AC Common Mode Noise and Common Mode to Differential Conversion Exploration

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IEEE 802.3ck Ad-Hoc

Supporters

- Ali Ghiasi, Ghiasi Quantum
- Geoff Zhang, Xilinx

Background – Common Mode

- Try to analyze the performance impact due to the following two effects
  - P/N skew mismatch and other sources of common mode to differential conversion (SDC21) from channel
  - AC common-mode (CM) noise
- Explore the suitable parameters to constraint SDC21
  - SDC21 peak value, IDCR (insertion loss to DC mode conversion ratio), INCM (integrated noise due to common mode)
- Two approaches of mitigating performance degradation due to SDC21
  - Add SDC21/IDCR/INCM spec limit
  - Modify AC CM spec

Performance Impact – SNR_TX Analysis

- Leverage the matlab code from Rich for further analysis [mellitz_3ck_adhoc_01_062420.pdf]
  - Sweeping AC CM values on more IEEE channels
  - Observing SNR_TX loss vs. SDC21 peak had been observed in wu_3ck_01_0720.pdf
  - We explored other indicators, IDCR & INCM, in this contribution

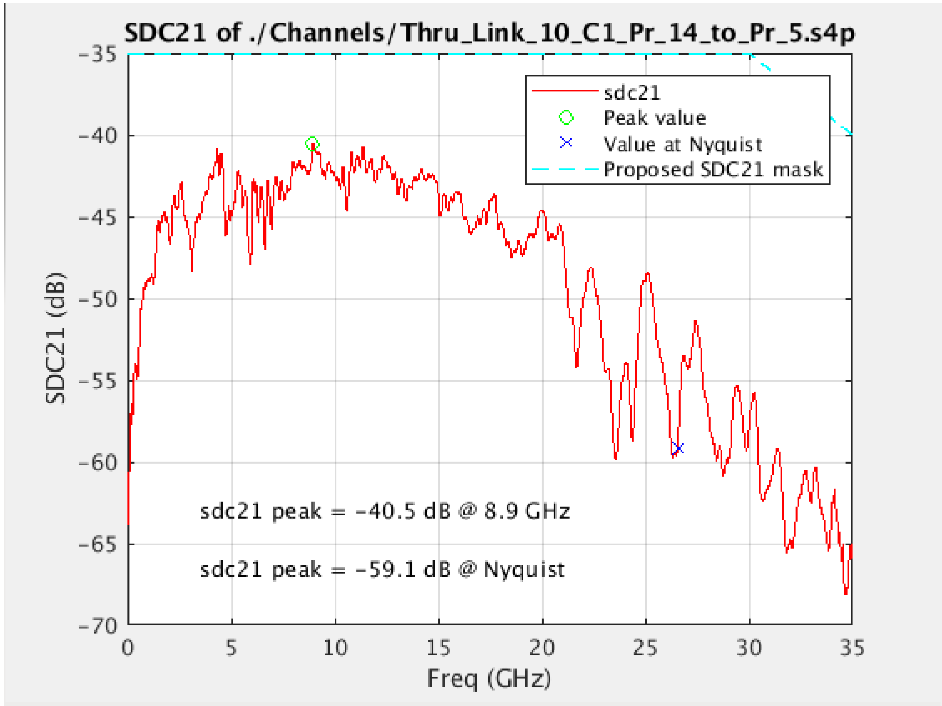
Gauging Study: Results with a Source of 30 mV, 10 mV, and 1 mV of AC CM

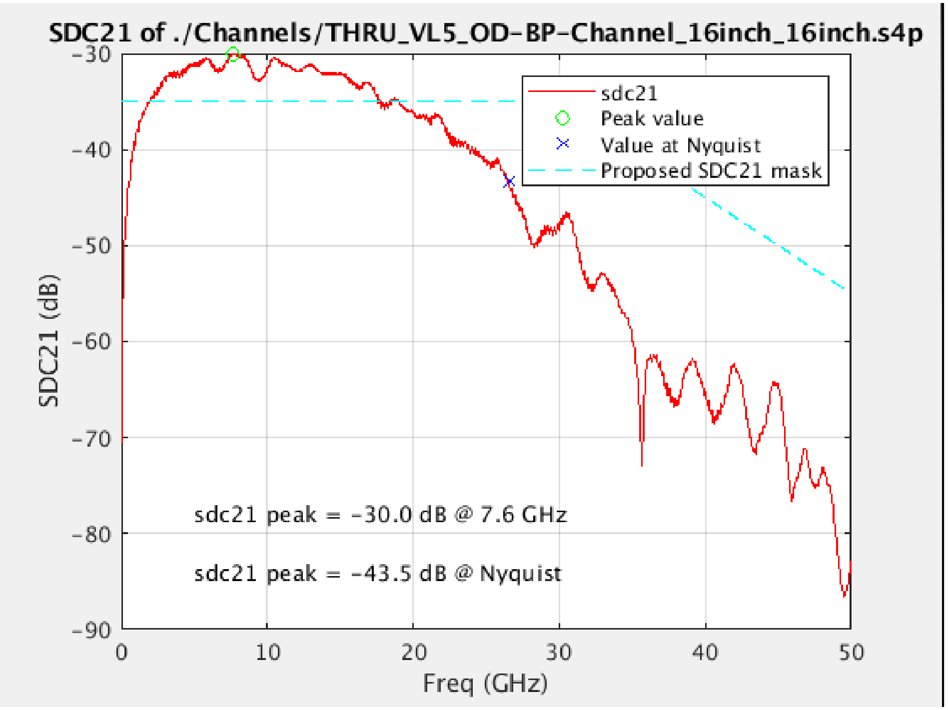
file	Old SNR_{Tx} (dB)	New SNR_{Tx} (dB) AC CM 30 mV	New SNR_{Tx} (dB) AC CM 10 mV	New SNR_{Tx} (dB) / AC CM 1 mV
Kateri/Bch2_b7p5_7_	32.5	32.0	32.4	32.5
Kateri/Bch2_b6_7_t	32.5	31.9	32.4	32.5
Kateri/CAch2_a2p5_t	32.5	30.4	32.2	32.5
Heck/.Cable_BKP_28dB_0p575m_more_isi_thru1	32.5	31.5	32.4	32.5
Mellitz/Via_Opt2_28dB_THRU	32.5	32.4	32.5	32.5
Zambell/Thru_Link_9_C1_Pr_14_to_Pr_5	32.5	31.7	32.4	32.5
Gore/C2C_PCB_SYSVIA_20dB_thru	32.5	31.3	32.4	32.5
Palkert/THRU_VL5_OD-BP-Channel_16inch_16inch	32.5	25.7	31.0	32.5
Rabinovich/Channel_Thru_P1_to_P2_01.s4p	32.5	30.4	32.2	32.4

