SerDes CM Noise: How Much is Too Much?

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Classifying Common Mode (CM)

How much Common Mode Noise is too much?

Classify CM may help

High level classes of common mode issues

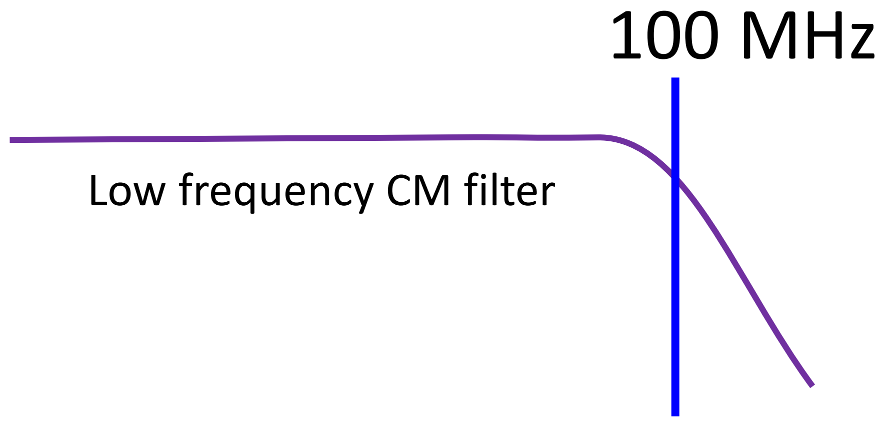
- Class 1: Common mode which changes the operation of serdes
- Class 2: Common mode which converts to differential mode noise and degrades SNR or BER
- Class 3: Common mode which radiates and create EMI problems
  - This is a separate topic and will not be included here

Organizing Sources of Common Mode (CM)

- Correlated to data pattern and/or transmit power
  - Mostly Class 2
  - Primary sources
    - Skew or imbalance
    - Crosstalk is correlated
- Uncorrelated CM is not correlated to the data pattern or transmit power
  - Mostly Class 1 but can affect BER
  - Primary sources: Power supply and power distribution
  - Other Asynchronous CM source examples usual have less power
    - Out of band buses
    - Transmitter CM random noise
    - EMI induction
- Mode conversion (mostly class 2)
  - Precise specifications of CM sources lead to a closed specification for mode conversion
  - In other words, tie all the specifications together

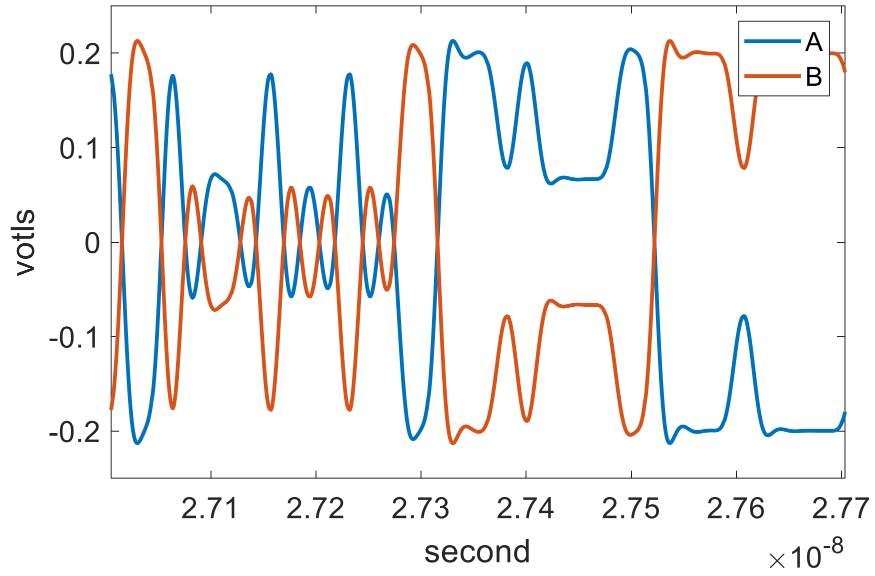
What New?

- Class 1 and Class 2 seem to apply to different frequency ranges
- IEEE802.3ck introduced a frequency classification for common mode
  - Low frequency CM is to capture Class 1 (**VCM_{LF}**)
  - Full band CM is to capture Class 2 (**VCM_{FB}**)
  - CM is measured as voltage derived from a cumulative distribution function (CDF)
  - AC CM RMS is no longer used
- Class 2 is linked to transmit power
  - IEEE802.3ck defines a new common mode specification: "Signal to AC common-mode noise ratio, *SCMR* (min)"
  - 20 log10 (v_{peak}/VCM_{FB})
  - v_{peak} is the peak of the pulse response fitted to a PRBS response
  - This is used for devices i.e. chips
  - VCM_{FB} is use for Hosts and Modules
- Explanation follows



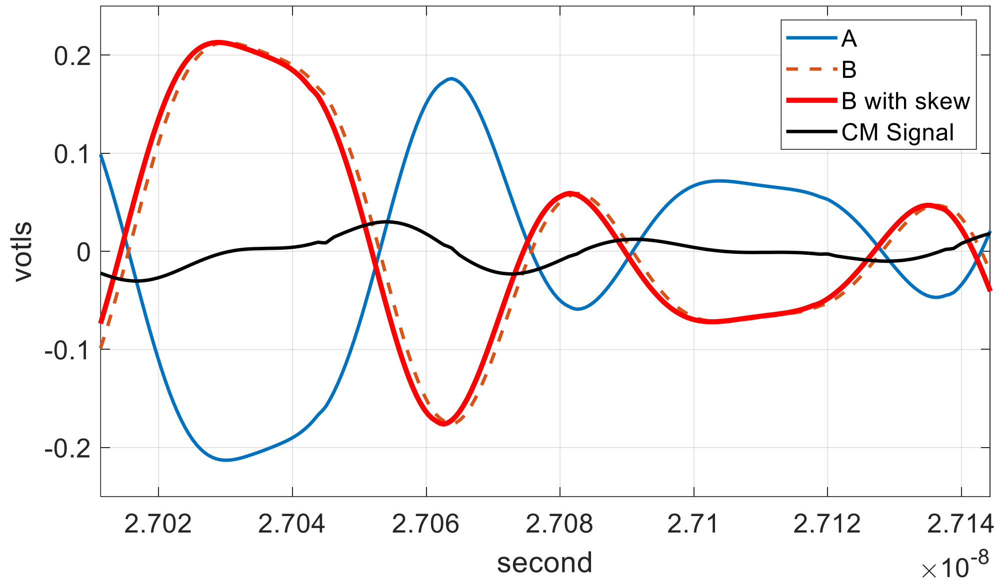
CM Basics for Class 2

- Given 2 signal waveforms, A and B
- The differential signal = A – B
- The common mode signal = A + B
- For differential signaling
- A and B are complimentary
- If A == -B
  - Common mode signal is 0
- Basically, imbalance causes common mode



