Bridging the Gap: Channel Operating Margin (COM) and IBIS-AMI for Analysis and Development of High-Speed SerDes Designs

Graham Kus, Signal Edge Solutions, LLC

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SPEAKERS

Graham J. Kus

Principal Signal and Power Integrity Engineer, Signal Edge Solutions, LLC

graham@signaledgesolutions.com | www.signaledgesolutions.com.com | @si_pi_expert

Graham Kus has over a decade of experience with Signal and Power Integrity workflows along with a background in Digital Signal Processing and Communications Systems engineering. His Industry and EDA efforts have included enterprise datacenter products with semi-custom ASICs, PHY and system reference designs, as well as IBIS-AMI model development for various SerDes and JEDEC DDR standards. He is a regular participant of engineering conferences including the DesignCon technical program and IEEE EMC+SIPI symposium. Graham is a member of IEEE, the ACM, is currently serving as Secretary on the IBIS Open Forum committee and holds a Bachelor of Science in Electrical and Computer Engineering from Northeastern University in Boston, Massachusetts.

Bridging the Gap Between COM and IBIS-AMI

Abstract:

This presentation discusses the advantages and disadvantages for two types of channel analysis applicable to hardware design. The channel links involve close-margin signal to noise such as with 112 or 224G PAM-4 per lane. The comparison is made between using Channel Operating Margin (COM) and IBIS-AMI (specifically Time Domain simulation). COM is first defined by IEEE 802.3bj-2014. The IBIS-AMI specification is defined by the IBIS Committee.

Key points of this presentation:

- In DOE efforts during system design, COM analysis has advantages over IBIS-AMI model simulations.
- Comparison is shown between COM and IBIS-AMI regarding compute execution performance.
- System design can be accelerated by combining COM-centric processes with IBIS-AMI capabilities.
- Proposal for IBIS to provide- and enforce- existing IBIS IQ Quality specification as a compliance or logo certification.

“Establish a Channel for Traffic”

Agpigeon, CC0, via Wikimedia Commons

- Ferry Line Solution:
- Not multiple lanes
- A “Packet” of vehicles
- A vessel: is always sinking

VS.

Estormiz, CC0, via Wikimedia Commons

- Causeway Solution:
- 1 Lane throughput
- Still a “packet” of vehicles
- Blocks naval traffic

These are ways to move traffic from point A to point B across an obstacle like water.

These are like communication channels to transport vehicle traffic.

“Next: Increase Channel Capacity”

[© Frank Schulenburg, via Wikimedia Commons](#)

- <u>Twin Tower Suspension Bridge:</u>
- Easy to build – but lots of material
- Moves multiple lanes
- Supports land and naval traffic

VS.

[Podstawko, CC BY-SA 4.0, via Wikimedia Commons](#)

- <u>Self-Anchored Suspension Bridge:</u>
- Difficult to build - but half the material
- Moves multiple lanes
- Supports land and naval traffic

These bridge designs are ways to think how <u>communications channels</u> can be designed.

Some can be good-performance and inexpensive.

Others can be high-performance and very expensive.

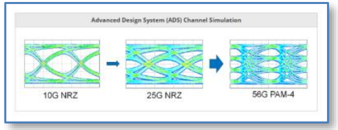
Bridging the Gap Between COM and IBIS-AMI

- COM Pros + Cons:

$$COM = 20 \cdot log_{10}\left(\frac{A_S}{A_{ni}}\right)$$

  - Standard or Custom?
  - Availability?
  - Transferrable results B2B?
  - Usefulness?

- IBIS-AMI Pros + Cons:



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- COM Pros + Cons:

$$COM = 20 \cdot log_{10}\left(\frac{A_S}{A_{ni}}\right)$$

  - Standard: Each specific standard details COM
    - ✓ *Documented: IEEE, OIF, PCI-SIG, USB, etc.*
    - ✓ *Open-source: defined with equations*
  - Availability:
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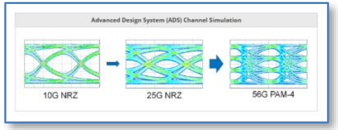
  - Usefulness:

- IBIS-AMI Pros + Cons:



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    - ✓ *Open-source: defined with equations*
  - Availability:
    - ✓ *Public reference code in 2+ languages*
    - ✓ *MATLAB® and Python®*
  - Transferrable results B2B:
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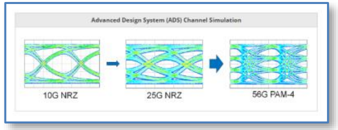

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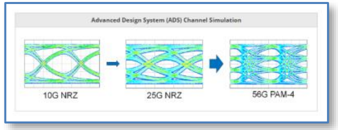

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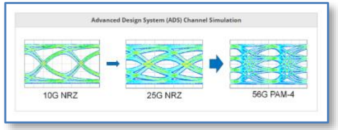
    - ✓ *Bugs possible- but peer reviewed code is public*
    - ✓ *Provides channel margin metric*
    - ✓ *Provides equalization solution for Tx and Rx*
    - ❖ *Fast EQ sweep but no waveforms for correlation*
    - ✓ *AI algorithms can utilize reference code*
    - ✓ *MLSE available as draft in current IEEE COM*



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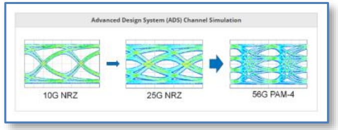

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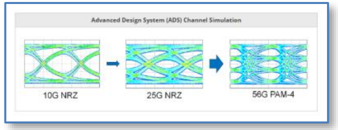

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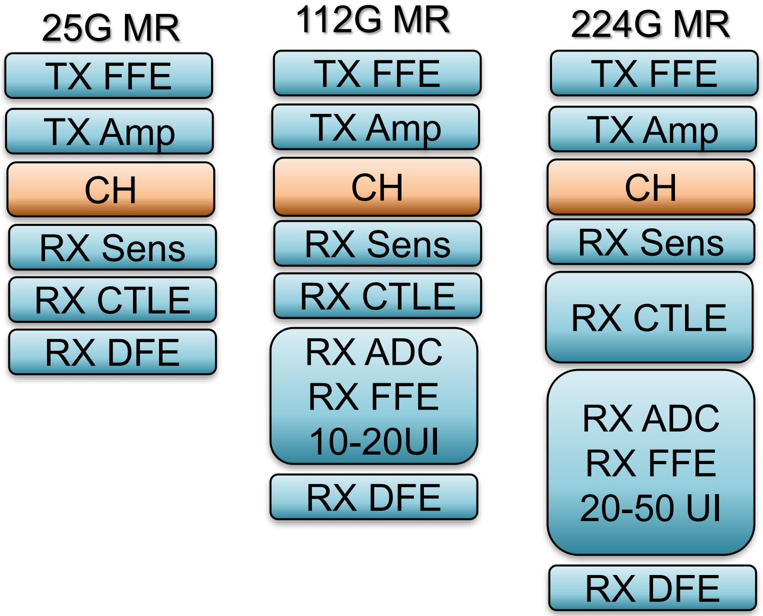
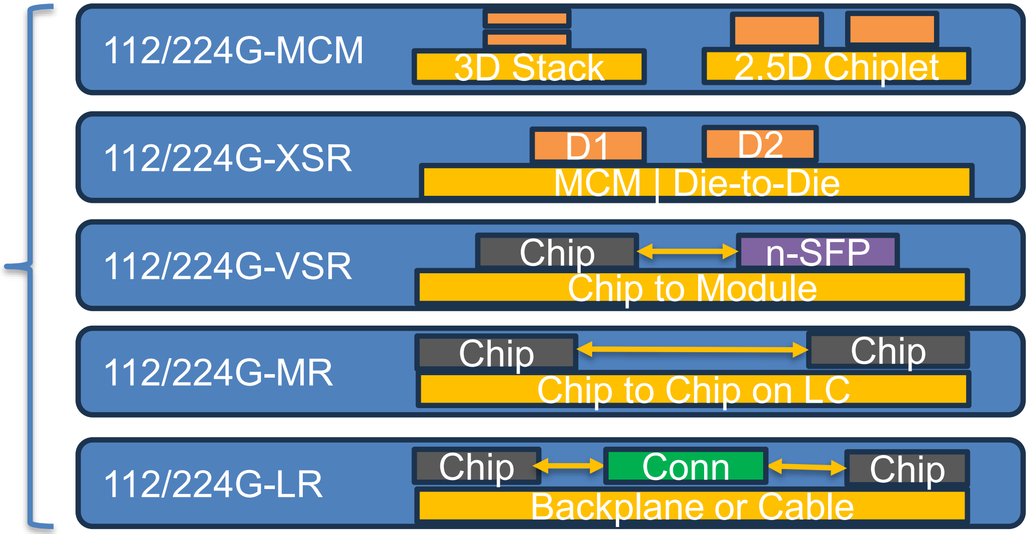
<u>Hybrid Workflow:</u>
Use COM to accelerate IBIS-AMI simulation