Channels & SDC21 Indicators

- Channels for analysis
  - 151 IEEE KR channels + 19 IEEE C2C channels
  - Channel list in appendix
- SDC21 indicators
  - SDC21 peak
    - The peak value of SDC21 within Nyquist frequency
  - IDCR (dB) – insertion loss to crosstalk ratio
    - IDCR (dB) = SDD21 (dB) – SDC21 (dB) at Nyquist frequency
  - INCM – integrated crosstalk noise
    - Calculate integrated crosstalk noise due to SDC21

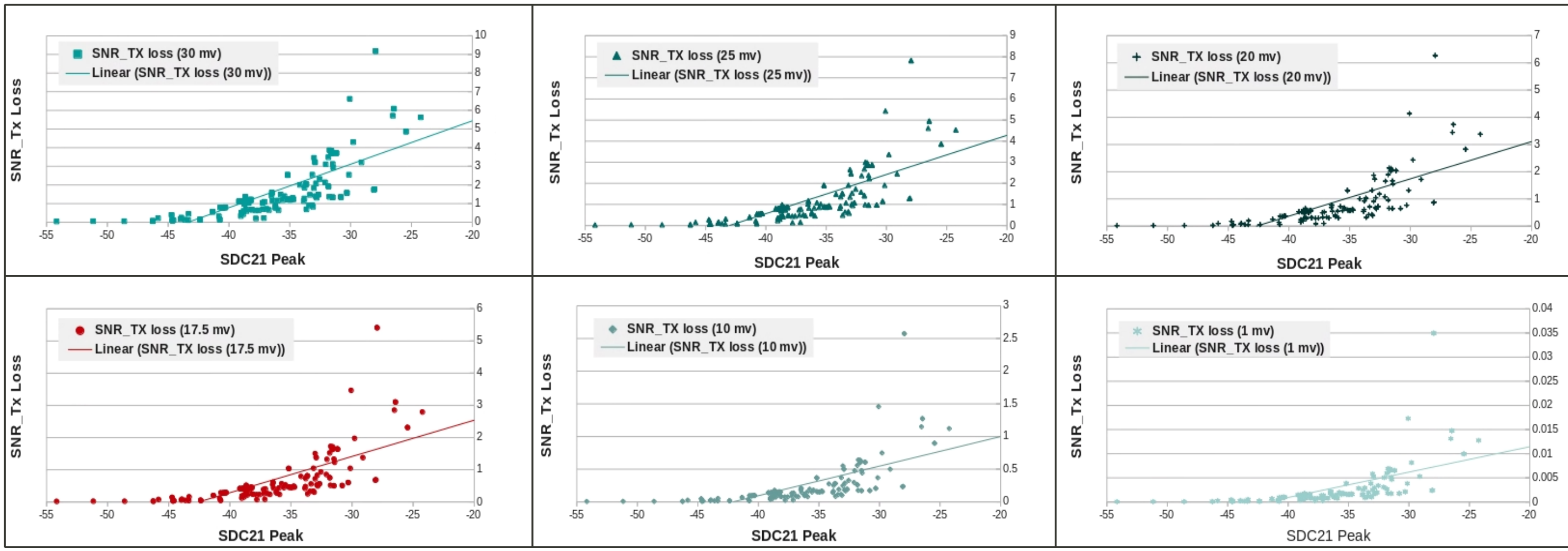
Analysis of SDC21 of Channels – Peak SDC21





