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IEEE Channel Operating Margin (COM)
For Channel Analysis

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INTRODUCTION

Do electrical specifications sometimes conflict for the sake of guaranteed operation? **Yes!**

Does margin to one specification imply margin to any other? **Not Clear!**

Specifically, is margin to a return loss mask worse than margin to an insertion loss mask? **It Depends!**

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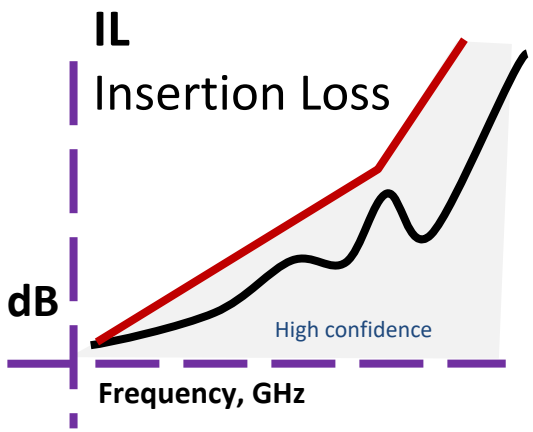
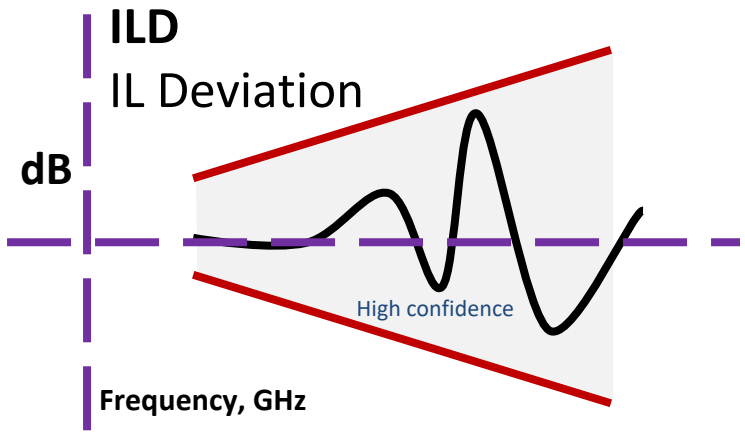
What We Will Cover

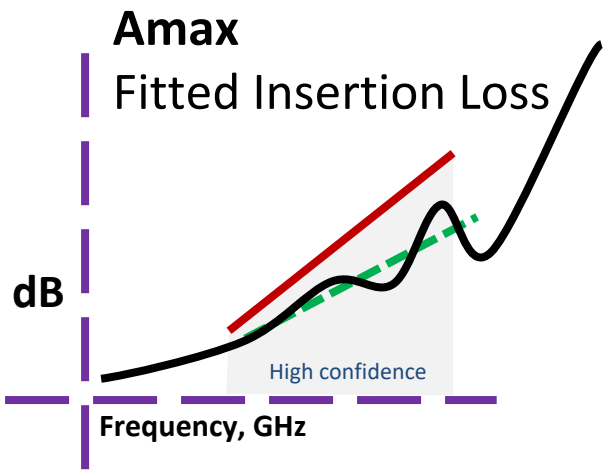
- The paradigm shift in IEEE channel budgeting above 25 Gbps
- What and Why of **C**hannel **O**perating **M**argin
- When to use **COM**
- Evolution of the IEEE package behavior model

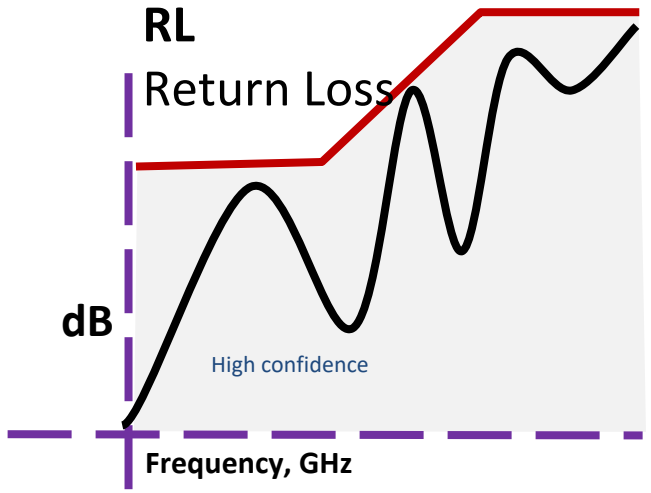
Frequency Domain Masks (≤ 10 Gbps)

