PKG and Interconnect COM Impact Analysis and “What-ifs”

Liav Ben-Artsi - Marvell Technology Group

Richard Mellitz – Intel

Contributors

- Adee Ran - Intel

Main Presentation Outcome

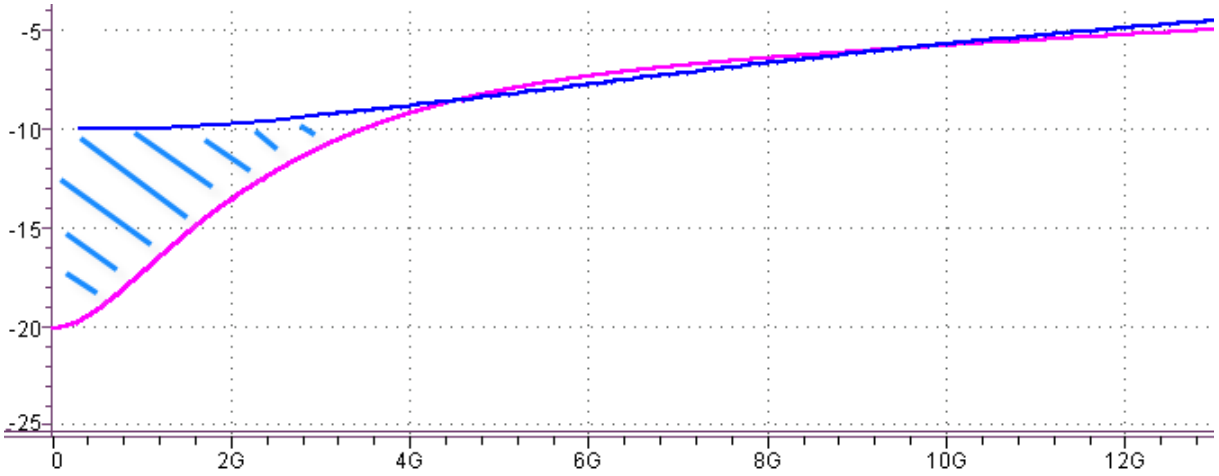
- This presentation will provide a correction for the PKG return loss as included in the COM code.
- It will be shown that given the corrected return loss, COM result increases and KR4 targets can be met.
- This presentation also provides resolution for comments: 44-48; 50-54; 56-58

D1.2 Status description

- 802.3bj KR4 targets 35dB @ fb/2 interconnects with FEC.
- D1.2 incorporated package and interconnect return loss limits.
  - Package return loss limit was based on package ball discontinuity, 0.25pF assumed die capacitance and package manufacturing tolerance.
  - Interconnect return loss was suggested to follow OIF-3.0 limit.
- D1.2 incorporated a reference package insertion loss model.
- Running "IBM 35" interconnect D1.2 return loss returned a marginal COM result after tweaking the Tx to best case.
- Package insertion loss model (with new PKG RL) has an influence of 1-1.5dB

So what is wrong with the D1.2 PKG RL model?

- The package return loss equation did not represent the real reflection from a package, taking non reasonable margin at the low frequency.
- The package insertion loss was accounted for twice (Tx, Rx), while 800mV should be defined at TP0 (with a test load)
  ➔ If including a package IL model, include only Rx PKG insertion loss - Cont. on slide 17



Proposed PKG Return Loss Equation

- The proposed package return loss equation (purple/lilac curve) is:

$$Z_{PKG} = \frac{-w^2 * a_2 + i * wa1 + a0}{-i * w^3 * b_3 - b_2 * w^2 + i * b_1 * w + 1}$$

a2= 5.112E-20
a1 = 3.2733E-09
a0 = 41
b3 = 8.9856E-33
b2 = 1.0895E-21
b1 = 3.729E-11

$$\text{PKG\_RetLoss} = \frac{Z_{PKG} - 50}{Z_{PKG} + 50} * exp^{-i*\pi}$$

- The equation resembles the phase of a reflection from a real package as well as provides the required return loss limit.

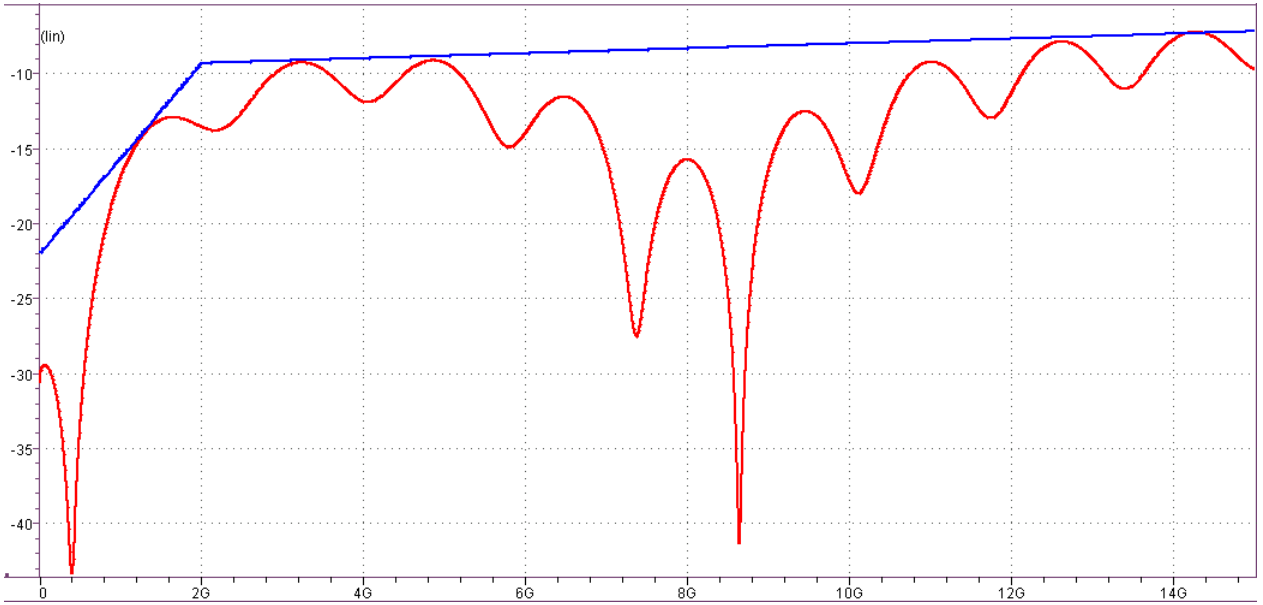
TP0a/TP5a Return Loss Measurements Limit

