PHY Complexity
Insertion Loss and Modulation

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TRANSFORMING HOW CARS OF THE FUTURE ARE BUILT

Overview

- Some measurements for insertion loss suggest more than 37 dB of loss at 7 GHz and *suck-outs* within the band
    - DiBiaso_Bergner_Cuesta_3cy_adhoc_01_091620
    - Patel_3cy_01a_0920
    - Boyer_3cy_01_10_14_20
    - Mueller_3cy_01c_10_21_20
    - Koeppendoerfer_3cy_01_10_28_20
- The analysis in sedarat_3cy_01_10_14_20 indicates that a highly complex PHY is needed to support this level of insertion loss
- This presentation extend the analysis to a few options for modulation and bandwidth

Agenda

- Focusing on basic constellations: PAM3, PAM4 and PAM5
  - Comparing to denser constellations, these modulations may offer simpler PHY
- Baud rate and bandwidth for various modulation schemes
- Noise floor for different modulation and bandwidths
- Insertion loss for various cable lengths and modulation
- Required SNR, tolerated noise floor and available noise margin
- Tolerated EMI
- Summary

Modulation and Baud Rate

- Higher order of modulation results in lower baud rate and bandwidth
- A lower baud rate offers numerous benefits
  - Lower power/complexity of the PHY:
    - Analog sampling rate, linearity, power, parasitics, etc.
    - Digital timing closure, power, etc.
    - PLL jitter, power, clock distribution, etc.
  - Easier limits on cable and connectors:
    - Insertion loss and suck-outs
    - Return loss
    - Coupling/shielding attenuation
  - Easier spec for board and discrete components:
    - Common-mode choke
    - ESD protection
    - AC coupling, power supply and PoDL
    - MDI return loss
    - CMRR

Data Rate (Gbps)	PAM	Baud Rate (GHz) *	Nyquist (GHz) *
25	3	17.7	8.9
	4	14.1	7.0
	5	12.1	6.1
10	4	5.6	2.8

* Assuming redundancy and other overheads similar to 802.3ch

Noise Floor: Alien Crosstalk + Thermal

- Consider the following noise sources:
  - Alien crosstalk (external noise source)
  - Thermal noise

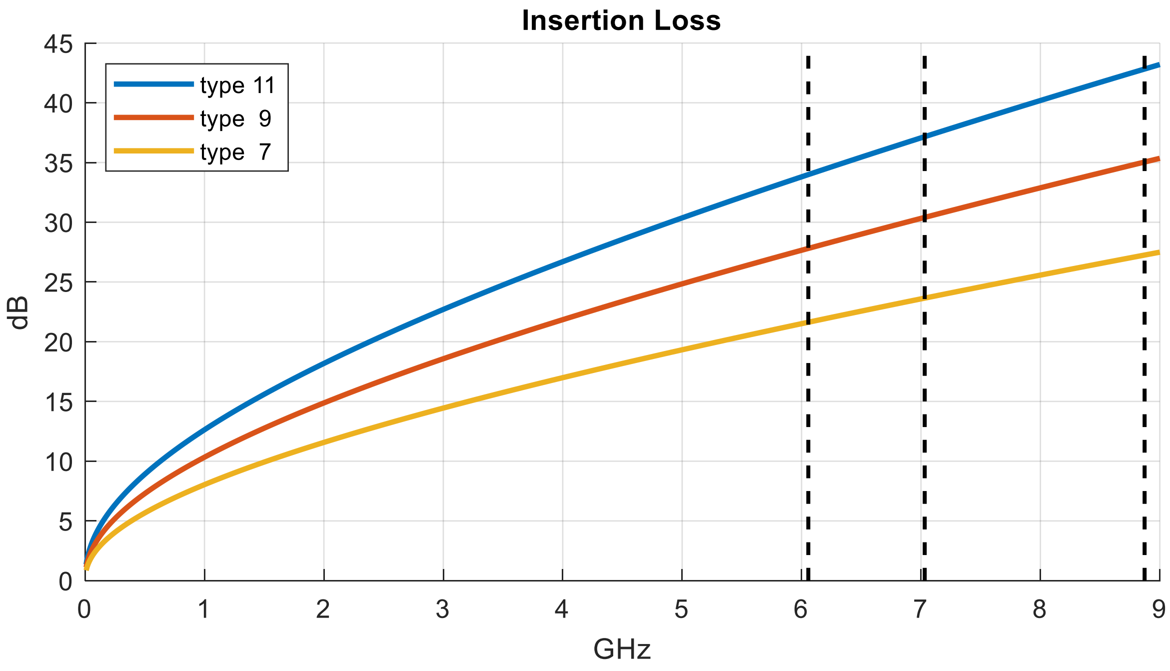
- Assuming:
  - 0.5 v peak transmit signal
  - Similar coupling and shielding attenuation for all cases
  - -160 dBm/Hz of overall thermal noise

