C_p Value Ratification

(A presentation in support of draft 1.4 comments #115, #116 and #117)

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Background and Recommendation

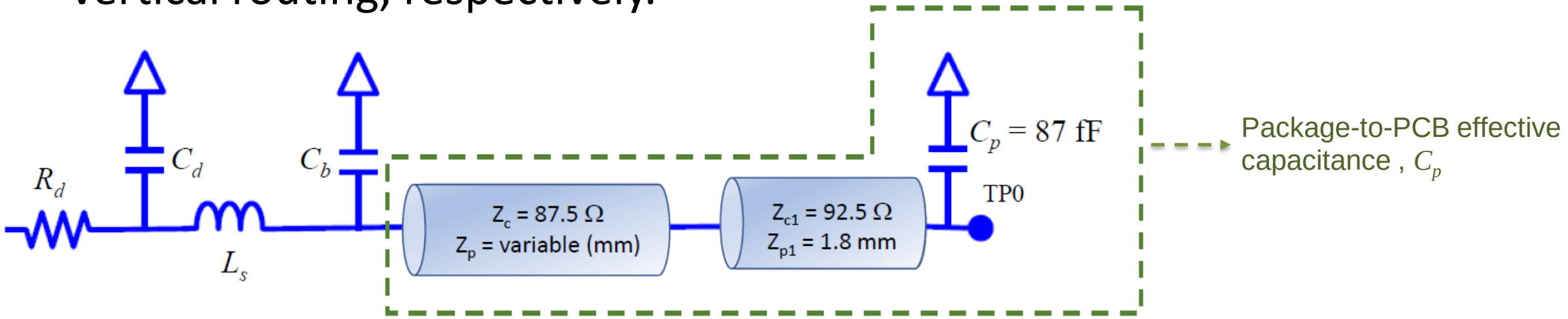
- Principles of transmission line equivalent circuit theory indicate that the quantity Cp should be reduced from 87 fF to 60 fF, as presented in the January 13 (2021) Ad Hoc meeting (bois_3ck_adhoc_01_011321)
  - See comments #115, #116 and #117 proposing change for C_p.

- Request was made for more data at the meeting.

- Data derived from rigorous simulation is provided in this current contribution in support of those three comments.

Current Topology for Refence Package

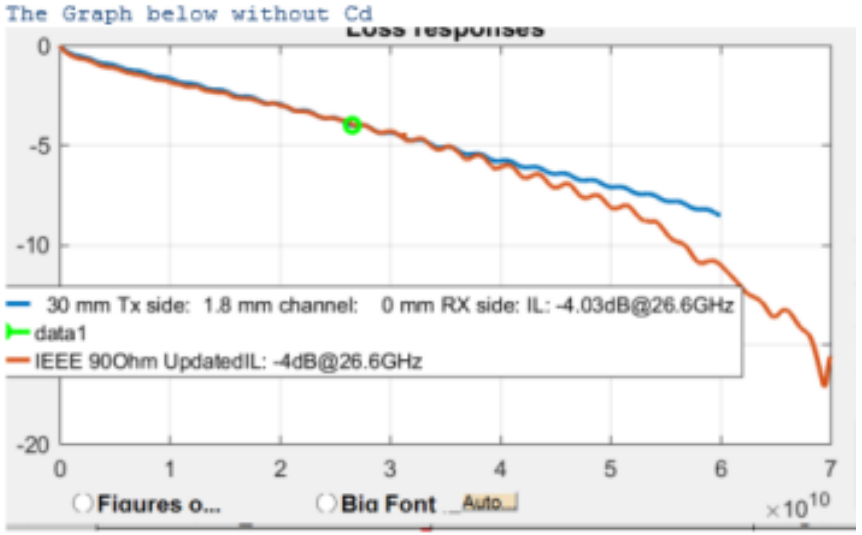
- R_d, C_d and L_s belong to the die.
- C_b is the die to package interface and includes the buildup vias.
- Series combination of two transmission lines for horizontal and vertical routing, respectively.



