	40
11	16	2	4	80

Sub-29/28dB Channel Analysis



# of floating taps showed no impact on the % of channels that meet 3dB COM.

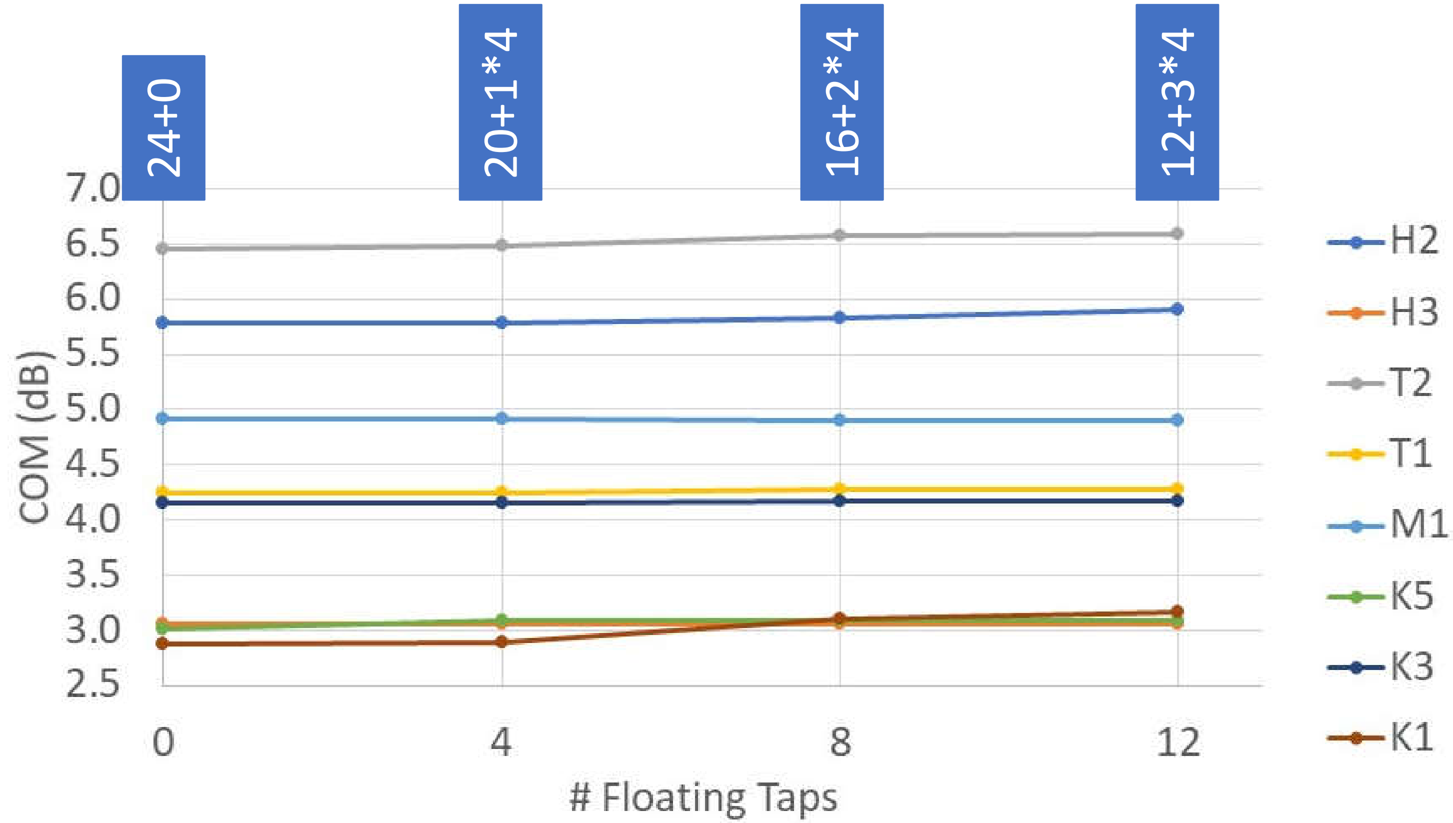
# of floating taps showed little impact on the COM average & variance.



Reference Rx Trends for Critical Channels

2 or 3 banks of 4 were needed to get all critical channels to meet 3dB COM.

The plot does not include results for case 11 (80UI span)



$\bar{X}$	4.42	4.42	4.47	4.49
S	1.36	1.36	1.35	1.35

Group recommendation:

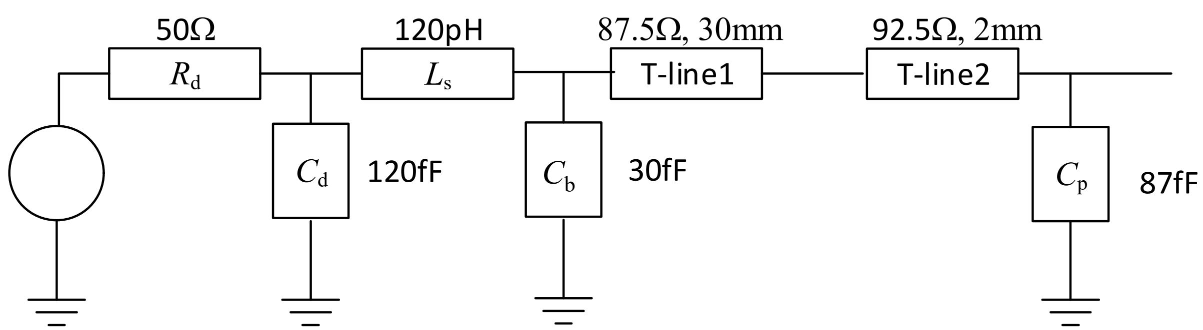
12 fixed taps, 3 banks of 3 or 4 floating taps with 40UI span.