Analysis of SDC21 and TX SNR

- Evaluation of SNR_TX loss vs. SDC21 peak value with varying CM noise

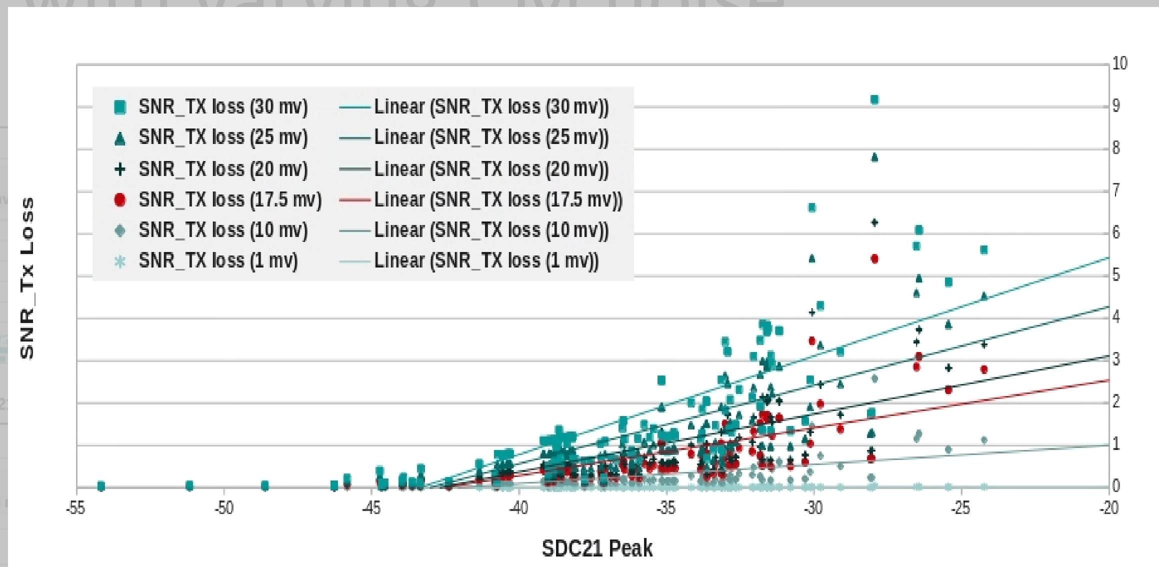


- If taking 1 dB SNR_TX loss as threshold,
  - It will require SDC21 peak <= -39.1 dB with CM noise = 30 mV
  - SDC21 peak <= -33.7 dB with CM noise = 17.5 mV

CM (mV)	30	25	20	17.5	10	1
SDC21 peak (dB)	-39.1	-37.6	-35.4	-33.7	-20	NA

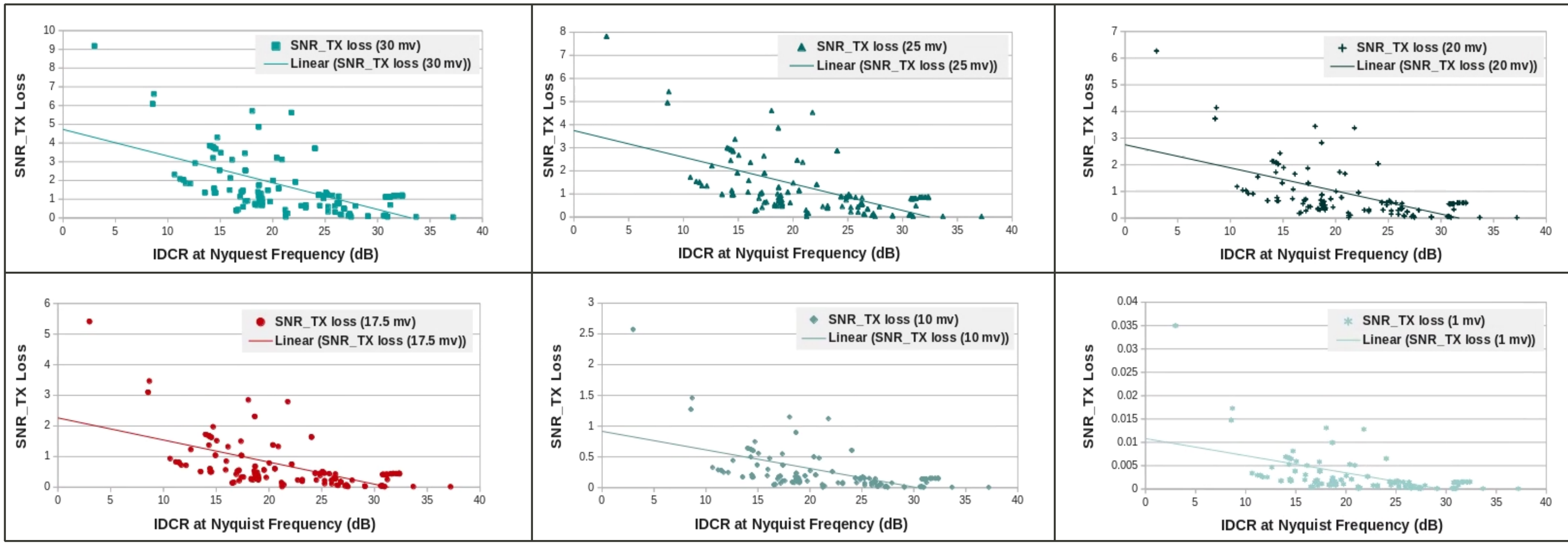
Analysis of SDC21 and TX SNR

- Evaluation of SNR_TX loss over SDC21 peak value with varying CM noise



Analysis of IDCR and TX SNR (1/2)

- Evaluation of SNR_TX loss vs. IDCR at Nyquist frequency with varying CM noise
  - IDCR (in dB) is computed as SDD21 – SDC21

