A path forward following lack of complete consensus on COM package models

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Contributor: Based on former work done by Richard Mellitz and jointly presented in benartsi_3df_01_2211
Agenda

- Recap on package model as presented Nov 2022

- What can we agree upon?! - Justifying model construction

- Package material loss consensus discussions ongoing, will be presented as part of consensus group presentation
Supporters

IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
Recap on Assumptions/Former Work

- A realistic package loss/mm for 40µ dielectric height + 27µ-45µ-27µ trace geometry was given as 0.21dB/mm (we will discuss possible cases of lowering loss); Other parts of the package model were optimistic - ~800µ core, 7-2-7 stack-up, no impedance manufacturing tolerance, etc.

- Routing of Tx, or Rx lanes can easily be 40-45mm long, or even longer in congestion cases – Length in this stage to be TBD

- 3D extraction was matched with a four sections package model for COM much better correlation than with 802.3ck model
  - The 4 sections are required to match higher frequency characteristics compared to 802.3ck. – Resulting COM run consistently better than when concatenating to extracted model (~0.2dB – probably some fine details are still left out when using matched model) – Slide #12
802.3dj suggested COM Model - Iteratively adjust $\gamma_0$, $a_1$, $a_2$, $\tau$

Also tune
- $Z_p$, $Z_c$, $C_b$, $C_p$

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**COM Model Results**

**COM MODEL: IEEE802.3 ANNEX 93A.1.2.3**

\[ \gamma_0 = 0, \ a_1 = 0.0008455, \ a_2 = 0.000340225, \ \tau = 0.00644805 \]

Die side

\[ C_b \]

\[ Z_{c1}, Z_{p1} \]

\[ Z_{c2}, Z_{p2} \]

\[ Z_{c3}, Z_{p3} \]

\[ Z_{c4}, Z_{p4} \]

\[ C_p \]

30ff 92 Ω, 12/30/45 mm 70 Ω, 1.0 mm 80 Ω, 1.0 mm 100 Ω, 0.5 mm 50ff

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Frequency Domain Comparison

(After concatenation, how well does the “model” channel match “HFSS” channel?)

Example case: 15 mm + 10 dB

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Time domain SBR comparison

Example case: 15 mm + 10 dB

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IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
## COM Config Settings

### Table 93A–3 parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>package_tl_gamma0_a1_a2</td>
<td>[0 0.0008455 0.000340225]</td>
<td></td>
</tr>
<tr>
<td>package_tl_tau</td>
<td>0.00644805</td>
<td>ns/mm</td>
</tr>
<tr>
<td>package_Z_c</td>
<td>[92 92; 70 70; 80 80; 100 100]</td>
<td>Ohm</td>
</tr>
</tbody>
</table>

### Example

<table>
<thead>
<tr>
<th>C_d</th>
<th>[0.4e-4 0.9e-4 1.1e-4; 0 0 0]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_s</td>
<td>[.12 .15 .14; 0 0 0]</td>
</tr>
<tr>
<td>C_b</td>
<td>[.3e-4 0]</td>
</tr>
<tr>
<td>z_p select</td>
<td>[1 2 3]</td>
</tr>
<tr>
<td>z_p (TX)</td>
<td>[12 30 45; 1 1 1; 1 1 1; 0.5 0.5 0.5]</td>
</tr>
<tr>
<td>z_p (NEXT)</td>
<td>[0 0 0; 0 0 0; 0 0 0; 0 0 0]</td>
</tr>
<tr>
<td>z_p (FEXT)</td>
<td>[12 30 45; 1 1 1; 0.1 0.1 0.1; 0.58 0.58 0.58]</td>
</tr>
<tr>
<td>z_p (RX)</td>
<td>[0 0 0; 0 0 0; 0 0 0; 0 0 0]</td>
</tr>
<tr>
<td>C_p</td>
<td>[0.5e-4 0]</td>
</tr>
</tbody>
</table>
## Test Cases