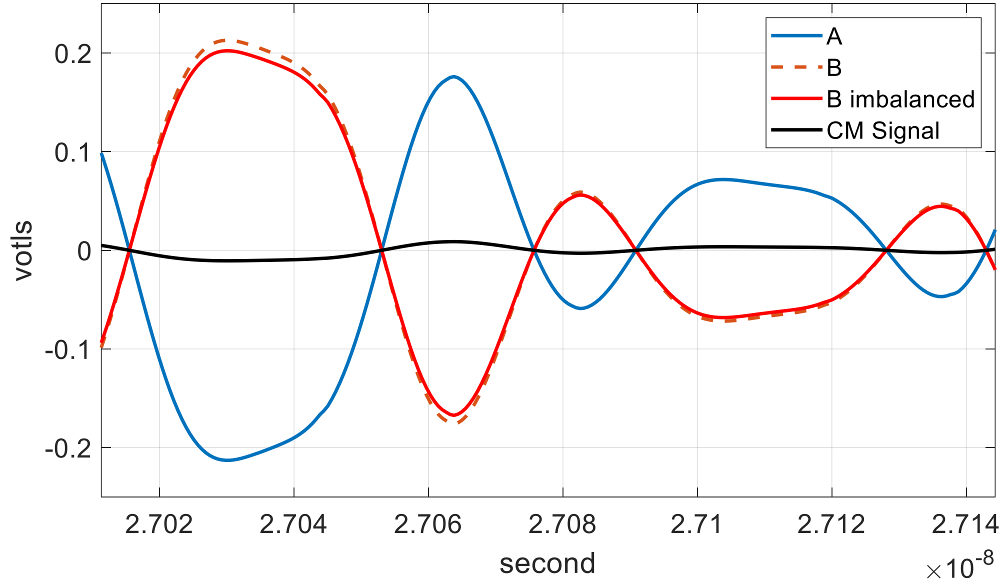
Coherent Sources of Common Mode (CM)

- Skew



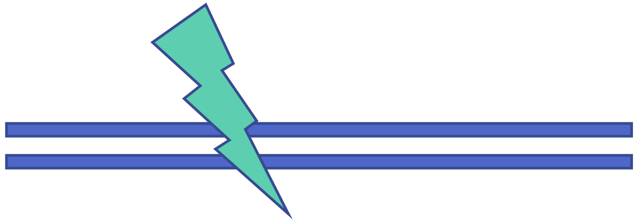
106.6 Gb/s PAM4 signaling

- Signal Imbalance

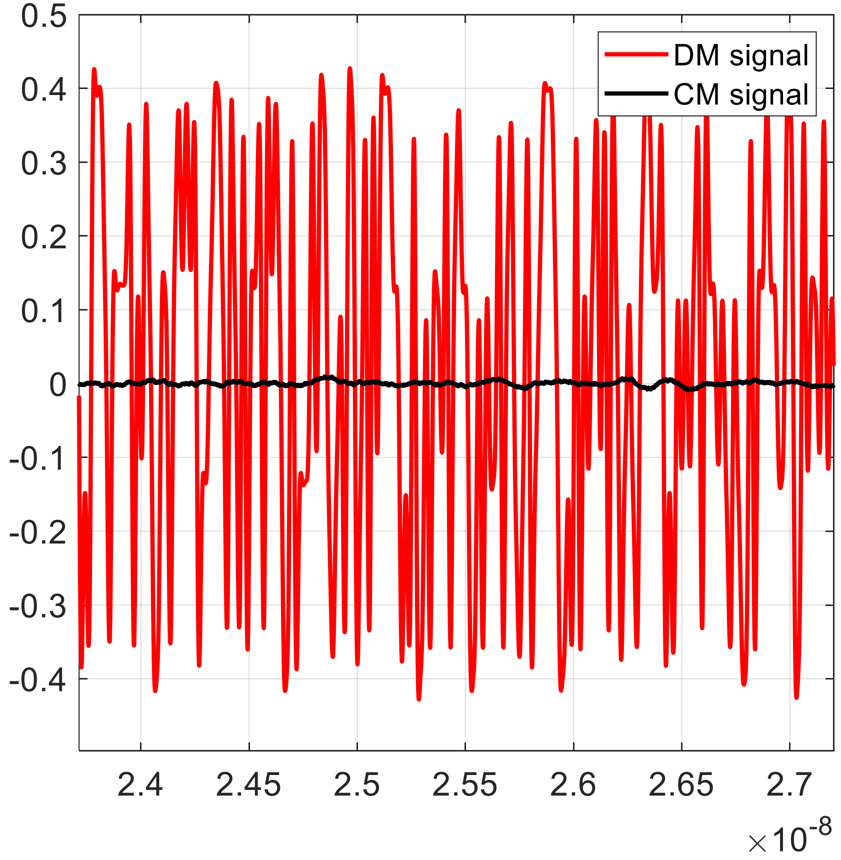


Asynchronous Sources of Common Mode (CM)