- The return loss at TP0a/tp5a as measured through the test fixture should meet:

  6.25*f-22 $0.05 \leq f \leq 2$

  0.163*f-9.62 $2 \leq f \leq 13$ (10 for KP4)

  f in GHz



Patel 30dB through interconnect

- "What if" analysis performed on the "Patel" 30dB through interconnect.

PKG return loss	PKG insertion loss	Interconnect return loss	COM result
OIF	D1.2	Original	4.4dB (10^-5)
D1.2	D1.2	Original	4.2 (10^-5)
Slide #6	D1.2	Original	4.88dB (10^-5)
Slide #6	D1.2	Original	5.85dB (10^-5) No XTalk

IBM ~36dB interconnect

- "What if" analysis performed on 35db_Loss_channel.zip.

PKG return loss	PKG insertion loss	Interconnect return loss	COM result
D1.2	D1.2	Original	2.95dB Tweaking the Tx settings
Slide #6	D1.2	Original	1.66dB (10^-5)
Slide #6	D1.2	Original	**3.21dB (10^-5) –** Tweaking the Tx settings
Slide #6	D1.2	Magnitude lowered by 20%	**3.51dB (10^-5) –** Tweaking the Tx settings

- 6-9mV available signal is "scary" low…
- With very low signal every "minor" effect is magnified. This indicates a border line case putting us on an "edge of a cliff"
- Results indicate the PKG return loss and IL models are "good enough" to meet target.
- It is most important to verify that the interconnect provides the required COM value under worst case manufacturing tolerance.

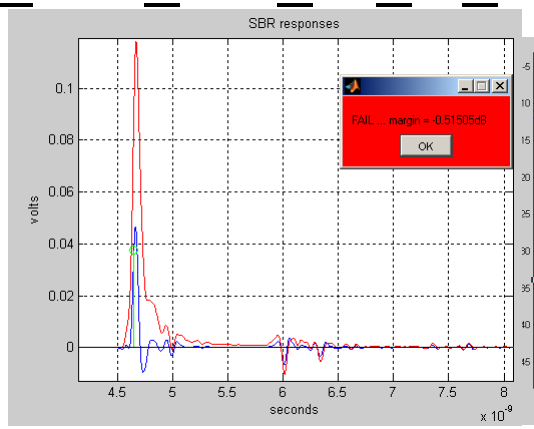
Note: Post tap was limited to -0.2

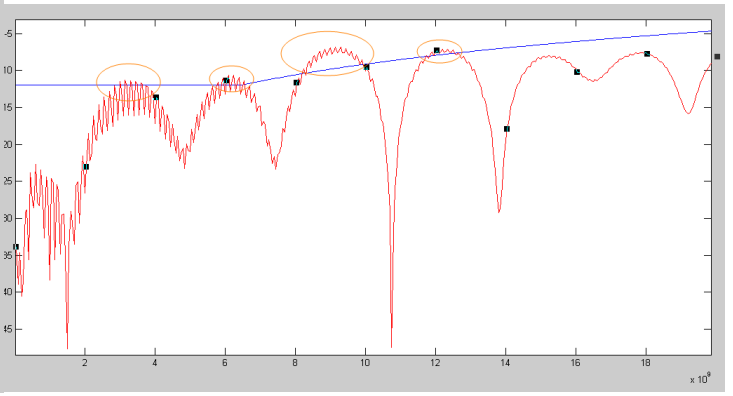
A Spotlight on Interconnect Return loss

- An informative interconnect return loss was adopted into D1.2.
- Main intention was to provide guidelines to interconnect design requirements.
- The actual interconnect return loss influence is included in the normative COM methodology.
- In order to allow a positive COM margin / operation with 25Gbps/lane NRZ the interconnect insertion loss is just a part of the whole picture…

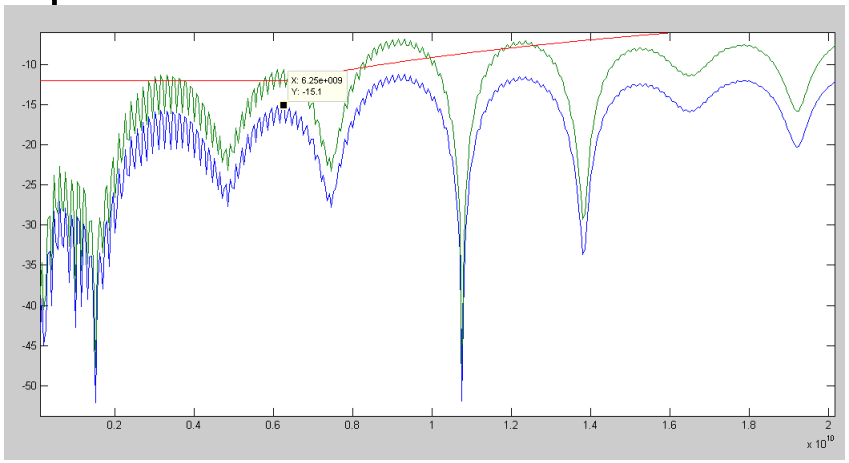
A Spotlight on Interconnect Return loss - Return Loss Example (1E-12)