Data Rate (Gbps)	PAM	Baud Rate (GHz)	Tx Power (dBm)	Noise Floor (dBm/Hz)
25	3	17.7	+1.1	**-155**
	4	14.1	+0.3	**-155**
	5	12.1	-0.1	**-154**
10	4	5.6	+0.3	-151

- Noise floor is not reduced proportionally for lower levels of modulation resulting in higher-than-expected noise power

Baud Rate and Insertion Loss

- Three types of cable with different limits for insertion loss are considered
- Cable types are identified by the length of 802.3ch-type cable
  - simple linear length-scaling of 802.3ch limit line for insertion loss



Insertion Loss (dB) at Nyquist Frequency for Various Bandwidths and Cable Lengths					
Bit Rate (Gbps)	PAM	Bandwidth (GHz)	Cable type		
			11	9	7
25	3	8.9	**42.8**	**35.0**	**27.3**
	4	7.0	**37.2**	**30.4**	**23.7**
	5	6.1	**34.0**	**27.8**	**21.6**
10	4	2.8	29.9		

Minimum Tolerated Input SNR

- Required SNR at slicer for BER=10^{-12}:
  - PAM3 = 21.3 dB
  - PAM4 = 24.0 dB
  - PAM5 = 26.1 dB
- Tolerated input noise level depends on modulation and insertion loss
- The required input SNR determines the dynamic range of the analog blocks and the resolution of the digital blocks in the PHY
  - The higher the SNR the more complex the PHY

➔ Cable type 11 demands a very high level of input SNR

Bit Rate (Gbps)	Cable Type	PAM	Baud Rate (GHz)	IL Nyquist (dB)	Required SNR (dB)
25	11	3	17.7	42.8	**33**
		4	14.1	37.2	**34**
		5	12.1	34.0	**35**
	9	3	17.7	35.0	**31**
		4	14.1	30.4	**31**
		5	12.1	27.8	**32**
	7	3	17.7	27.3	**27**
		4	14.1	23.7	**29**
		5	12.1	21.6	**30**
10	15	4	5.6	29.9	31

Maximum Tolerated Input Noise

- The maximum tolerated noise floor is calculated from signal power and the required input SNR
- Tolerated noise floor affects the complexity and the power consumption of the analog front-end
  - The lower the noise floor the more complex the PHY
- The margin to noise floor determines the budget for PHY self noise
  - The lower the margin the more complex the PHY

➔ Cable type 11 tolerates very low noise floor and offers a very low noise margin

Bit Rate (Gbps)	Cable Type	PAM	Baud Rate (GHz)	Tolerated Noise (dBm/Hz)	Noise Margin (dB) *
25	11	3	17.7	**-147**	**8**
		4	14.1	**-146**	**9**
		5	12.1	**-146**	**8**
	9	3	17.7	**-142**	**13**
		4	14.1	**-142**	**13**
		5	12.1	**-142**	**12**
	7	3	17.7	**-137**	**18**
		4	14.1	**-137**	**17**
		5	12.1	**-138**	**16**
10	15	4	5.6	-138	13

* margin to noise floor

RF Immunity

- Some portion of noise margin (3 dB in this analysis) may be allocated to achieve some level of RFI immunity
- Shielding/coupling attenuation is typically lower at high frequencies
  - Need higher immunity for lower PAM
- The tolerated level of RF interference is typically reduced with
  - higher order of modulation
  - lower tolerated noise power

➔ Cable type 11 tolerates very low EMI level

Bit Rate (Gbps)	Cable Type	PAM	Tolerated EMI (mv)
25	11	3	**3.2**
		4	**3.1**
		5	**2.9**
	9	3	**5.6**
		4	**5.1**
		5	**4.6**
	7	3	**9.8**
		4	**8.3**
		5	**7.2**
10	15	4	5.0

Summary and Conclusions

- It is hard to support cable type 11 with any modulation scheme
- PAM3 requires a higher baud rate and does not offer any significant benefit
- PAM4 and PAM5 both offer good solutions for cable type 7
- PAM5 may offer a good solution for cables that exhibit suck-outs at around 7 GHz

Bit Rate (Gbps)	Cable Type	PAM	Baud Rate (GHz)	Required SNR (dB)	Tolerated Noise (dBm/Hz)	Noise Margin (dB)	Tolerated EMI (mv)
25	11	3	17.7	33	-147	8	3.2
		4	14.1	34	-146	9	3.1
		5	12.1	35	-146	8	2.9
	9	3	17.7	31	-142	13	5.6
		4	14.1	31	-142	13	5.1
		5	12.1	32	-142	12	4.6
	7	3	17.7	27	-137	18	9.8
		4	14.1	29	-137	17	8.3
		5	12.1	30	-138	16	7.2
10	15	4	5.6	31	-138	13	5.0

THANK YOU

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