Achievable Cable Reach

for different cable models and PAM sizes

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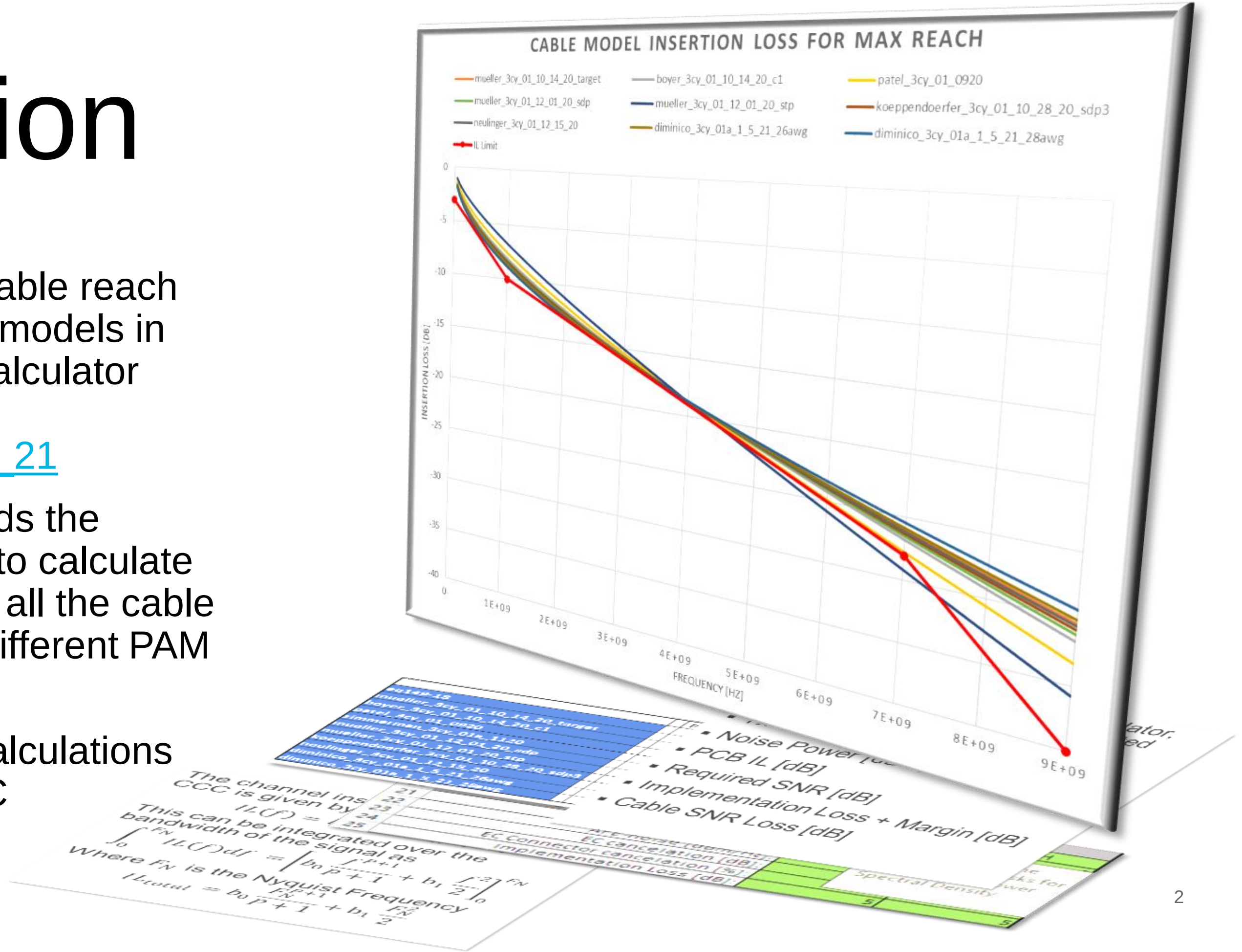
802.3cy

Introduction

- We examine the achievable reach for the different channel models in the Channel Capacity Calculator (CCC) tool in [jonsson_3cy_01_01_12_21]
- This contribution expands the calculations in the CCC to calculate the achievable reach for all the cable models and number of different PAM sizes
- In this contribution all calculations are done assuming 20ºC



Calculating Excess Margin

In the Channel Capacity Calculator, the theoretical excess margin is calculated based on the following:

Excess Margin =

Tx Power [dBm]

- Noise Power [dBm]

- PCB IL [dB]

- Required SNR [dB]