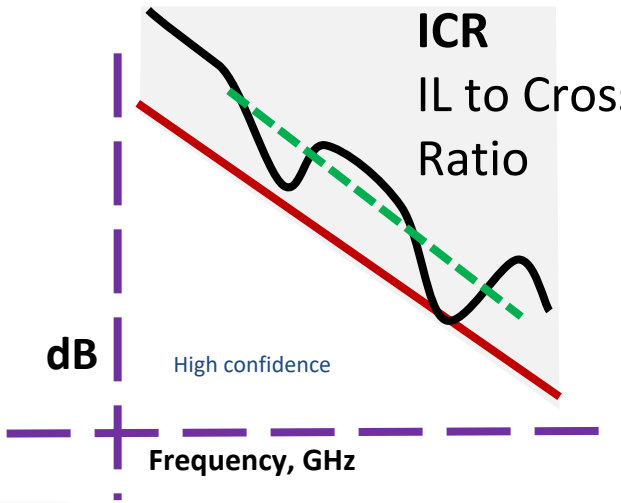




- Margin to masks
- Limited trade-off possibilities
- Are excursions failures

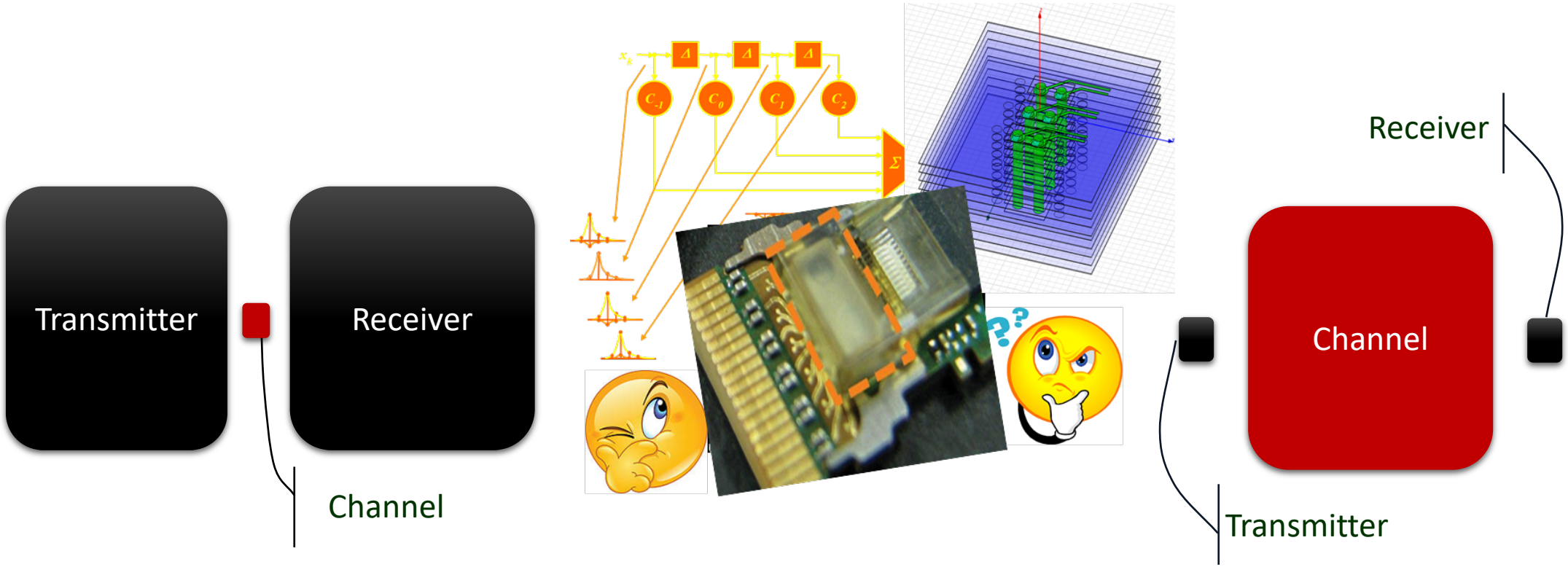






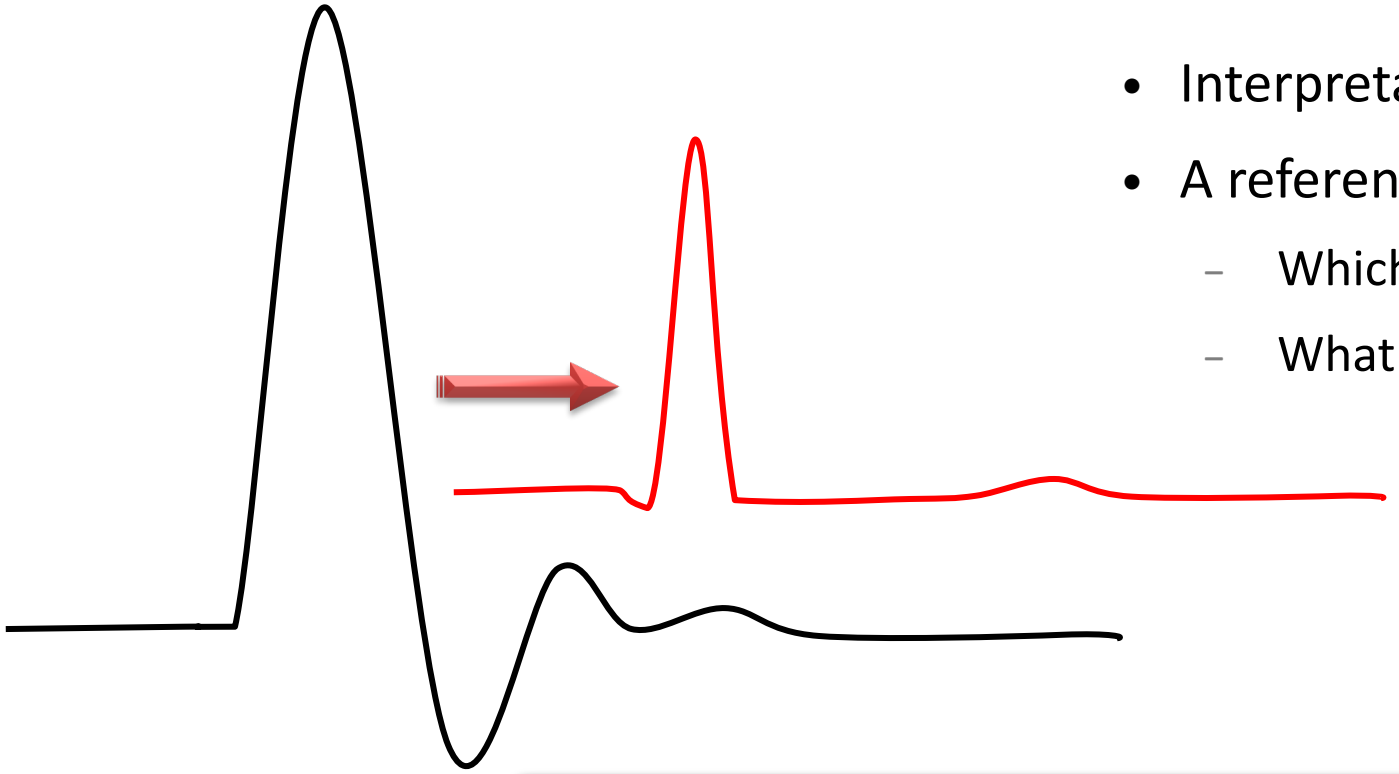
Budgeting Dilemmas

Channel Compliance for both Si and Interconnect



The Paradigm Shift (≥ 25 Gbps)

A single bit response (SBR) may be used to determine a realistic figure of merit



- Interpretation requires “context”
- A reference signaling architecture addresses:
  - Which parts of the signal matter?
  - What is expected filtering?

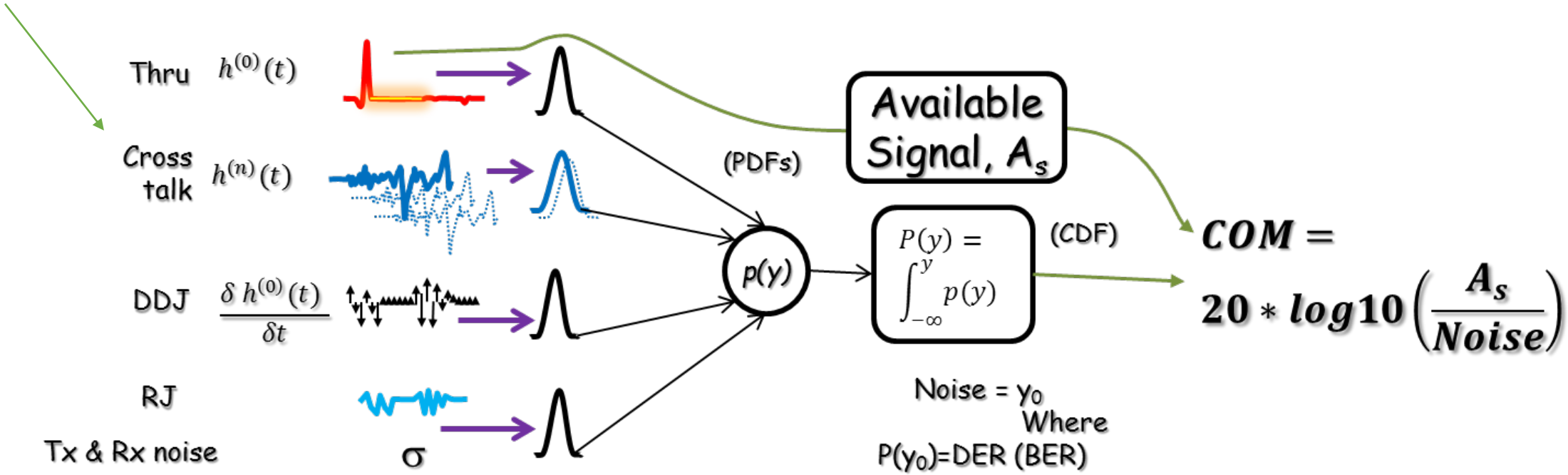
Buffers Operate in Time Not Frequency

COM (Channel Operating Margin)

- Is computed from the **time domain**
- Is a **single metric** good for a wide range of designs
- Is a **closed budget** for allocation of
  - Compensable and un-compensable ISI
  - Crosstalk
  - Loss
  - Tx and Rx specifications
- Utilizes an agreed upon minimum **reference signaling architecture**
- Produces interim results for separating and budgeting channel impairments (Bathtub Curves, ICN, etc.)