External Noise



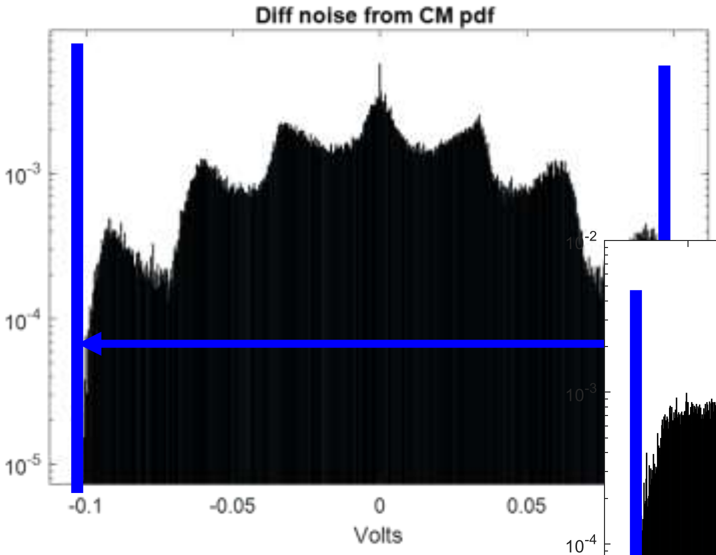
106.6 Gb/s PAM4 signaling



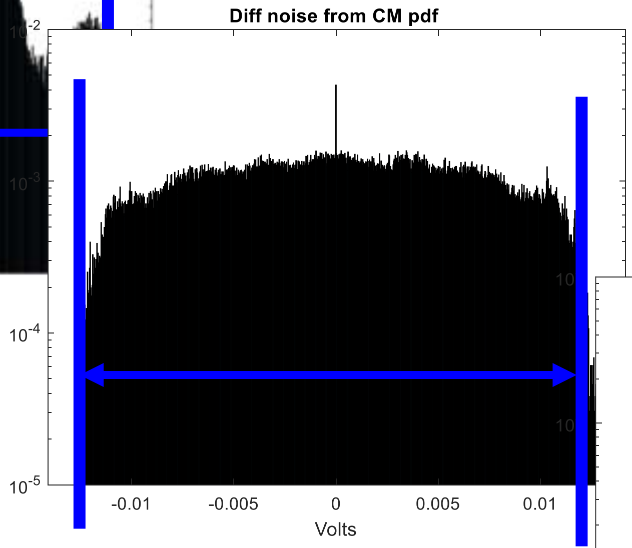
Common Mode Noise has a Variety of Noise Histograms