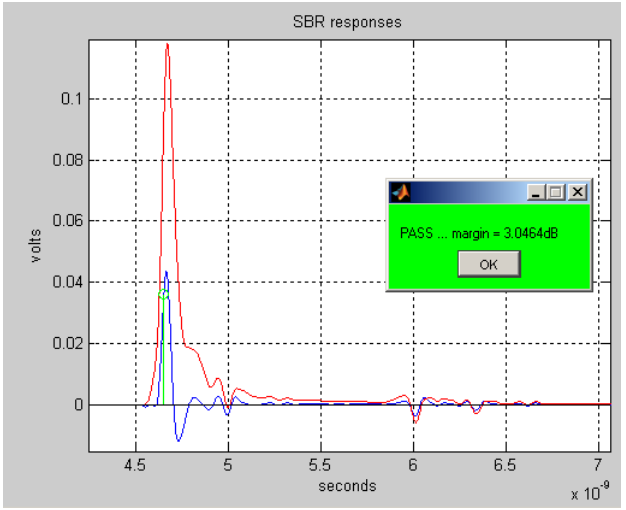
- FCI_CC_Long_Link_Pair_15_to_Pair_7 Returns a failing COM number.





- Update the interconnect RL…

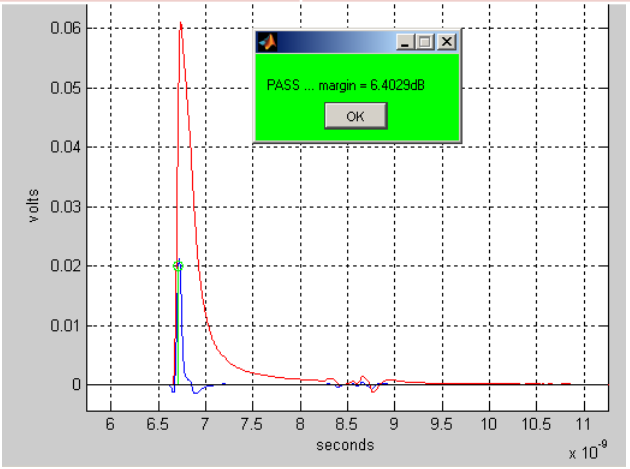




Strada Whisper Interconnects

- Running Strada Whisper interconnects with PKG RL, PKG IL and full XTalk. Modeling.

Interconnect	PKG insertion loss	PKG RL	COM result
42p8in - Meg6	D1.2	Slide 6	6.4dB
29.8dB – Nelco 6	D1.2	D1.2	4.18dB
29.8dB – Nelco 6	D1.2	Slide 6	4.56dB



Calculated effective voltage transfer ratio using a standard specified RL.

- Taking into account an 800mV (at the ball) + ~30dB channel +~2.5dB Rx PKG ➔ 1010…Signal before equalization = 19mV
- Taking into account 1mV RMS noise at the receiver (sigma_r) ➔ There is no room for any other distortion source…
- Looking at the way SDD21 is updated with return losses impact:

$$H_{21}proposed1 = \frac{S_{21}}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

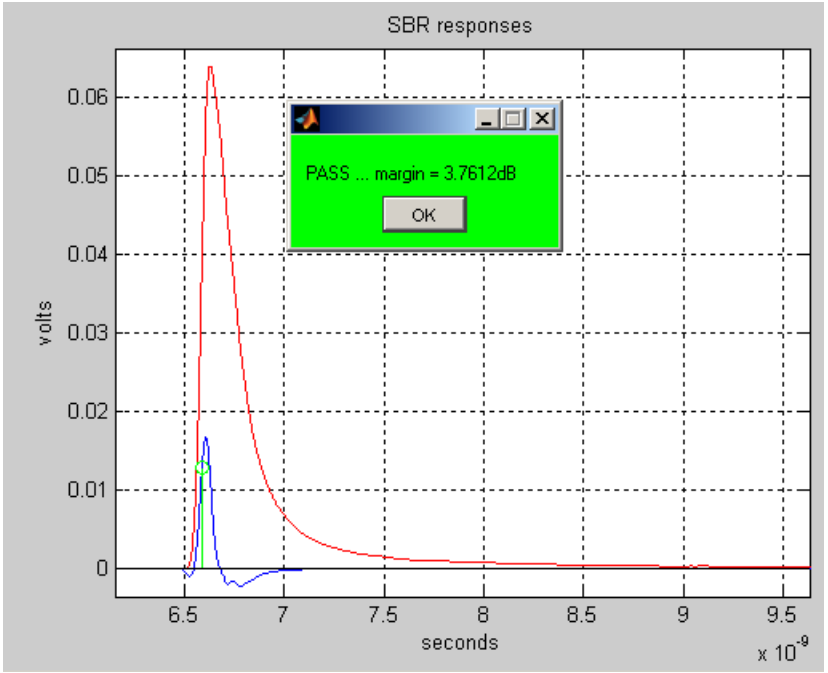
Gain based on waves

$$H_{21}proposed3 = \frac{S_{21}\,(1 + \Gamma_{RX})}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

- It is essential to minimize any other external distortion sources.

~30dB channel vs. 25Gbps

- So, Can a 30dB channel really work @ 25Gbps?
- An ideal (sampled, not simulated) ~32dB channel COM results:
- VTF = 3 ; Inclusion of PKG
- Main difference is a great interconnect return loss.



The Package Return Loss is Based on Physical Design Realities

- Assumed capacitance was taken from numerous former presentations (250fF).
- The die and ball discontinuities influence the return loss curves.
- The return loss curves are highly influenced by the discontinuities at the ball and the die and represent no added discontinuity along the package trace.
- The return loss curves take into account package traces of various length.
- Conclusion: The suggested return loss is based on ball-discontinuity extraction and die parasitic capacitance.