<table>
<thead>
<tr>
<th>Channels</th>
<th>$z_p=15$</th>
<th>$z_p=30$</th>
<th>$z_p=45$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2M_PCB_93ohms_10dB_202208016_v2_thru1.s4p</td>
<td>concat_pkg_15mm_pcb_10dB</td>
<td>concat_pkg_30mm_pcb_10dB</td>
<td>concat_pkg_45mm_pcb_10dB</td>
</tr>
<tr>
<td>C2M_PCB_93ohms_26dB_202208016_v2_thru1.s4p</td>
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<td>concat_pkg_45mm_pcb_26dB</td>
</tr>
</tbody>
</table>

Channels are from [akinwale_3df_elec_01_220921](akinwale_3df_elec_01_220921)

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COM Results Comparison

- COM results with the updated fitted model *(blue)* are consistently higher than with HFSS S-parameter concatenation *(green)*
  - The difference is usually 0.2-0.5 dB
  - The “shortest” combination is an exception

- For the high loss channel, the new model is closer to the HFSS results than the ck model *(red)*
  - For the low loss channel, the ck model had worse COM in 2 cases!

- The fitted model is somewhat optimistic...?
  - but in a more consistent way than the old model
Conclusions & Recommendations

- Providing a package model for COM to account for 200Gbps PAM4 signaling requires “high amount of” details in higher frequency than before
- Former .ck package model failed to supply required accuracy
- A suggested higher details model showed relatively consistent results compared to concatenated 3D extracted model
- Recommend adopting new, 4 TL model as the COM model; parameters yet to be decided according to consensus group work
Backup
Ali Ghiasi’s Suggested BGA Configuration

Hypothetical 512x200G Switch

- Likely will require 90x90 BGA
  - Provides V2 for FEXT pairs
  - Provides 2 balls separations for NEXT
  - For the hypothetical switch with 28x34 mm
    die results in 42 mm long substrate trace!

For the BGA ball grid assumed, see https://opg.optica.org/oe/fulltext.cfm?uri=oe-23-3-2085&id=310831

IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
No overhead was taken for CMOS, PCIe, or any addition signals.

Routing of Tx, or Rx lanes can easily be 40-45mm long, or even longer in congestion cases.
Expected Losses of Next Gen Material

- ghiasi_3df_01_220927.pdf: “benartsi_3df_01b_2207 uses best ABF conventional 27-45-27 μm construction and reports trace loss of 0.31 dB/mm @53 GHz (loss include transition via/BGA) • Benartsi loss expect to be lower ~0.22 dB/mm after accounting for improved surface roughness”

CK and Next Gen Package Losses for Reduced Trace Width

- Adjust trace width to 27 μm as suggested by benartsi_3df_01b_2207
  - Use the same Hurray surface roughness model that was previously matched best ABF film in 2018/2019
  - Reduced trace width may be required for some high radix switches implementations
  - Losses for 27 μm wide 92.5 Ω stripline traces
    - For best ABF film from 2018/2019 the CK 30 mm package trace loss is 3.94 dB or 0.13 dB/mm instead of assumed 0.109 dB/mm assumed loss @26.56 GHz
    - Next Gen 2022 ABF film the 30 mm package trace loss would be 5.6 dB or 0.19 dB/mm @53.1 GHz (6.75 dB or ~0.225 dB/mm 90°C).

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IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
Adjusted Extraction of Loss/mm

- 40µ dielectric height; 15µ copper thickness; 27µ-45µ-27µ trace geometry
- The resulting loss/mm ≈ 0.21dB
- Conductivity was updated to correlate and account for high temperature
- Correlates to the expected and measured loss/mm
S-parameter Concatenation (HFSS model)

Example case: 15 mm + 10 dB

IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
TDR Verification of the Concatenation

Example case: 15 mm + 10 dB

IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
COM model parameters
(pkg model added only at Tx/TP0 side)

**Table 93A**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
<th>Units</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIAGNOSTICS</strong></td>
<td>logical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_bg</td>
<td>3</td>
<td>0 1 2 or 3 groups</td>
<td></td>
</tr>
<tr>
<td>f_b</td>
<td>106.25</td>
<td>GBd</td>
<td></td>
</tr>
</tbody>
</table>