Termination Analysis

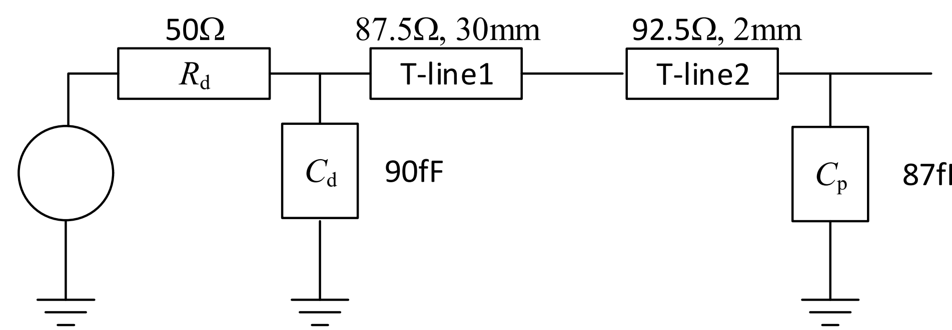
Proposed vs. Simple Termination Analysis

- Objective: Determine whether the proposed termination model gives different COM performance than a simple model with C_d =90fF.
- Analysis:
  - All sub-29dB channels & sub-28dB channels
  - η_0=0.82×10^{-8} V^2/GHz
  - Reference Rx cases per the table

Case	# Fixed Taps	# Banks	# Taps per Bank	Span
1	24	0	-	-
15	20	1	4	40
10	16	2	4	40
5	12	3	4	40
11	16	2	4	80



Proposed Termination & Flex Package



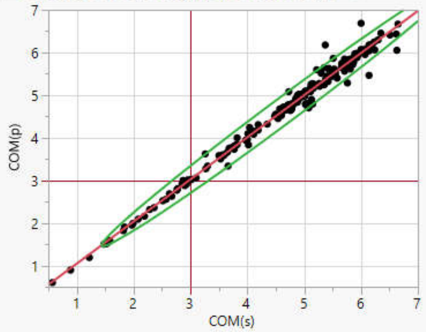
Simple Termination & Flex Package

Proposed Termination v Simple 90fF Termination

Rx Taps 24+0 20+1*4 16+2*4 12+3*4 16+2*4 (80UI)

24+0

Bivariate Fit of COM(p) By COM(s) Case=1



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

COM(p) = 0.0586352 + 0.9885565*COM(s)

Summary of Fit

RSquare	0.986218
RSquare Adj	0.986143
Root Mean Square Error	0.151129
Mean of Response	4.595897
Observations (or Sum Wgts)	186

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	300.71966	300.720	13166.29
Error	184	4.20258	0.023	Prob > F
C. Total	185	304.92224		<.0001*

Parameter Estimates

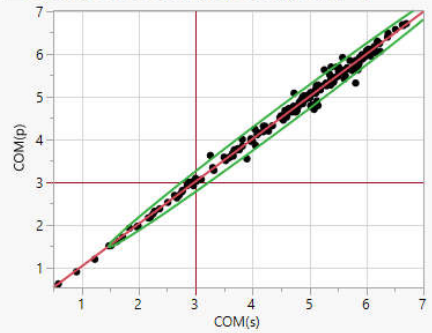
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0586352	0.041066	1.43	0.1550
COM(s)	0.9885565	0.008615	114.74	<.0001*

Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.589785	1.289714	0.993085	<.0001*	186
COM(p)	4.595897	1.283833			

20+1*4

Bivariate Fit of COM(p) By COM(s) Case=15



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

COM(p) = 0.028082 + 0.9952797*COM(s)

Summary of Fit

RSquare	0.992182
RSquare Adj	0.99214
Root Mean Square Error	0.114171
Mean of Response	4.627612
Observations (or Sum Wgts)	186

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	304.39583	304.396	23352.10
Error	184	2.39845	0.013	Prob > F
C. Total	185	306.79428		<.0001*

Parameter Estimates

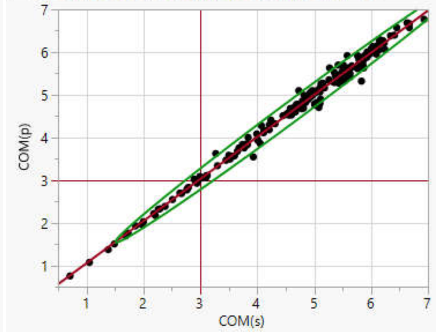
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.028082	0.031241	0.90	0.3699
COM(s)	0.9952797	0.006513	152.81	<.0001*

Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.621344	1.288808	0.996083	<.0001*	186
COM(p)	4.627612	1.287768			

16+2*4

Bivariate Fit of COM(p) By COM(s) Case=10



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

COM(p) = 0.0664946 + 0.9869931*COM(s)

Summary of Fit

RSquare	0.99144
RSquare Adj	0.991393
Root Mean Square Error	0.11836
Mean of Response	4.658029
Observations (or Sum Wgts)	186

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	298.54399	298.544	21310.84
Error	184	2.57766	0.014	Prob > F
C. Total	185	301.12165		<.0001*