- Implementation Loss [dB]

- Required Operating Margin [dB]

- Cable Insertion Loss [dB]

- It is possible to calculate each of these factors independently, by summing up over frequency
- Because the Channel Capacity Calculator uses parametric models for all the factors, it is possible to calculate values for all the factors algebraically
- The Noise Power and the Required SNR are slightly more complicated, but all other are simple to calculate

Calculating SNR Budget

The table below shows the SNR loss due to different factors and for different PAM sizes. It assumes -140dBm/Hz AFE noise floor

* The Cable SNR Loss Budget is how much SNR loss we can have in the channel without having negative SNR margin

PAM		PAM2	PAM3	PAM4	PAM5	PAM6	PAM7	PAM8
Tx Power [dBm]		0.0	0.0	0.0	0.0	0.0	0.0	0.0
Noise Power [dBm]		-37.5	-39.3	-40.0	-40.3	-40.6	-41.0	-41.22
PCB IL [dB]		2.3	1.5	1.2	1.1	1.0	0.9	0.8
Required SNR [dB]		10.5	14.6	17.2	19.2	20.7	22.1	23.2
Nyquist Frequency [GHz]		14.1	8.9	7.0	6.1	5.4	5.0	4.7
Implementation Loss + Margin [dB]		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Cable SNR Loss Budget* [dB]		19.6	18.2	16.6	15.1	13.9	13.0	12.2

Channel SNR Loss

The channel insertion loss model in CCC is given by

$$IL(f) = b_0\, f^P + b_1 f \text{ [dB]}$$

This can be integrated over the bandwidth of the signal as

$$\int_0^{F_N} IL(f)df \;= \left[b_0 \frac{f^{P+1}}{P+1} + \mathrm{b}_1 \frac{f^2}{2}\right]_0^{F_N}$$

Where F_N is the Nyquist Frequency

$$IL_{total} = b_0 \frac{F_N^{P+1}}{P+1} + \mathrm{b}_1 \frac{F_N^2}{2}$$

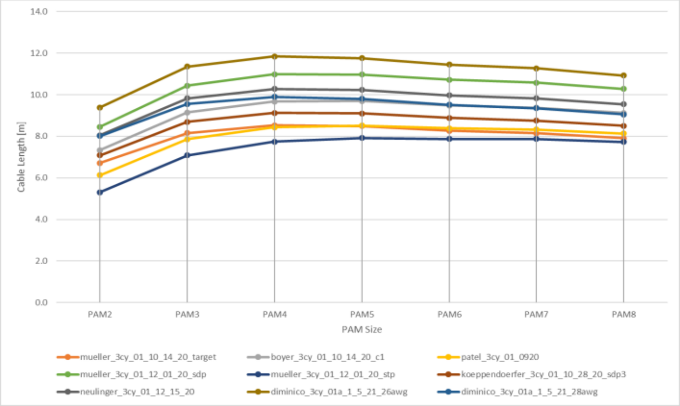
The Nyquist Frequency depends on the symbol rate, which in turn depends on the PAM size

The table below shows the 20ºC SNR loss per meter in dB/m

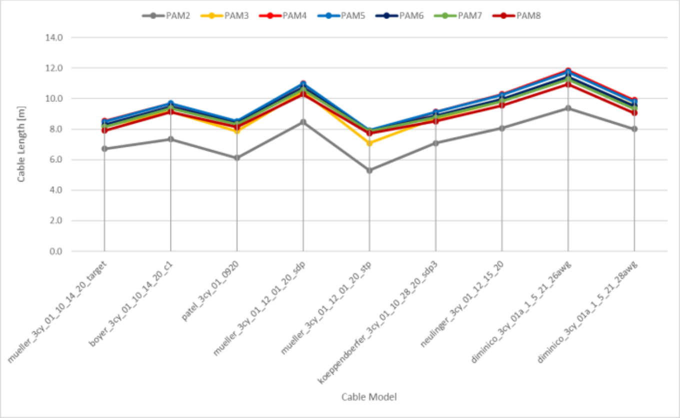
PAM	PAM2	PAM3	PAM4	PAM5	PAM6	PAM7	PAM8
eq149-18	-3.24	-2.46	-2.15	-1.98	-1.86	-1.78	-1.72
mueller_3cy_01_10_14_20_target	-2.93	-2.22	-1.94	-1.78	-1.68	-1.60	-1.54
boyer_3cy_01_10_14_20_c1	-2.68	-1.98	-1.71	-1.56	-1.46	-1.39	-1.33
patel_3cy_01_0920	-3.21	-2.31	-1.97	-1.78	-1.65	-1.56	-1.50
zimmerman_3cy_01a_1120	-2.59	-2.01	-1.78	-1.64	-1.55	-1.49	-1.44
mueller_3cy_01_12_01_20_sdp	-2.32	-1.74	-1.51	-1.38	-1.29	-1.23	-1.18
mueller_3cy_01_12_01_20_stp	-3.71	-2.57	-2.14	-1.91	-1.76	-1.65	-1.57
koeppendoerfer_3cy_01_10_28_20_sdp3	-2.77	-2.09	-1.82	-1.66	-1.56	-1.49	-1.43
neulinger_3cy_01_12_15_20	-2.44	-1.85	-1.61	-1.48	-1.39	-1.32	-1.27
diminico_3cy_01a_1_5_21_26awg	-2.09	-1.60	-1.40	-1.29	-1.21	-1.16	-1.11
diminico_3cy_01a_1_5_21_28awg	-2.45	-1.90	-1.67	-1.54	-1.46	-1.39	-1.34
kadry_3cy_02_0820	-30.64	-19.91	-16.06	-14.00	-12.69	-11.77	-11.08