Sidebar: Equalizer Stacks

Generic Complexity Comparison for TX/RX:



Goal: Support these channel classes:



- Complete equalizer stack supports all channel classes
- Power/Cost/Size may exceed needs for channel class in system design

Bridging the Gap Between COM and IBIS-AMI

- COM Pros + Cons:

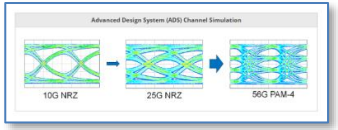
$$COM = 20 \cdot log_{10}\left(\frac{A_S}{A_{ni}}\right)$$

  ✓ FAST:

  1. Equalizer steps <u>compound</u> and cost CPU cycles:
  2. Tx FFE{range}*CTLE{range}*CTLE 2{range}…
  3. Blind sweeps cost 100k+ simulation cycles
  4. <u>Key Advantages:</u>
     - *COM allows "envelope" EQ vs. channel loss*
     - *COM is all convolution on a pulse response*
     - *COM has no GetWave() function*

  ✓ **<u>Cost is minutes.</u>**

- IBIS-AMI Pros + Cons:



  ❖ SLOW: Provides equalization solution for Tx and Rx

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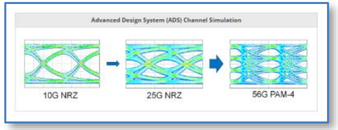
- IBIS-AMI Pros + Cons:



  - ❖ SLOW: Provides equalization solution for Tx and Rx
  1. Equalizer steps compound and cost more CPU cycles:
  2. Tx FFE{range}*CTLE{range}*CTLE 2{range}…
  3. Blind sweeps cost 100k+ simulation cycles
  4. Each sweep requires GetWave() if enabled- and it is for:
     1. *Finding DFE trained taps*
     2. *Calculate TD waveform with protocol-encoding*
  - ❖ **Cost is potentially hours per channel class**

COM equation: Annex 93A.1, Channel Operating Margin, IEEE Standard for Ethernet, IEEE Std 802.3bj-2014, IEEE-SA Standards Board, 2014.
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Bridging the Gap Between COM and IBIS-AMI

Speed to EQ

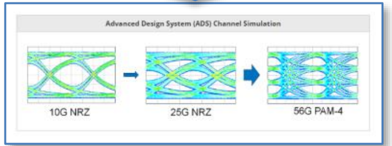
Run COM

$$COM = 20 \cdot log_{10}\left(\frac{A_s}{A_{ni}}\right)$$

Find equalizer solution sets

GetWave with EQ

Use COM EQ values as bracketed solution-set for IBIS-AMI EQs



GetWave() from known-solution set

First use COM to find EQ ranges (gamut)

Then run IBIS-AMI using smaller gamut of EQ values from COM

COM equation: Annex 93A.1, Channel Operating Margin, IEEE Standard for Ethernet, IEEE Std 802.3bj-2014, IEEE-SA Standards Board, 2014.
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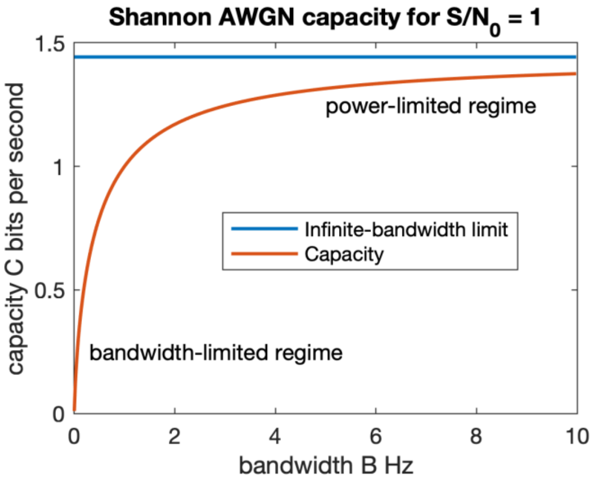
Bridging the Gap Between COM and IBIS-AMI

