# Package Modeling and Return Loss Limits

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# Supporters

- Your name can be here ☺

# Agenda

- Present the target and motivation
- Discuss package models that were used for the analysis
- Discuss suggested package insertion loss and return loss equations for COM code
- Suggest remedies to related comments

# Target and Motivation

- COM code used to evaluate interconnects lacks a representation of device package effects.
- To have a more accurate assessment of interconnects we suggest adding:
  - Package insertion loss representation equation
  - Package return loss representation equation
  - Return loss limit @TP0a to correspond with return loss equation of the COM code

# Package Models Used for the analysis

- Synthetic model were used to represent the package
- Discontinuities taken into account at both ends on the package – Die side & ball side.
  - 0.25pF was taken as die side parasitic capacitance (correlates to former suggestions).
  - Ball discontinuity was correlated to HFSS extraction results.
- Package trace took into account manufacturing tolerance inaccuracy.
- Die impedance accuracy = ±5%
- In correlation to former PAM2 feasibility presentations package insertion loss @ Fb/2 was limited to ~2.5dB

# Package Insertion Loss Modeling

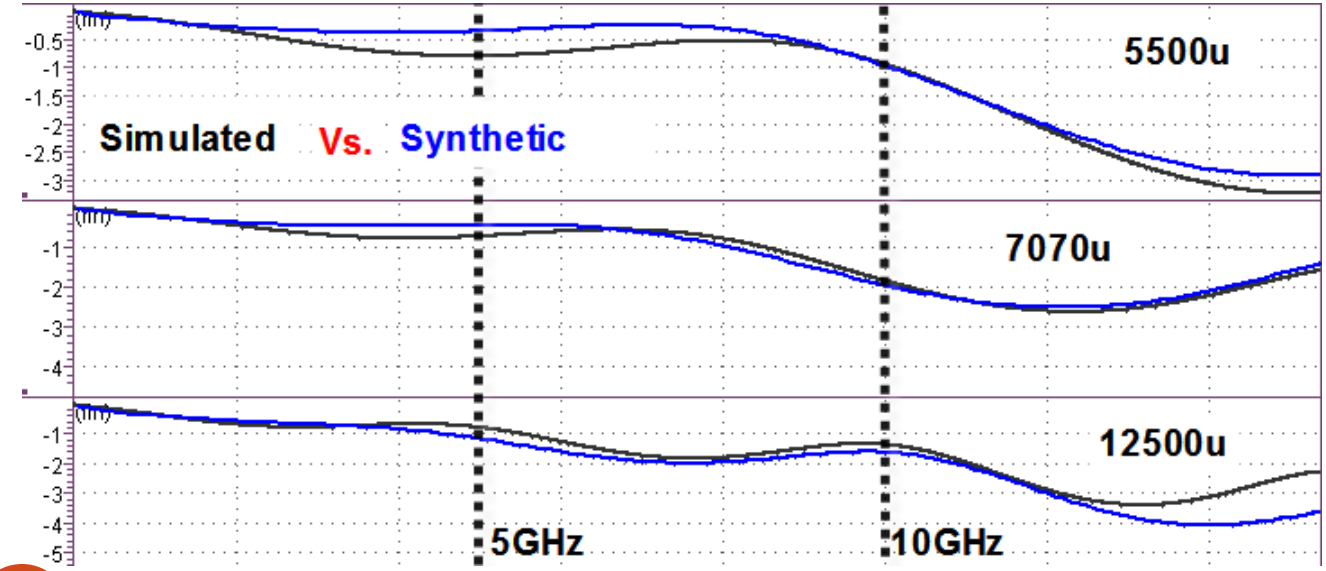
- An analytic equation is meant to represent package insertion loss including loss and package level multiple reflections.
- The insertion loss equation is not meant to represent a reference package frequency domain limit.
- The insertion loss equation represents the package SNR impact.

# Insertion Loss Equation Basics

- The insertion loss equation is based on a representation of pure frequency dependent loss + representation of package level distortion.
  - $IL_{dB}(f) = -Lpkg\left(a_0 * \sqrt{f} + a_1 * f + a_2 * f^2\right)$
  - $ILP(f) = 10^{\frac{IL_{dB}(f)}{20}} * e^{\frac{-j*2*\pi*f*lpkg}{Velocity}}$
  - Distortion due to multiple reflections:
  - $HP_{tx}(f) = HP_{rx}(f) = \frac{ILP(f)}{1-((G_d(f)+G_b(f))*\Gamma_{tl}+(G_d(f)*G_b(f))*(ILP(f)^2-{\Gamma_{tl}}^2))}$
  - $G_d(f) = \frac{-j*2500*2*\pi*f*C_d}{100+j*2500*2*\pi*f*C_d}$
  - $G_b(f) = \frac{-j*2500*2*\pi*f*C_b}{100+j*2500*2*\pi*f*C_b}$

# Insertion Loss Model – Simulation Correlation

- The parameters of the mathematical representation were optimized according to simulation results (and may be further tweaked).
- Mathematical model was shown to have a reasonable correlation to the simulated insertion loss.
- Reference code in backup slides




| Parameter | Value |
|---|---|
| A0 | 8E-10 |
| A1 | 4.2E-15 |
| A2 | 5.1E-25 |
| Velocity | 182E12 |
| Die_cap | 0.25pF |
| Ball_cap | 0.22pF |

# Voltage gain for package inclusion into channel gain depends on package/die model

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

Gain based on waves

$$H_{21}proposed2 = \frac{S_{21}\,(1 + \Gamma_{RX})(1 - \Gamma_{TX})}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