Peak to peak (p-p) seems more relevant than RMS

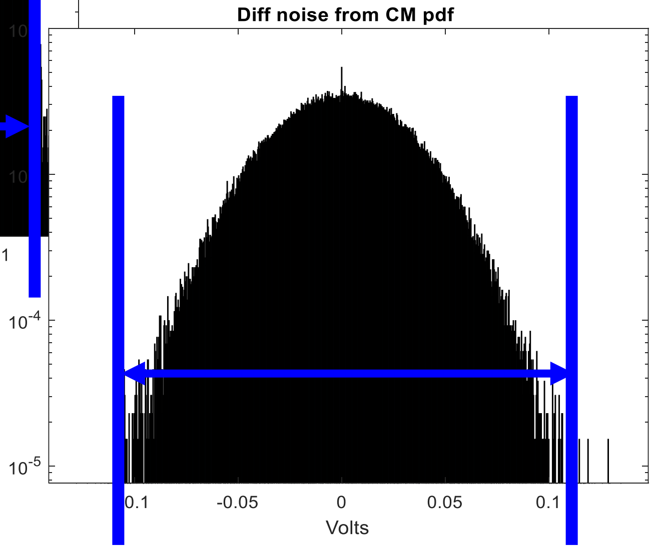
5 ps Skew



10 % imbalance

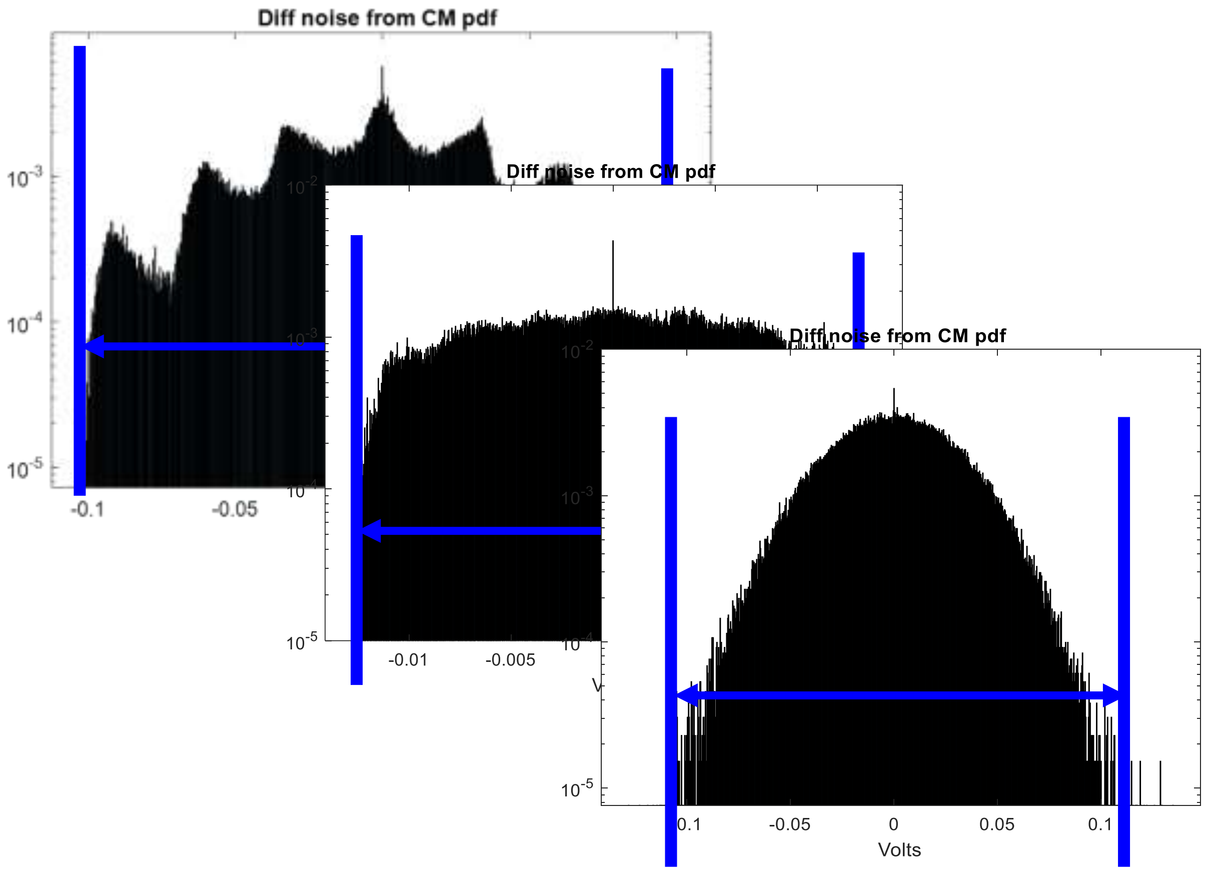


CM AWGN

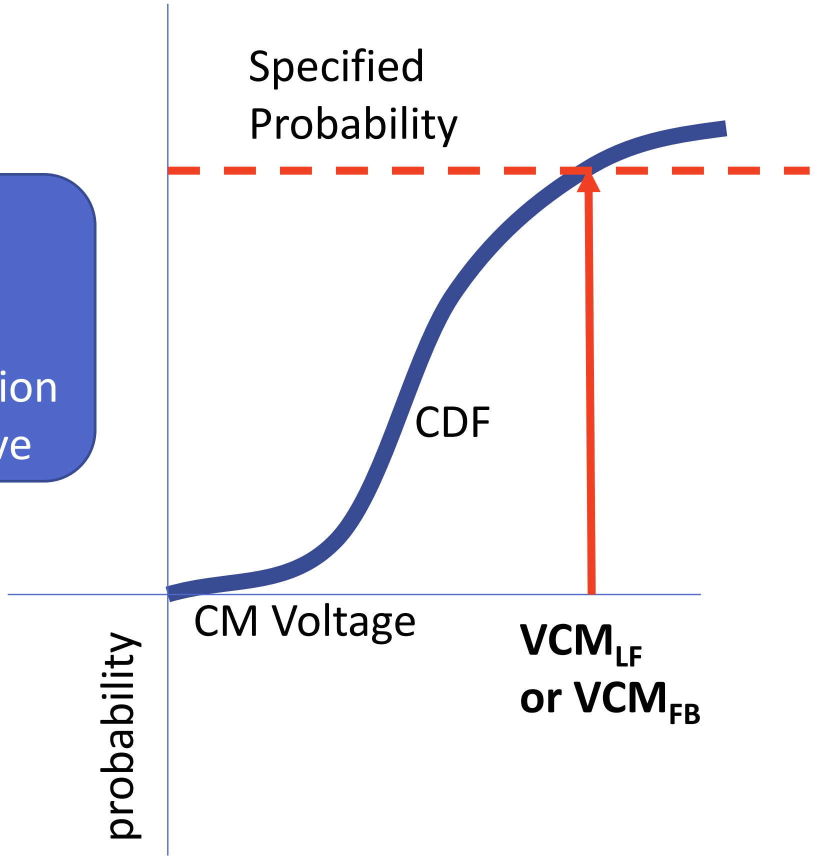


- Extremes of CM possibilities
- Illustration of CM histograms

Common Mode Noise Specification is Derived From a CM CDF (Not RMS)

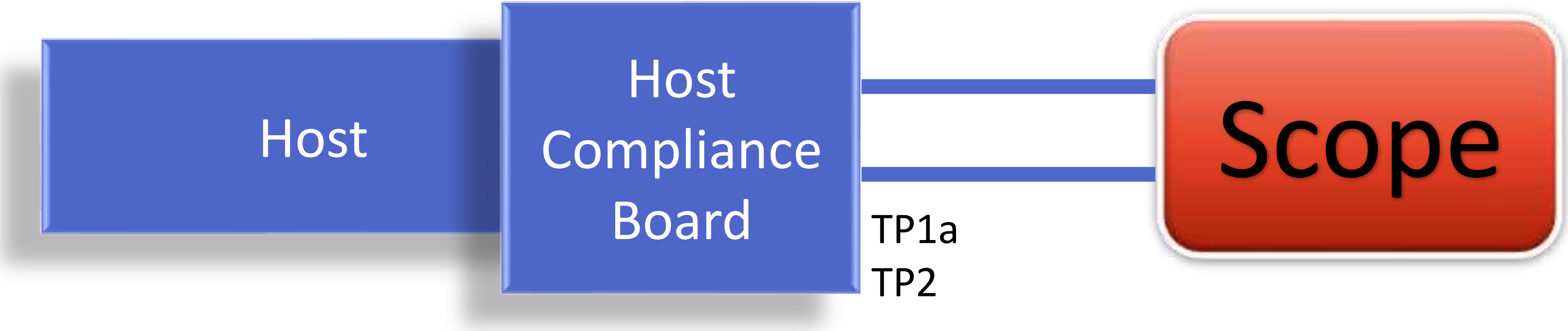


Convert CM measurement histogram to a cumulative distribution function (CDF) curve



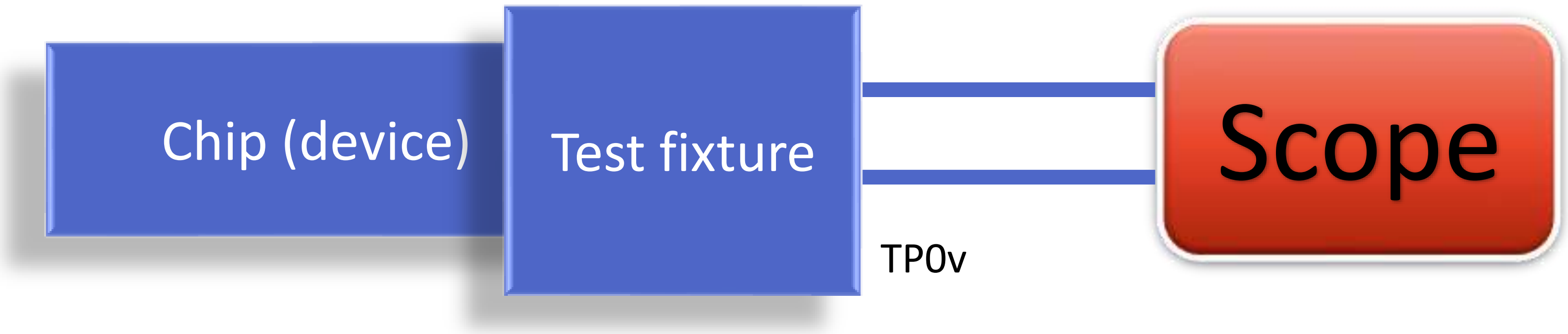
New CM Host Spec Parameters for DAC (CR) and Optics Modules (C2M)

Parameter	Reference	Value	Units	Test Point
Common-mode peak-to-peak voltage (max) Low-frequency, VCM_{LF} Full-band, VCM_{FB}	162.9.4.4	30 80	mV mV	TP1a
Common-mode peak-to-peak voltage (max) Low-frequency, VCM_{LF} Full-band, VCM_{FB}	120G.5.1	32 80	mV mV	TP2



New CM Spec Parameters for Backplane and Chip to Chip (AUI) Devices

Parameter	Reference	Value	Units	Test Point
Low-frequency peak-to-peak AC common-mode voltage, VCM_{LF} (max)	162.9.4.4	30	mV	TP0v
Signal to AC common-mode noise ratio, *SCMR* (min)	163.9.2.6	15	dB	TP0v
Low-frequency peak-to-peak AC common-mode voltage, VCM_{LF} (max)	120F.3.1.1	32	mV	TP0v
Signal to AC common-mode noise ratio, *SCMR* (min)	120F.3.1.4	15	dB	TP0v