Reach for Different Cables and PAM Sizes

- The reach for each cable model can be found by dividing the Cable SNR Loss Budget by the SNR Loss per Meter
- Comparison of different PAM sizes shows that PAM-4 gives the best reach for almost all the cable models



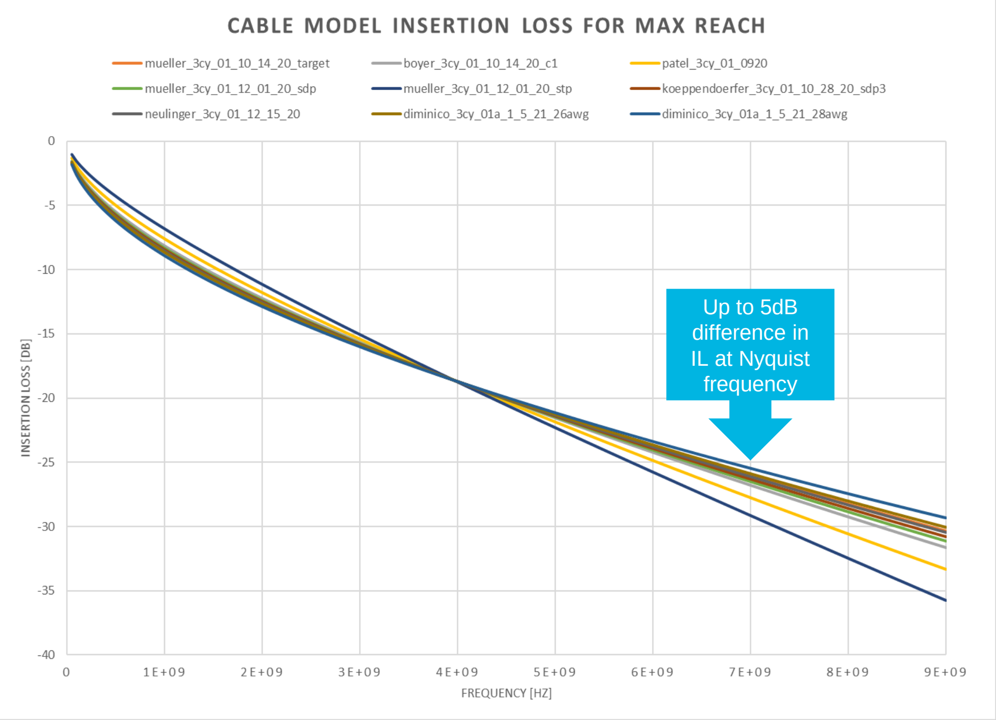
	PAM2	PAM3	PAM4	PAM5	PAM6	PAM7	PAM8
eq149-18	6.1	7.4	7.7	7.6	7.4	7.3	7.1
mueller_3cy_01_10_14_20_target	6.7	8.2	8.5	8.5	8.3	8.1	7.9
boyer_3cy_01_10_14_20_c1	7.3	9.2	9.7	9.7	9.5	9.4	9.1
patel_3cy_01_0920	6.1	7.9	8.4	8.5	8.4	8.3	8.1
zimmerman_3cy_01a_1120	7.6	9.0	9.3	9.2	8.9	8.8	8.5
mueller_3cy_01_12_01_20_sdp	8.5	10.4	11.0	10.9	10.7	10.6	10.3
mueller_3cy_01_12_01_20_stp	5.3	7.1	7.7	7.9	7.9	7.9	7.7
koeppendoerfer_3cy_01_10_28_20_sdp3	7.1	8.7	9.1	9.1	8.9	8.8	8.5
neulinger_3cy_01_12_15_20	8.1	9.8	10.3	10.2	10.0	9.8	9.5
diminico_3cy_01a_1_5_21_26awg	9.4	11.4	11.8	11.7	11.4	11.3	10.9
diminico_3cy_01a_1_5_21_28awg	8.0	9.6	9.9	9.8	9.5	9.3	9.1