COM (Simplified)

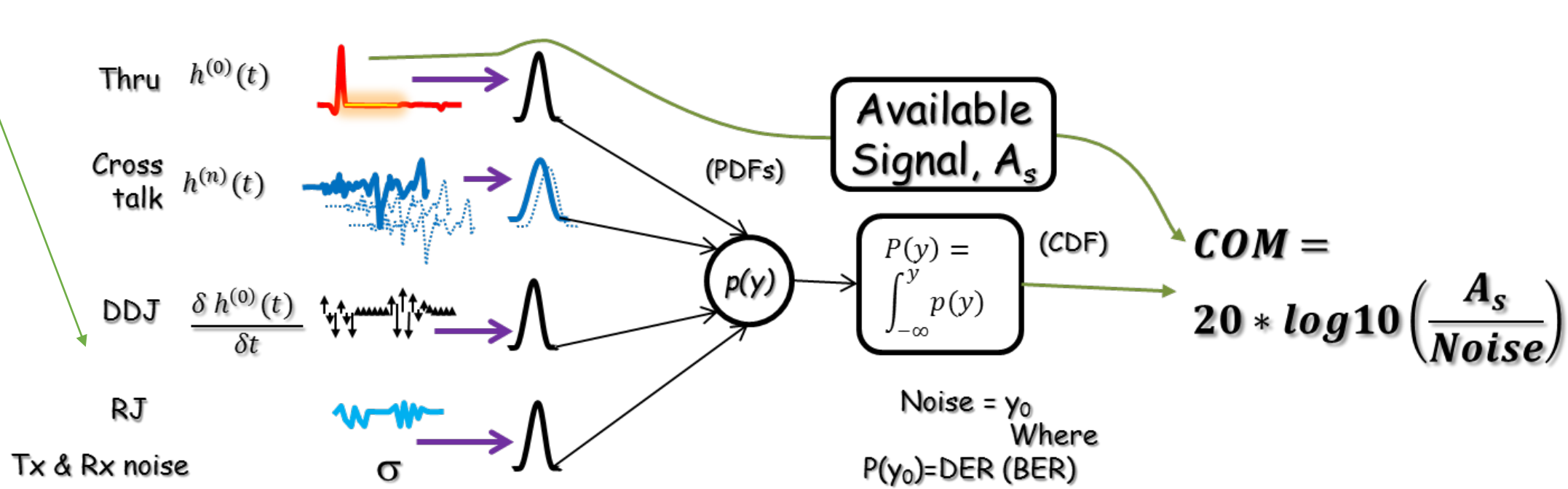
- Convert filtered s-parameters into SBRs $h^{(0)}(t)$, $h^{(n)}(t)$
- Convolution converts ISI and crosstalk into voltage PDFs



(http://www.ieee802.org/3/bj/public/jul12/mellitz_01_0712.pdf)

COM (Simplified)

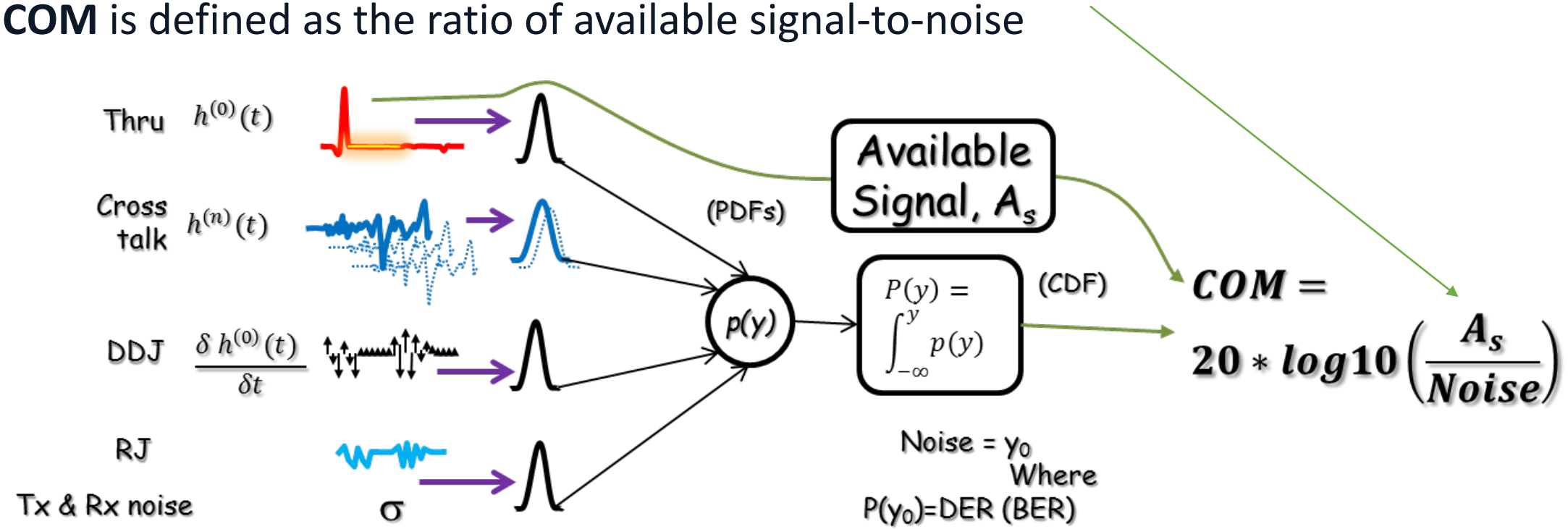
- The derivative of the thru SBR is used to compute the jitter PDF
- Tx and Rx noise determine another PDF



(http://www.ieee802.org/3/bj/public/jul12/mellitz_01_0712.pdf)

COM (Simplified)

- Noise at BER from the noise cumulative distribution function (CDF) created from the combined PDFs
- **COM** is defined as the ratio of available signal-to-noise