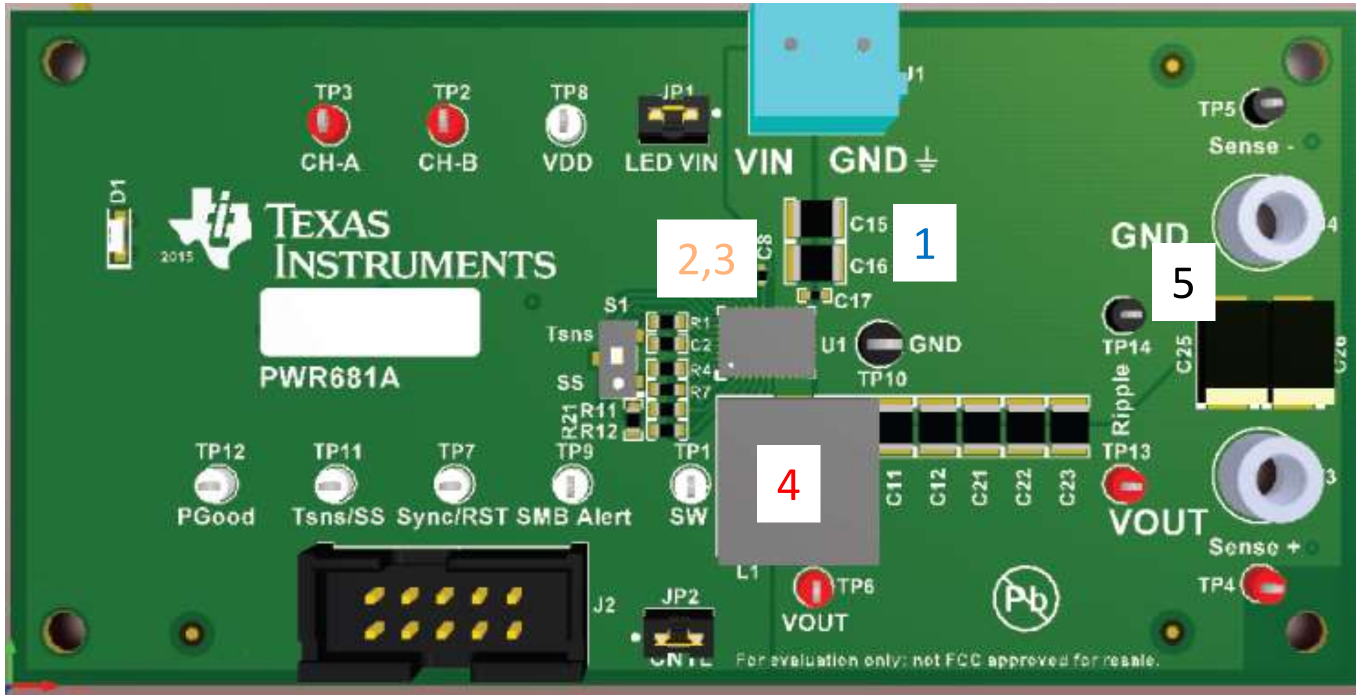
Host Board Mitigation Options

- Skew and channel imbalance effects higher frequency CM
  - Although it may show up as a VEC or SNDR performance degradation
- Lower frequency mitigations discussed by Istvan Novak

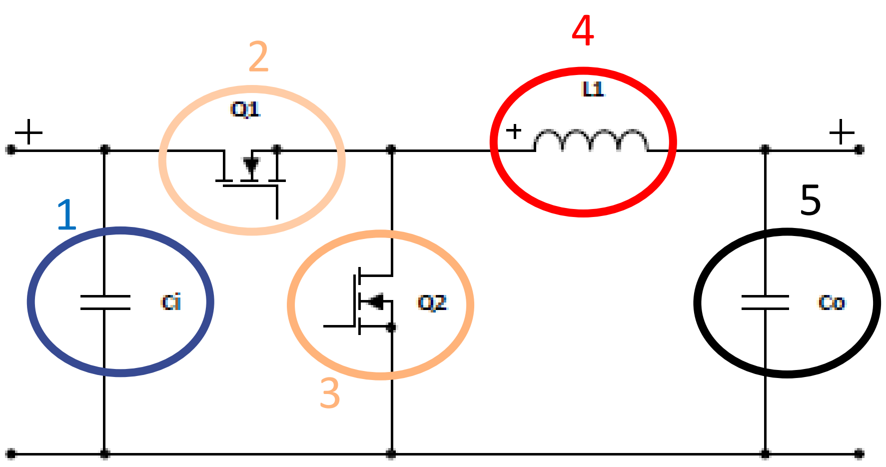
Typical Noise Sources

Magnetic noise from high-current power devices

- DC-DC converter power devices
- Motors (fans)



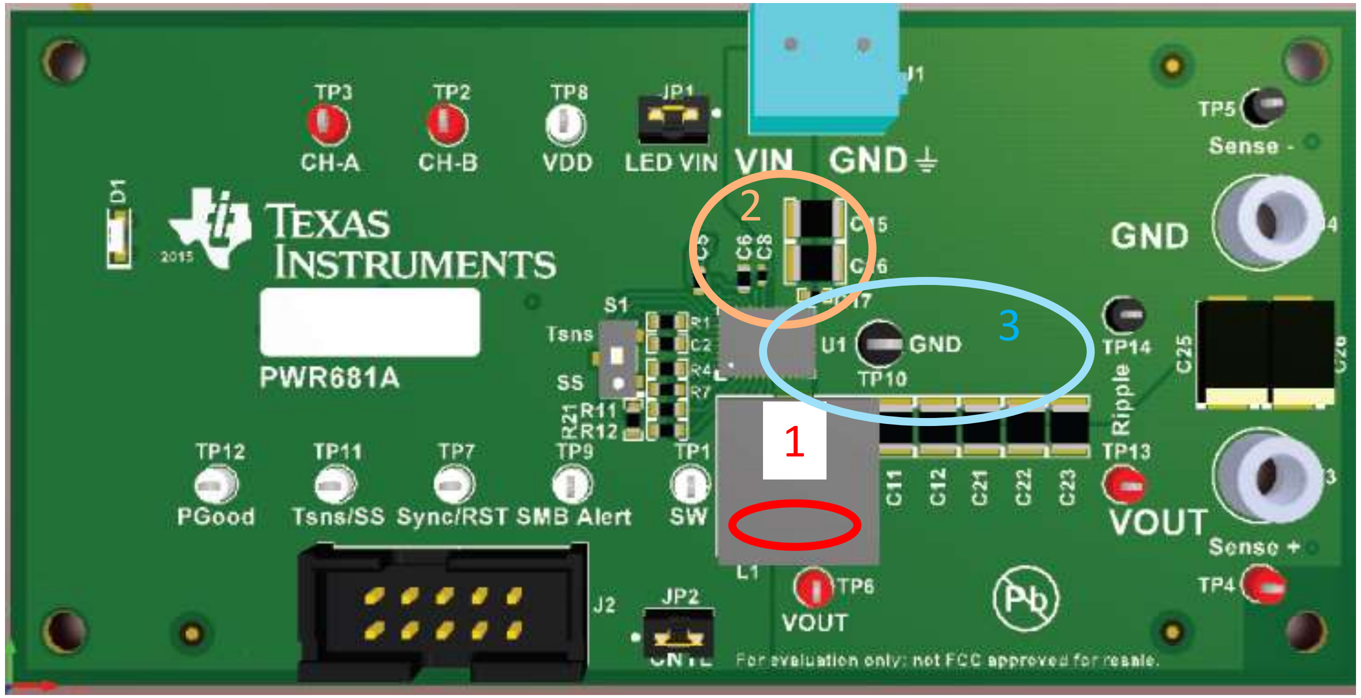
Example circuit: synchronous buck converter