- A tutorial on Channel Operating Margin:

Channel Capacity vs. Reliable Communication

Getting Started:
- Comms Theory- channel capacity definition:



Channel Capacity vs. Bandwidth

Theoretical Channel Capacity

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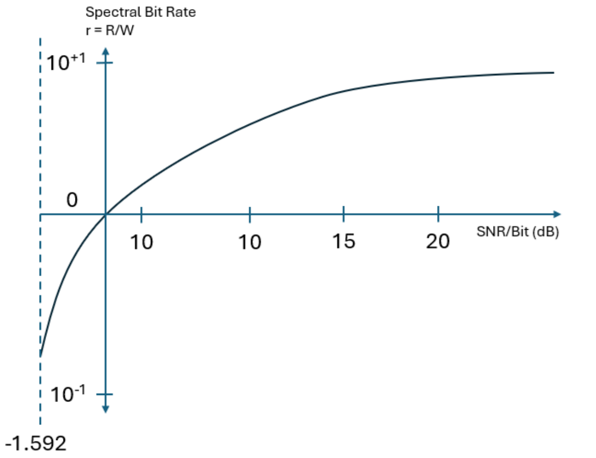
Channel Capacity vs. Reliable Communication

Maximum rate for reliable communication

(Still) Getting Started:

- Maximum bit rate governed by SNR per bit:



Spectral Bit Rate vs. SNR per bit:
Minimum SNR is theoretical limit

Sec 10.3, Bounds on Communication, Communications Systems Engineering, Proakis and Salehi, 1994.

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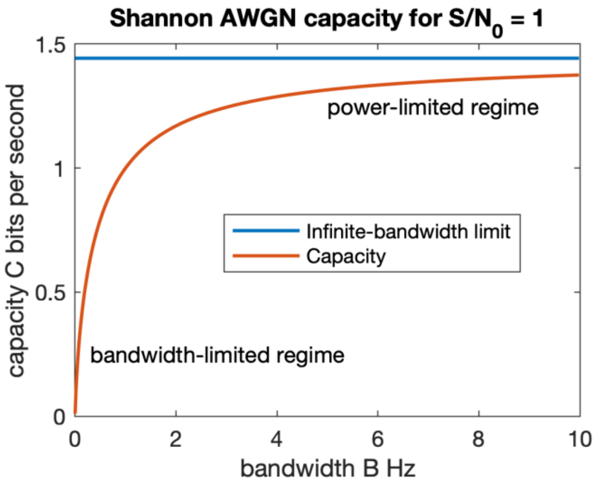

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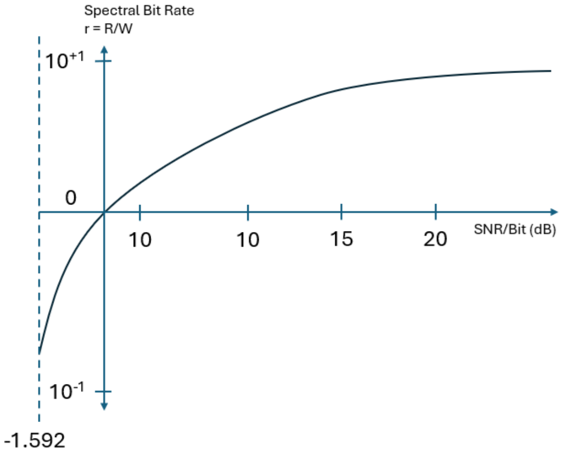

Spectral Bit Rate vs. SNR per bit:
Minimum SNR is theoretical limit

<u>Some Mathematics:</u>

<u>Channel Capacity:</u>

Spectral Bit Rate r = R/W

R = transmission rate

W = available bandwidth

r << 1: W is large

r >> 1: W is limited

$$r = \log(1 + r\frac{Eb}{No})$$

$$\frac{Eb}{No} = -1.592dB$$

$$\frac{Eb}{No} > 0.693 = SNRmin$$

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$$COM = 20 \cdot log_{10}\left(\frac{A_s}{A_{ni}}\right) \qquad (93A\text{-}1) \qquad \Big\} \quad COM \geq 3\ dB$$