Parameter Estimates

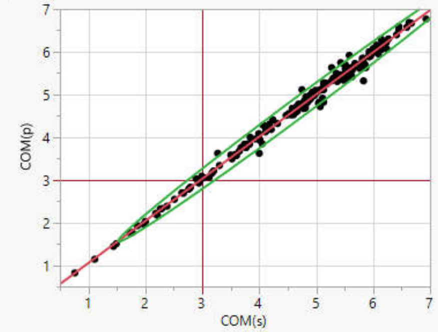
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0664946	0.032628	2.04	0.0430*
COM(s)	0.9869931	0.006761	145.98	<.0001*

Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.652043	1.287076	0.995711	<.0001*	186
COM(p)	4.658029	1.275807			

12+3*4

Bivariate Fit of COM(p) By COM(s) Case=5



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

COM(p) = 0.0650819 + 0.9876367*COM(s)

Summary of Fit

RSquare	0.991978
RSquare Adj	0.991934
Root Mean Square Error	0.114519
Mean of Response	4.672567
Observations (or Sum Wgts)	186

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	298.37748	298.377	22751.59
Error	184	2.41308	0.013	Prob > F
C. Total	185	300.79056		<.0001*

Parameter Estimates

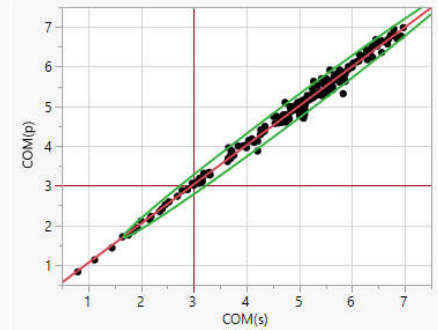
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0650819	0.031679	2.05	0.0414*
COM(s)	0.9876367	0.006548	150.84	<.0001*

Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.665161	1.285878	0.995981	<.0001*	186
COM(p)	4.672567	1.275106			

16+2*4 (80UI)

Bivariate Fit of COM(p) By COM(s) Case=11



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

COM(p) = 0.0627772 + 0.989909*COM(s)

Summary of Fit

RSquare	0.990833
RSquare Adj	0.990783
Root Mean Square Error	0.123052
Mean of Response	4.831744
Observations (or Sum Wgts)	186

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	301.14525	301.145	19888.26
Error	184	2.78610	0.015	Prob > F
C. Total	185	303.93136		<.0001*

Parameter Estimates

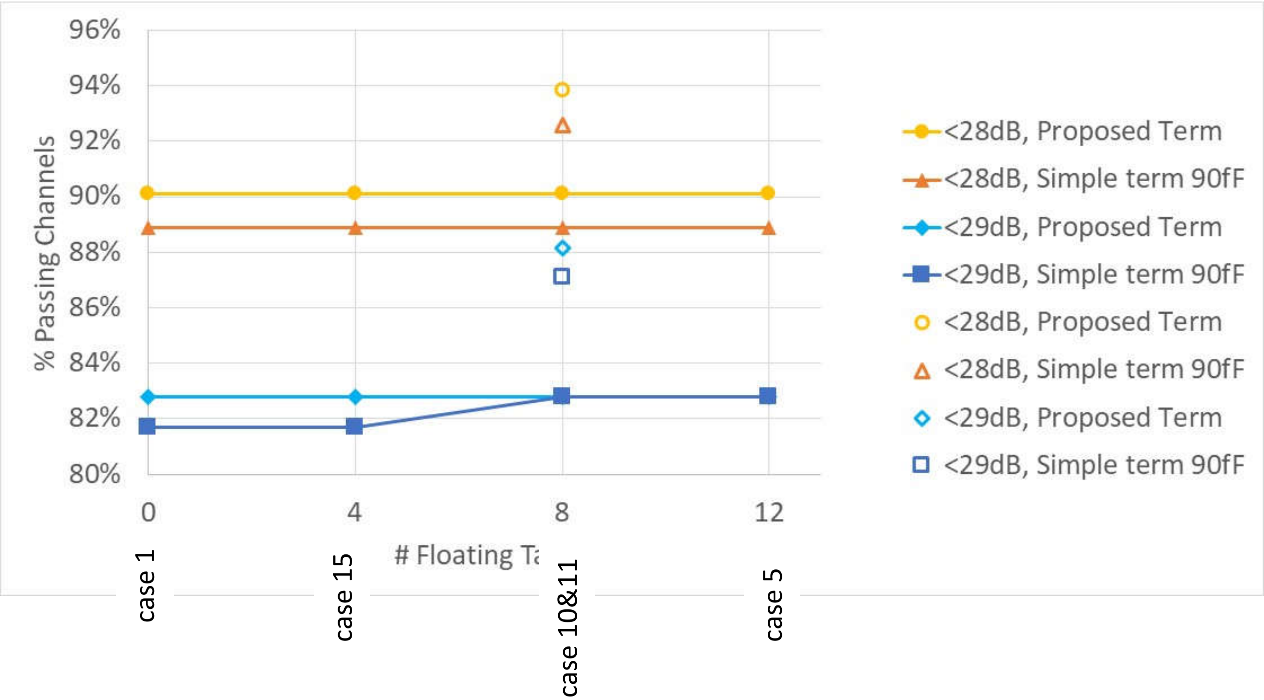
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0627772	0.034999	1.79	0.0745
COM(s)	0.989909	0.007019	141.03	<.0001*