Gain based on ideal voltage source

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

Gain based in voltage source with parallel RC

$$H_{21}proposed4 = \frac{S_{21}\,(1 - \Gamma_{TX})}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

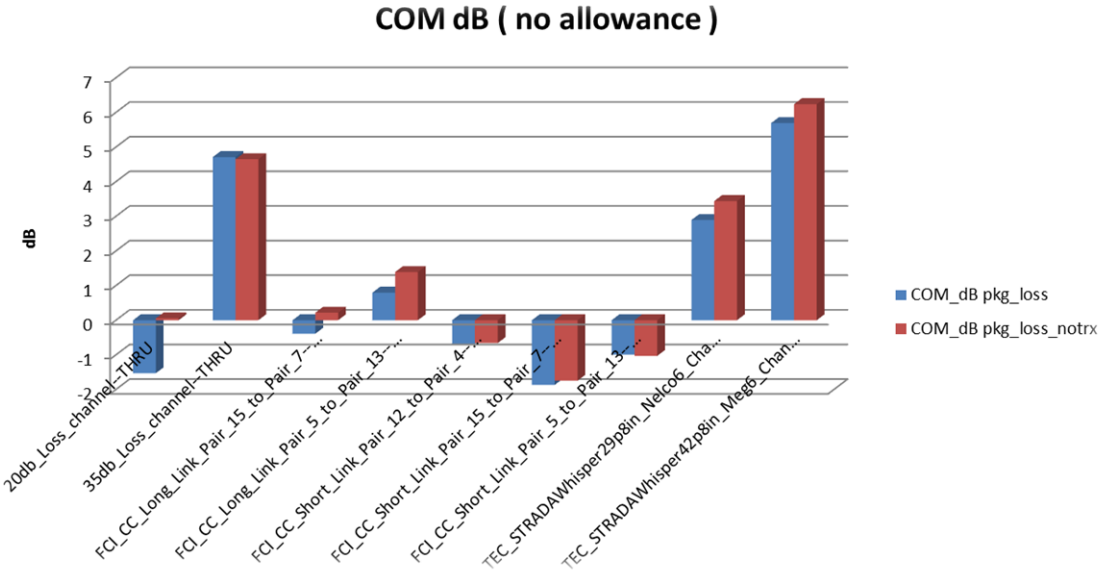
Gain based voltage source with series R and C parallel with channel

To be resolved by consensus

All following data used proposal 1 (only expect 1dB difference between any of the methods)

# Comment 130: Risetime filter

- It can be seen that the when the package is considered in the channel rise time impact is < 1dB of COM on passing channels
- Gamma = 0.315 F=.8Fb package model and h21(f) proposal 1 used
- Added pkg. loss to through and crosstalk channels
- Recommendation: Keep risetime filter.



# Return Loss Limits and Model for COM

- Package return loss simulations were compared to several possible limits using

$$RL \geq 20\log_{10}\left(ABS\left|\frac{Gamma - \left(i\frac{f}{F1}\right)}{1 + \left(i\frac{f}{F1}\right)}\right|\right)$$

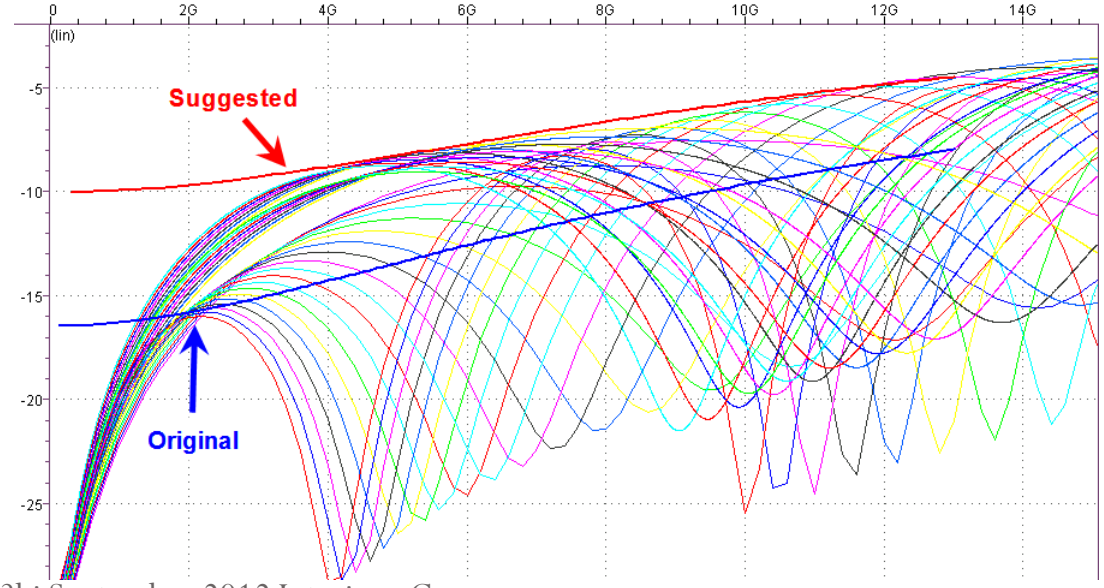
- The return loss limit equation was used in the COM code to determine the SNR impact amount.

$$RL = \left(\frac{Gamma - \left(i\frac{f}{F1}\right)}{1 + \left(i\frac{f}{F1}\right)}\right)$$

- ➔ recommend Gamma and F1 values for the return loss equation in the COM code.
- Extrapolate the Gamma and F1 values from TP0 to TP0a and suggest return loss equation limits.