Insertion Loss at Maximum Reach

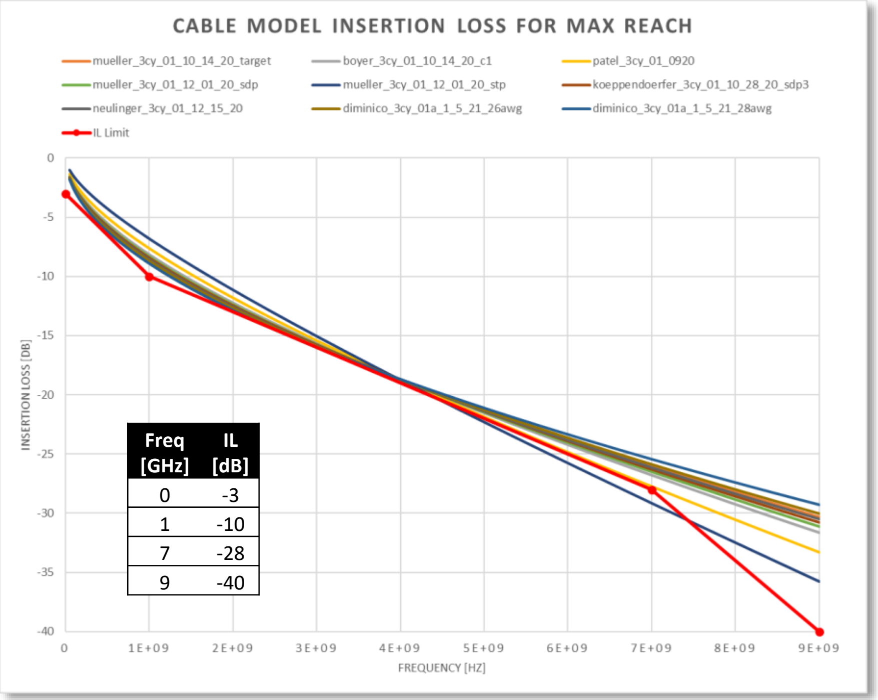
- For the cable models used in jonsson_3cy_01_01_12_21, the maximum insertion loss for the different cables is very similar
- Plot to the right shows the maximum insertion loss for PAM4

	PAM2	PAM3	PAM4	PAM5	PAM6	PAM7	PAM8
eq149-18	6.1	7.4	7.7	7.6	7.4	7.3	7.1
mueller_3cy_01_10_14_20_target	6.7	8.2	8.5	8.5	8.3	8.1	7.9
boyer_3cy_01_10_14_20_c1	7.3	9.2	9.7	9.7	9.5	9.4	9.1
patel_3cy_01_0920	6.1	7.9	8.4	8.5	8.4	8.3	8.1
zimmerman_3cy_01a_1120	7.6	9.0	9.3	9.2	8.9	8.8	8.5
mueller_3cy_01_12_01_20_sdp	8.5	10.4	11.0	10.9	10.7	10.6	10.3
mueller_3cy_01_12_01_20_stp	5.3	7.1	7.7	7.9	7.9	7.9	7.7
koeppendoerfer_3cy_01_10_28_20_sdp3	7.1	8.7	9.1	9.1	8.9	8.8	8.5
neulinger_3cy_01_12_15_20	8.1	9.8	10.3	10.2	10.0	9.8	9.5
diminico_3cy_01a_1_5_21_26awg	9.4	11.4	11.8	11.7	11.4	11.3	10.9
diminico_3cy_01a_1_5_21_28awg	8.0	9.6	9.9	9.8	9.5	9.3	9.1



