Discussion of System Noise and Receiver Noise in COM

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Outline

- Motivations
- System noise COM benchmark – legacy vs. new models
- Receiver noise model
- Performance impact of receiver noise in COM_{min} bucket
- Conclusions & summary
- Proposals

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Motivation

- Currently, ‘Eta_0’ is applied in COM 2.60 for modeling system noise and/or receiver noise
- The following questions were raised
  - Which model is appropriate for system & receiver noise?
  - What’s the impact to COM_{min} budget?
- In [1], the authors highlighted COM is sensitive to wideband ‘Eta_0’
  - 1.0 dB COM loss comparing Eta_0 = 16e-9 to 8e-9
- In [2], Richard proposed new “Bandlimited” model for system noise
- In [3], Adam reviewed all implementation allowance “bucket”
- We tried to address the following topics here
  - What’s the impact of “Bandlimited” system noise?
  - How to model system & receiver noise in COM?
- Observations & proposal
  - Bandlimited system noise is not significant to COM
  - Need to include RX noise to improve Channel Test accuracy
  - Propose several options for system noise & RX noise modeling for discussion

Richard's Bandlimited System Noise *

- In [2], Richard proposed to adopt new model for system noise

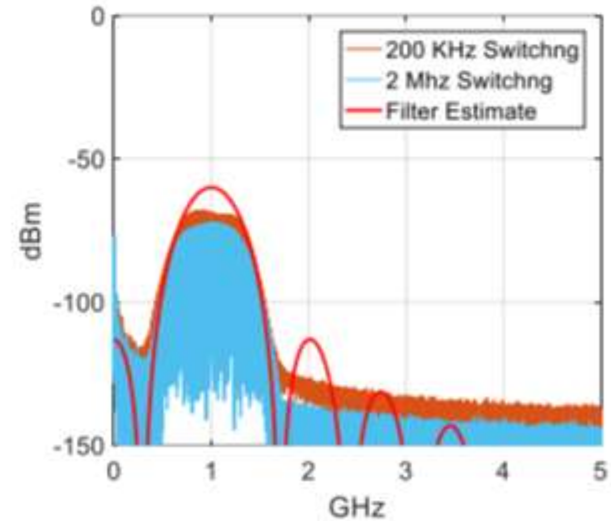
Filter estimate by comparing to PSD of the noise

$$H_e(f) = sinc\left(\frac{f - f_{spike}}{f_{spike}}\sqrt{2}\right)^2$$

$$\eta_0 = \frac{\sigma^2}{\Sigma_0^{f_b} sinc\left(\frac{f - f_{spike}}{f_{spike}}\sqrt{2}\right)^2 \Delta f}$$

η_0 =2.1238e-06 V²/GHz

assuming σ of 1 mV RMS and f_{spike} = 1 GHz



- We tried to evaluate performance impact by this new Bandlimited system noise model
  - Case 1: 1mV system noise: use η_0 = 2.1238e-06 V^2/GHz
  - Case 2: 0.5mV system noise: use η_0 = 5.3096e-07 V^2/GHz

Adopted COM Parameters (COM 260)

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42 channel properties

- Analysis of 42 channels as [1]
- By COM 260
  - By enabling Richard's new system noise model by 'Bandlimited' style [2]
  - C_d = 120 fF
  - b_max[1] = 0.85, b_max[2..N_b] = 0.3

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]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 32; 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	0.413	V	vp/vf=.694
A_fe	0.413	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)	[-0.2:0.05:0]		[min:step:max]
N_b	24	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		
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		

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	0	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\100GEL_WG_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	CR_eval_	
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	1000	
TDR_Butterworth	1	logical
beta_x	1.70E+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	0	V^2/GHz
SNR_TX	33	dB
R_LM	0.95	
USE_ETA0_PSD	1	

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

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Four Scenarios – Settings

- We tried to compare COM of legacy and new system noise models
  - Legacy: wideband used in 802.3cd
  - New: Bandlimited proposed by Richard [2]
- We compared for 0.5 mV_{rms} & 1 mV_{rms} system noise
  - By legacy model
    - 1mV: $\eta_0 = 2.5098e{-}08\ V^2/GHz$ [Scenario 1]
    - 0.5mV: $\eta_0 = 6.2745e{-}09\ V^2/GHz$ [Scenario 2]
  - By new model
    - 1mV: $\eta_0 = 2.1238e{-}06\ V^2/GHz$ [Scenario 3]
    - 0.5mV: $\eta_0 = 5.3096e{-}07\ V^2/GHz$ [Scenario 4]

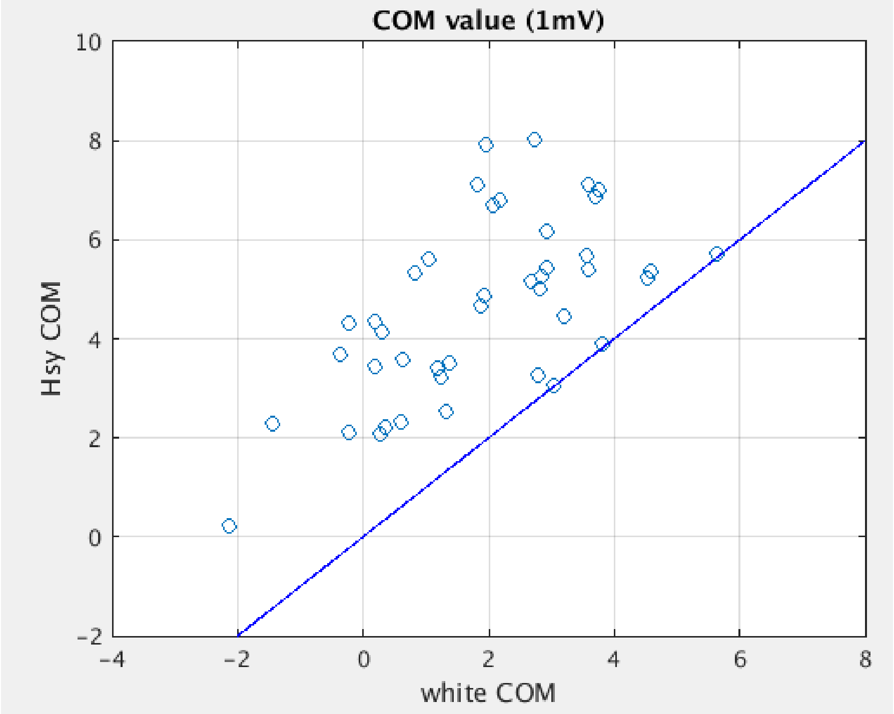
Noise level \ Model	Legacy (white)	New (Narrow-band)
1mV_{rms}	Scenario 1	Scenario 3
0.5mV_{rms}	Scenario 2	Scenario 4