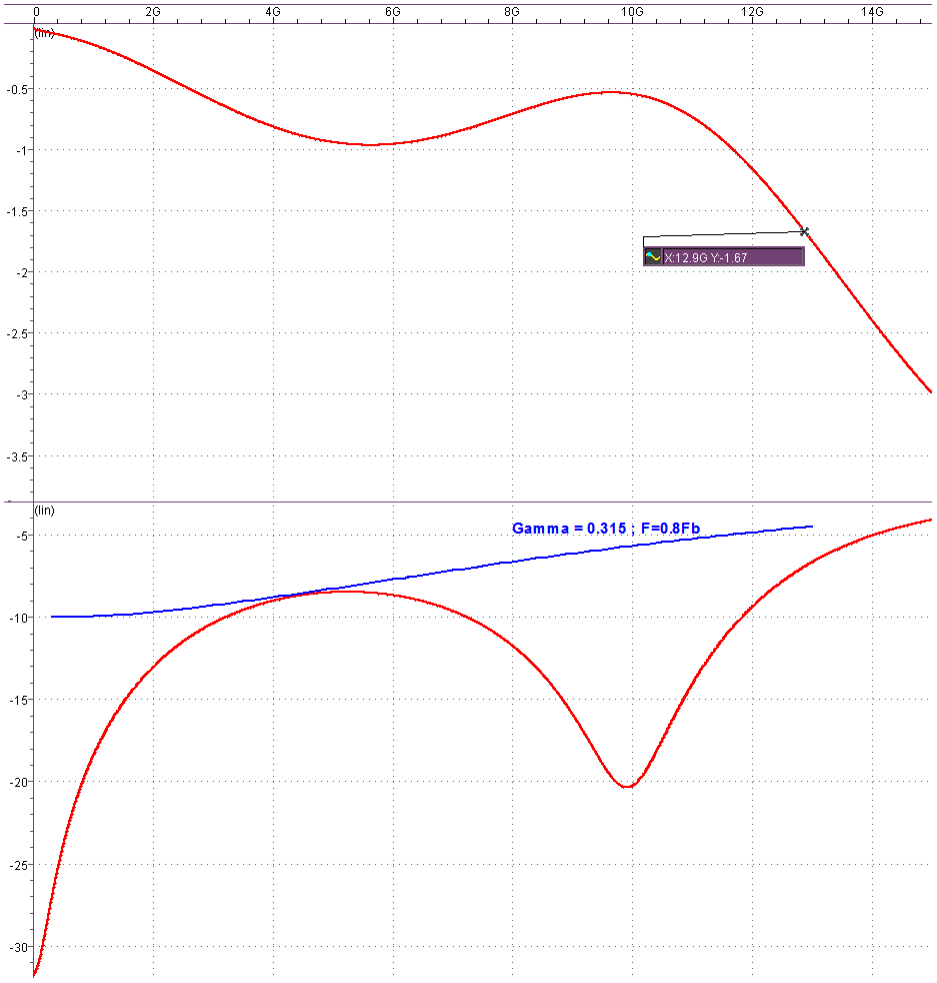
# Return Loss Target COM Analysis

- Reference return loss was proven to be non feasible in real case package.
- The recommendation for return loss equation is: Gamma = 0.315 & F=0.8Fb
- The suggested return loss impact was very similar to other return loss suggestions, which could limit package optimization possibilities.