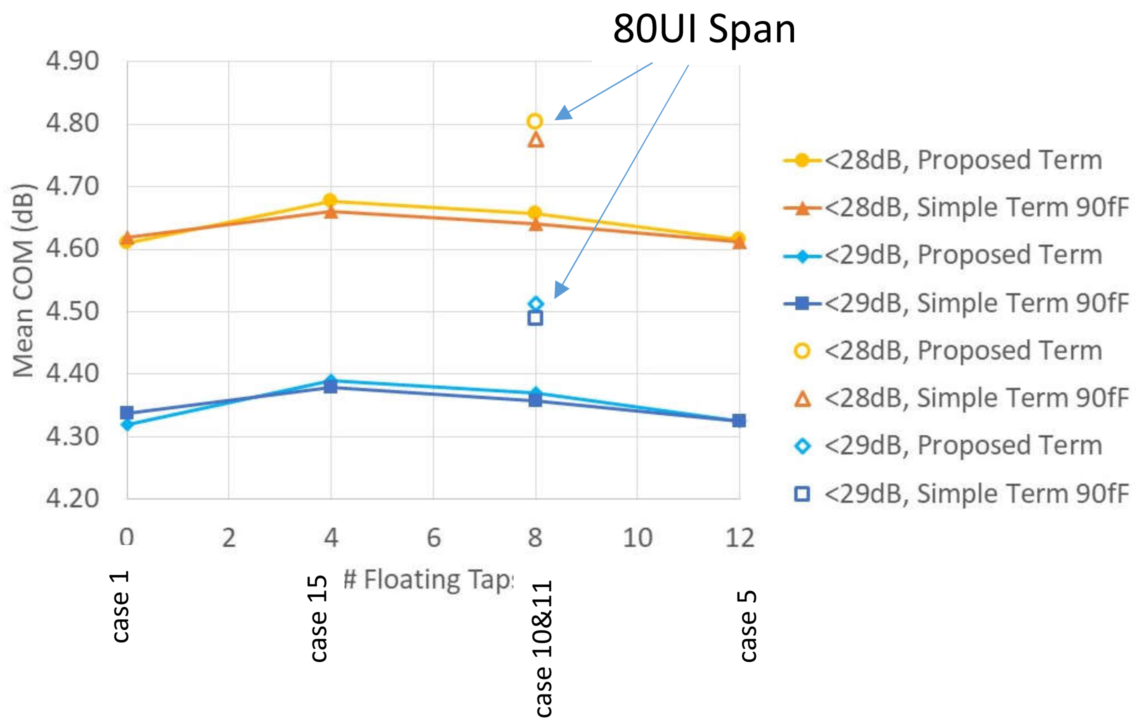
Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.817581	1.288863	0.995406	<.0001*	186
COM(p)	4.831744	1.281746			

COM results are strongly correlated between the two termination types.

Proposed Termination v Simple 90fF Termination





Case	# Float Taps	<29dB				<28dB			
		COM Mean (dB)		COM Standard Deviation (dB)		COM Mean (dB)		COM Standard Deviation (dB)	
		Proposed	Simple	Proposed	Simple	Proposed	Simple	Proposed	Simple
1	0	4.32	4.34	1.29	1.30	4.61	4.62	1.03	1.05
5	4	4.39	4.38	1.27	1.27	4.68	4.66	1.03	1.03
10	8	4.37	4.36	1.28	1.27	4.66	4.64	1.03	1.02
15	12	4.32	4.33	1.29	1.28	4.62	4.61	1.03	1.03
11	8	4.51	4.49	1.29	1.28	4.80	4.78	1.04	1.03

Welches' t- test shows no difference in means.

Termination Recommendation

Group recommendation: Adopt the proposed termination.

- The more complex reference Rx (e.g. DFE w/ floating taps) washes out the differences between the two termination models.
- With simpler equalizers (e.g. chip-to-module) the difference appears to be larger.
  - For example, refer to http://www.ieee802.org/3/ck/public/adhoc/jun26_19/sun_3ck_adhoc_01_062619.pdf.

Rx Noise

Rx Noise Sensitivity

Objective: Determine the impact of increasing η_0 on channel performance.

Metrics:

- % passing channels & mean COM for sub-29dB, sub-28dB
- COM results for critical channels

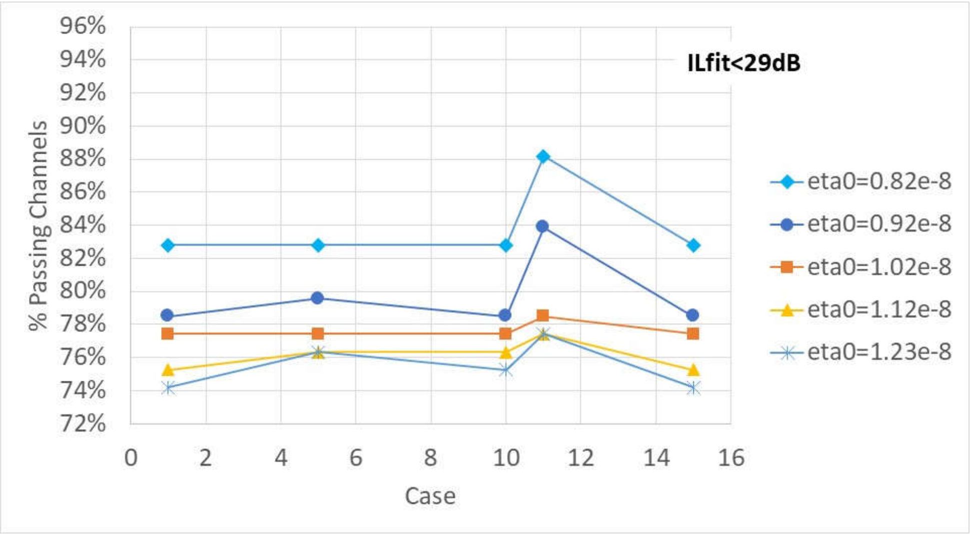
Analysis Features:

- 24 taps total in each case
- Termination model: C_d=120fF, L_s=120pH, C_b=30fF

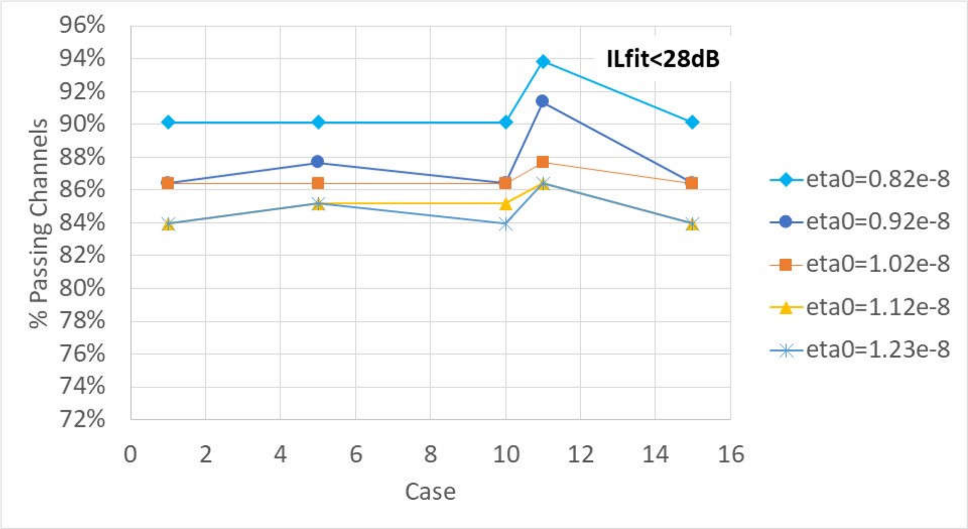
Case	η_0 (V²/GHz)
i	0.82×10^{-8}
ii	0.92×10^{-8}
iii	1.02×10^{-8}
iv	1.12×10^{-8}
v	1.23×10^{-8}

Case	# Fixed Taps	# Banks	# Taps per Bank	Span
1	24	0	-	-
15	20	1	4	40
10	16	2	4	40
5	12	3	4	40
11	16	2	4	80