COM Comparison

Detailed Analysis

- COM of new model (H_{sy} COM) is much better than legacy one (white COM)

- For H_{sy} COM –white COM 1mV [Scenario 3 – Scenario 1]
  - Mean = 2.73 dB
  - Min = 0.01 dB
  - Max = 5.96 dB
  - Std= 1.50 dB
- Same trend as 0.5 mV [Scenario 4 – Scenario 2]
  - Mean = 1.06 dB
  - Min = -0.02 dB
  - Max = 2.98 dB
  - Std= 0.73 dB



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System Noise COM Benchmark

Scenario	Noise (mV_{rms})	Model		COM Loss (dB, comparing to NO system noise)			
		Legacy (white)	New (N.B.)	Mean	Min	Max	Std
1	1	V		**3.31**	0.51	**6.68**	1.50
2	0.5	V		**1.26**	0.13	**3.19**	0.73
3	1		V	**0.58**	0.22	0.93	0.15
4	0.5		V	**0.21**	0.06	0.36	0.07

- By new (Bandlimited) system noise model
  - Mean of COM loss is much smaller comparing to wideband model
  - The variation among channels is also small
- “Bandlimited” noise from external is NOT so critical to COM performance
- Input-referred white noise is critical
  - Details in following analysis

Selected 9 → 7 KR Channels

- 9 KR channels were selected as baseline in ‘kochuparambil_3ck_01c_0119.pdf’

Contribution	Channel	CH ID
heck_3ck_01_1118	28dB Cabled Backplane/Cable_BKP_28dB_0p575m_more_isi	1
	16dB Cabled Backplane/Cable_BKP_16dB_0p575m_more_isi	2
mellitz_3ck_adhoc_02_081518	24,28,30dB including BGA Via/CaBP_BGAVia_Opt2_28dB	3
tracy_3ck_01_0119	Traditional Backplane Channels/Std_BP_12inch_Meg7	4
	Orthogonal Backplane Channels/DPO_IL_12dB	5
kareti_3ck_01a_1118	Measured Orthogonal Backplane Channels/OAch4	6
	~~Measured Orthogonal Backplane Channels/Och4~~	~~7~~
	Measured Cabled Backplane Channels/CAch3_b2	8
	~~Measured Traditional Backplane Channels/Bch2_a7p5_7~~	~~9~~

COM Parameters of 9 KR channels

Selected 7 KR Channels – System Noise

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- If we don't model RX noise in COM &
  - By Bandlimited system noise model,
    - All 7 KR channels pass 3dB COM no matter with 0.5mV or 1mV system noise
    - Q: Is it too optimistic to "including RX noise" into 3dB COM bucket?
- Let's explore this in the following

CH ID	IL (wo PKG, dB)	ICN (mV)	FOM_ILD (dB)	COM (dB)				
				NO noise	N.B.		White	
					0.5mV	1.0mV	0.5mV	1.0mV
1	29.42	1.571	1.074	4.72	4.63	4.31	2.78	-0.21
2	16.39	2.151	0.864	5.71	5.53	5.21	5.38	4.52
3	26.72	0.659	0.514	7.29	7.09	6.71	4.90	2.07
4	16.49	8.317	0.876	3.91	3.65	3.05	3.68	3.04
5	13.10	1.750	1.036	6.32	6.16	5.72	6.14	5.62
6	28.72	0.700	0.899	4.22	4.03	3.68	2.38	-0.36
8	27.81	0.475	0.274	6.23	5.97	5.60	4.07	1.04

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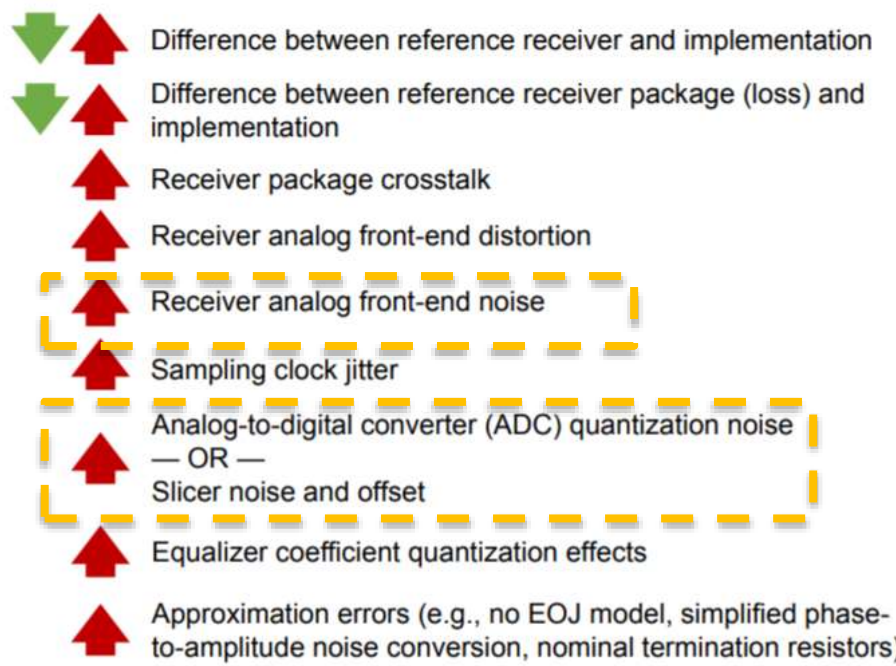
Receiver Noise in COM_{min} Bucket