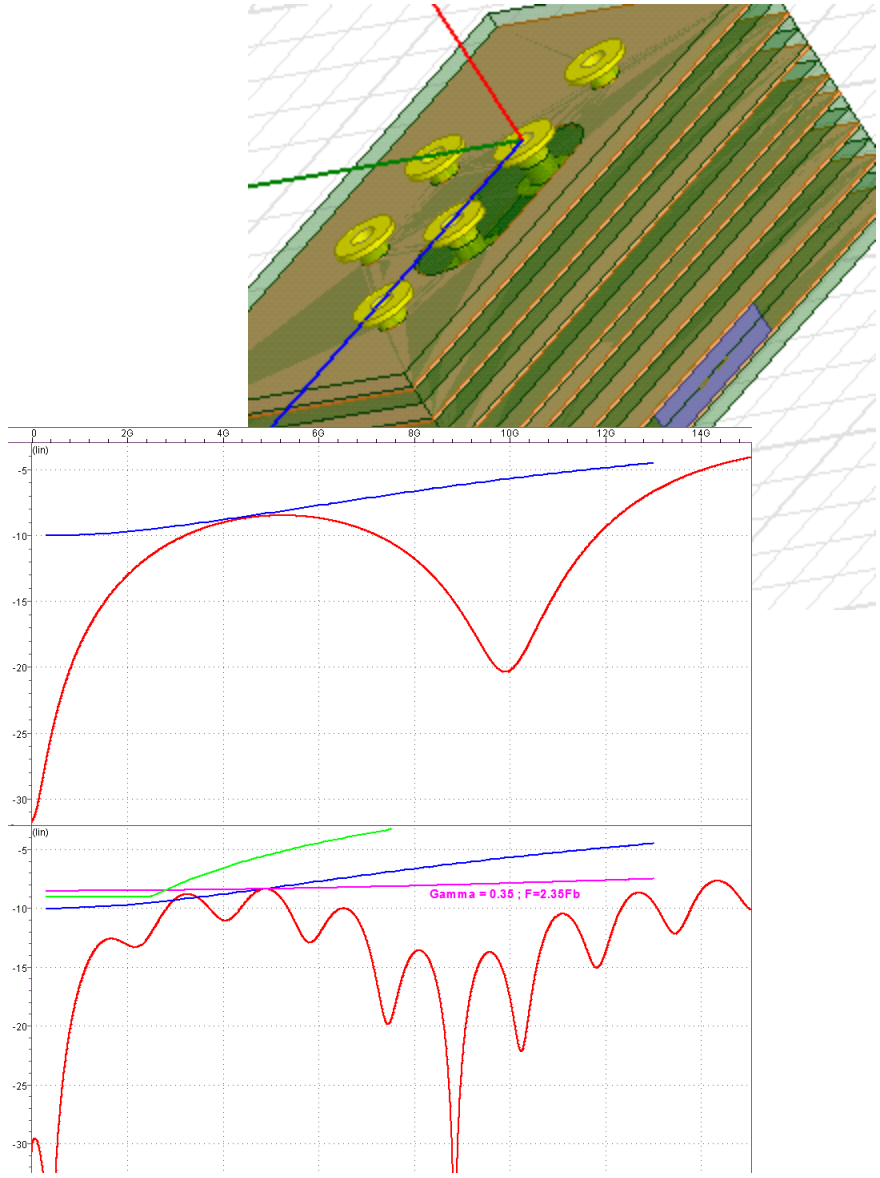
# Package Suggested Return Loss Limit

- Examine the return loss of the following package:
- Package designed to have:
  - Return loss meets: (Gamma = 0.315 ,F1=0.8Fb)
  - Loss @Fb/2 <2.5dB (easy to get lower loss @ Fb/2)
- Recommend PAM4 to follow the same target with max freq = 10GHz (third harmony of 3300…)



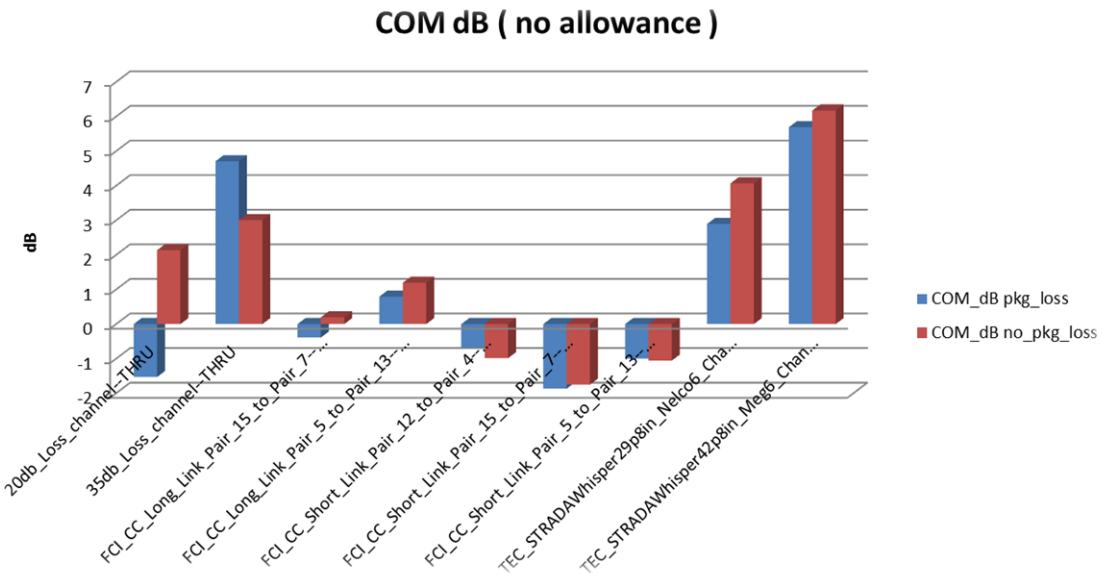
# Package Suggested Return Loss TP0a Limit.

- Recommend measured return loss limit as measured through a fixture that correlates to BenArtsi_01_0912
  - Gamma = 0.35
  - F=2.35Fb
- Low frequency updated upward to allow multi-reflection between chip and interconnect.
- High frequency updated downward to account for fixture loss.
- Correlates to (Gamma = 0.315 ,F1=0.8Fb) on device pins.



# Package Insertion Loss Affects COM

- Gamma = 0.315 F=.8Fb package model and h21(f) proposal 1 used
- Added pkg. loss to through and crosstalk channels
- > 1 dB impact on some channels is uniquely colored by combination of ILD, crosstalk, and loss
  - Not obvious without detailed examination of ILD, crosstalk, and losses, detailed data in backup



# Conclusions / recommendations

- Comment 130 (double counting rise time filtering)
  - Recommend: Keep tx filter
- Comments 168 & 169 & 422 (package return loss model)
  - Correct Equations 93-a3 and 93-a4 to follow eq. on slide 11 and Mellitz_01_0712 slide 13 which are equivalent (reasoning on slide 19)
  - Recommend: Use corrected equation 93a-3 with Gamma = 0.315 ; F1 = 0.8Fb
- Comment 167 & 171 (measured return loss limit @TP0a / TP5a)
  - Recommend: Use eq. of slide 11 with the following values: Gamma = 0.35 ; F1 = 2.35
- Comment 170 & 422 – (Package insertion loss model)
  - Recommend: Add package insertion loss equation according to slide 7 with coefficients according to slide 8.