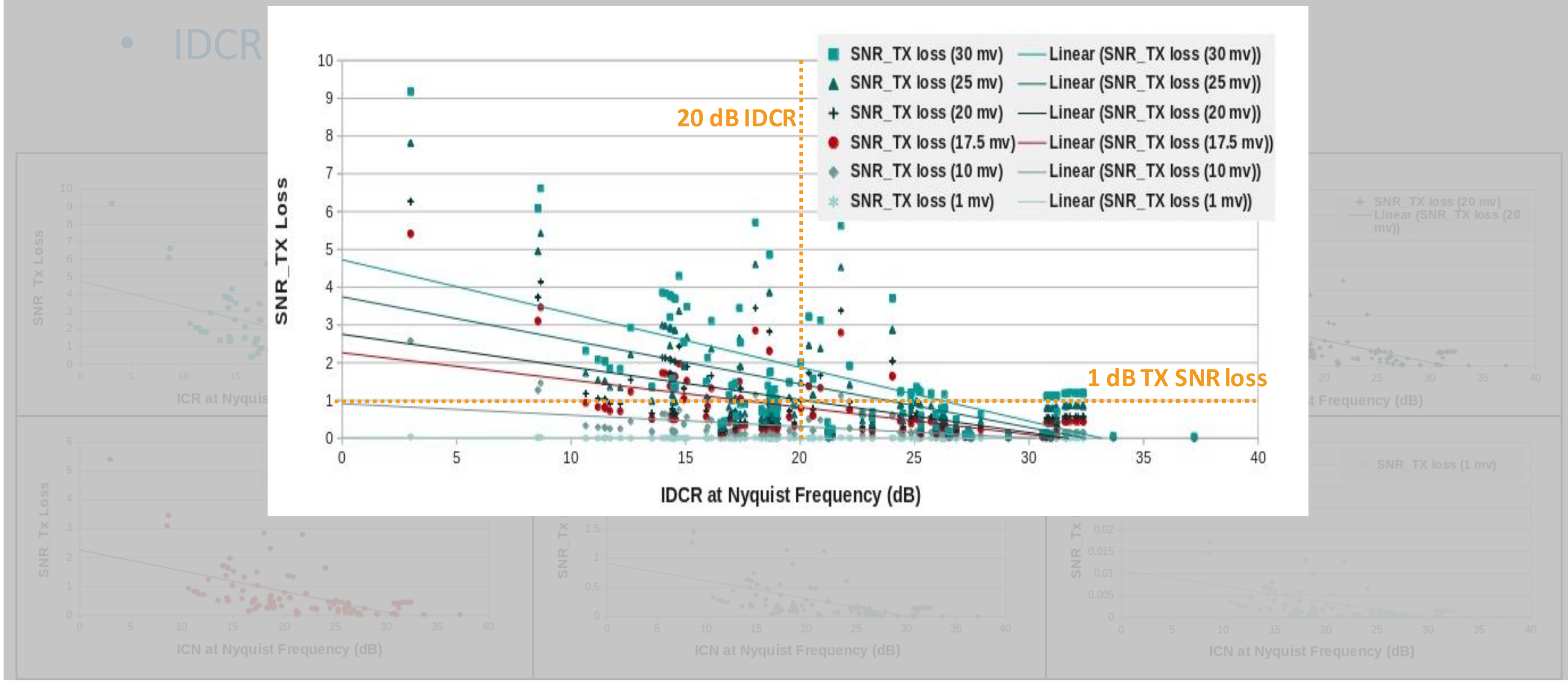


- If taking 1 dB SNR_TX loss as threshold,
  - It will require IDCR >= 26.2 dB with CM noise = 30 mV
  - IDCR >= 17.5 dB with CM noise = 17.5 mV

CM (mV)	30	25	20	17.5	10	1
IDCR (dB)	26.2	23.8	20.2	17.5	NA	NA

Analysis of IDCR and TX SNR (1/2)

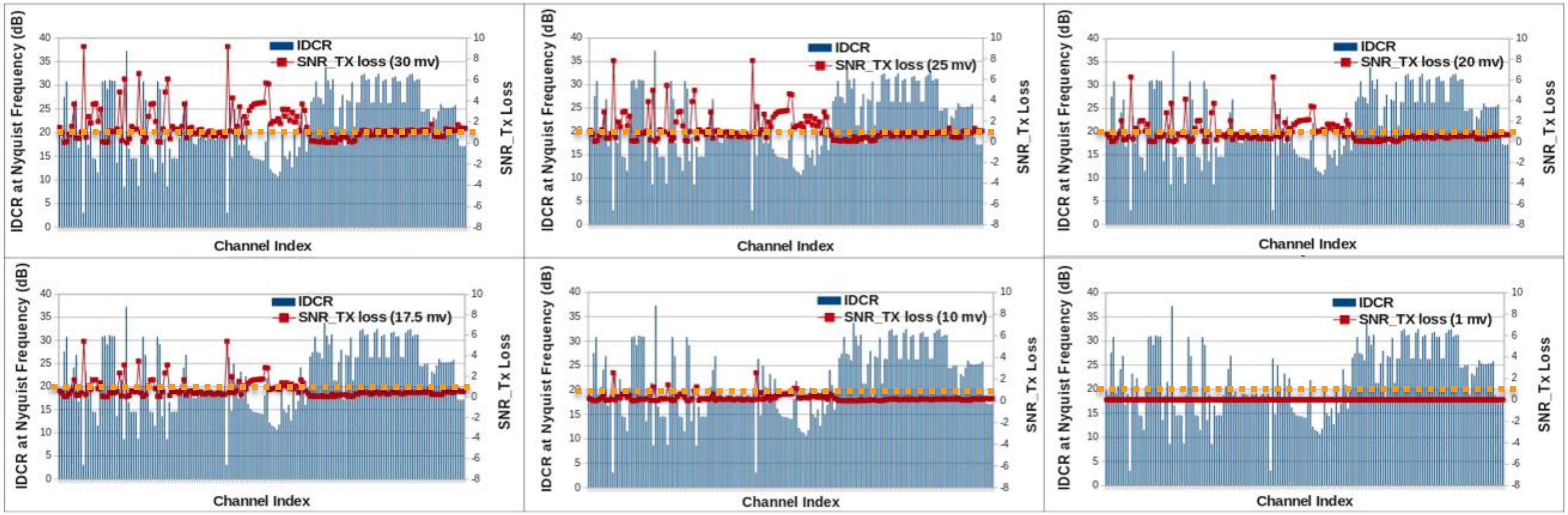
- Evaluation of SNR_TX loss over IDCR at Nyquist frequency with varying CM noise
  - IDCR