- As raised in [3], we need to evaluate the impact of ‘Receiver Noise’ to COM_{min} bucket
- ‘Receiver Noise’ includes
  - Analog front-end noise
  - ADC quantization noise or Slicer noise & offset
- ‘Receiver noise’ could be modeled as ‘input-referred’ noise at RX input by wideband style η_0
- We try to analyze COM_{min} impact by different η_0 values among
  - 0 V^2/GHz
  - 0.82e-8 V^2/GHz
  - 1.23e-8 V^2/GHz
  - 1.64e-8 V^2/GHz



RX Noise Model – Noise Floor

- Boltzmann noise floor per Hz for a resistor is $N_p = 10log10(k_b * T_k) + 30$
  - where k_b = 1.38064852e-23 W/T_k
  - T_k = degrees Kelvin
  - The 30 is the 'W' to 'mW' conversion
  - -173.97 dBm/Hz at 16.85° C (~= -174 dBm/Hz)
  - -172.88 dBm/Hz at 100° C (~= -173 dBm/Hz)
- The quantum nature of electron-hole pairing on a semiconductor substrate adds between 10 to 20 dB (implementation noise figure, NF) above the Boltzmann noise floor
  - So it look like are working with -163 to -153 dBm/Hz

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RX Noise Model – NF vs. Eta_0

- Let R = 100 ohms, T = 100° C
- Noise (N_{RX} , dBm/Hz) = Thermal noise floor (-173) + receiver noise figure (NF)
  - $N_{RX} = 10log10\left(\frac{\eta_0}{R}/1e9 * 1e3\right)$
- What's the appropriate level?
  - ~15 dB NF? This is what we adopted in 802.3cd
    - Shall be independent of symbol rate!!
  - 0.5mV? It's critical to achieve this due to higher f_b!

η_0 (V²/GHz)	N_{RX} (dBm/Hz)	NF (dB)	V_{rms} (mV @ 0.75f_b)
5.0119e-10	-173.00	0.00	0.14
0.627e-8	-162.03	10.97	0.50
0.82e-8	-160.86	12.14	0.57
1.23e-8	-159.10	13.90	0.70
1.64e-8	**-157.85**	**15.15**	**0.81**
2.51e-8	-156.00	17.00	1.00

System & Receiver Noise Models

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- We model system & receiver noises in COM as below
- System noise
  - by Richard's 'Bandlimited' model [with 0.5 mV_{rms}]
- Receiver noise
  - by input-referred noise spectral density, η_0

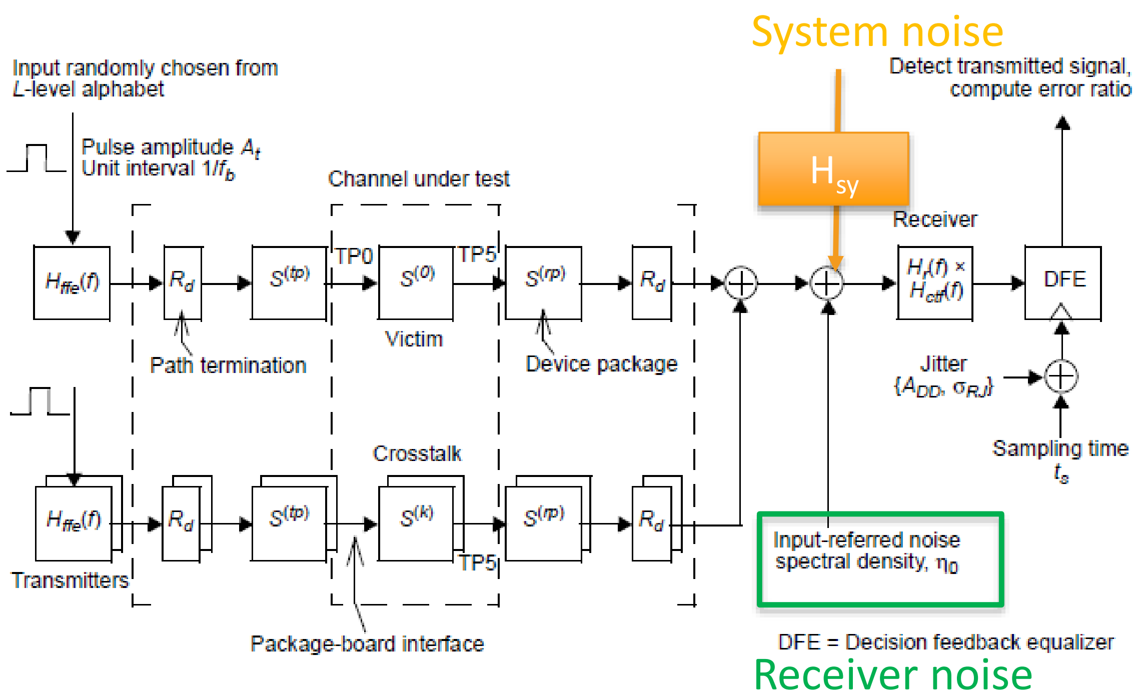


Figure 93A–1—COM reference model

Receiver Noise in COM_{min} Bucket

Conf.	Sys. Noise	RX Noise	COM loss in dB (to Conf. 1, which is w.o. RX noise)			
			Mean	Min	Max	Std
0	Off	Off	-0.21	-0.36	-0.06	0.07
1	On	Off	0	0	0	0
2	On	η_0 = 0.82e-8 V^2/GHz	1.52	0.18	3.61	0.83
3	On	η_0 = 1.23e-8 V^2/GHz	2.03	0.25	4.55	1.05
4	On	**η_0 = 1.64e-8 V^2/GHz**	**2.46**	0.32	**5.29**	**1.21**