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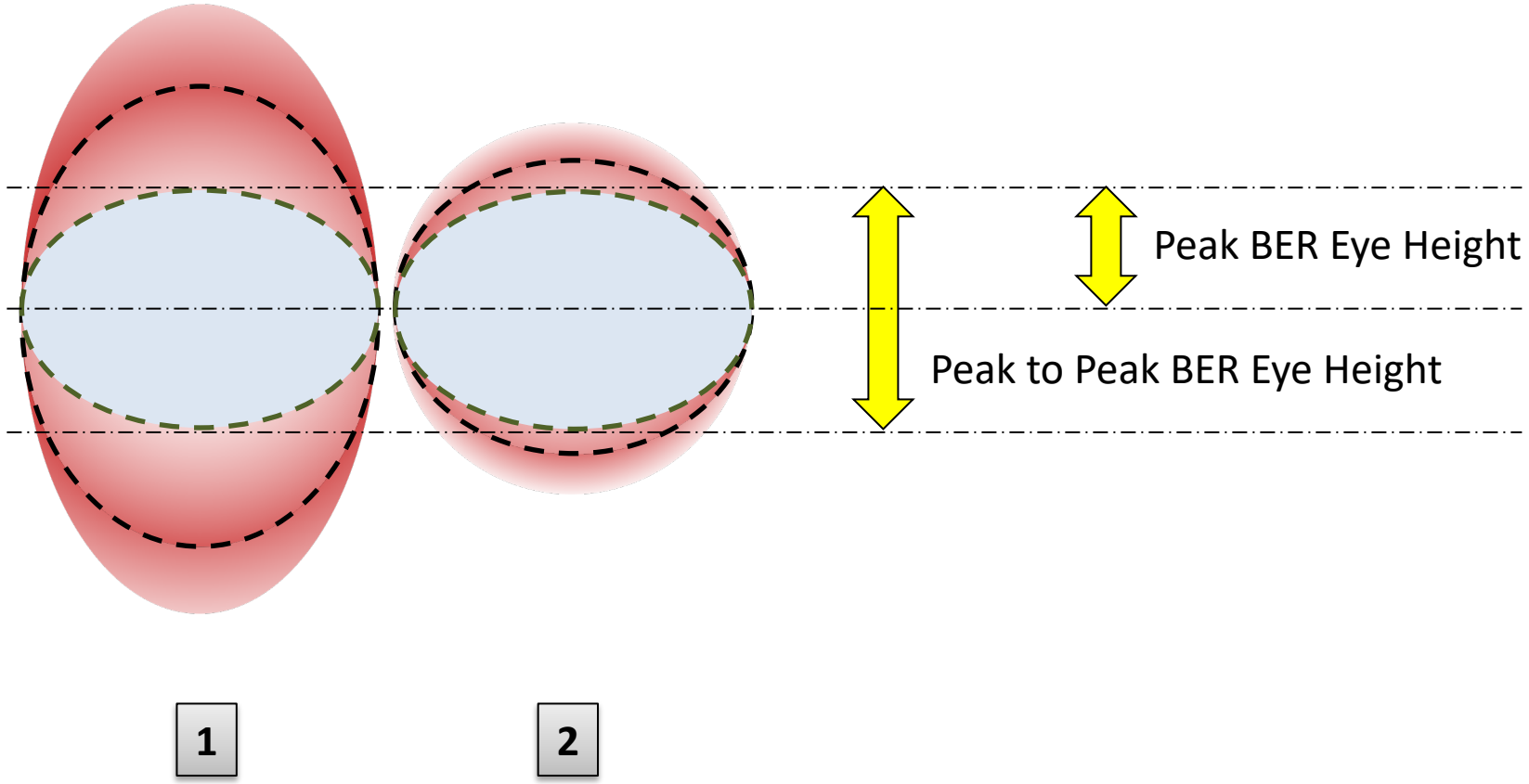
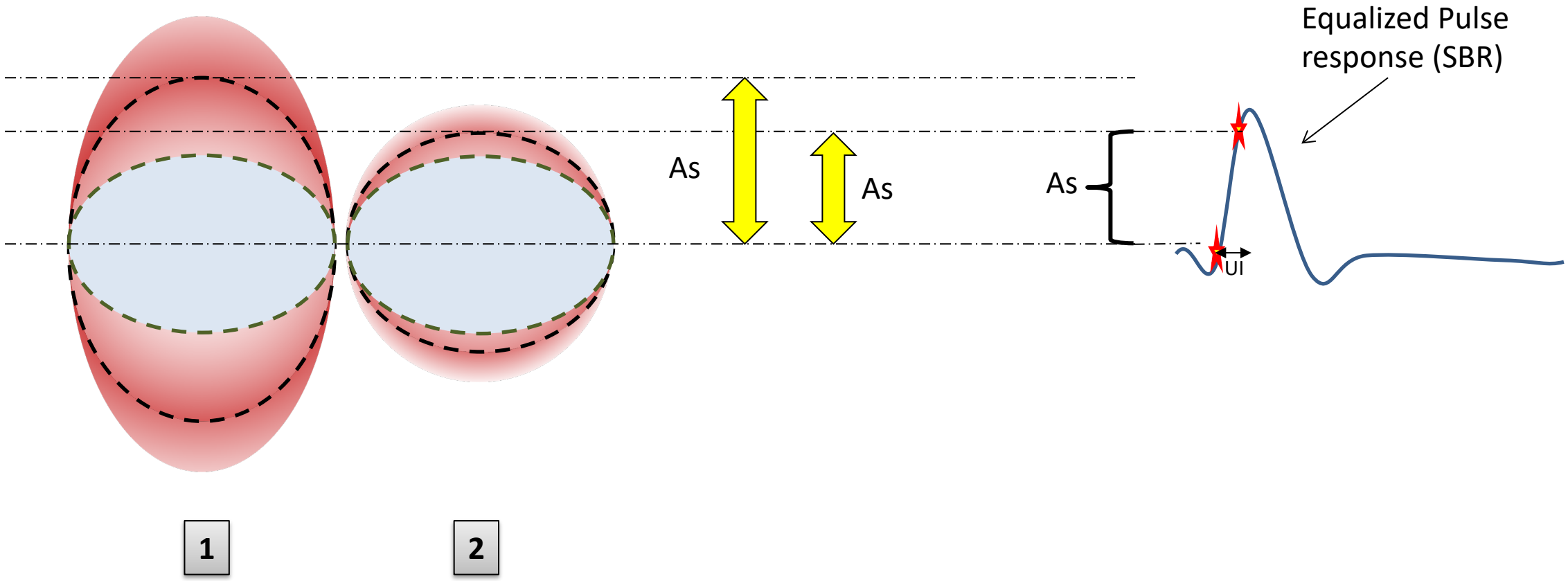
COM (Visualized)



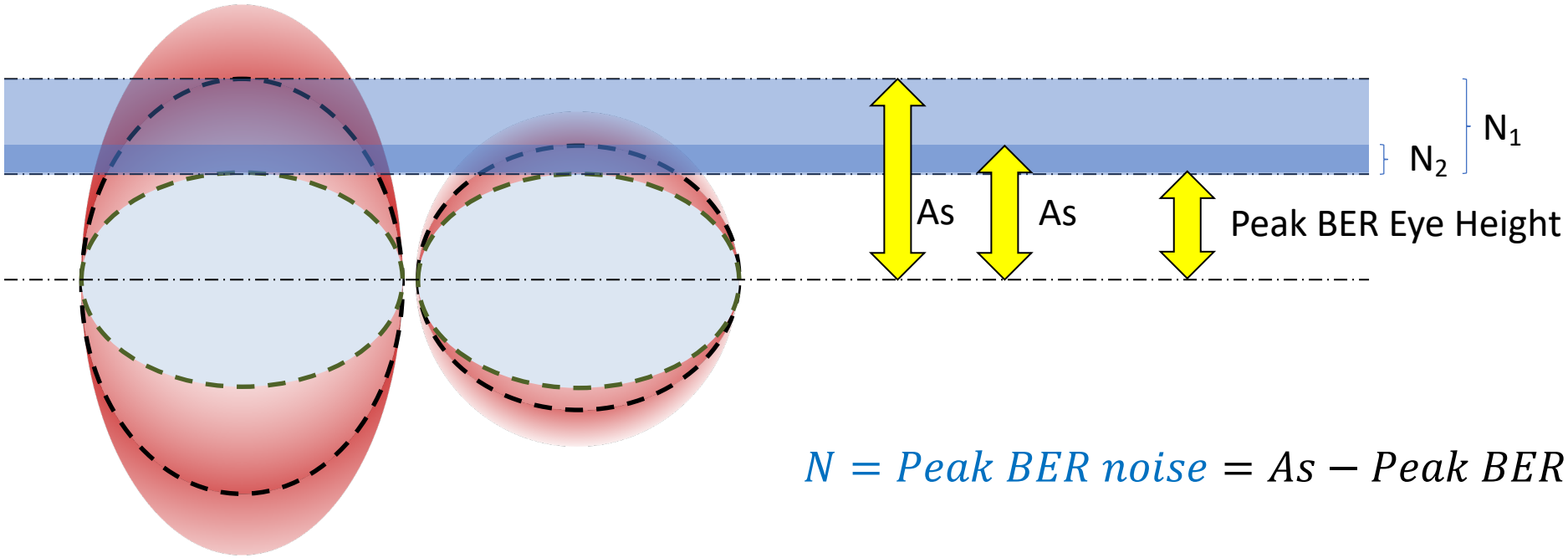
Peak BER Eye Heights are the same

COM (Visualized)



Available signal is greater for channel 1

COM (Visualized)