Thank you

# Backup slides

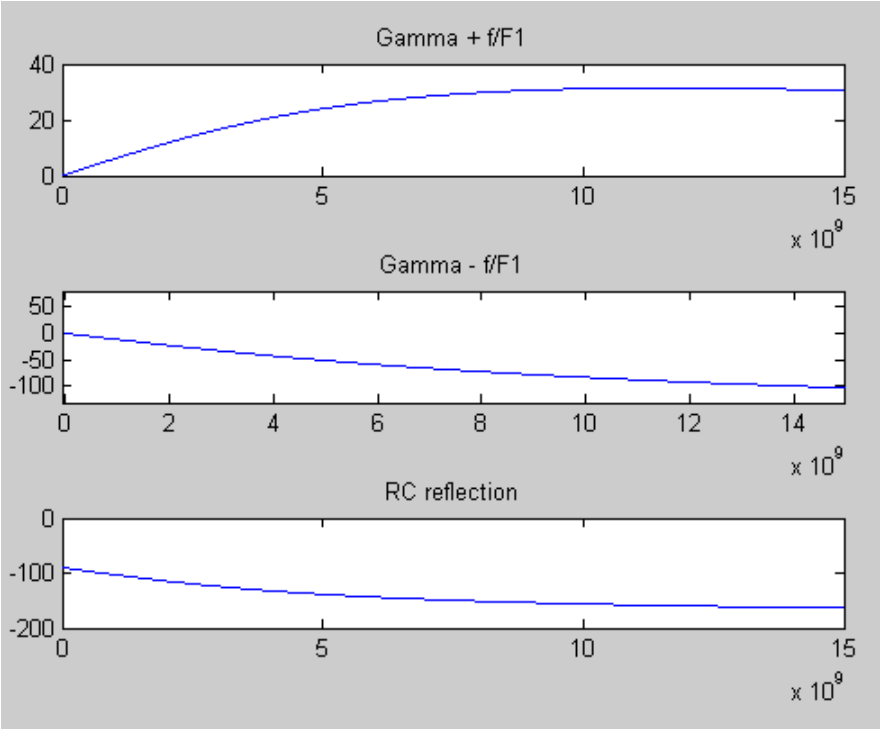
# Why Fix Eq. 93-A3

- To get the phase to behave similarly to reflection from a capacitive load change:

$$RL = \left( \frac{Gamma + \left( i \frac{f}{F1} \right)}{1 + \left( i \frac{f}{F1} \right)} \right)$$

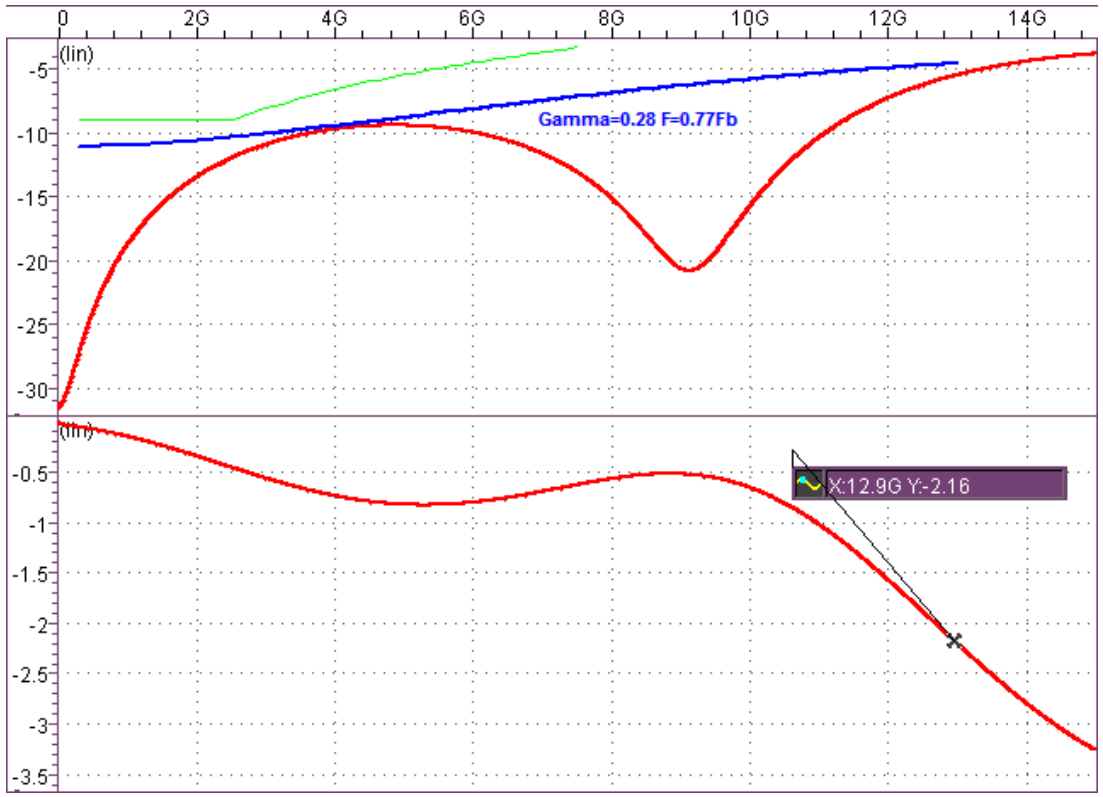
to:

$$RL = \left( \frac{Gamma - \left( i \frac{f}{F1} \right)}{1 + \left( i \frac{f}{F1} \right)} \right)$$