- COM losses are quite different among different channels
  - Some are sensitive, while others are not
  - Detailed analysis followed
- Take η_0 =1.64e-8 as reasonable level
  - ~2.5 dB COM loss contribute a lot to COM budget, if we don't include RX noise in COM
  - Can we take 2.5 dB from 3 dB COM_{min} bucket just for two noise terms? → definitely not!

Model of RX Noise – Options Comparison

Conf.	Sys. Noise	RX Noise	COM loss in dB (to Conf. 1)			
			Mean	Min	Max	Std
1	On	Off	0	0	0	0
3	On	**η_0 = 1.64e-8 V^2/GHz**	**2.46**	0.32	**5.29**	**1.21**

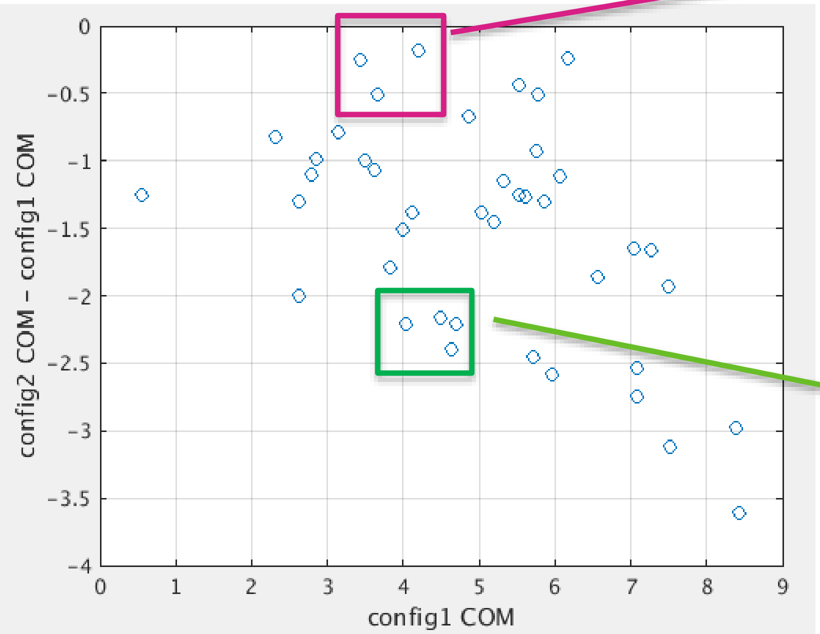
- Let's allocate 0.5 dB COM loss for RX noise, under COM_{min} = 3 dB
- Option 1 – exc. RX noise with extended COM_{min}
  - Since Mean of COM loss is 2.46 dB, we may set COM_{min} = 3 + (2.46 – 0.5) ~= 5.0 dB & excluding RX noise in COM
- Option 2 – inc. RX noise with reduced COM_{min}
  - Reduce COM_{min} to 3 – 0.5 = 2.5 dB

Option \ Models	With RX noise	COM_{min}
1	No	5.0
2	Yes	2.5

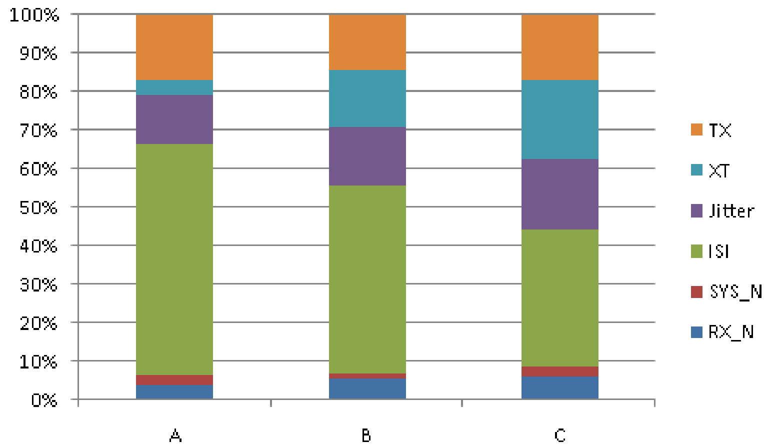
- Take Option 2 as golden, to calculate the *Channel Test Error Rate* = *Missing Rate* + *False Alarm Rate*
  - Missing : Channel passed COM by option 2, but failed COM by option 1
  - False Alarm : Channel failed COM by option 2, but passed COM by option 1

COM Loss vs. COM Analysis

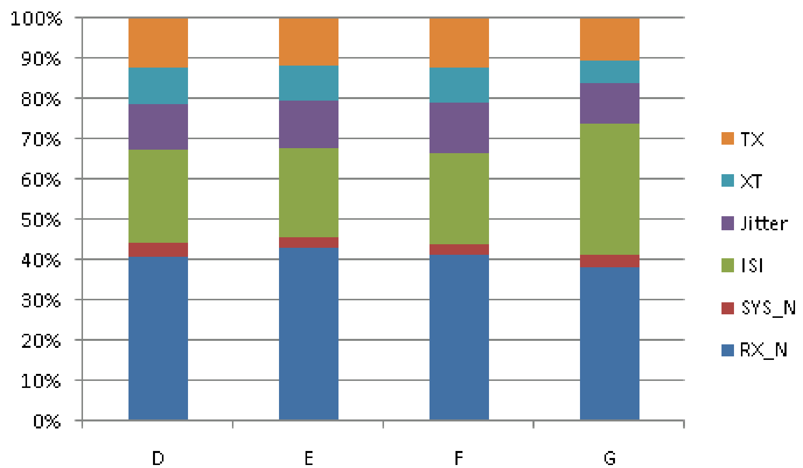
- For some channels, RX noise is not dominant term
  - COM loss is small → Option 1 is too pessimistic, may over-kill some qualified channels → Missing
- For some channels, RX noise dominates
  - COM loss is large → Option 1 is too optimistic, some disqualified channels may pass COM_{min} → False alarm