$$N = Peak\ BER\ noise = As - Peak\ BER\ Height$$

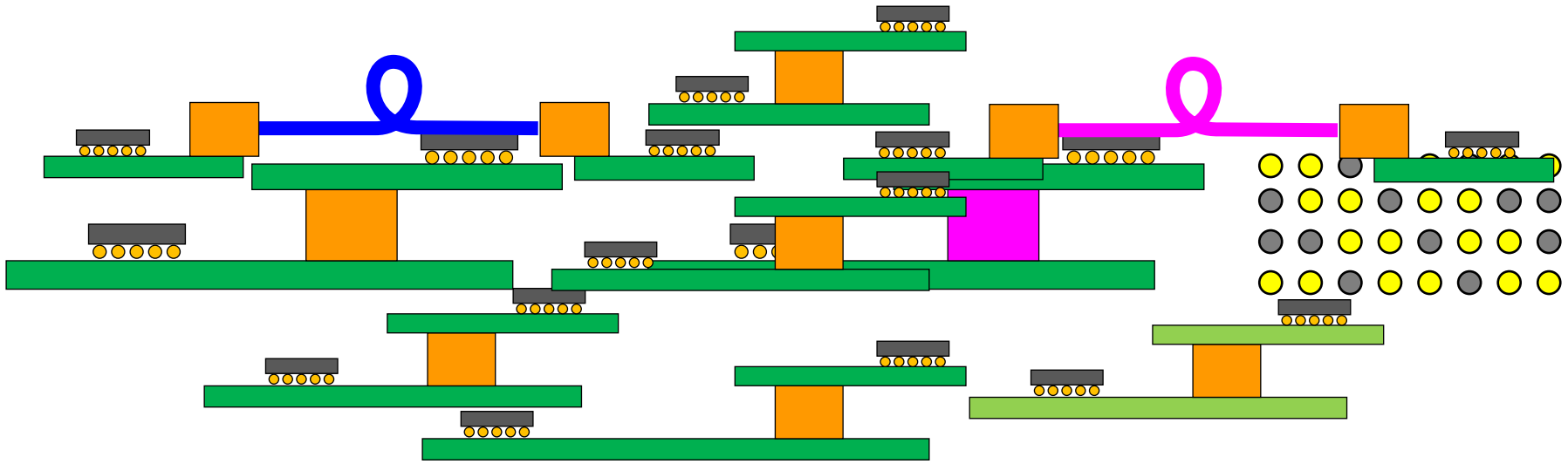
1 2

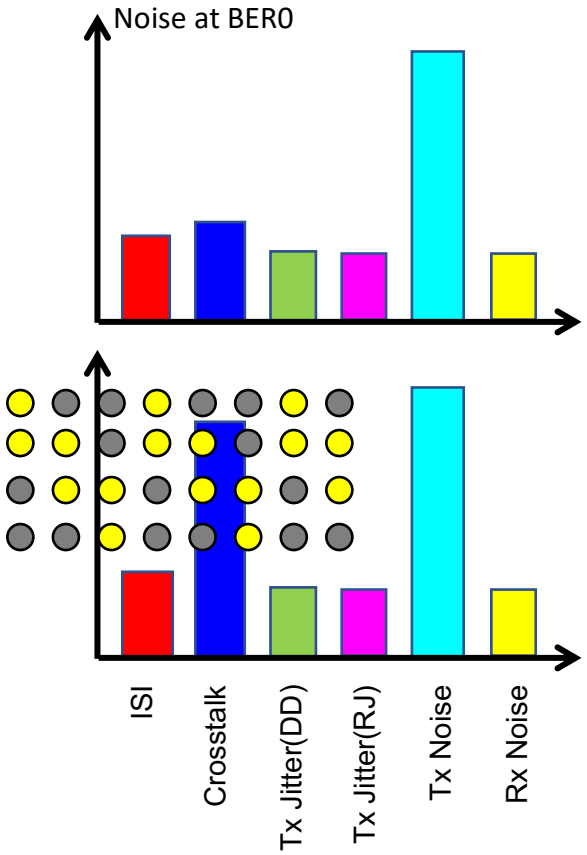
$$COM = 20 * log10\left(\frac{A_s}{N}\right)$$

Power Noise Immunity

When to use **COM**?

1. To determine if a channel will pass a certain Standard that uses **COM**
2. To determine the noise bottleneck in a system
3. To determine connector or S/G configuration
4. Design decisions (cable selection, PCB material selection, …)
5. Maximum PCB length a system

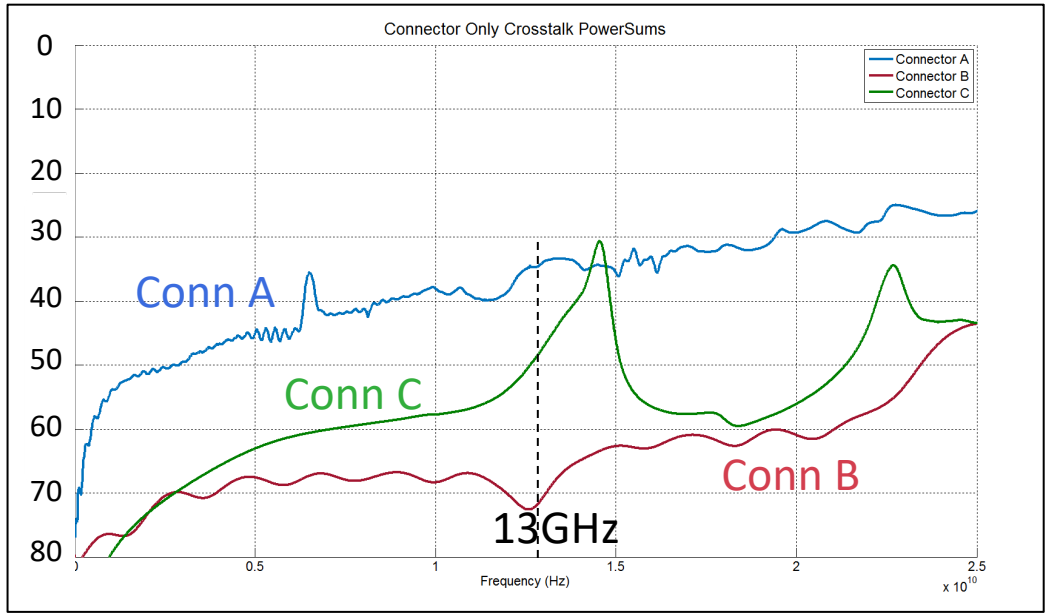




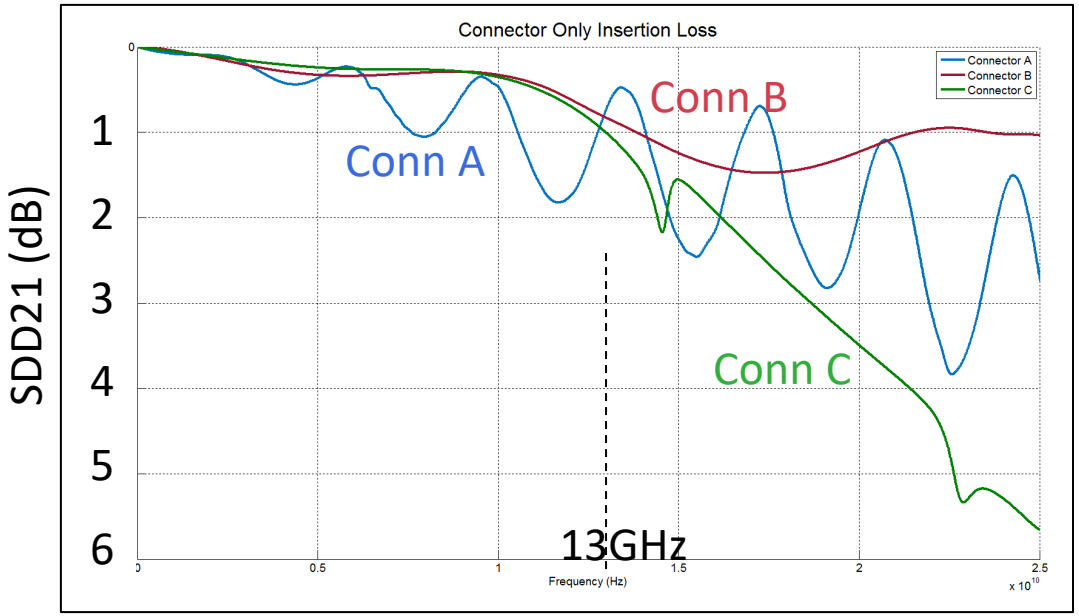
Example of Component Selection

- Very different connector performance
- Connector A has more Crosstalk Power Sum and Insertion Loss