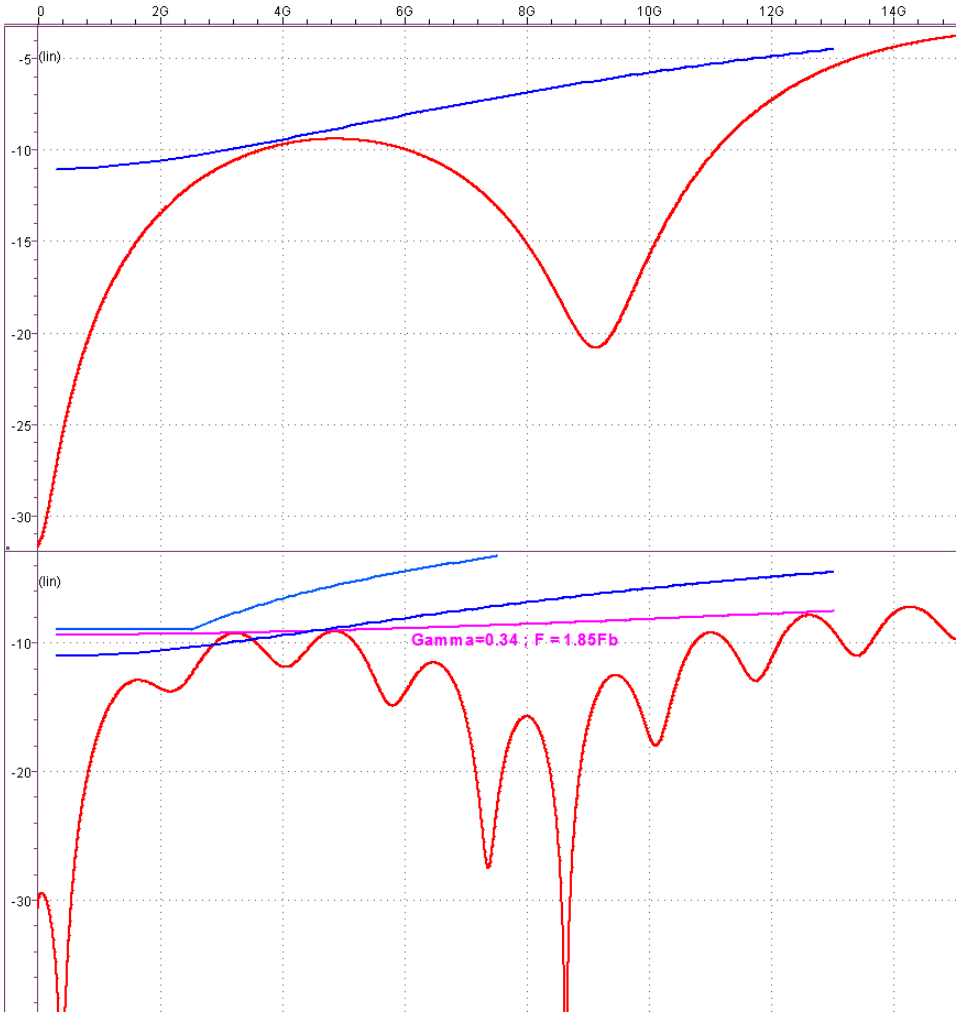
# Package Return Loss Limit option #2

- Examine the return loss of the following package:
- Package designed to have:
  - Return loss meets: Li (0.28 ,0.77Fb)
  - Loss @Fb/2 <2.5dB



# Package Return Loss Option #2 – TP0a Limit

- Suggested measured return loss limit:
  - Gamma = 0.34
  - F=1.85Fb
- Low frequency updated upward to allow multi-reflection between chip and interconnect.
- High frequency updated downward to account for fixture loss.
- Correlates to Li (0.28 ,0.77Fb) at device pins.



# Reference code

```
a0 = 8e-10;
a1 = 4.2E-15;
a2 = 5.1e-25;
Length =    ; % insert value in microns
Vel = 182E12;
C_die = 0.25e-12;
C_ball = 0.22e-12;
Pure_Loss_dB = -Length * (a0*sqrt(f) + a1*f + a2*f.^2);
Pure_Loss = 10.^(Pure_Loss_dB / 20) .* exp(-1i*2*pi*f*Length/Vel);
G_die = -2500*1i*2*pi*f*C_die./(100+2500*1i*2*pi*f*C_die);
G_ball = -2500*1i*2*pi*f*C_ball./(100+2500*1i*2*pi*f*C_ball);
S11 = 0.056;
S22 = S11;
H_f = Pure_Loss ./ (1 - (G_die.* S11 + G_ball.*S22 + G_die.*G_ball.*Pure_Loss.^2 -
G_die.*G_ball.*S11.*S22));
```