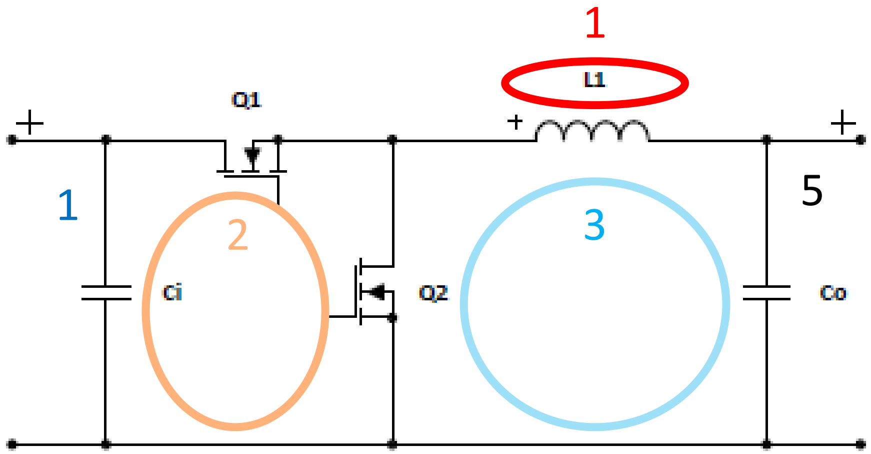


Aggressor Current Loops

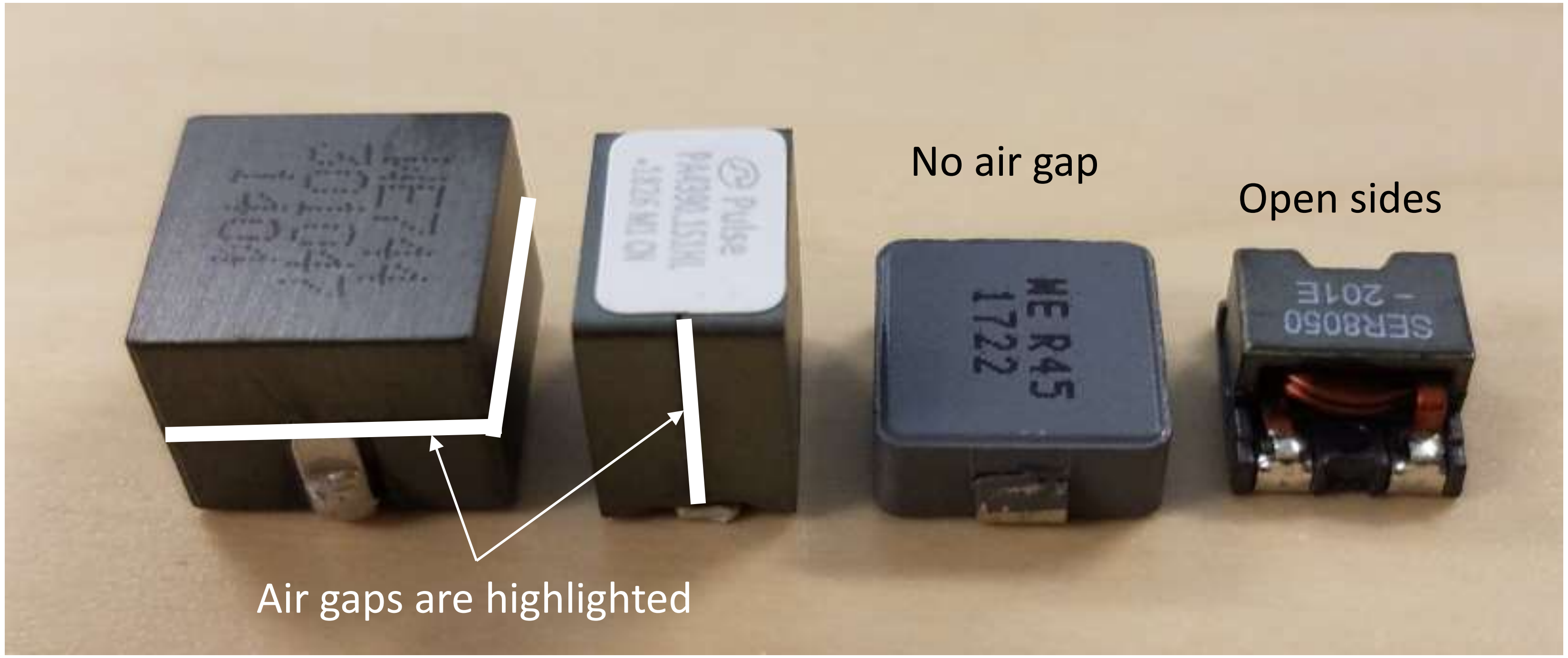
The major aggressor current loops in a buck converter