- Q: How many channels can pass this spec?
  - By outage

Analysis of IDCR and TX SNR (2/2)

- Performance criterion: SNR_Tx loss < 1dB and IDCR at Nyquist frequency > 20 dB



- Outage (%)
  - # of channels with IDCR/SNR_TX loss didn't meet the above criterion out of 170 channels

CM (mV)	30	25	20	17.5	10	1
IDCR Outage	45.9 %					
SNR_TX Outage	61.8 %	35.3 %	24.7 %	20.6 %	4.1 %	0 %

INCM Model – for Xtalk Noise due to SDC21

- **INCM: integrated noise due to common mode [similar to 92.11.3.6.3]**

$$\sigma_{CM} = \left(2 \cdot \sum_n W(f_n) \cdot VTF_{dc} \right)^{1/2}$$

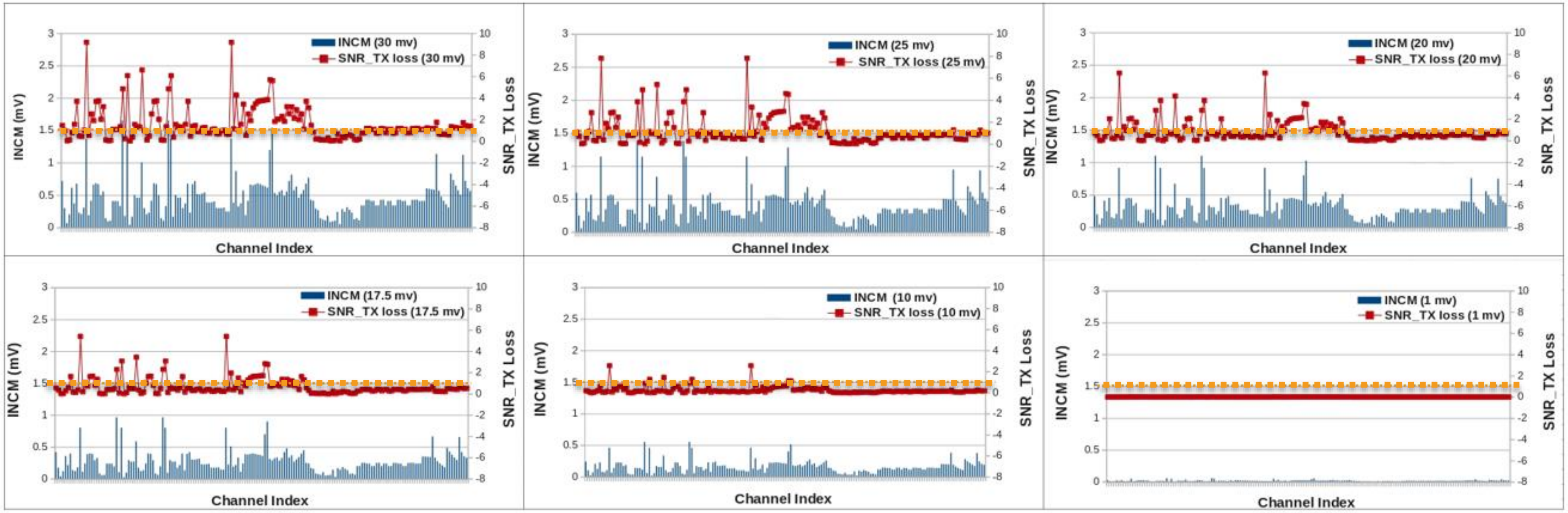
- VTF_{dc}: AC CM TF (voltage transfer function)
  - Ref: [slide 6 in mellitz_3ck_adhoc_01_061720.pdf]
- Power weight function

$$W(f_n) = A_{cm}^2 \mathrm{sinc}^2(f_n/f_b) \left[\frac{1}{1+\left(f_n/f_{T_r}\right)^4} \right] \left[\frac{1}{1+(f_n/f_r)^8} \right]$$

  - A_{CM}: CM noise amplitude
    - ✓ A_{CM} is $\sqrt{2}$ times higher than AC CM RMS voltage
  - f_{T_r}/f_r: cut-off frequency for the transmitting/receiving filter

Analysis of INCM and TX SNR

- Performance criterion: SNR_Tx loss < 1dB and INCM < 1.5 mV
  - INCM: aggregated common mode noise



- Outage (%)
  - # of channels with INCM/SNR_TX loss didn't meet the above criterion out of 170 channels