# Data: pkg loss, pkg loss no trf filter, no pkg loss

## No pkg loss, Trf filter

| File set | COM_dB no_pkg | peak_inte | peak_char | peak_ISI_ | peak_MDI | ICN | peak_MDI | peak_MDI | fit_loss_d | IL_loss_dE | ILD RMS | available_ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20db_Loss_channel--THRU | 2.14 | 25.90 | 22.70 | 20.10 | 6.20 | 2.94 | 0.00 | 6.20 | 22.44 | 24.11 | 0.91 | 33.12 |
| 35db_Loss_channel--THRU | 3.01 | 8.20 | 6.80 | 6.20 | 0.60 | 1.23 | 0.00 | 0.60 | 33.60 | 36.00 | 1.03 | 11.59 |
| FCI_CC_Long_Link_Pair_15_to_Pair_7--FCI_CC_Long_Link_Pair_15_to_Pair_7_Through | 0.20 | 58.10 | 52.40 | 48.10 | 12.30 | 2.32 | 10.90 | 2.00 | 17.96 | 16.78 | 1.34 | 59.42 |
| FCI_CC_Long_Link_Pair_5_to_Pair_13--FCI_CC_Long_Link_Pair_5_to_Pair_13_Through | 1.19 | 55.80 | 49.50 | 44.60 | 12.10 | 2.54 | 10.40 | 2.30 | 17.61 | 15.71 | 1.03 | 64.03 |
| FCI_CC_Short_Link_Pair_12_to_Pair_4--FCI_CC_Short_Link_Pair_12_to_Pair_4_Through | -0.99 | 259.40 | 236.70 | 233.10 | 24.20 | 5.24 | 17.20 | 12.80 | 3.37 | 3.00 | 1.60 | 231.57 |
| FCI_CC_Short_Link_Pair_15_to_Pair_7--FCI_CC_Short_Link_Pair_15_to_Pair_7_Through | -1.75 | 272.60 | 251.20 | 247.10 | 26.90 | 5.46 | 19.80 | 14.30 | 3.33 | 2.06 | 2.08 | 222.84 |
| FCI_CC_Short_Link_Pair_5_to_Pair_13--FCI_CC_Short_Link_Pair_5_to_Pair_13_Through | -1.05 | 271.80 | 248.00 | 240.90 | 31.90 | 7.10 | 20.30 | 20.20 | 3.12 | 4.26 | 1.68 | 240.73 |
| TEC_STRADAWhisper29p8in_Nelco6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whi | 4.07 | 7.30 | 5.70 | 2.30 | 3.40 | 1.38 | 2.80 | 0.60 | 34.19 | 34.98 | 0.33 | 11.66 |
| TEC_STRADAWhisper42p8in_Meg6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whisp | 6.18 | 10.00 | 7.50 | 3.70 | 3.80 | 1.59 | 2.60 | 1.20 | 26.83 | 27.28 | 0.27 | 20.36 |

## Pkg loss, Trf filter

| File set | COM_dB p | peak_inte | peak_char | peak_ISI_ | peak_MDI | ICN | peak_MDI | peak_MDI | fit_loss_d | IL_loss_dE | ILD RMS | available_ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20db_Loss_channel--THRU | -1.53 | 17.50 | 16.20 | 14.80 | 2.60 | 2.94 | 0.00 | 2.60 | 22.44 | 24.11 | 0.91 | 14.67 |
| 35db_Loss_channel--THRU | 4.71 | 3.90 | 2.90 | 2.90 | 0.00 | 1.23 | 0.00 | 0.00 | 33.60 | 36.00 | 1.03 | 6.71 |
| FCI_CC_Long_Link_Pair_15_to_Pair_7--FCI_CC_Long_Link_Pair_15_to_Pair_7_Through | -0.39 | 27.70 | 25.10 | 22.00 | 5.50 | 2.32 | 4.90 | 0.60 | 17.96 | 16.78 | 1.34 | 26.49 |
| FCI_CC_Long_Link_Pair_5_to_Pair_13--FCI_CC_Long_Link_Pair_5_to_Pair_13_Through | 0.80 | 25.90 | 22.90 | 18.40 | 5.70 | 2.54 | 4.60 | 1.10 | 17.61 | 15.71 | 1.03 | 28.38 |
| FCI_CC_Short_Link_Pair_12_to_Pair_4--FCI_CC_Short_Link_Pair_12_to_Pair_4_Through | -0.68 | 165.50 | 150.50 | 148.70 | 13.40 | 5.24 | 8.80 | 6.80 | 3.37 | 3.00 | 1.60 | 153.06 |
| FCI_CC_Short_Link_Pair_15_to_Pair_7--FCI_CC_Short_Link_Pair_15_to_Pair_7_Through | -1.87 | 179.70 | 165.80 | 163.70 | 15.70 | 5.46 | 10.70 | 8.60 | 3.33 | 2.06 | 2.08 | 144.93 |
| FCI_CC_Short_Link_Pair_5_to_Pair_13--FCI_CC_Short_Link_Pair_5_to_Pair_13_Through | -0.99 | 175.10 | 159.70 | 156.10 | 18.00 | 7.10 | 10.10 | 12.10 | 3.12 | 4.26 | 1.68 | 156.17 |
| TEC_STRADAWhisper29p8in_Nelco6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whispe | 2.89 | 4.40 | 3.60 | 1.60 | 2.00 | 1.38 | 1.80 | 0.20 | 34.19 | 34.98 | 0.33 | 6.14 |
| TEC_STRADAWhisper42p8in_Meg6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whisper | 5.69 | 5.40 | 3.90 | 1.70 | 2.20 | 1.59 | 1.60 | 0.60 | 26.83 | 27.28 | 0.27 | 10.40 |