**DISPLAY_WINDOW**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
<th>Units</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_bf</td>
<td>3</td>
<td>taps per group</td>
<td></td>
</tr>
<tr>
<td>f_min</td>
<td>0.02</td>
<td>GHz</td>
<td></td>
</tr>
</tbody>
</table>

**CSV_REPORT**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
<th>Units</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>package_tl_gamma0_a1_a</td>
<td>8.455e-4</td>
<td>3.40225e-4</td>
<td></td>
</tr>
<tr>
<td>N_f</td>
<td>80</td>
<td>UI span for floating taps</td>
<td></td>
</tr>
<tr>
<td>Delta_f</td>
<td>0.02</td>
<td>GHz</td>
<td></td>
</tr>
</tbody>
</table>

**RESULT_DIR**

Path

Path: `package_Z_c` [92 92; 70 70; 80 80; 100 100] Ohm

bmaxg | 0.2 | max DFE value for floating taps |

**C_d** [40 90 110; 40 90 110] * 1e-6 nF [TX RX]

**SAVE_FIGURES**

0 | logical |

**ICN & FOM_ILD**

parameters

N_tail_start | 24 |

**COM_CONTRIBUTION**

0 | logical |

**f_n** | 0.371 | GHz |

**z_p select** [test cases to run]

**z_p (TX)** [0.13 0.15 0.14; 0.13 0.15 0.14] nH [TX RX]

**Port Order** [ 1 3 2 4 ]

**f_v** | 0.371 * Fb |

**B_float_RSS_MAX** | 0.1 |

**f_2** | 58.4375 | GHz |

**C_b** [30e-6 30e-6] nF [TX RX]

**RUNTAG**

**C2M_eval_** f_f | 0.371 | GHz |

**f_f** | 0.371 | GHz |

**z_p (NEXT)** [0 0 0; 0 0 0; 0 0 0; 0 0 0] mm [test cases]

**Operational**

A_ft | 0.600 | V |

**z_p (FEXT)** [15 30 45; 1 1 1; 1 1 1; 0.5 0.5 0.5] mm [test cases]

**COM Pass threshold** 3 | dB |

**A_nt** | 0.600 | V |

**z_p (RX)** [0 0 0; 0 0 0; 0 0 0; 0 0 0] mm [test cases]

**C_p** [50e-6 0] nF [TX RX]

**ERL Pass threshold** 7.3 | dB |

**Histogram_Window_Weigh**

Gaussian, triangle, rectangle

**R_0** | 50 | Ohm |

**sigma_r** | 0.02 | |

**R_d** [50 50] Ohm [TX RX]

**A_v** | 0.413 | V |

**T_r** | 6.00E-03 | ns |

**A_ne** | 0.608 | V |

**PMD_type**

C2C

**L** | 4 |

**BREAD_CRUMBS**

0 | logical |

**board_tl_tau** | 0.00579 | ns/mm |

**M** | 32 |

**Samp/UI**

**SAVE_CONFIG2MAT**

1 | logical |

**board_Z_c** | 100 | Ohm |

**samples_for_C2M** | 100 | Samp/UI |

**PLOT_CM**

0 | logical |

**z_bp (TX)** | 407 | mm |

**T_O** | 50 | mUI |

**TDR and ERL options**

**z_bp (NEXT)** | 407 | mm |

**AC_CM_RMS**

0 | V [test cases]

**TDR**

1 | logical |

**z_bp (FEXT)** | 407 | mm |

**filter and Eq**

**ERL**

1 | logical |

**z_bp (RX)** | 407 | mm |

**c(0)** | 0.5 | min |

**TR_TDR** | 0.01 | ns |

**c(-1)** [ -0.34:0.02:0 ] [min:step:max]

**N** | 1200 | |

**c(-2)** [0:0.02:0.14] [min:step:max]

**beta_x** | 0 |

**c(-3)** [ -0.06:0.02:0 ] [min:step:max]

**rho_x** | 0.618 |

**c(-4)** [ -0.06:0.02:0 ] [min:step:max]

**fixture delay time** [0 0] different for each test fixture

IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force
Thank You!