Mellitz, Richard, "COM 2.75 Update," IEEE 802.3 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Task Group Ad hoc, October 2 (2019)

Source of Current Values

- The following contribution is the source of the current package reference values, including Cp =87 fF: benartsi_3ck_adhoc_01_121218
- The main goal is to achieve: “Resulting loss ≈ 4dB @ Nyquist – Correlated to inputs”



Source: benartsi_3ck_adhoc_01_121218

Observation

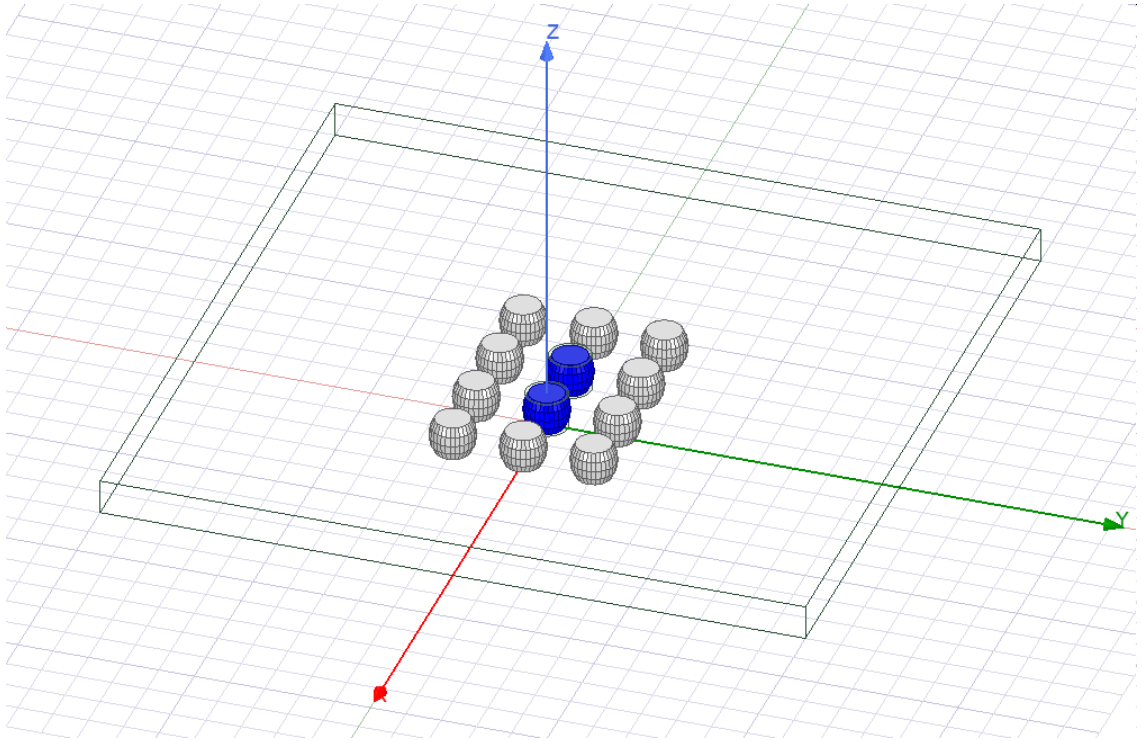
- Fitted insertion loss is a fit of S_{21} of the form, $IL_{fitted}(f) = a_1\sqrt{f} + a_2 f + a_4 f^2$, where the loose variables are meant to fit the raw insertion loss.
- This equation has a multiplicity of solution to obtain $IL_{fitted}(26.5GHz) = 4\ dB$.
- Moreover, the package reference model has 11 variables (e.g., C_d and C_p) which will lead to a composite package S_{21}.
- The target value is the result of the multivariate fit of a multivariate equation.
- Comments #115, #116, and #117 reduce the system of variables with a data driven value.