RX noise power is not dominant term (<6%)
→ COM is not sensitive to RX noise



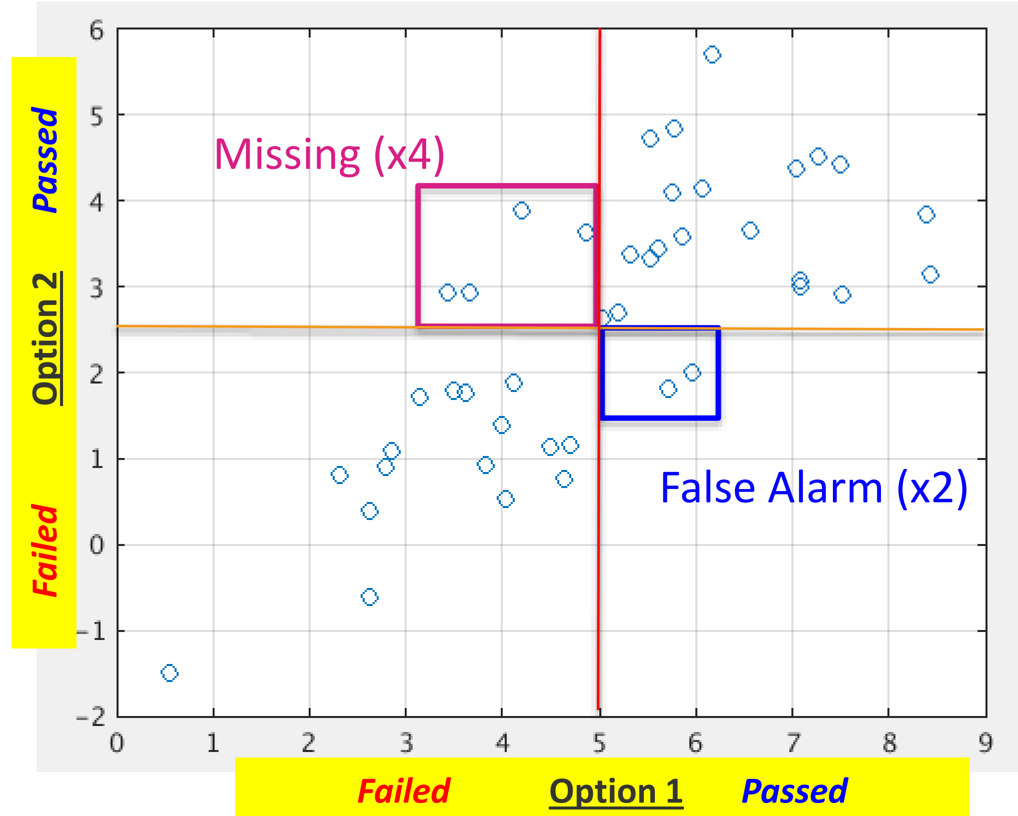
RX noise power is not dominant term(>38%)
→COM is sensitive to RX noise



Channel List: **details**

Channel Test Error Rate – 14%

- Calculate Channel Test Error Rate
  - Missing + False Alarm Rates
- Config. 4 case is shown in the figure
  - 6/42 = 14% test error rate!!
- We may consider to include Receiver Noise in COM for channel test – Option 2
- Channel Test Error Rate for all configurations in the table below



Config. 2 & 3 – details

Config.	η_0 (V²/GHz)	COM_{min}		Channel Pass Rate		Missing/ False Alarm	Error Rate
		Option 1	Option 2	Option 1	Option 2		
2	0.82e-8	4.0	2.5	71%	71%	x4 / x4	19%
3	1.23e-8	4.5	2.5	60%	60%	x3 / x3	14%
4	1.64e-8	5.0	2.5	52%	57%	x4 / x2	14%

Selected 7 KR Channels – COM Values *

- Too optimistic to model Bandlimited system noise only
- By modeling Receiver noise & take COM_{min} = 2.5 dB
  - Channel 2, 3, 4, & 5 can pass for all RX noise cases
  - Channel 1 & 6 fails for all RX noise cases
  - Channel 8 is sensitive to RX noise
- May need some improvements on Channels 1 & 6

CH ID	IL (wo PKG, dB)	ICN (mV)	FOM_ILD (dB)	COM (dB)				
				Conf. 0	Conf. 1	Conf. 2	Conf. 3	Conf. 4
		System noise		0mV	0.5mV	0.5mV	0.5mV	0.5mV
		RX noise		0mV	0mV	0.57mV	0.70mV	0.81mV
1	29.42	1.571	1.074	4.72	4.63	2.23	1.43	0.76
2	16.39	2.151	0.864	5.71	5.53	5.10	4.91	4.73
3	26.72	0.659	0.514	7.29	7.09	4.35	3.62	3.01
4	16.49	8.317	0.876	3.91	3.65	3.15	3.04	2.94
5	13.10	1.750	1.036	6.32	6.16	5.93	5.81	5.71
6	28.72	0.700	0.899	4.22	4.03	1.82	1.08	0.52
8	27.81	0.475	0.274	6.23	5.97	3.39	2.63	2.00