COM Table 93A-1 complexity grows with each subsequent Standard for Ethernet:

- 802.3bj (25G NRZ per lane) - introduction of Channel Operating Margin:
  - COM Table 93A-1
  - COM calculation (93A-1)
  - FOM calculation (93A-36) including determination of variable equalizer parameters.
- 802.3ck (112G PAM4 per lane) – increases EQ ranges, adds DFE to COM table:
  - FOM includes additional equalizer parameters,
  - addition of DFE determination of floating tap locations and magnitudes (93A.1.6.1)
- 802.3dj (224G PAM4 per lane) – changes architecture of equalization:
  - introduction of ADC-based equalizer and MSLE for receiver.

COM is basically an SNR and relates to:

- ✓ Channel Capacity
- ✓ Max reliable data rate

Annex 93A.1, Channel Operating Margin, IEEE Standard for Ethernet, IEEE Std 802.3bj-2014, IEEE-SA Standards Board, 2014.
Annex 93A.1, Channel Operating Margin, IEEE Standard for Ethernet, IEEE Std 802.3ck-2022, IEEE-SA Standards Board, 2022.

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$$FOM = 10 \cdot \log_{10}\left(\frac{{A^2}_s}{{\sigma^2}_{TX} + {\sigma^2}_{ISI} + {\sigma^2}_J + {\sigma^2}_{XT} + {\sigma^2}_N}\right) \quad (93A\text{-}36)$$

Figure of Merit (FOM): how and where Equalization is incorporated into COM:

Determination of variable equalizer parameters (93A.1.6):

"FOM is calculated for each permitted combination [EQ] values per Table 93A–1.

The combination of values that maximizes the FOM [...] is used for the calculation of:

a) *The interference and noise amplitude in equation 93A.1.7,*

b) *and the calculation of COM in equation 93A.1."*

Determination of DFE floating tap locations and magnitudes (93A.1.6.1):

c) *Find the locations of the floating banks of taps*

d) *then compute the coefficient magnitudes for all floating taps*

FOM is also an SNR and relates to:

- ✓ EQ values
- ✓ IF and noise terms
- ✓ Part of COM calculation

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Adoption of COM by standards organizations:

- 2014: IEEE introduces Channel Operating Margin (COM) in 2014 with 802.3bj Standard for Ethernet
- 2017: OIF-CEI 5.0 adopts COM as part of 56G and higher throughputs
- 2019: PCI-SIG adopts COM for PCIe 6.0
- 2020: USB-IF adopts eCOM for USB4 v2
- Recommend engineering professionals to pay attention to upcoming standards!

Bridging the Gap Between COM and IBIS-AMI

- How can the IBIS Open Forum help?
  - Quality:
    - *IBIS Quality currently provided as a specification*
    - *IBIS Quality is not enforced*
    - *IBIS Quality can be enforced*
  - Documentation: Model from Vendor or EDA-Library
    - *Model documentation is not part of IBIS IQ*
    - *IBIS Quality can also enforce documentation*
  - Solution:
    - *IBIS Logo-testing issued to model vendors*
    - *Potential for certified Quality levels*
  - Justification:
    - *Model users avoid wasted engineering cycles*
    - *Vendors become encouraged to join IBIS*

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Did you know?
These organizations require certification testing to use their official logos.
(Each uses COM and IBIS-AMI)

PCI SIG

USB Enabling Connections | CELEBRATING 30 YEARS

Bridging the Gap Between COM and IBIS-AMI

- How can IBIS-AMI model users take action?
  - Quality:
    - *Require an IBIS IQ report from your vendor*
  - Standard: silicon is made to support at least one:
    - *Require Documentation: how to use model*
    - *EQ curves for TX and RX given test load*
    - *Require correlation to IEEE, OIF, USB, etc.*
  - Availability:
    - *First choice: get EQ values from COM*
    - *Second choice: get a reference AMI model for the standard the system requires*
    - *Vendor-specific model: should be 3rd choice*
  - Transferrable results B2B:
    - *Remind the legal department: IBIS is designed to be sharable performative model, with no IP.*

- IBIS member organizations registered during 2025:

Bridging the Gap Between COM and IBIS-AMI

- How else can IBIS-AMI model users take action?
  - Quality:
    - *Get IBIS IQ reports from vendors as IBIS members*
  - Availability:
    - *Some EDA vendors provide reference AMI models*
    - *Vendor-specific model: require user documentation*
  - Engagement:
    - *Encourage your model vendor to join IBIS*
  - Participate in IBIS activities and get latest news:
    - *Subscribe to IBIS email reflector*
    - *Join IBIS Open Forum and Task Group meetings*
  - More information:
    - *See the [IBIS website (www.ibis.org)](www.ibis.org)*
    - *Or find the IBIS Open Forum on social media*

- IBIS member organizations registered during 2025:

AMD, Analog Devices, Applied Simulation Technology, arm, Aurora System, Broadcom, cadence, ciena, Cisco, Dassault Systemes, GE HealthCare, Google, Huawei, Infineon, intel, Keysight, Marvell, MathWorks, micron, Missouri S&T, NVIDIA, SI-Clarity, Siemens, Signal Edge Solutions, ST, Synopsys, ZTE, Zuken

(*IBIS Members 2025: www.ibis.org/poster*)

Bridging the Gap Between COM and IBIS-AMI

IBIS Quality Level Definitions:

The quality level is defined as a combination of correctness checks and correlation checks. The correctness level is a number, and other special designations such as correlation are shown as appended letters. Some examples:

- ✓ IQ0 - No IQ checking at all
- ✓ IQ1 - Passes IBISCHK without errors or unexplained warnings
- ❑ IQ2 - IQ1 + data for basic simulation checked
- ❑ IQ3 - IQ2 + data for timing analysis checked
- ❑ IQ4 - IQ3 + data for power-aware analysis checked
- ❑ IQ3M - IQ3 + correlated against hardware measurements
- ❑ IQ3MS - IQ3 + correlated against measurements and simulation
- ❑ IQ3GS - IQ3 + golden waveforms + correlated against simulation
- ❑ IQ4X - IQ4, but exception(s) to check(s) commented in file

IQ1:
"The Basics"
Does it pass the IBIS Golden Parser?

Any Warnings?
Data or Syntax Errors?

The 5 recognized levels of correctness checks and 3 levels of correlation checks are discussed [in the specification].

Details of the referenced checks and correlation tests are given in sections 2 through 7 [in the specification].

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IQ2 and IQ3:
"Code Review"

Was AMI input vs. output data reviewed by the model vendor?

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IQ4:
"Power Aware"

Was power-aware
data reviewed
by the model vendor?

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- ✓ IQ4 - IQ3 + data for power-aware analysis checked
- ➢ IQ3M - IQ3 + correlated against hardware measurements
- ➢ IQ3MS - IQ3 + correlated against measurements and simulation
- ➢ IQ3GS - IQ3 + golden waveforms + correlated against simulation
- ❖ IQ4X - IQ4, but exception(s) to check(s) commented in file

IQ3M/MS/GS:
"correlation"

Hardware measurements and sim data reviewed by the model vendor?

The 5 recognized levels of correctness checks and 3 levels of correlation checks are discussed [in the specification].

Details of the referenced checks and correlation tests are given in sections 2 through 7 [in the specification].

Thank you!

QUESTIONS?

Graham Kus

Principal Signal and Power Integrity Engineer, Signal Edge Solutions, LLC

Graham@SignalEdgeSolutions.com | SignalEdgeSolutions.com

MORE INFORMATION

IEEE COM reference code in MATLAB®:

- IEEE 802.3 COM Open Source Project Ad Hoc:
- Link: (https://www.ieee802.org/3/ad_hoc/COM/index.html)

IEEE COM reference code in Python® :

- COM: A Link Designer's Field Guide, David Banas and Keysight Technologies, Inc., Signal Integrity Journal, June 2024.
- Ref: (https://www.signalintegrityjournal.com/articles/3578-com-a-link-designers-field-guide)
- GitHub: (GitHub - Python implementation of COM, as per IEEE 802.3-22 Annex 93A.)

More topics on Signal and Power Integrity available at these links:

- www.SignalEdgeSolutions.com
- https://www.signaledgesolutions.com/blog
- Graham@SignalEdgeSolutions.com

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Bridging the Gap: Channel Operating Margin (COM) and IBIS-AMI for Analysis and Development of High-Speed SerDes Designs

Graham Kus, Signal Edge Solutions, LLC