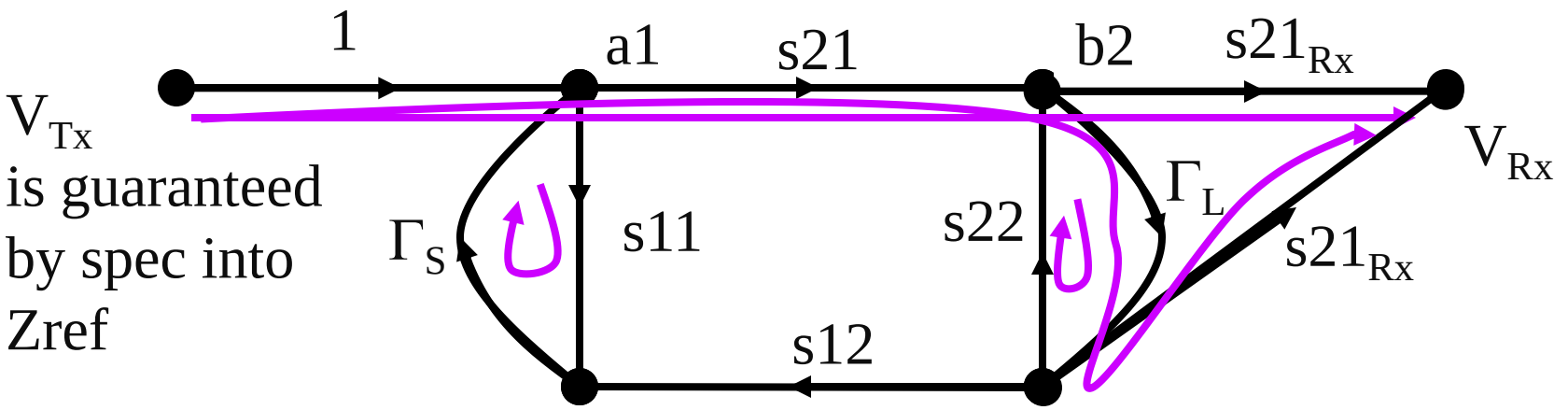
The PKG Insertion Loss Model

- A non-causal behavior can be observed with "problematic" interconnects (mainly when including return loss…).
- The PKG model integrates no package level crosstalk.
- In ran_01_0712.pdf it a Rx PKG COM impact of 3dB was assumed.
- Recommendation: Given all the above inaccuracies, Remove the PKG insertion loss model and integrate an extra xdB required margin (1.5dB as an initial number).
  (up to the floor to decide?!)
  - Note: A more complicated & accurate model is ready for integration if needed.

Inclusion of a Tx Side Package

- The spec guaranties a specific minimal voltage (800mV) at the device balls (or at TP0a) when driving a Zref.
- Inclusion of a Tx side PKG does not fulfill this requirement.
- Exercise: Driving an ideal load will supply Vload to be $Vs*S_{PKGTx}$ ➔ The minimal requirement is to multiply V_{drv} by the Tx_{PKG} inverse transfer function.
- Doing so is the same as using the graph on the next slide

Forward + reverse wave paths



$$\frac{V_{Rx}}{V_{Tx}} = \frac{s21 * (s21_{Rx}) * (1 + \Gamma_{Rx})}{1 - s11 * \Gamma_{Tx} - s22 * \Gamma_{Rx} - s21 * s12 * \Gamma_{Tx} * \Gamma_{rx} + s11 * s22 * \Gamma_{Tx} * \Gamma_{rx}}$$

- Resolution for comment 57, 54: Define transmitter and far end aggressor @TP0 and use the above equation to calculate the voltage transfer function (VTF#3) – can remove $S21_{Rx}$ if so decided.
- $\Gamma_{Tx} = \Gamma_{Rx} = Suggested\ in\ slide\#9$

KR4 Interference tolerance testing

- Intended to provide resolution for comment 46
- Recommend adding COM requirement per interconnect (an initial max value of 4.5dB (if PKG insertion loss model removed / 3dB if PKG IL exists) is recommended.
- A higher COM value can be determined for shorter channels which are meant to have higher noise.
- Since the test equipment is characterized by a great return loss: A switch to be added to the COM code to bypass the influence of the Tx PKG RL /add a test equipment characteristic RL avoiding under-stress :

$$H_{21}proposed3 = \frac{S_{21}\,(1+\Gamma_{RX})}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

Conclusions / Recommendations

- Target Interconnect can be met with suggested PKG return loss.
- Target Interconnects can be met with current D1.2 PKG IL model.
- Comments 51, 52, 44, 45 - PKG return loss model in COM: Use the equation from slide 6.
- Comments 47, 48: Decide if to remove the package insertion loss model and include an additional COM requirement according to slide 16.
- Comment 46 (Com for interference tol test): follow slide #19
- Comments 50,53,56,58: Measured return loss: follow the equation from slide 7.
- Comments 54, 57: Please refer to slide 16