Conclusions

- Analysis of Richard's proposed system noise
  - CTLE will reduce system noise a lot
  - Outperforms the legacy model
  - Not significant to COM
- Receiver noise impacts to COM_{min} bucket
  - Average of 2.46dB by $\eta_0 = 1.64e\text{-}8\ V^2/GHz$
  - Variation is large

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Proposal Options

- Based on the above analysis, we proposed the following proposal options for discussion

Option	η_0 (V²/GHz) – wideband "input referred" noise	Rx Noise Factor, (NF in dB) (Informational)	η_0 (V²/GHz) – bandlimited "system" noise *1	COM_{min} (dB)	Comments for consensus discussion
Option 1	0.82e-8	12.14	NA	3.0	Present working spreadsheets
Option 2	1.64e-8	15.15	5.3096e-07	2.5	Balanced missing/false alarm
Option 3	1.23e-8	13.90	NA	3.0	Model only RX noise with more appropriate levle
Option 4	5.0119e-10	0	5.3096e-07	3.0 or TBD	Only consider resistor thermal noise and system noise. NF included in COM_{min} budget
Option 5					Something else

- *1 The bandlimited "system" noise is modeled as proposed by Richard [2]

References

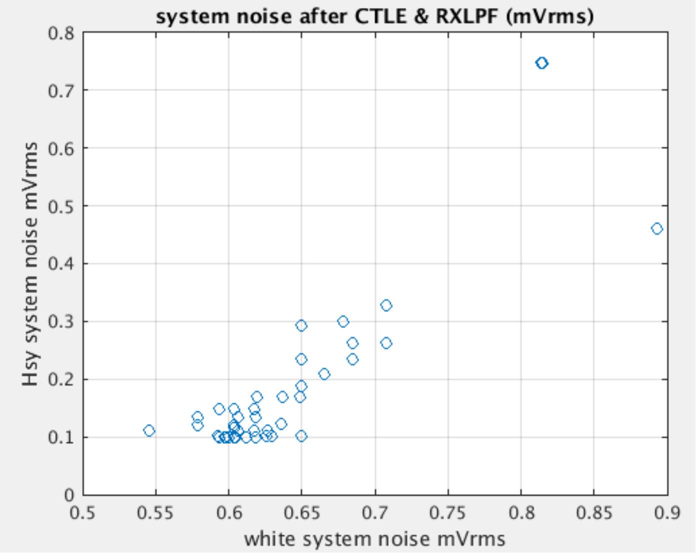
- [1] Mau-Lin Wu, et al., "COM Parameters Proposal for KR", IEEE 802.3ck 2019 March Plenary Meeting [wu_3ck_01b_0319.pdf]
- [2] Richard Mellitz, "Exploring System Noise, η_0 , for Usage in COM", IEEE 802.3ck 2019 March Plenary Meeting [mellitz_3ck_01_0319.pdf]
- [3] Adam Healey, "Considerations for the minimum COM limit", IEEE 802.3ck 2019 March Plenary Meeting [healey_3ck_01_0319.pdf]
- [4] Beth Kochuparambil, "Summary of System Discussion of Backplane Channels", IEEE 802.3ck 2019 January interim Meeting [kochuparambil_3ck_01c_0119.pdf]

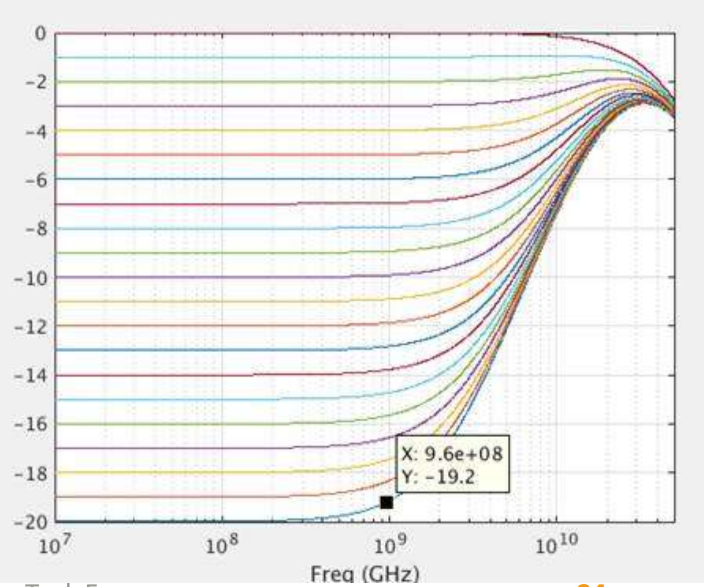
MEDIATEK

everyday genius

New Model Outperforms Legacy? *

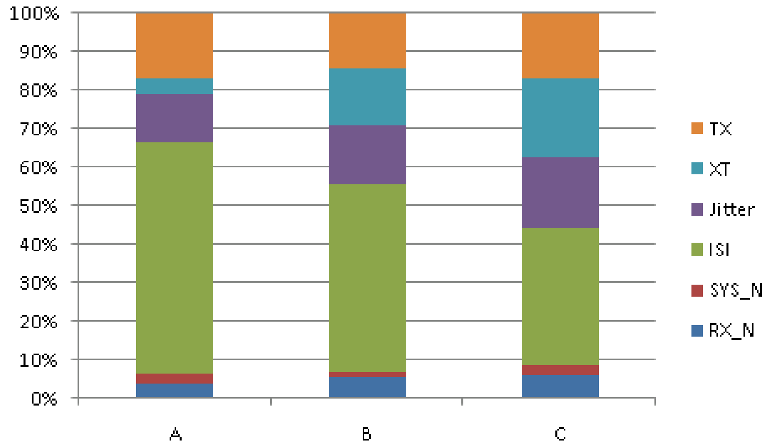
- By modeling system noise as ‘low-frequency’ (1GHz) Bandlimited noise
  - System noise level is reduced by CTLE up to ~20 dB → 1 mV_{rms} becomes 0.1 mV_{rms}
- By modeling system noise is ‘white’
  - System noise level is reduced not so much (up to 5.2 dB) → 1 mV_{rms} becomes 0.55 mV_{rms}
- That’s the major reason for COM difference
- Q: What’s the appropriate level of system noise?