Crosstalk Power Sum



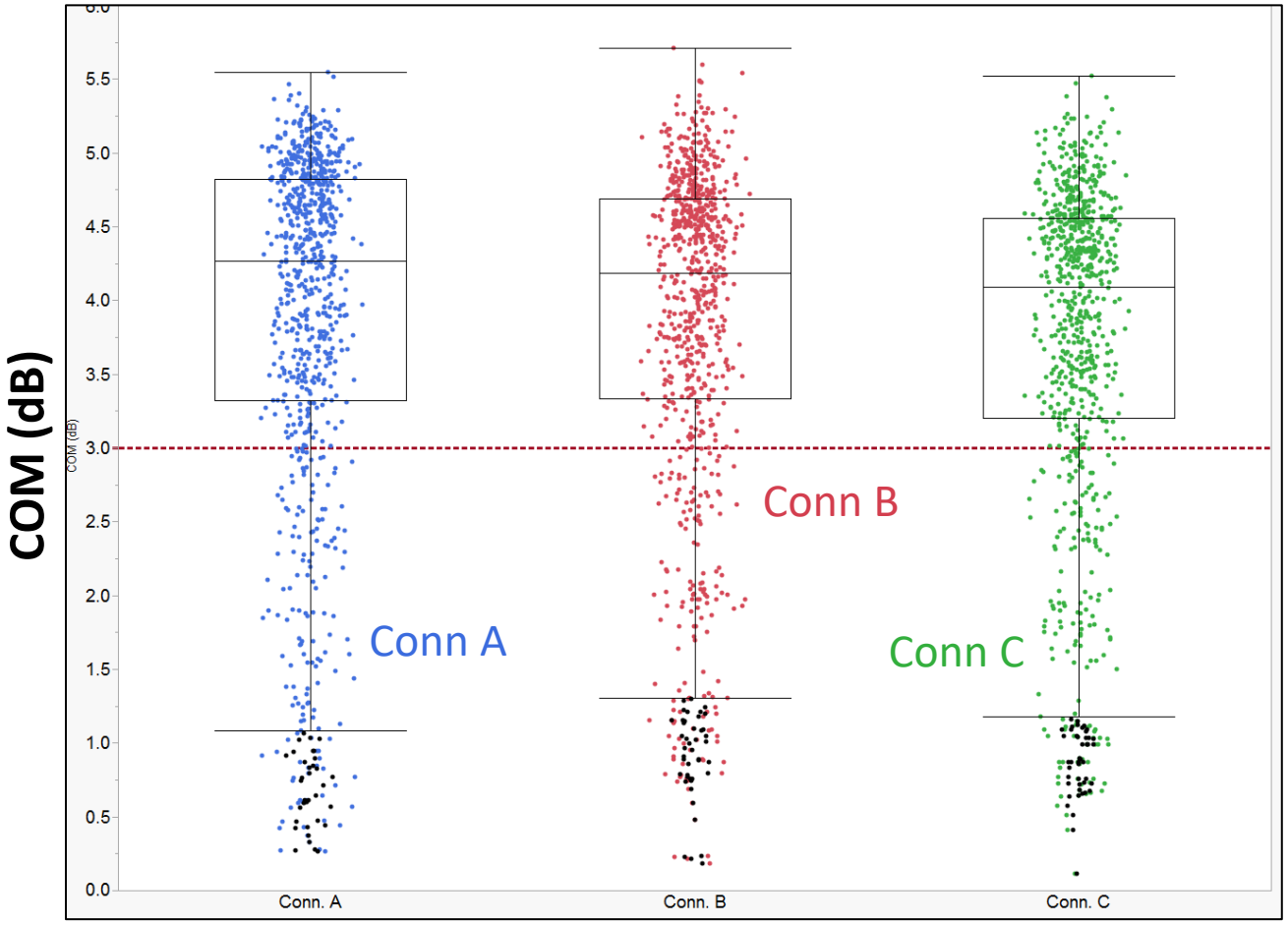
Insertion Loss



Example of Component Selection

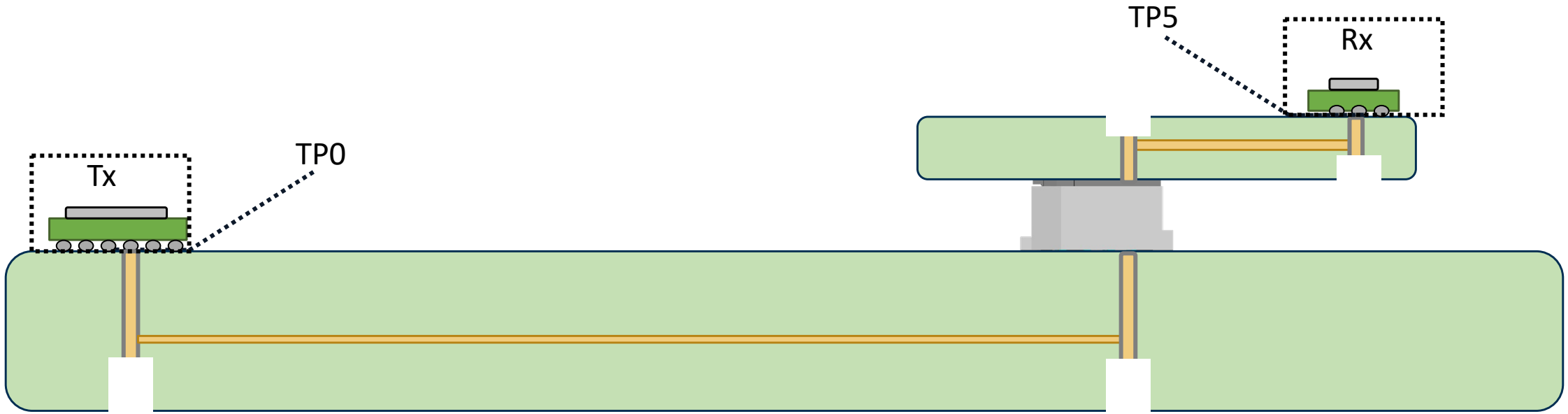
- Datamining all variable in a topology (~7k 25 Gbps **COM** evaluations)
- In context decisions possible with **COM** evaluation