CM (mV)	30	25	20	17.5	10	1
INCM Outage	1.8 %	0 %	0 %	0 %	0 %	0 %
SNR_TX Outage	61.8 %	35.3 %	24.7 %	20.6 %	4.1 %	0 %

CM Noise at TP0 vs. TP0v

- CM noise value at TP0 is adopted for analysis of performance impact here
- Need to derive the relationship of CM noise (RMS) at TP0v to CM noise (RMS) at TP0
  - Strongly depends on IL (insertion loss) of TP0 to TP0v test fixture
  - Suggest the following relationship
    - $CM(RMS)\ at\ TP0v = CM(RMS)\ at\ TP0 * 10^{(-0.5*IL_{TP0\_TP0v}/20)}$ (1)
    - Where IL_{TP0_TP0v} is the insertion loss (dB) of TP0 to TP0v test fixture

Corresponded CM noise value at TP0v (in mV)

		TP0 to TP0v IL (dB)					
		1	2	3	4	5	6
CM noise at TP0 (mV)	30	28.1	26.4	24.8	23.4	22.1	20.9
	25	23.4	22.0	20.7	19.5	18.4	17.4
	20	18.7	17.6	16.5	15.6	14.7	13.9
	17.5	16.4	15.4	14.5	13.6	12.9	12.2
	10	9.4	8.8	8.3	7.8	7.4	7.0

Ratio (dB) of CM noise at TP0 to CM noise at TP0v

		TP0 to TP0v IL (dB)					
		1	2	3	4	5	6
CM noise at TP0 (mV)	30	0.57	1.11	1.65	2.16	2.65	3.14
	25	0.57	1.11	1.64	2.16	2.66	3.15
	20	0.58	1.11	1.67	2.16	2.67	3.16
	17.5	0.56	1.11	1.63	2.19	2.65	3.13
	10	0.54	1.11	1.62	2.16	2.62	3.10

Summary & Discussion

- In order to achieve limited SNR_TX loss, there is trade-off between
  - AC CM noise
  - SDC21/IDCR/INCM
- Proposals to mitigate SDC21 impacts by
  - Adopt SDC21/IDCR/INCM spec limits
    - One or all of them
  - Modify AC CM noise RMS spec @ TP0v (KR & C2C, C163 & A120F)
    - Define spec @ TP0: 30 mV → 17.5 or 20 mV
    - Derive spec @ TP0v by formula (1) in slide 14 in this contribution

MEDIATEK

everyday genius

Channel Lists (1/3)

Channel index 1-151: KR
Channel index 152-170: C2C

Ind.	Channel
1	Cable_BKP_16dB_0p575m_more_isi_thru1.s4p
2	Cable_BKP_28dB_0p575m_thru1.s4p
3	CaBP_BGAVia_Opt2_28dB_THRU.s4p
4	Std_BP_12inch_Meg7_Thru_B56.s4p
5	DPO_4in_Meg7_THRU.s4p
6	OAch4_t.s4p
7	CAch3_b2_t.s4p
8	Bch2_b7p5_7_t.s4p
9	DPO_12in_Meg7_THRU.s4p
10	Cable_BKP_28dB_0p575m_more_isi_thru1.s4p
11	THRU_VL5_palkert_BP_channel.s4p
12	OAch6_t.s4p
13	OAch7_t.s4p
14	Och1_t.s4p
15	Och4_t.s4p
16	Och5_t.s4p
17	CAch2_a10_t.s4p
18	CAch2_b10_t.s4p
19	Bch2_a0_7_t.s4p
20	Bch2_a5_7_t.s4p
21	Bch2_a7p5_7_t.s4p
22	Thru_Link_14_C1_Pr_14_to_Pr_5.s4p
23	Thru_Link_20_C1_Pr_14_to_Pr_5.s4p
24	Thru_Link_7_C1_Pr_14_to_Pr_5.s4p
25	CABLE_BP_and_cards_300mm30AWG_2000mm28AWG_300mm30AWG_THRU.s4p
26	BP__Z100sm_IL15to16_BC-BOR_N_N_N_THRU.s4p
27	B56_Thru_CblBP.s4p
28	Thru_Cable_Backplane_Pr_14_to_Pr_6.s4p
29	CaBP_BGAVIas_Opt1_32dB_THRU.s4p
30	DPO_14in_Meg7_THRU.s4p

Ind.	Channel
31	BP_2conn_85ohm_30dB_HzLzHz_thru.s4p
32	BP_2conn_85ohm_30dB_LzHzLz_thru.s4p
33	BP_2conn_85ohm_30dB_Nom_thru.s4p
34	THRU_VL5_OD-BP-Channel_4inch_28inch.s4p
35	Cable_BKP_28dB_0p575m_thru1.s4p
36	Std_BP_12inch_Meg7_Thru_B56.s4p
37	Bch2_b7p5_7_t.s4p
38	OAch7_t.s4p
39	Och4_t.s4p
40	Och5_t.s4p
41	CAch2_a10_t.s4p
42	Bch2_a0_7_t.s4p
43	Bch2_a7p5_7_t.s4p
44	CABLE_BP_and_cards_300mm30AWG_2000mm28AWG_300mm30AWG_THRU.s4p
45	BP__Z100sm_IL15to16_BC-BOR_N_N_N_THRU.s4p
46	Thru_Cable_Backplane_Pr_14_to_Pr_6.s4p
47	DPO_14in_Meg7_THRU.s4p
48	BP_2conn_85ohm_30dB_HzLzHz_thru.s4p
49	BP_2conn_85ohm_30dB_LzHzLz_thru.s4p
50	BP_2conn_85ohm_30dB_Nom_thru.s4p
51	Cable_BKP_28dB_0p575m_thru1.s4p
52	OAch4_t.s4p
53	CAch3_b2_t.s4p
54	Bch2_b7p5_7_t.s4p
55	Cable_BKP_16dB_0p575m_thru1.s4p
56	Cable_BKP_16dB_0p575m_more_isi_thru1.s4p
57	Cable_BKP_16dB_0p995m_more_isi_thru1.s4p
58	Cable_BKP_16dB_0p995m_thru1.s4p
59	Cable_BKP_20dB_0p575m_thru1.s4p
60	Cable_BKP_20dB_0p575m_more_isi_thru1.s4p