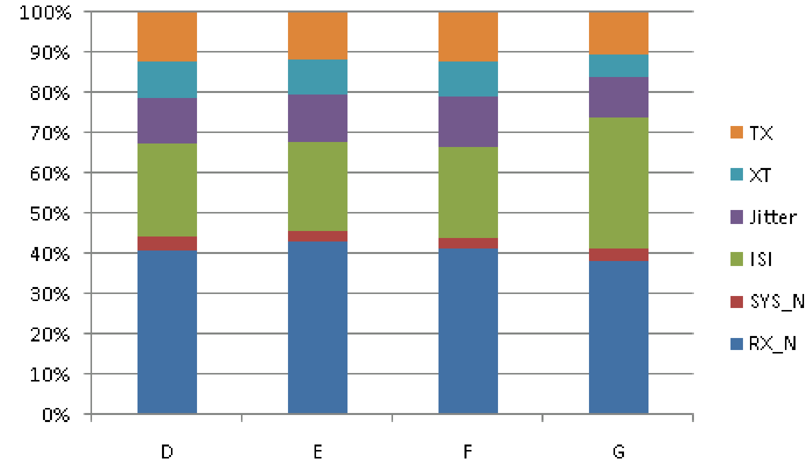


Channel List of A~G

RX noise power is not dominant term (<6%)
→ COM is not sensitive to RX noise

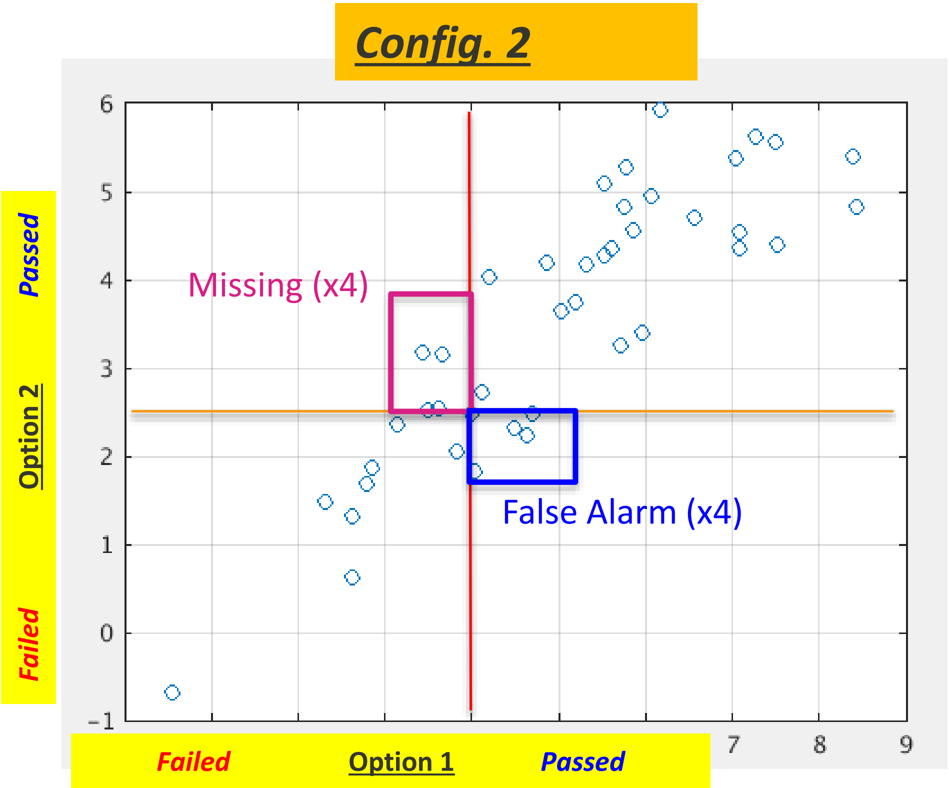


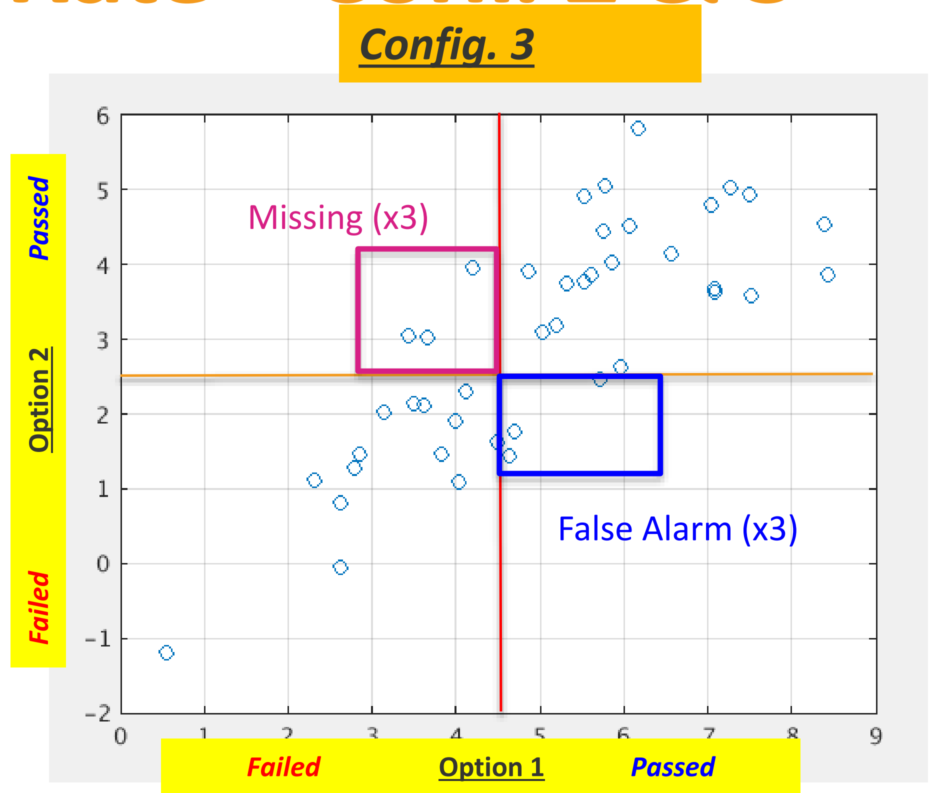
RX noise power is not dominant term(>38%)
→COM is sensitive to RX noise