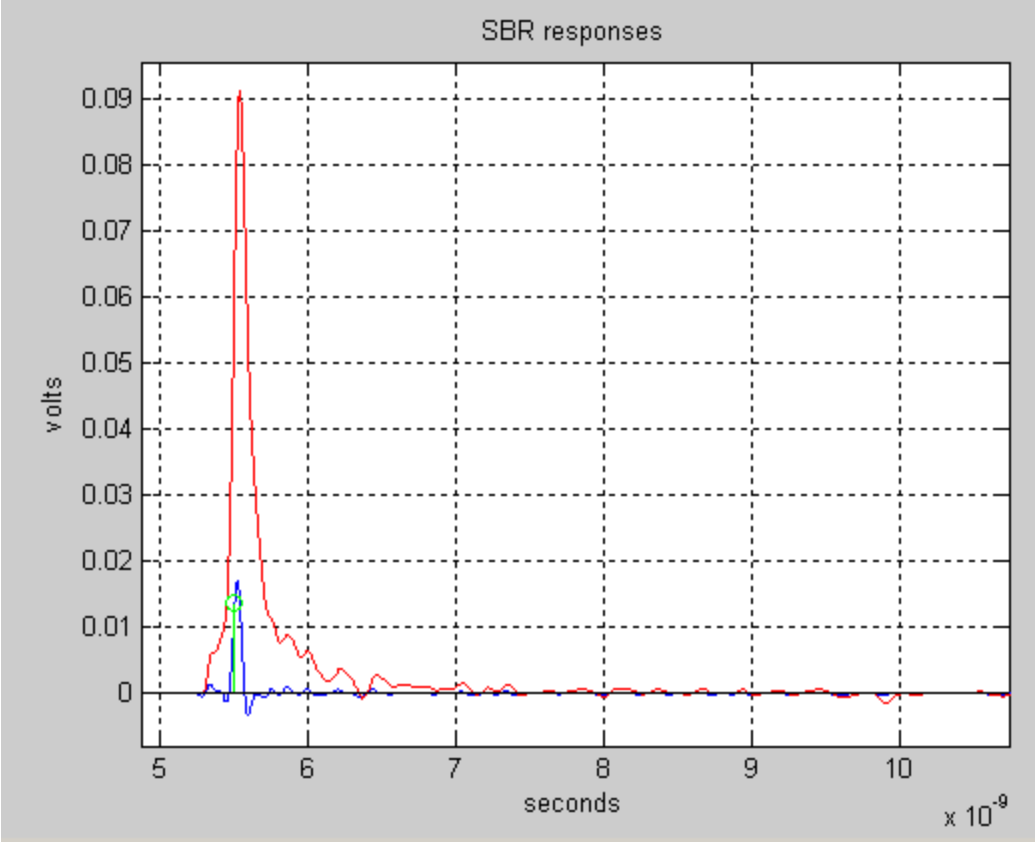
Next Steps / Follow up

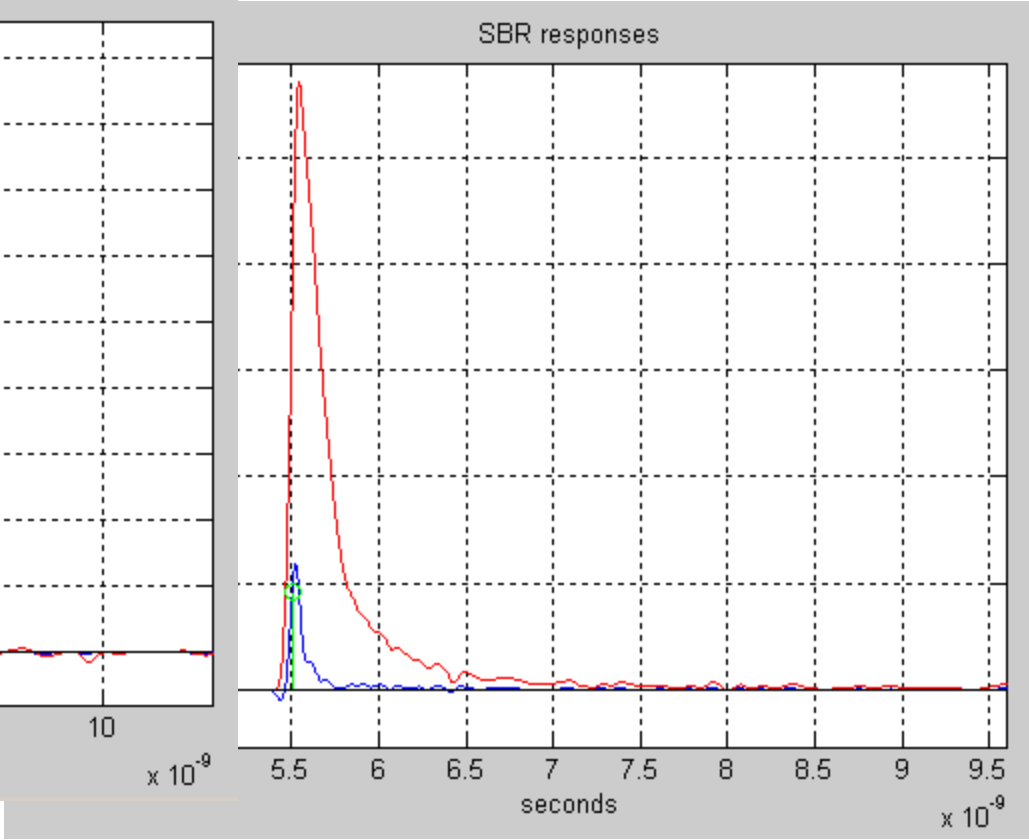
- If decide to remove Rx PKG insertion loss:
  Check the exact margin needed for Rx package and define COM accordingly. – A.I. – Liav.
- If decided to include Rx PKG IL, provide updated KP4 PKG model and consider updating the KR4 PKG IL model.
- Define exact COM numbers per interconnect for KR4 interference tolerance test.