Rx Noise Impactw/ sub-29/28dB Channels

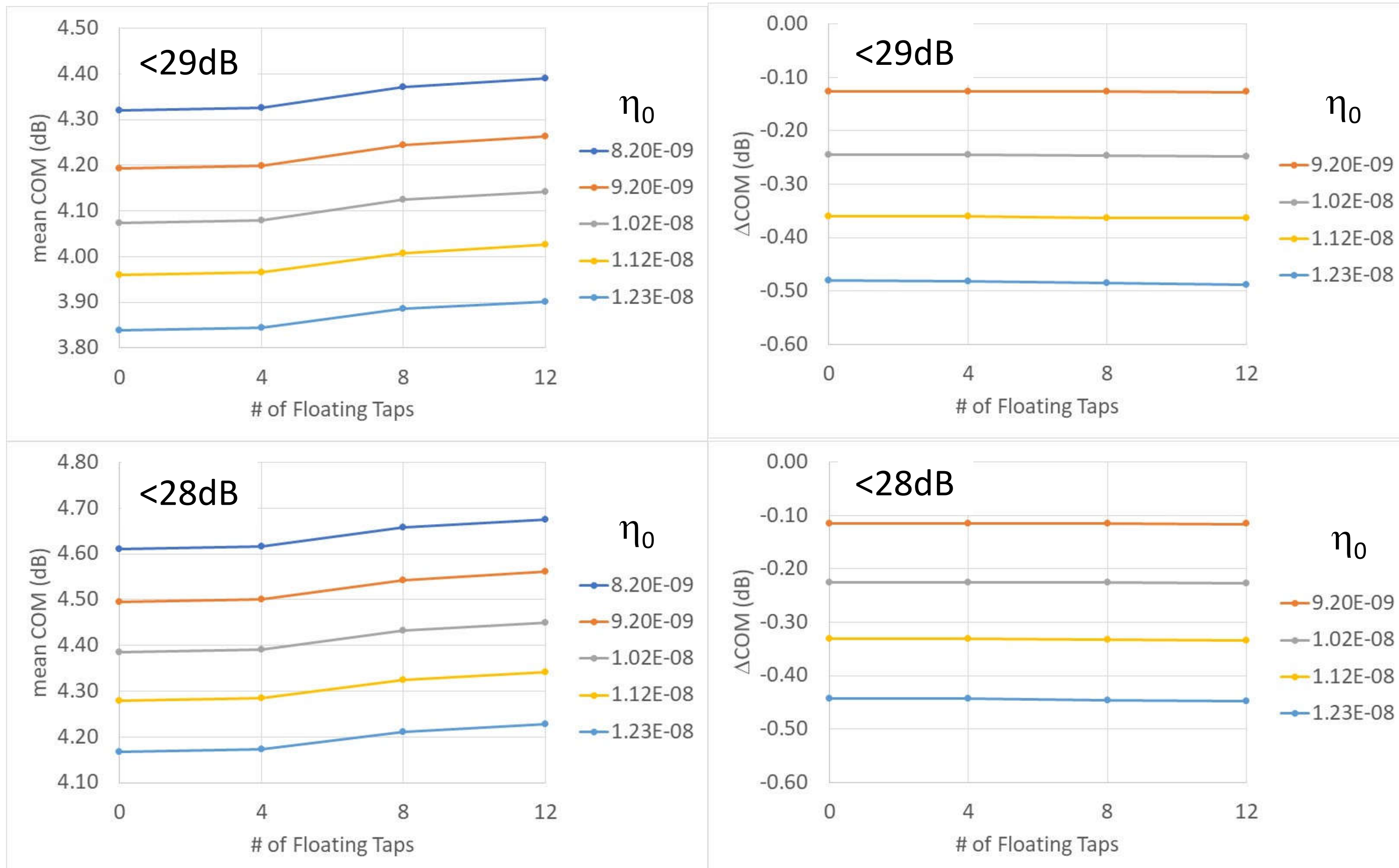


Increasing η_0 by 50% reduces the % passing channels by 6%-8%.



Noise Sensitivity w/ sub-29/28dB Channels

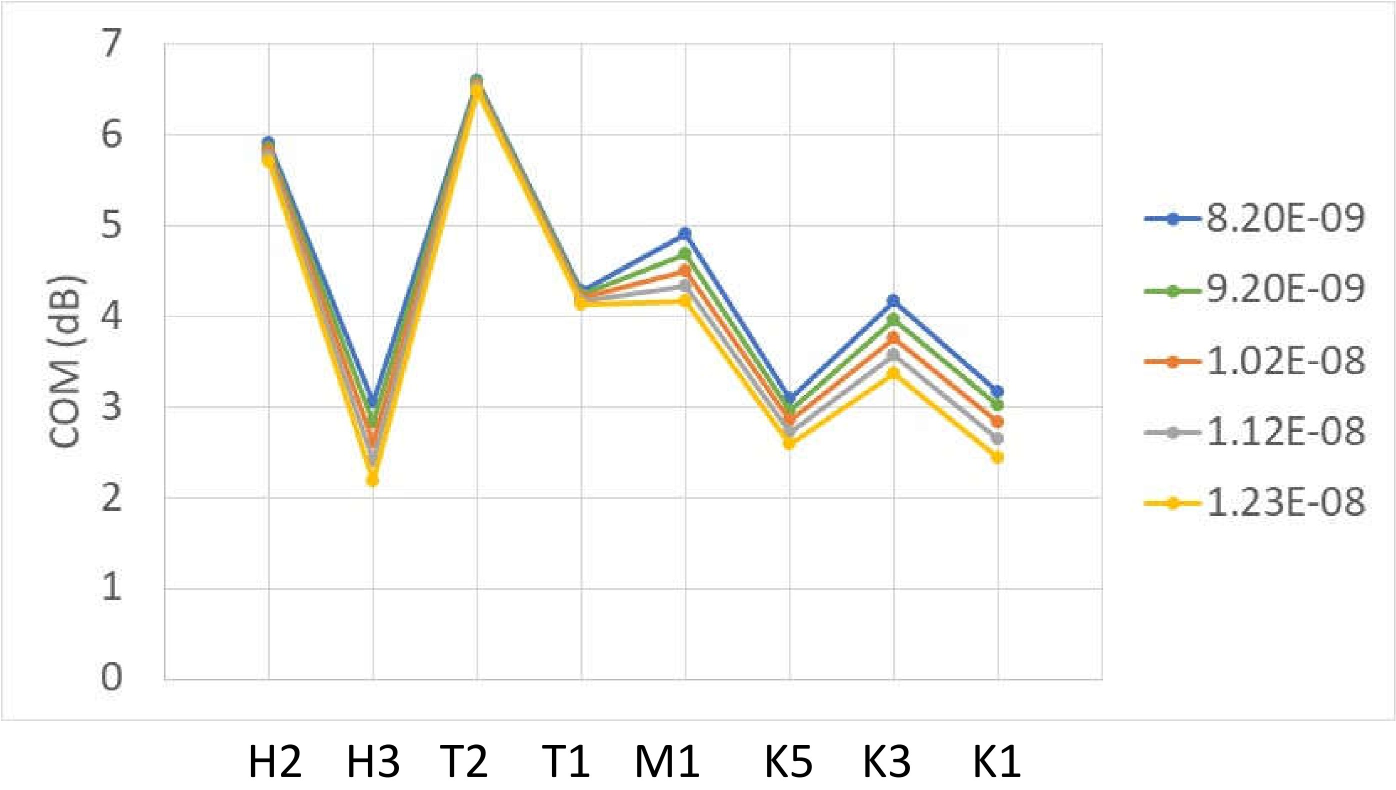
COM impact is roughly 0.1dB per 10^{-9} V^2/GHz beyond the baseline value (8.2×10^{-9} V^2/GHz).



Recommendation: Adopt the baseline value (8.2×10^{-9} V^2/GHz) that we have been using.

Rx Noise Impact on Critical Channels

- All sims used:
  - Fixed: 12 taps
  - Floating: 3 banks, 4 taps/bank
  - Proposed termination model
  - Flex package with 31mm Tx, 29mm Rx
- Results show that increasing η_0 beyond 0.82e-8 V^2/GHz causes three of the channels to fail.



Group Recommendation:

Adopt the baseline value (8.2×10^{-9} V^2/GHz) that we have been using.