COM vs. **Connector**

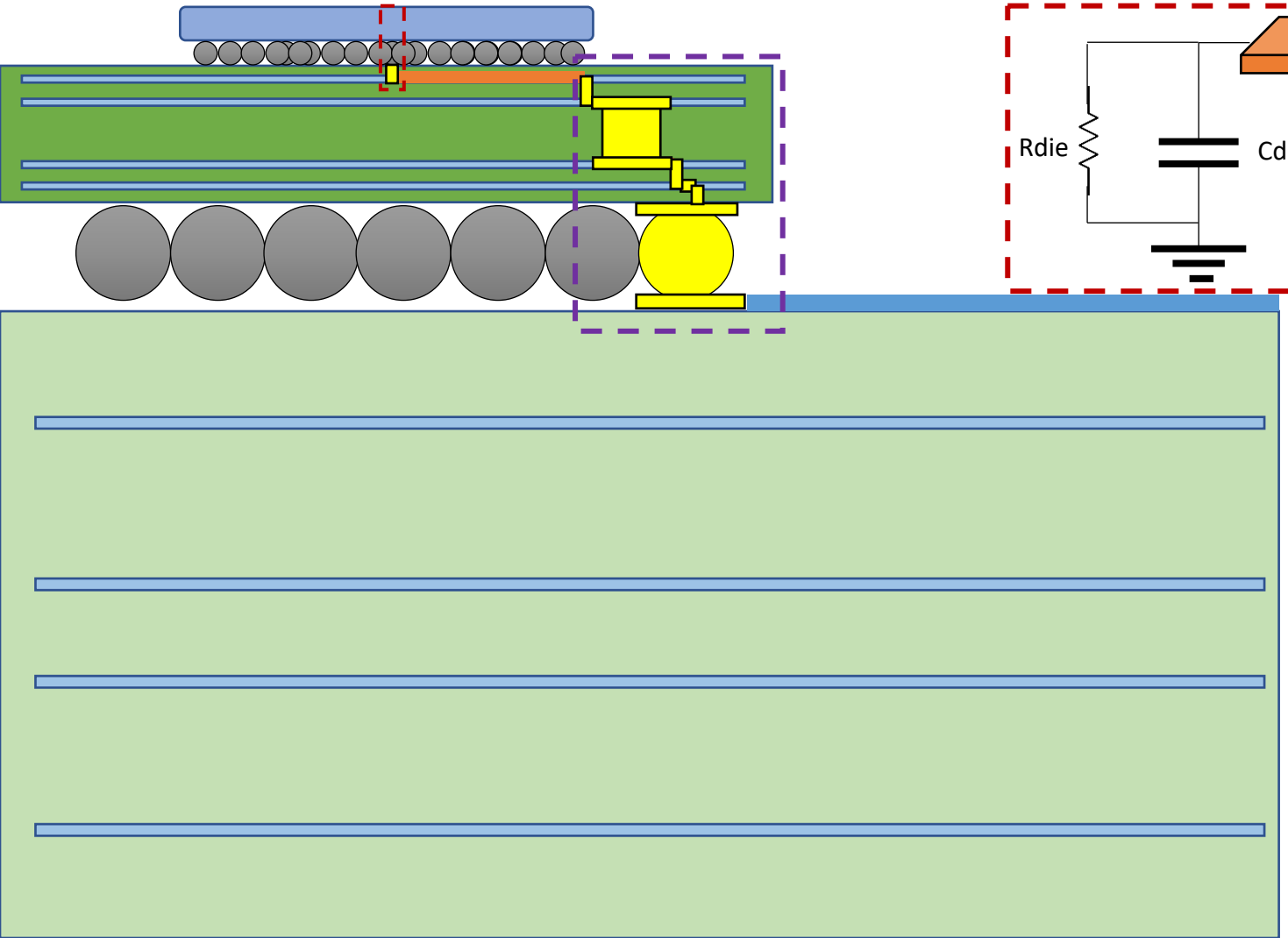


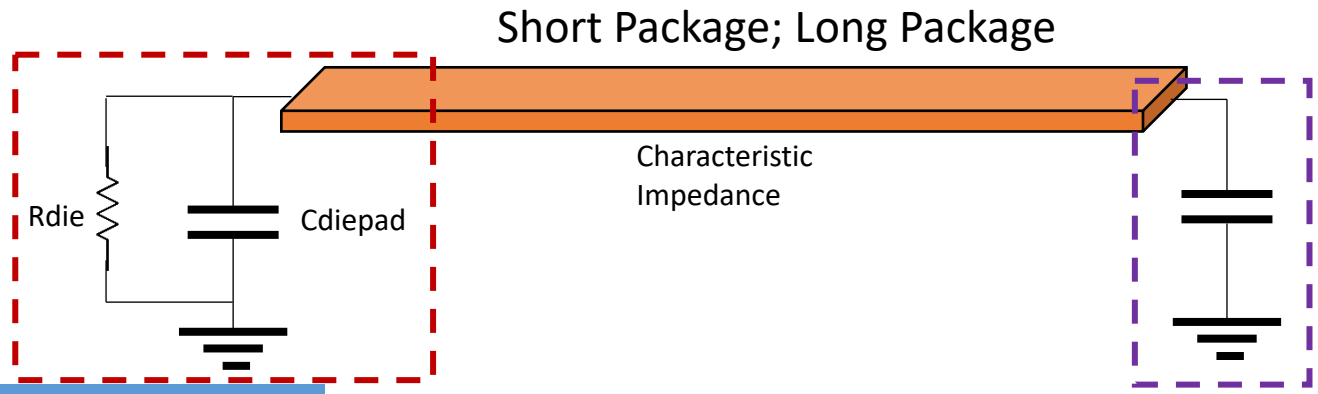
Evolution of the IEEE Package

- Channel is defined between test points (e.g. TP0 and TP5)
- The Tx and Rx include reference package behavior
- Increasing the data rate leads to increased reference package complexity



Synthetic Reference Package





- Values agreed upon by participants in IEEE
- Package + Silicon termination (Rdie, Cdiepad)
- Cdiepad is an effective performance and can include compensation

The Package uses a Causal-By-Design Tline Model

- Fit to 3D EM simulation of 1mm length
- Propagation constant and reflection coefficient to get s11(RL) and s21(IL)

Extensible by length

$$\gamma(f) = \begin{cases} \gamma_0 & f = 0 \\ \gamma_0 + \gamma_1\sqrt{f} + \gamma_2(f)f & f > 0 \end{cases}$$

$$\gamma_1 = a_1(1 + j)$$

$$\gamma_2(f) = a_2[1 - j(2/\pi)\log_e(f/1\ \text{GHz})] + j2\pi\tau$$

$$\rho = \frac{Z_c - 2R_0}{Z_c + 2R_0}$$

$$s_{11}(f) = s_{22}(f) = \frac{\rho(1 - e^{-\gamma(f)2d})}{1 - \rho^2 e^{-\gamma(f)2d}}$$

$$s_{21}(f) = s_{12}(f) = \frac{(1 - \rho^2)e^{-\gamma(f)d}}{1 - \rho^2 e^{-\gamma(f)2d}}$$

Package transmission line

Table 93A−3—Transmission line model parameters

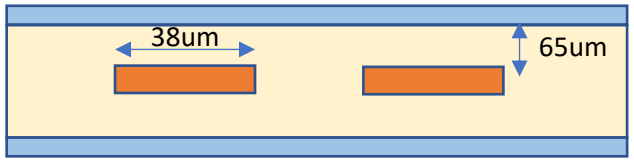
Parameter	Value	Units
γ_0	0	1/mm
a_1	1.734×10^{-3}	$ns^{1/2}$/mm
a_2	1.455×10^{-4}	ns/mm
τ	6.141×10^{-3}	ns/mm
Z_c	78.2	Ω

Annex 93A of IEEE Std 802.3

Why is Loss so High? No Crosstalk?

- The capacitors account for reference package loss
  - ~ 1.3dB @13GHz (25G NRZ)

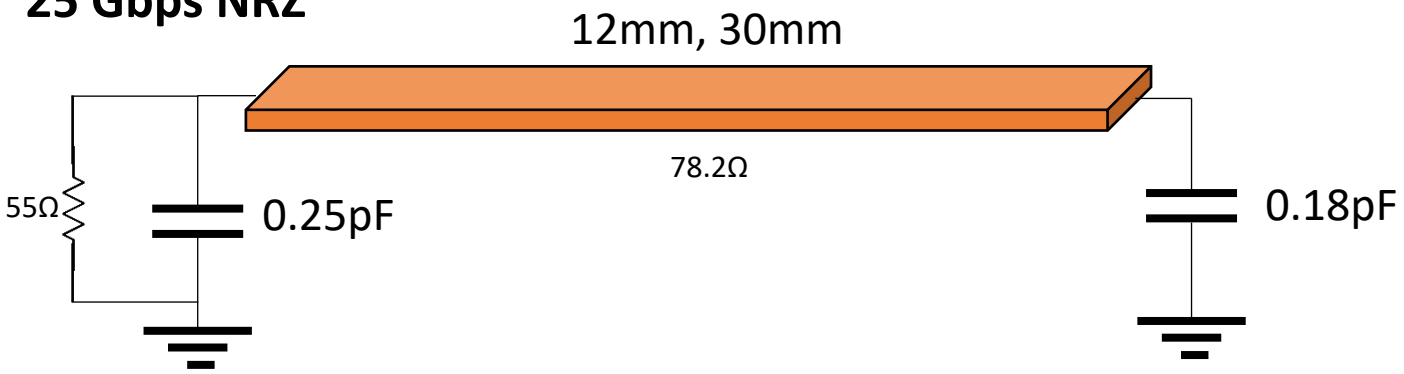
- The cross-section build-up that the package model modeled
  - Thinner build-up and narrow conductors will introduce more loss/mm



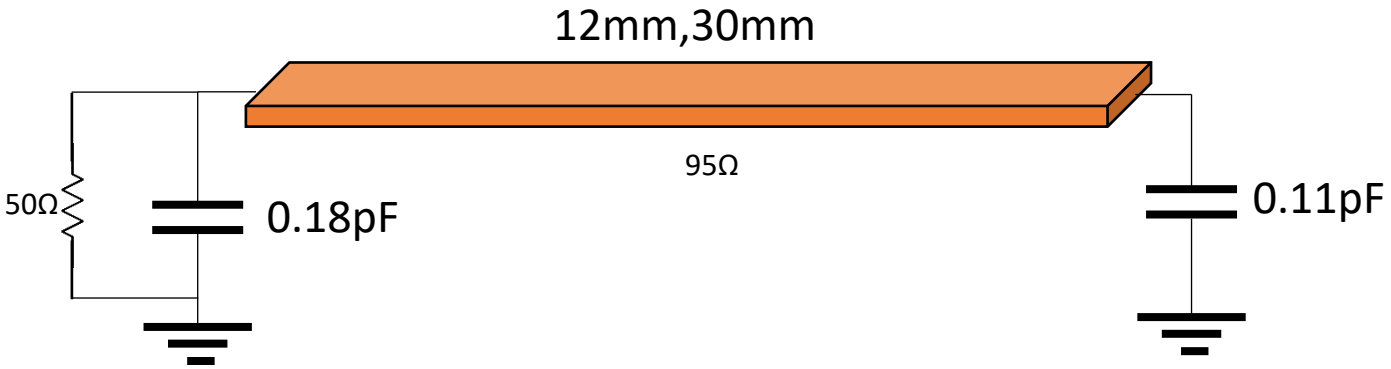
- Crosstalk is not explicitly accounted for in the package model
  - Tx package crosstalk is budgeted into TX SNDR
  - Rx package crosstalk is budgeted into the 3dB of COM margin