Channel Lists (2/3)

Channel index 1-151: KR
Channel index 152-170: C2C

Ind.	Channel
61	Cable_BKP_20dB_0p995m_more_isi_thru1.s4p
62	Cable_BKP_20dB_0p995m_thru1.s4p
63	Cable_BKP_24dB_0p575m_thru1.s4p
64	Cable_BKP_24dB_0p575m_more_isi_thru1.s4p
65	Cable_BKP_24dB_0p995m_more_isi_thru1.s4p
66	Cable_BKP_24dB_0p995m_thru1.s4p
67	Cable_BKP_28dB_0p575m_thru1.s4p
68	Cable_BKP_28dB_0p575m_more_isi_thru1.s4p
69	Cable_BKP_28dB_0p995m_more_isi_thru1.s4p
70	Cable_BKP_28dB_0p995m_thru1.s4p
71	THRU_VL5_palkert_BP_channel.s4p
72	OAch1_t.s4p
73	OAch2_t.s4p
74	OAch3_t.s4p
75	OAch4_t.s4p
76	OAch5_t.s4p
77	OAch6_t.s4p
78	OAch7_t.s4p
79	Och1_t.s4p
80	Och2_t.s4p
81	Och3_t.s4p
82	Och4_t.s4p
83	Och5_t.s4p
84	Och6_t.s4p
85	Och7_t.s4p
86	Och8_t.s4p
87	CAch1_b2_t.s4p
88	CAch1_t.s4p
89	CAch2_a0_t.s4p
90	CAch2_a10_t.s4p

Ind.	Channel
91	CAch2_a2p5_t.s4p
92	CAch2_a5_t.s4p
93	CAch2_a7p5_t.s4p
94	CAch2_b10_t.s4p
95	CAch2_b2_t.s4p
96	CAch2_b2p5_t.s4p
97	CAch2_b4_t.s4p
98	CAch2_b6_t.s4p
99	CAch2_b7p5_t.s4p
100	CAch2_b8_t.s4p
101	CAch2_t.s4p
102	CAch3_b2_t.s4p
103	CAch3_t.s4p
104	CAch4_b2_t.s4p
105	CAch4_t.s4p
106	Bch1_3p5_t.s4p
107	Bch2_7_t.s4p
108	Bch2_a0_7_t.s4p
109	Bch2_a10_7_t.s4p
110	Bch2_a12p5_7_t.s4p
111	Bch2_a15_7_t.s4p
112	Bch2_a2p5_7_t.s4p
113	Bch2_a5_7_t.s4p
114	Bch2_a7p5_7_t.s4p
115	Bch2_b10_7_t.s4p
116	Bch2_b15_7_t.s4p
117	Bch2_b2_7_t.s4p
118	Bch2_b2p5_7_t.s4p
119	Bch2_b4_7_t.s4p
120	Bch2_b6_7_t.s4p

Channel Lists (3/3)

Channel index 1-151: KR
Channel index 152-170: C2C

Ind.	Channel
121	Bch2_b7p5_7_t.s4p
122	Bch2_b8_7_t.s4p
123	Bch3_14_t.s4p
124	Bch4_30_t.s4p
125	Thru_Link_10_C1_Pr_14_to_Pr_5.s4p
126	Thru_Link_11_C1_Pr_14_to_Pr_5.s4p
127	Thru_Link_12_C1_Pr_14_to_Pr_5.s4p
128	Thru_Link_13_C1_Pr_14_to_Pr_5.s4p
129	Thru_Link_14_C1_Pr_14_to_Pr_5.s4p
130	Thru_Link_15_C1_Pr_14_to_Pr_5.s4p
131	Thru_Link_16_C1_Pr_14_to_Pr_5.s4p
132	Thru_Link_17_C1_Pr_14_to_Pr_5.s4p
133	Thru_Link_18_C1_Pr_14_to_Pr_5.s4p
134	Thru_Link_19_C1_Pr_14_to_Pr_5.s4p
135	Thru_Link_1_C1_Pr_14_to_Pr_5.s4p
136	Thru_Link_20_C1_Pr_14_to_Pr_5.s4p
137	Thru_Link_21_C1_Pr_14_to_Pr_5.s4p
138	Thru_Link_22_C1_Pr_14_to_Pr_5.s4p
139	Thru_Link_23_C1_Pr_14_to_Pr_5.s4p
140	Thru_Link_24_C1_Pr_14_to_Pr_5.s4p
141	Thru_Link_25_C1_Pr_14_to_Pr_5.s4p
142	Thru_Link_26_C1_Pr_14_to_Pr_5.s4p
143	Thru_Link_27_C1_Pr_14_to_Pr_5.s4p
144	Thru_Link_2_C1_Pr_14_to_Pr_5.s4p
145	Thru_Link_3_C1_Pr_14_to_Pr_5.s4p
146	Thru_Link_4_C1_Pr_14_to_Pr_5.s4p
147	Thru_Link_5_C1_Pr_14_to_Pr_5.s4p
148	Thru_Link_6_C1_Pr_14_to_Pr_5.s4p
149	Thru_Link_7_C1_Pr_14_to_Pr_5.s4p
150	Thru_Link_8_C1_Pr_14_to_Pr_5.s4p