Channel	File Name	Author, Year/Month
A	Bch1_3p5	Kareti, 2018/Nov
B	BP__Z100sm_IL15to16_BC-BOR_N_N_N	Mellitz, 2018/Jan
C	Std_BP_12inch_Meg7_THRU_B56	Tracy, 2019/Jan
D	CABLE_BP_and_cards_300mm30AWG_2000mm28AWG_300mm30AWG	Mellitz, 2017/May
E	Cable_BKP_28dB_0p575m_more_isi	Heck, 2018/Nov
F	Cable_BKP_28dB_0p995m_more_isi	Heck, 2018/Nov
G	OAch4	Kareti, 2018/Nov

Channel Test Error Rate – Conf. 2 & 3

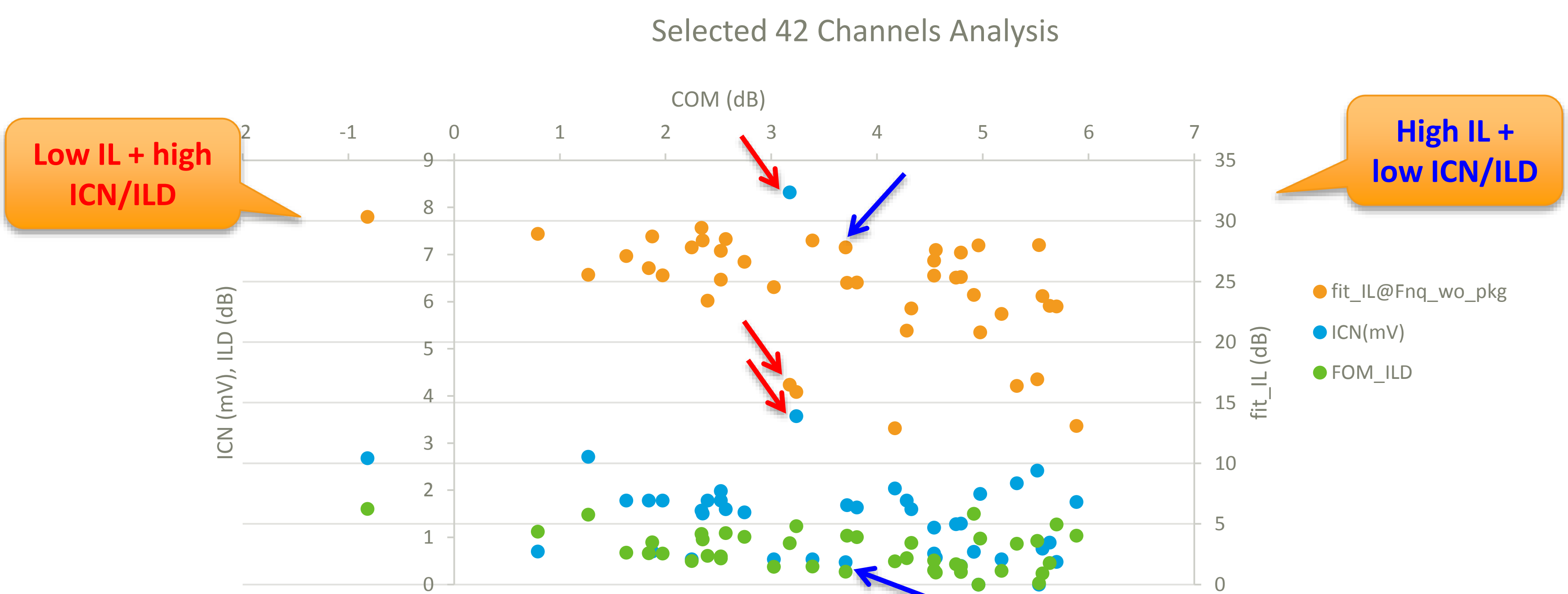




Config.	η_0 (V^2/GHz)	COM_{min}		Channel Pass Rate		Missing/ False Alarm	Error Rate
		Option 1	Option 2	Option 1	Option 2		
2	0.82e-8	4.0	2.5	71%	71%	x4 / x4	19%
3	1.23e-8	4.5	2.5	60%	60%	x3 / x3	14%
4	1.64e-8	5.0	2.5	52%	57%	x4 / x2	14%

Selected KR Channels Policy

- All 9 KR baseline channels & all 15 KR channels before 2018 Nov.
- Select 18 channels from IEEE 2018 Nov. channels
  - Try to cover wide ranges from different perspectives
  - IL (ball-2-ball): 13 – 30 dB
  - COM: -0.8 – 6.0 dB
- Some low IL with high ICN/ILD channels: IL ~= 16 dB, ICN = 3.6mV & 8.3mV
- Some high IL with low ICN/ILD channels : IL = 27.8 dB, ICN = 0.5mV, ILD = 0.3 dB



Selected 9 KR Channels – Analysis

- Show basic COM parameters for 9 KR channels