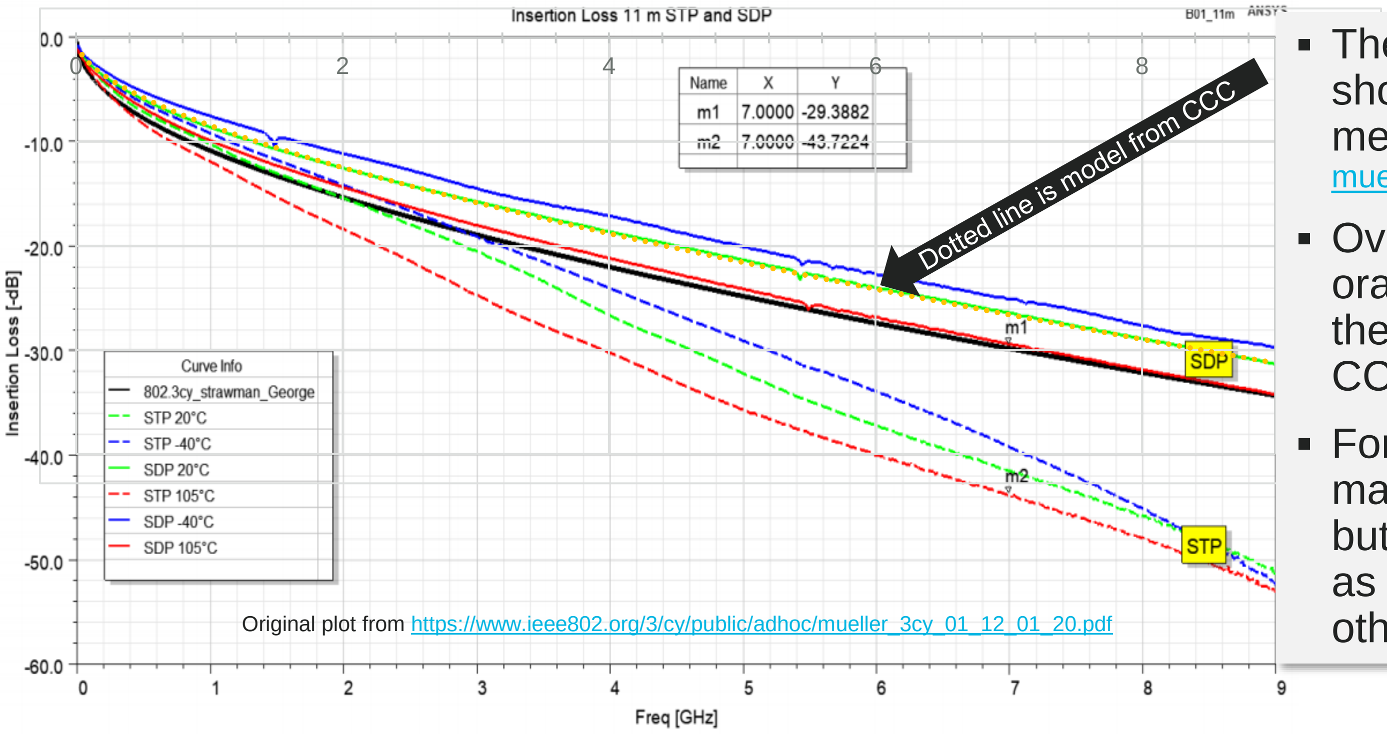
Piecewise-Linear Limit Line

- Piecewise-linear limit line for the Insertion Loss simplifies the fitting to different cable Insertion Loss characteristics
- Makes it easy to relax out-of-band cable requirements
- Eliminates the misconception that the limit line is an actual Insertion Loss model
- For most cable models in CCC, the cable length derived from the limit line in the plot is within 100 cm of the maximum reach



Freq [GHz]	IL [dB]
0	-3
1	-10
7	-28
9	-40

Accuracy of the CCC Channel Models



Original plot from https://www.ieee802.org/3/cy/public/adhoc/mueller_3cy_01_12_01_20.pdf

- The figure to the left shows plotted measurements from mueller_3cy_01_12_01_20
- Overlaid as an orange dotted line is the corresponding CCC model for 20ºC
- For this cable, the match is very good, but the match is not as good for some other cables

Summary

- We calculated the achievable reach for different cable models and different PAM sizes at temperature of 20ºC
- PAM4 has the best reach for almost all the cables and some cables can reach 11m
- The Insertion Loss for the different channels at maximum reach is similar, but do not have the exact same shape
- At maximum reach, the Insertion Loss at Nyquist frequency can vary by 5dB
- Piecewise-linear limit line for the Insertion Loss appears to be a good way to limit the channel Insertion Loss

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