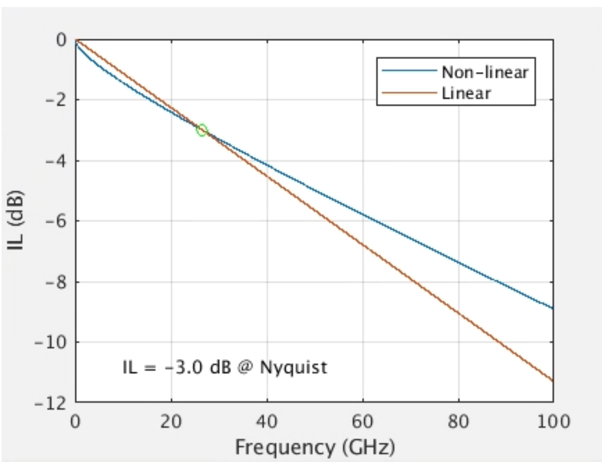
Ind.	Channel
151	Thru_Link_9_C1_Pr_14_to_Pr_5.s4p
152	Asic_Mezz_Retimer_L10_Thru.s4p
153	Asic_Mezz_Retimer_L23_Thru.s4p
154	Asic_Mezz_Deep_Retimer_L10_Thru.s4p
155	Asic_Mezz_Deep_Retimer_L23_Thru.s4p
156	Impaired_C2C_6p75in_P1_to_P2_thru.s4p
157	C2C_CA_CONN_SYSVIA_12dB_thru.s4p
158	C2C_CA_CONN_SYSVIA_14dB_thru.s4p
159	C2C_CA_CONN_SYSVIA_16dB_thru.s4p
160	C2C_CA_CONN_SYSVIA_18dB_thru.s4p
161	C2C_CA_CONN_SYSVIA_20dB_thru.s4p
162	C2C_PCB_SYSVIA_12dB_thru.s4p
163	C2C_PCB_SYSVIA_14dB_thru.s4p
164	C2C_PCB_SYSVIA_16dB_thru.s4p
165	C2C_PCB_SYSVIA_18dB_thru.s4p
166	C2C_PCB_SYSVIA_20dB_thru.s4p
167	Impaired_C2C_10dB_P1_to_P2_THRU_ExtPEC.s4p
168	Impaired_C2C_16dB_P1_to_P2_THRU_ExtPEC.s4p
169	Impaired_C2C_18dB_P1_to_P2_THRU_ExtPEC.s4p
170	Impaired_C2C_20dB_P1_to_P2_thru_ExtPEC.s4p

SNR_TX analysis: leverage the Matlab code from Rich [mellitz_3ck_adhoc_01_062420.pdf]

TP0-TP0v CM Noise Conversion

- Conversion of AC RMS from TP0 to TP0v done with integration

TP0-TP0v IL



Corresponded CM noise value at TP0v (in mV)

Linear

CM noise at TP0 (mV)	TP0 to TP0v IL (dB): 1	2	3	4	5	6
30	28.4	26.9	25.5	24.2	23.1	22.1
25	23.6	22.4	21.2	20.2	19.3	18.4
20	18.9	17.9	17.0	16.2	15.4	14.7
17.5	16.5	15.7	14.9	14.1	13.5	12.9
10	9.5	9.0	8.5	8.1	7.7	7.4

Non-linear

CM noise at TP0 (mV)	TP0 to TP0v IL (dB): 1	2	3	4	5	6
30	28.1	26.4	24.8	23.4	22.1	20.9
25	23.4	22.0	20.7	19.5	18.4	17.4
20	18.7	17.6	16.5	15.6	14.7	13.9
17.5	16.4	15.4	14.5	13.6	12.9	12.2
10	9.4	8.8	8.3	7.8	7.4	7.0

Ratio (dB) of CM noise at TP0 to CM noise at TP0v

Linear

CM noise at TP0 (mV)	TP0 to TP0v IL (dB): 1	2	3	4	5	6
30	0.48	0.95	1.41	1.87	2.27	2.65
25	0.50	0.95	1.43	1.85	2.25	2.66
20	0.49	0.96	1.41	1.83	2.27	2.67
17.5	0.51	0.94	1.40	1.88	2.25	2.65
10	0.45	0.92	1.41	1.83	2.27	2.62

Non-linear

CM noise at TP0 (mV)	TP0 to TP0v IL (dB): 1	2	3	4	5	6
30	0.57	1.11	1.65	2.16	2.65	3.14
25	0.57	1.11	1.64	2.16	2.66	3.15
20	0.58	1.11	1.67	2.16	2.67	3.16
17.5	0.56	1.11	1.63	2.19	2.65	3.13
10	0.54	1.11	1.62	2.16	2.62	3.10