Thank you

Backup slides

Non-Causal Behavior Removed

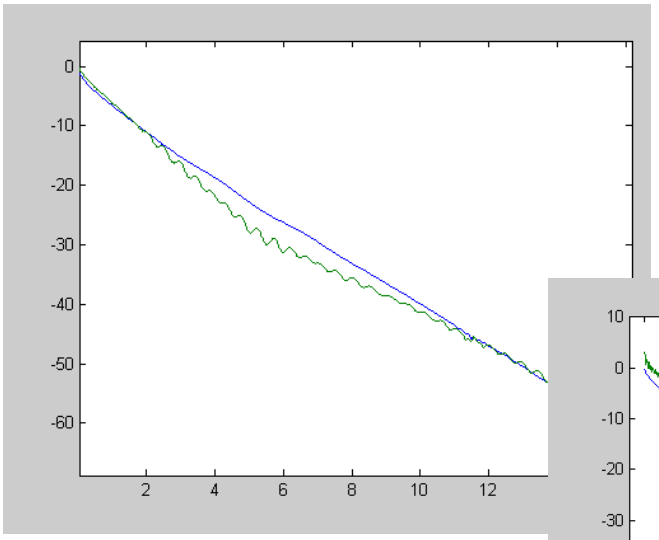




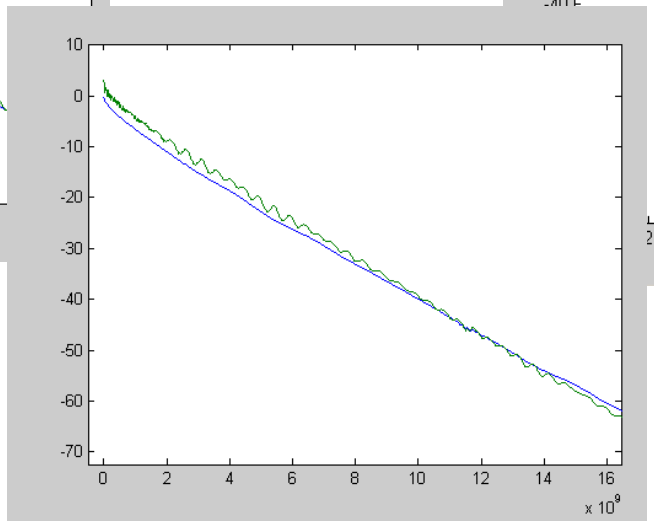
Gamma Frequency Domain Influence

- All analysis with VTF=3

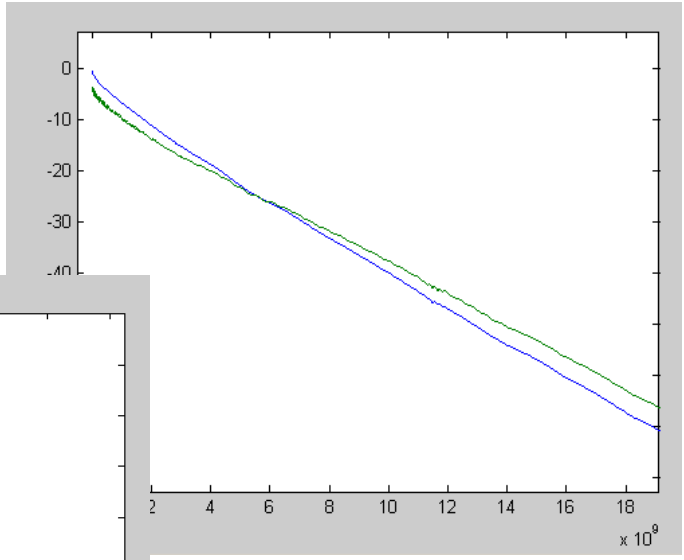
Suggested



Old Gamma



Current COM code



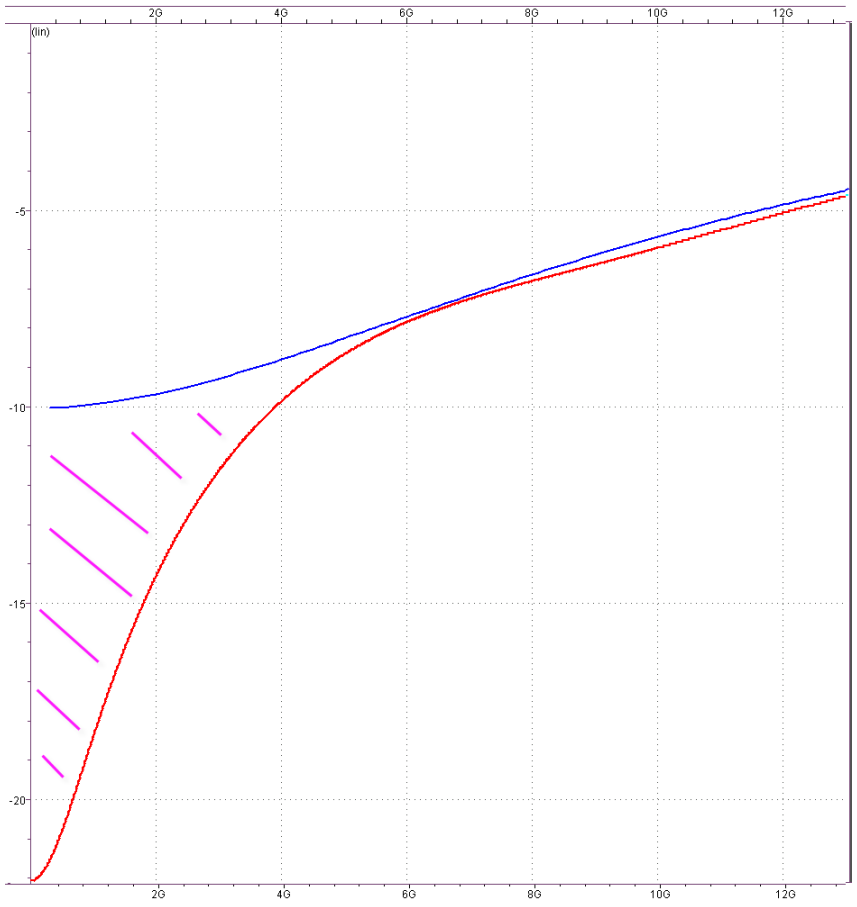
Correlated Synthetic Model as Ball

- A correlation was performed between HFSS extracted ball discontinuity and a synthetic model

So what is wrong with the model?

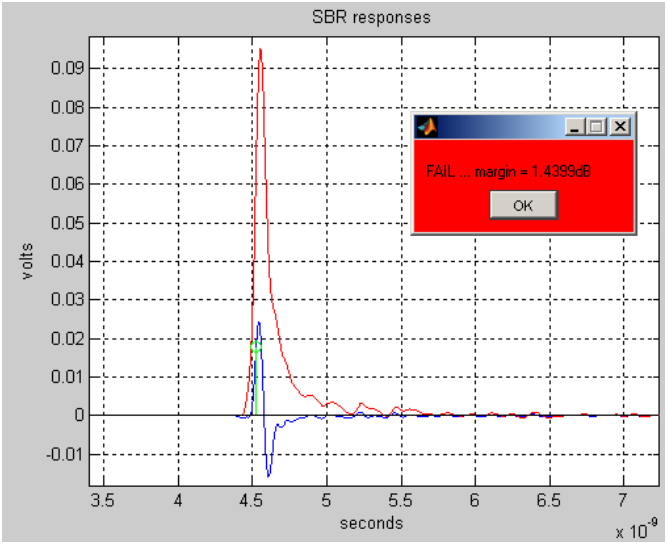
- The package return loss equation did not represent the real reflection from a package, taking non reasonable margin at the low frequency.
- The package insertion loss was accounted for twice (Tx, Rx), while 800mV should be defined at TP0

  ➔ If including a package IL model, include only Rx PKG insertion loss.