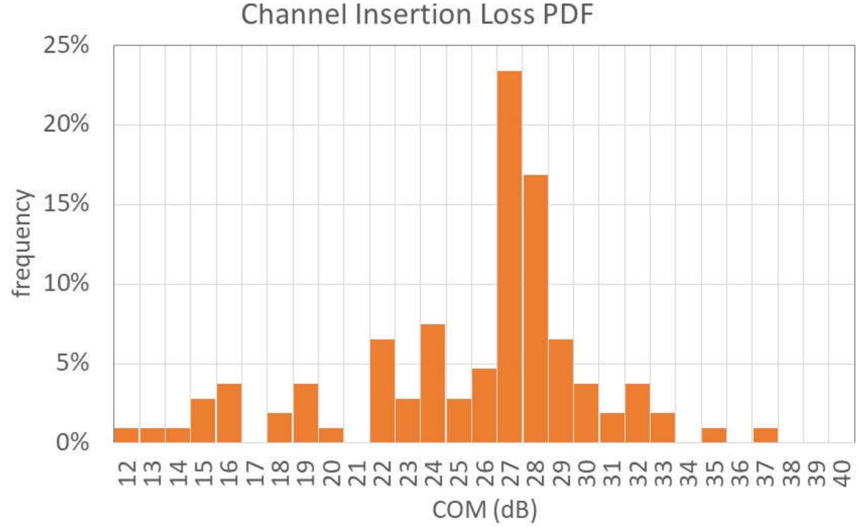
Objectives & Recommendations

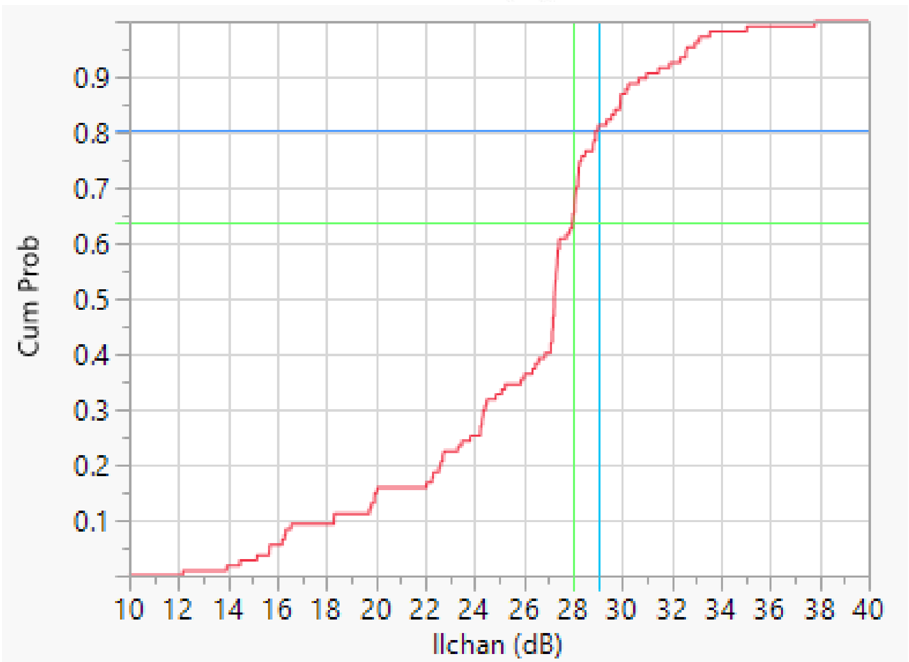
Provide analysis & recommendations for

- Reference receiver (# taps, # banks, span)
  - ⇒ Group recommendation: 12 fixed taps, 3 banks of 3 or 4 floating taps with 40UI span
- Termination model
  - ⇒ Group recommendation: Adopt the termination model described in http://www.ieee802.org/3/ck/public/adhoc/jun12_19/healey_3ck_adhoc_01_061219.pdf.
- Rx noise figure (η_0)
  - ⇒ Group recommendation: Adopt the baseline value (8.2×10^{-9} V^2/GHz) that we have been using.