- 1: Within the inductor
- 2: Input side of switch
- 3: Output side of switch





DC-DC Converter Inductors

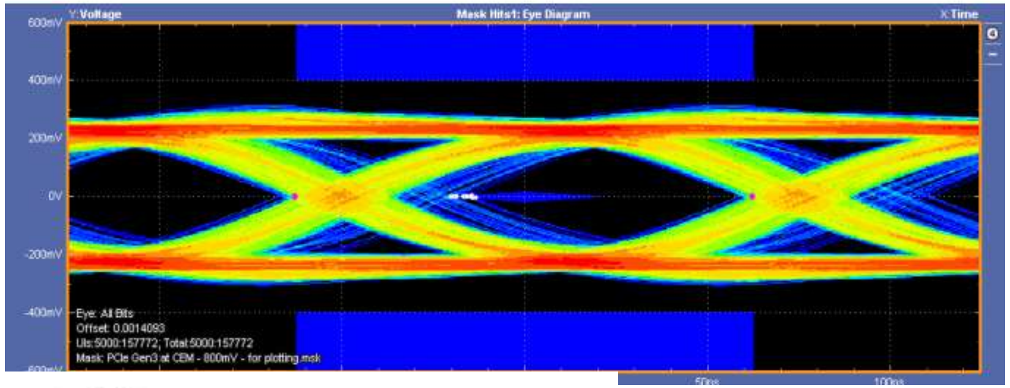


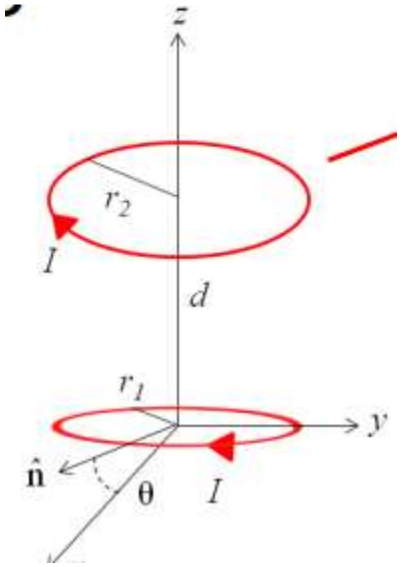
Flux in inductors with cores is the highest near the air gap

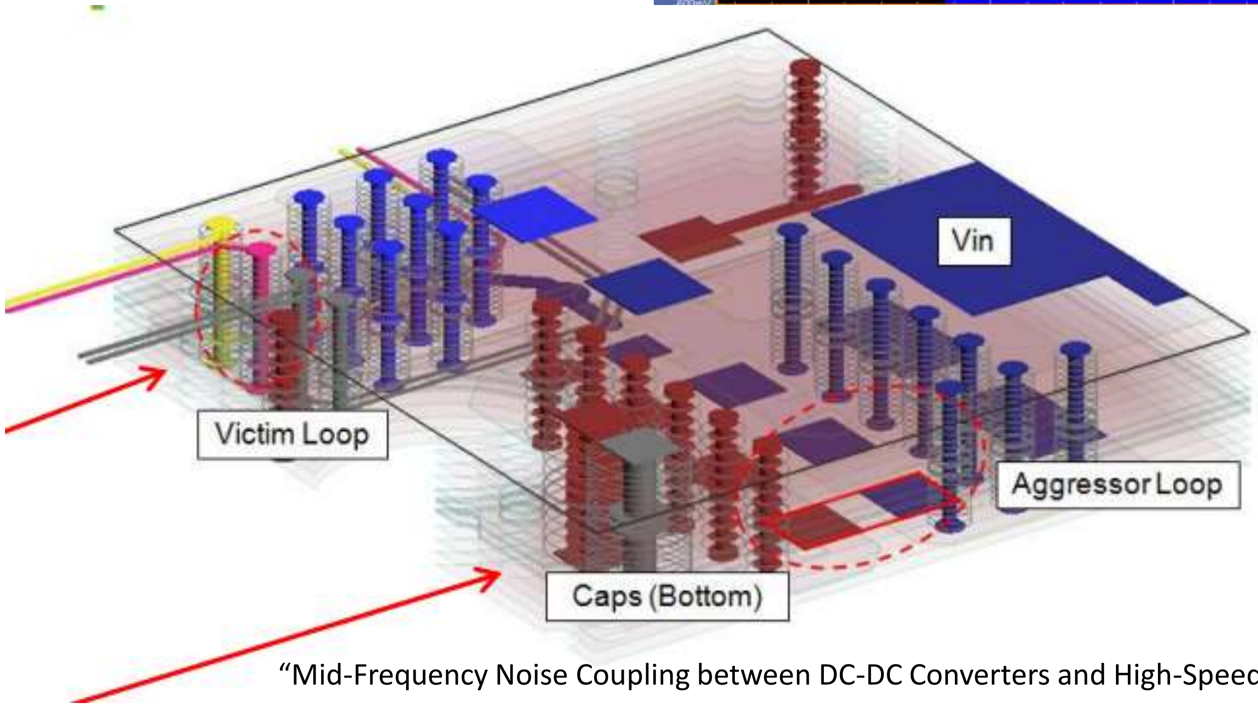
Where PDN Noise Gets into the SerDes Path

Magnetic noise couples through loops

- Trace to reference plane loop
- Via loops
- Cable shield to center-wire loop



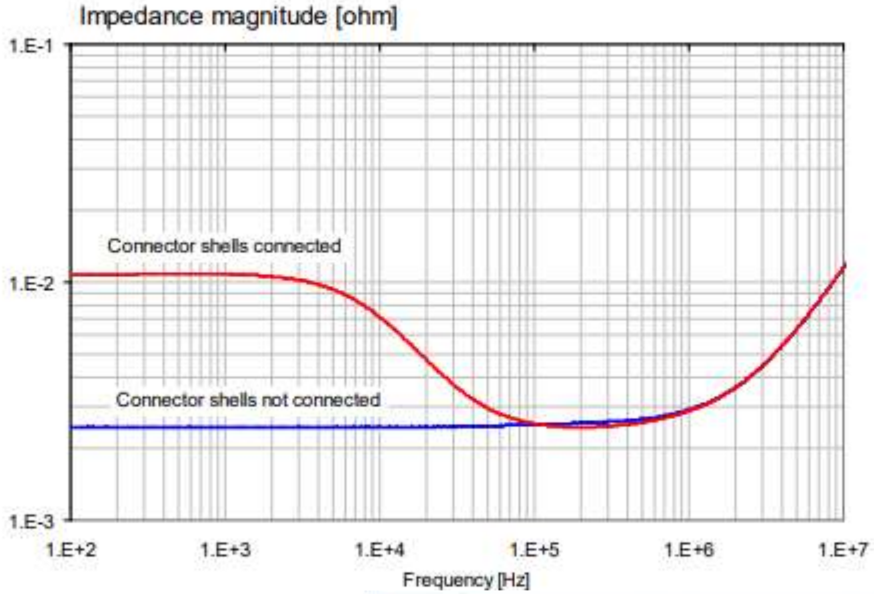




“Mid-Frequency Noise Coupling between DC-DC Converters and High-Speed Signals,” DesignCon 2016

The Real Size of Loops

- At low frequencies shield metals gradually become transparent to magnetic field
- ~10MHz for 1oz copper
  - Below ~10MHz the signal loop can expand, can pick up more noise
- ~2kHz for a typical braided coax cable
  - Below ~2kHz the coax shield becomes transparent, can pick up more noise
- External reference connection can create big ground loops, diminishing shielding