Main Observation @ 1e-12 (return loss impact)

- Running the IBM 30dB interconnect – (meets the interconnect RL with minor violations) + OIF package / D1.2 package return loss returns a failing COM result w/o FEC.
- ➔Specifying the OIF targets as PKG and interconnect return loss limits does not guarantee a passing COM result.
  - Note: no package insertion loss model was included in the analysis.



Patel 30dB through interconnect

- "What if" analysis performed on the "Patel" 30dB through interconnect.

PKG return loss	PKG insertion loss	Interconnect return loss	COM result
OIF	D1.2	Original	2.44dB (10^-12)
Slide #7	D1.2	Original	2.48dB (10^-12)
Slide #7	None	Original	3.49dB (10^-12)
Slide #7	D1.2	Lower reflection magnitude by 20%	**3.05dB** (10^-12)
Slide #7	D1.2	Original	**5.85dB (10^-5)**
Slide #7	D1.2	Original	**4.88dB (10^-5 & full Xtalk)**

IBM ~36dB interconnect

- "What if" analysis performed on 35db_Loss_channel.zip.

PKG return loss	PKG insertion loss	Interconnect return loss	COM result
Slide #7	D1.2	Original	-2.22dB (10^-12)
Slide #7	D1.2	Original	1.66dB (10^-5)
Slide #7	D1.2	Original	**3.21dB (10^-5) –** Tweaking the Tx settings
Slide #7	D1.2	Magnitude lowered by 20%	**3.51dB (10^-5) –** Tweaking the Tx settings

- 6-9mV available signal is "scary" low…
- With very low signal every "minor" effect is magnified. This indicates a border line case putting us on an "edge of a cliff"
- Results indicate the PKG return loss and IL models are "good enough" to meet target.
- It is most important to verify that the interconnect provides the required COM value under worst case manufacturing tolerance.

Note: Post tap was limited to -0.2

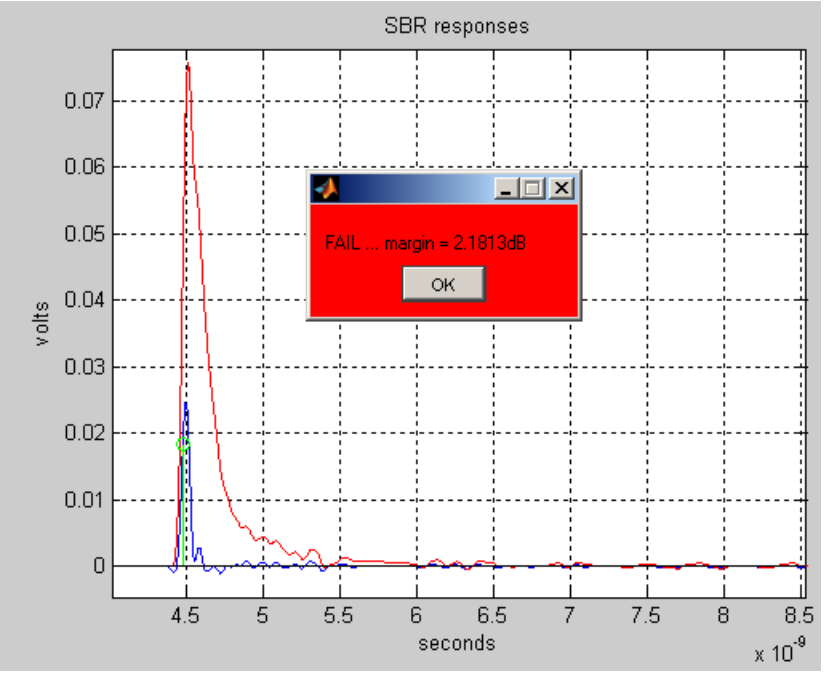
Strada Whisper Interconnects

- Running Strada Whisper interconnects with PKG RL, PKG IL and full XTalk. Modeling.

Interconnect	PKG insertion loss	FEC (1e-12 / 1e-5)	COM result
42p8in - Meg6	D1.2	Yes	6.4dB
42p8in - Meg6	D1.2	No	3.12dB
29.8dB – Nelco 6	D1.2	Yes	4.56dB