Additional Data

Channel Insertion Loss Statistics

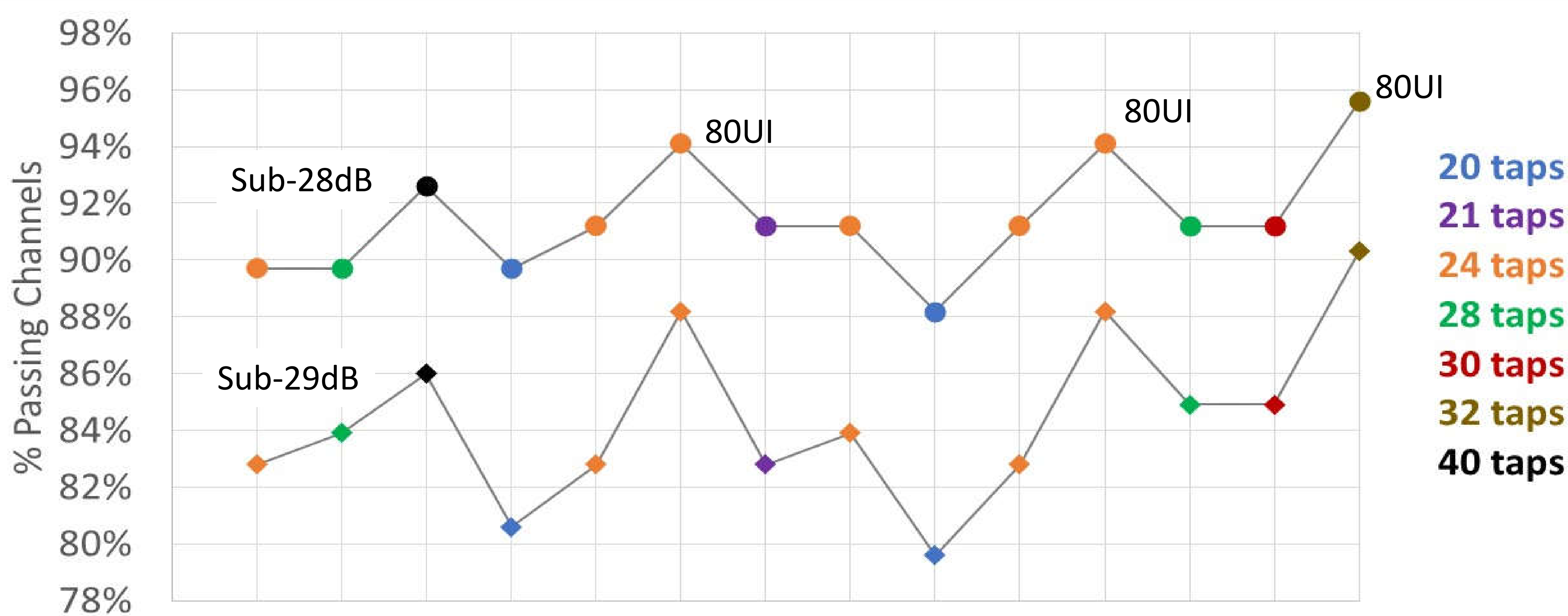




IL (dB)	# Channels	Cum %
28.0	68	63.6%
28.1	74	69.2%
28.2	77	72.0%
28.3	80	74.8%
28.5	82	76.6%
29.0	86	80.4%
30.0	93	86.9%
31.0	97	90.7%
32.0	99	92.5%
33.0	103	96.3%
34.0	105	98.1%
35.0	105	98.1%
36.0	106	99.1%
37.0	106	99.1%
38.0	107	100.0%

All of the .ck ‘highlighted’ channels fit within 29dB.

Analysis: % Passing Channels



case		1	2	3	4	5	6	7	8	9	10	11	12	13	14
# fixed taps	n_b	24	28	40	12	12	12	12	12	16	16	16	24	24	24
# floating banks	n_{bg}	0	0	0	2	3	3	3	4	1	2	2	1	2	2
# taps/bank	n_{bf}	0	0	0	4	4	4	3	3	4	4	4	4	3	4
floating span (UI)	n_f				40	40	80	40	40	40	40	80	40	40	80
total # taps		24	28	40	20	24	24	21	24	20	24	24	28	30	32

Proposed Termination v Simple 90fF Termination

Linear Fit

COM(p) = 0.0553345 + 0.9898595*COM(s)

Summary of Fit

RSquare	0.990546
RSquare Adj	0.990536
Root Mean Square Error	0.124593
Mean of Response	4.67717
Observations (or Sum Wgts)	930

Lack Of Fit

Analysis of Variance

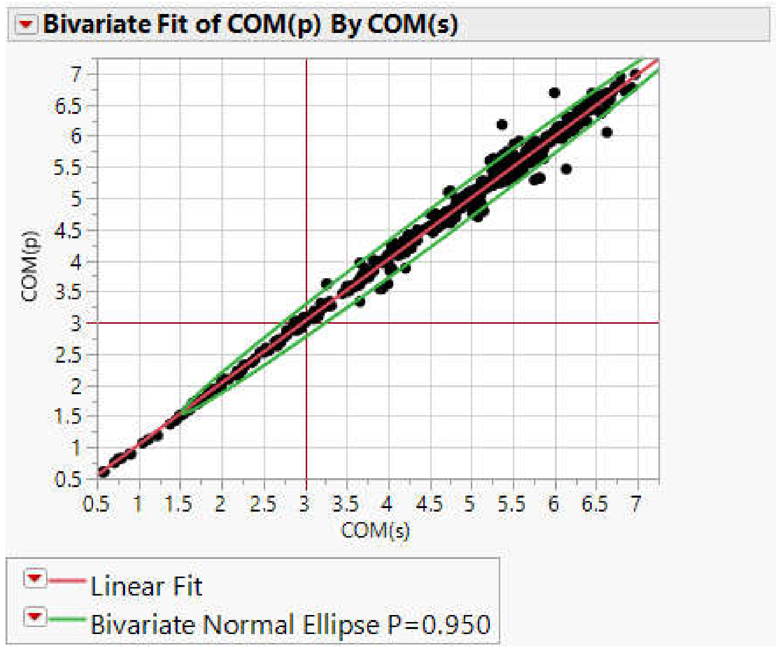
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1509.3561	1509.36	97231.65
Error	928	14.4056	0.015523	Prob > F
C. Total	929	1523.7617		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0553345	0.015375	3.60	0.0003*
COM(s)	0.9898595	0.003174	311.82	<.0001*

Bivariate Normal Ellipse P=0.950

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
COM(s)	4.669183	1.287699	0.995262	<.0001*	930
COM(p)	4.67717	1.28071			



η_0=0.82e-8

Rx Cases:

Case	# Fixed Taps	# Banks	# Taps per Bank	Span
1	24	0	-	-
15	20	1	4	40
10	16	2	4	40
5	12	3	4	40
11	16	2	4	80

COM(p) = proposed term with C_d=120fF, C_b=30fF, L_s=120pH

COM(s) = simple term with C_d=90fF

COM results are strongly correlated between the two termination types.