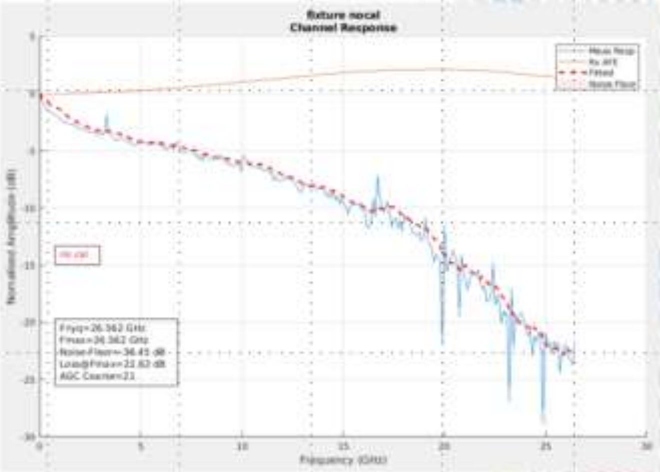
"How the Braid Impedance of Instrumentation Cables Impact PI and SI Measurements," DesignCon 2019

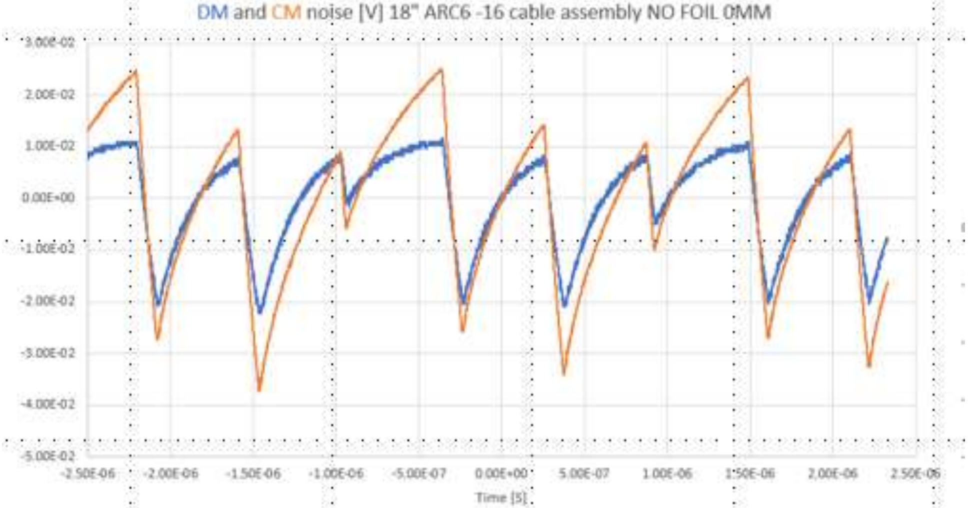
Impact on SerDes Signals

BER TEST#1
18" – VICTIM ISOLATED – LOW TX SWING

	ratio BER $_{noise}$ / BER $_{nominal}$		
Height (mm)	**No foil**	**Foil wrapped around cable**	**Foil flat on top of spacer**
0.0	345	1.34	2.20
0.5	22.9	1.20	1.19
1.0	6.68	1.16	1.17
1.5	2.72	1.10	1.07
2.0	2.37	0.98	1.02
2.5	1.80		
3.0	1.56		
3.5	1.37		
4.0	1.28		
4.5	1.36		
5.0	1.29		
5.5	1.34		
6.0	1.12		
6.5	1.09		
7.0	0.82		
7.5	0.99		
8.0	1.07		

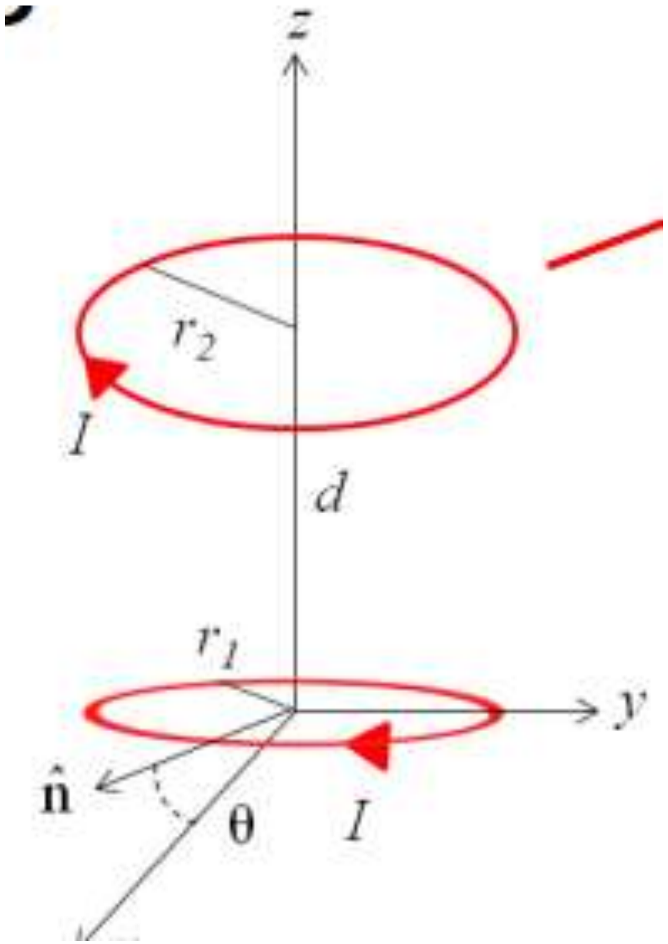
Nominal BER ~ 3e-8
IL ~ 23dB (using chip estimator)





	Max DM noise (mv)		
Height (mm)	**No foil**	**Foil wrapped around cable**	**Foil flat on top of spacer**
0.0	34.00	4.67	9.67
1.0	15.67	3.67	6.67
2.0	10.67	3.00	2.83
3.0	7.33		
4.0	6.00		
5.0	5.00		
6.0	4.17		

Mitigation Options



Increase the distance (increase d)

Make the loops smaller (reduce r1 and r2)

Adjust orientation (make loops orthogonal)

Apply shielding either on aggressor or on victim

Summary

New IEEE 802.3ck CM specifications

- Separate high and low frequency CM
- Common mode voltages become statistical bases not RMS based
- A device's (chip's) high frequency CM is linked to transmitter signal strength
  - Because high frequency common mode is expected to degrade with loss as the signal degrades with loss
- Switching regulator can be low-frequency noise source
- Mitigate by increased spacing, and/or reduced loop size, and/or shielding

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