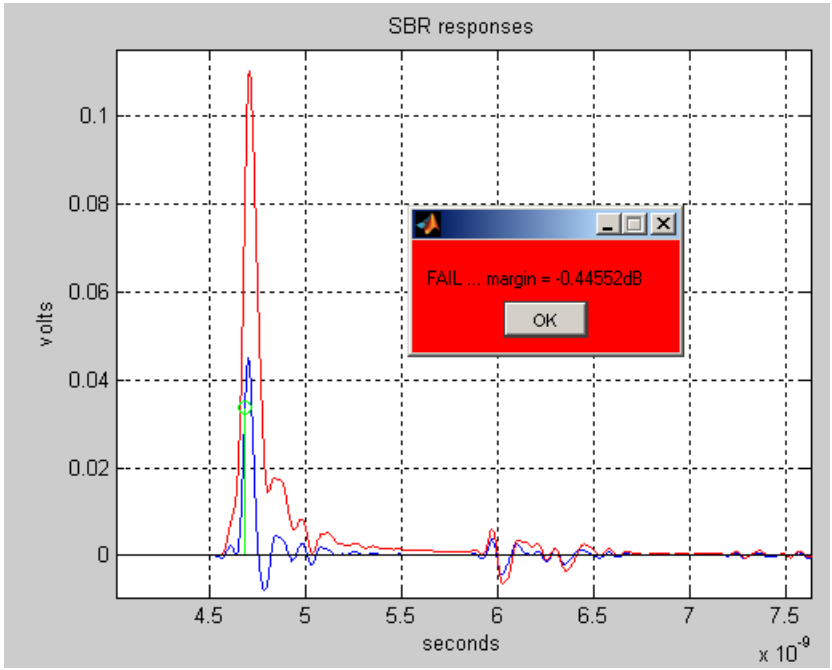
IBM30dB - An Improved PKG Return Loss

- Running the IBM 30dB channel with an improved (low frequency) PKG return loss (no PKG ins loss) returns a failing COM result (2.18dB)



FCI - Would a 200fF related PKG return loss help?

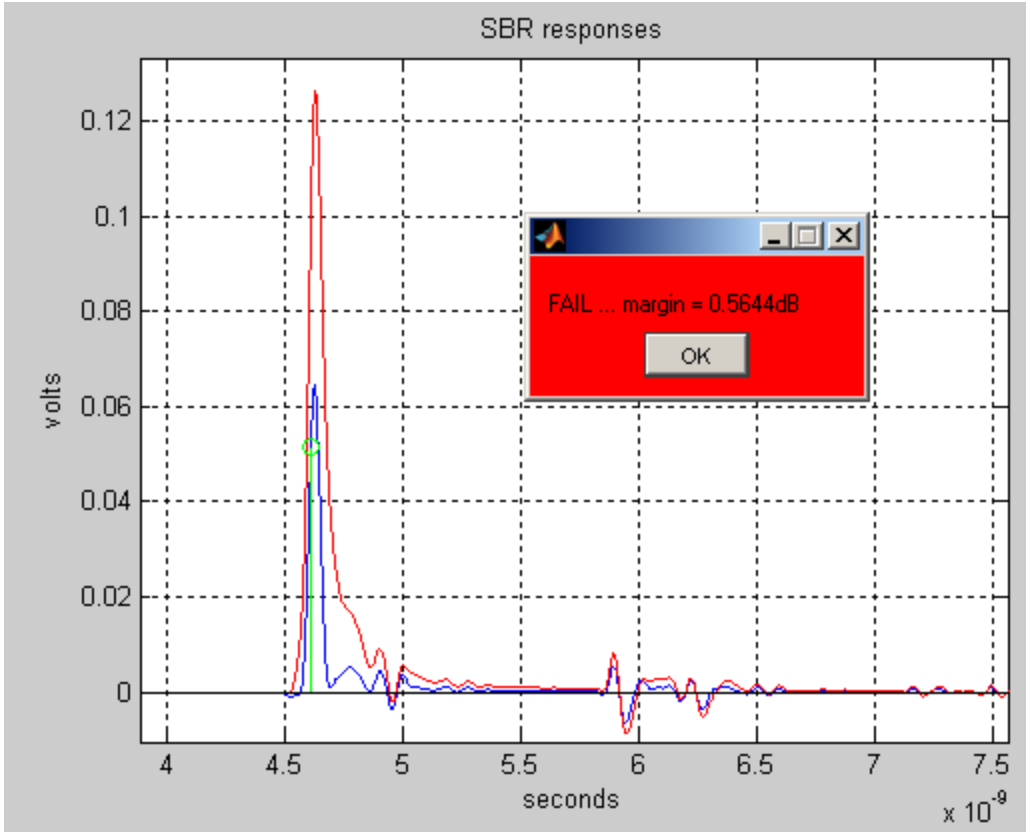
- Changing the PKG return loss to a "better" one that correlates to 200fF @ the die:



- No major effect…

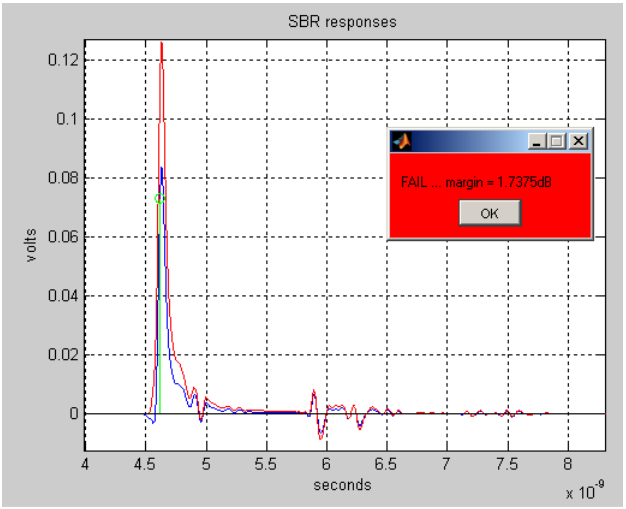
FCI - Is the PKG model the problem here?

- No! low effect of the PKG model



FCI - Pre-Cursor TAP Increased

- No PKG IL, Better PKG RL, pre-cursor tap limited to -0.3 instead of -0.1…
- Still not enough…
- Most of the analysis was performed with VTF = 1 (which is easier), but still it was not enough…
  Will be discussed on a later slide.



- *Conclusion: Need to tighten Return loss or rely on FEC…*

What is the amount of needed COM margin?

- Based on ran_01_0712.pdf (Adee Ran – July 2012)

COM calculation

COM = 20*log10(S/I_peak) – Allowance

- Allowance set to 8 dB, comprised of:
  - ~~2 dB for TX jitter & distortion~~ Integrated in the code
  - 1.5 dB for RX jitter & distortion
  - 1.5 dB for RX sensitivity
  - 3 dB for RX package loss and xtalk effects
    - Can be reduced with more accurate package model — Integrated in the code
- Final allowance factors may vary
  - May also be different for NRZ and PAM4