Comparison of IEEE Package Models

25 Gbps NRZ



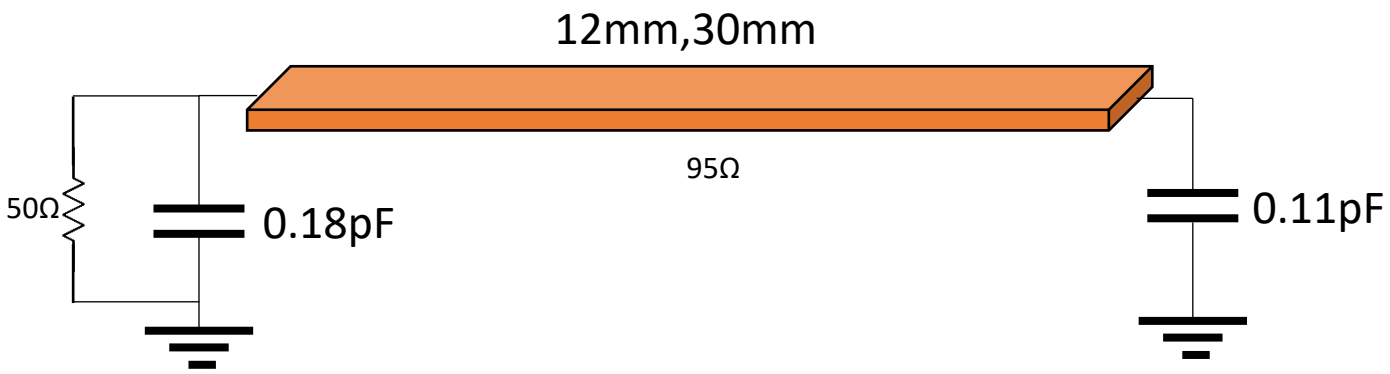
50 Gbps PAM4



Parameter	Value	Units
γ_0	0	$1/mm$
α_1	1.734 x 10^{-3}	$\sqrt{ns}/mm$
α_2	1.455 x 10^{-4}	$(ns)/mm$
τ	6.141 x 10^{-3}	$(ns)/mm$
Z_c	78.2	Ω

Comparison of IEEE Package Models

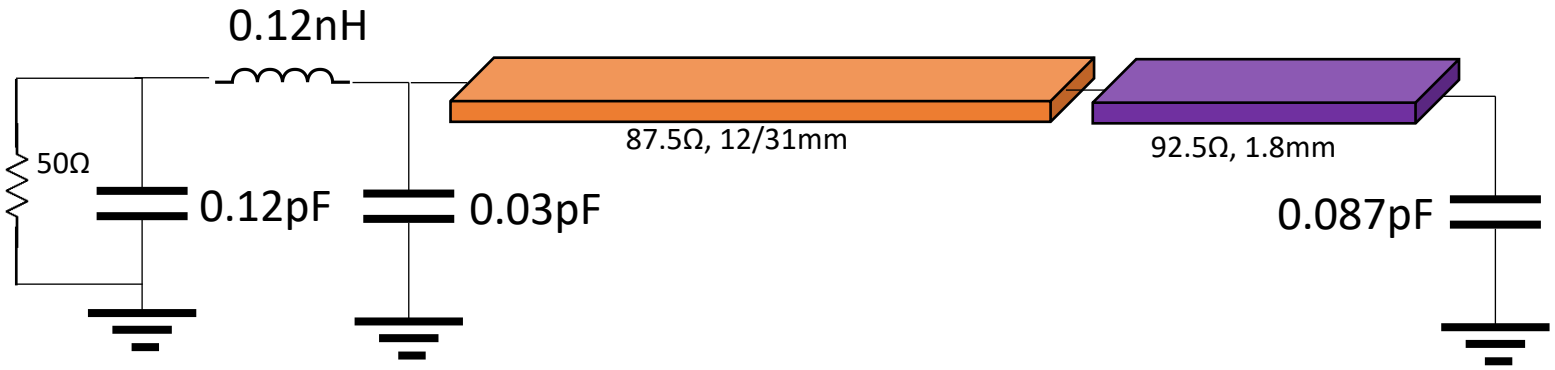
50 Gbps PAM4

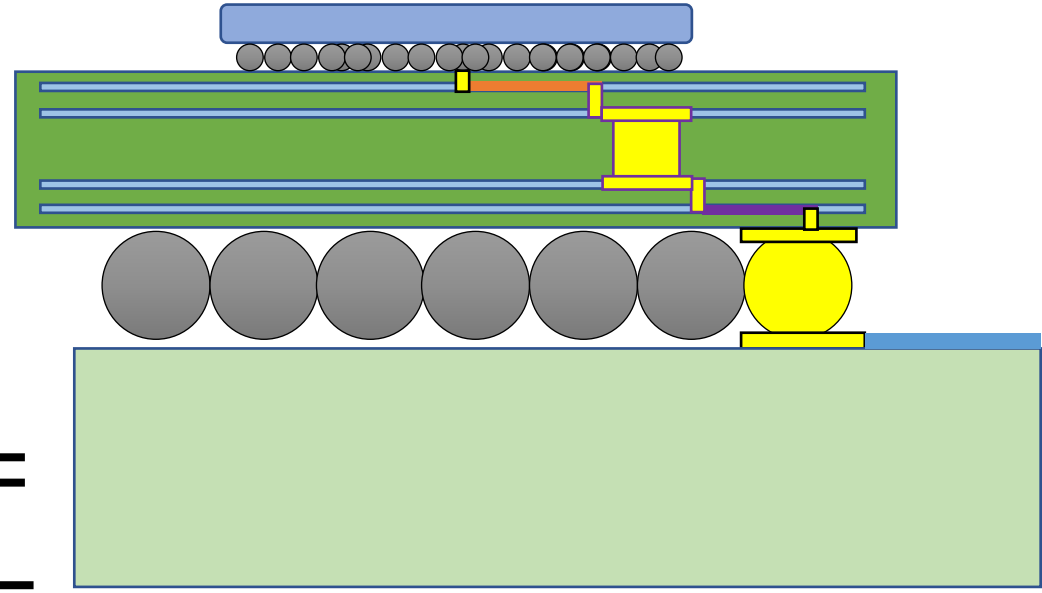


Parameter	50G	112G	Units
γ_0	0	0	$1/mm$
α_1	1.734 x 10^{-3}	9.909 x10^{-4}	$\sqrt{ns}/mm$
α_2	1.455 x 10^{-4}	2.772 x 10^{-4}	$(ns)/mm$
τ	6.141 x 10^{-3}	6.141 x 10^{-3}	$(ns)/mm$

112 Gbps PAM4

Parameters fit rather than physical





http://www.ieee802.org/3/ck/public/19_01/benartsi_3ck_01_0119.pdf
http://www.ieee802.org/3/ck/public/19_01/mellitz_3ck_01_0119.pdf

CONCLUSION

Channel **O**peration **M**argin (**COM**): A single metric for computing channel performance in the context of Tx and Rx capability

Useful for channel component selection and tradeoffs for particular applications

The IEEE reference package model has become a complex behavioral model for representing 112G PAM4 capability

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