## Pkg loss, no Trf filter

| File set | COM_dB p | peak_inte | peak_char | peak_ISI_ | peak_MDI | ICN | peak_MDI | peak_MDI | fit_loss_d | IL_loss_dE | ILD RMS | available_ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20db_Loss_channel--THRU | 0.05 | 19.30 | 17.40 | 15.80 | 3.60 | 3.14 | 0.00 | 3.60 | 22.44 | 24.11 | 1.22 | 19.42 |
| 35db_Loss_channel--THRU | 4.65 | 4.20 | 3.20 | 3.10 | 0.10 | 1.28 | 0.00 | 0.10 | 33.60 | 36.00 | 1.44 | 7.17 |
| FCI_CC_Long_Link_Pair_15_to_Pair_7--FCI_CC_Long_Link_Pair_15_to_Pair_7_Through | 0.22 | 33.30 | 29.90 | 26.60 | 6.70 | 2.39 | 5.90 | 0.80 | 17.96 | 16.78 | 1.64 | 34.14 |
| FCI_CC_Long_Link_Pair_5_to_Pair_13--FCI_CC_Long_Link_Pair_5_to_Pair_13_Through | 1.39 | 31.80 | 28.00 | 24.40 | 6.20 | 2.64 | 4.60 | 1.60 | 17.61 | 15.71 | 1.22 | 37.32 |
| FCI_CC_Short_Link_Pair_12_to_Pair_4--FCI_CC_Short_Link_Pair_12_to_Pair_4_Through | -0.66 | 188.50 | 171.20 | 169.00 | 15.40 | 5.53 | 9.00 | 9.60 | 3.37 | 3.00 | 1.90 | 174.70 |
| FCI_CC_Short_Link_Pair_15_to_Pair_7--FCI_CC_Short_Link_Pair_15_to_Pair_7_Through | -1.75 | 204.10 | 188.00 | 185.50 | 17.70 | 5.69 | 11.20 | 10.70 | 3.33 | 2.06 | 2.55 | 166.90 |
| FCI_CC_Short_Link_Pair_5_to_Pair_13--FCI_CC_Short_Link_Pair_5_to_Pair_13_Through | -1.03 | 200.50 | 182.70 | 178.00 | 21.70 | 7.44 | 11.20 | 15.70 | 3.12 | 4.26 | 1.96 | 178.06 |
| TEC_STRADAWhisper29p8in_Nelco6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whi | 3.44 | 4.60 | 3.60 | 1.60 | 2.00 | 1.39 | 1.80 | 0.20 | 34.19 | 34.98 | 0.41 | 6.84 |
| TEC_STRADAWhisper42p8in_Meg6_Channel_IEEE802_3_100GbCu_04282011--TEC_Whis | 6.24 | 5.70 | 4.00 | 1.80 | 2.20 | 1.61 | 1.60 | 0.60 | 26.83 | 27.28 | 0.31 | 11.69 |

| Parameter | Setting |
|---|---|
| Coding/Port Type | NRZ Clause 93 D1.1 |
| Unit Interval (UI) | 3.87879E-11 |
| tx_ffe | [.1 .4] |
| ndfe | 12 |
| max_ctle | 12 |
| a_thru | 0.4 |
| a_fext | 0.4 |
| a_next | 0.6 |
| AG | 1 |
| specBER | 1.00E-12 |
| Allowance | 0 |
| G_s_noise | 0.01 |
| g_dd_noise | 0.1 |
| Na_rms | 0 |
| Samples Per UI | 32 |
| Port Order | [1 3 2 4] |
| G01 | 0.315 |
| G02 | 0.315 |
| Fscale1 | 0.77 |
| Fscale2 | 0.77 |
| ctle_step | 1 |
| tx_ffe_step | 0.02 |
| maxc1 | 1 |
| maxcx | 1 |
| f_v | 0.55 |
| f_f | 0.55 |
| f_n | 1 |
| f_r | 0.75 |

| Config/Interface Types |
|---|
| NRZ Clause 93 |
| NRZ/FEC Clause 93 |
| PAM4 Clause 94 |
| NRZ Clause 93 D1.1 |
| NRZ/FEC Clause 93 D1.1 |
| PAM4 Clause 94 D1.1 |

| Operational Control | |
|---|---|
| INCLUDE_CTLE | 1 |
| INCLUDE_FILTER | 1 |
| DEBUG | 0 |
| DISPLAY_WINDOW | 1 |
| CSV_REPORT | 1 |
| SAVE_RESP | 0 |
| GET_FD | 1 |
| INC_PACKAGE | 1 |
| USE_EXTERNAL_PARAM | 0 |
| RESULT_DIR | \Pkg_loss\ |
| PKG_LOSS | 1 |

# COM spreadsheet for pkg. loss

| Parameter | Setting |
|---|---|
| Coding/Port Type | NRZ Clause 93 D1.1 |
| Unit Interval (UI) | 3.87879E-11 |
| tx_ffe | [.1 .4] |
| ndfe | 12 |
| max_ctle | 12 |
| a_thru | 0.4 |
| a_fext | 0.4 |
| a_next | 0.6 |
| AG | 1 |
| specBER | 1.00E-12 |
| Allowance | 0 |
| G_s_noise | 0.01 |
| g_dd_noise | 0.1 |
| Na_rms | 0 |
| Samples Per UI | 32 |
| Port Order | [1 3 2 4] |
| G01 | 0.315 |
| G02 | 0.315 |
| Fscale1 | 0.77 |
| Fscale2 | 0.77 |
| ctle_step | 1 |
| tx_ffe_step | 0.02 |
| maxc1 | 1 |
| maxcx | 1 |
| f_v | 3 |
| f_f | 3 |
| f_n | 3 |
| f_r | 0.75 |

| Config/Interface Types |
|---|
| NRZ Clause 93 |
| NRZ/FEC Clause 93 |
| PAM4 Clause 94 |
| NRZ Clause 93 D1.1 |
| NRZ/FEC Clause 93 D1.1 |
| PAM4 Clause 94 D1.1 |

| Operational Control | |
|---|---|
| INCLUDE_CTLE | 1 |
| INCLUDE_FILTER | 1 |
| DEBUG | 0 |
| DISPLAY_WINDOW | 1 |
| CSV_REPORT | 1 |
| SAVE_RESP | 0 |
| GET_FD | 1 |
| INC_PACKAGE | 1 |
| USE_EXTERNAL_PARAM | 0 |
| RESULT_DIR | g_loss_notrx\ |
| PKG_LOSS | 1 |

# COM spreadsheet for pkg. loss no risetime filter