Full 3D Simulation

- Full 3D simulation of BGA fields with 0.8mm and 1mm pitch were conducted.
  - 1mm pitch BGA grid ➔ 600 microns BGA balls, and
  - 0.8mm pitch BGA grid ➔ 500 microns BGA balls.
- The modeling takes into consideration
  - Top and bottom flattening of the BGA ball,
  - Bulging of the BGA ball,
  - Effect of neighboring BGA balls, and
  - Proximity of top and bottom ground planes: bottom of reference plane of package substrate and top reference plane of PCB.

Full 3D Simulation (in Pictures)

Defeatured 3D Geometrical Model



- Picture was defeatured for IP.
- The modeling included all factors and was not restricted to the BGA ball array.
- BGA balls were fully connected to,
  - substrate pads (and associated plane/features), and
  - PTH pads and resulting structures.

Computation of C_p

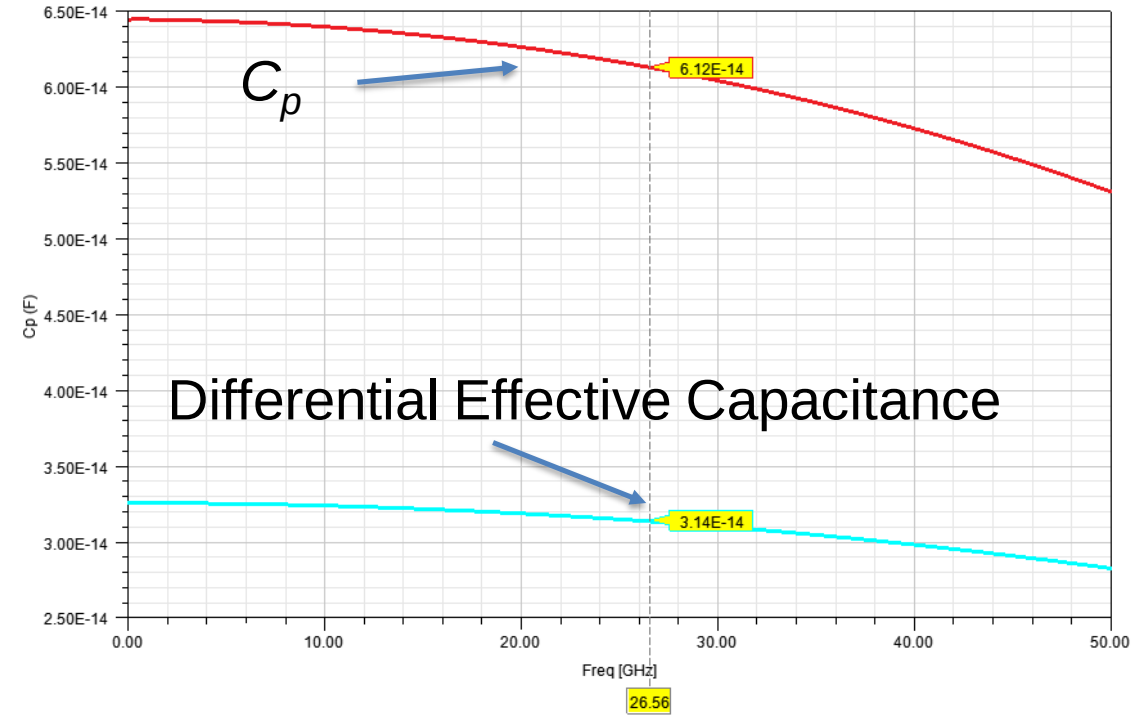
1. Compute S-parameters
2. Compute Z-parameters
   – The impedance of a shunt element for a reciprocal system is simply $Z_{21}(f)$.
3. $C_p(f) = j/(2\pi f Z_{21})$
   – No fitting requirement and no TDR extractions are required to get the actual value of C_p.

- Note: C_p is a single ended value, but the differential equivalent representation across virtual ground simply resolves to $C_p/2$ with no coupling (minimum value). Coupling leads to higher value.

Results for 1.0mm Pitch

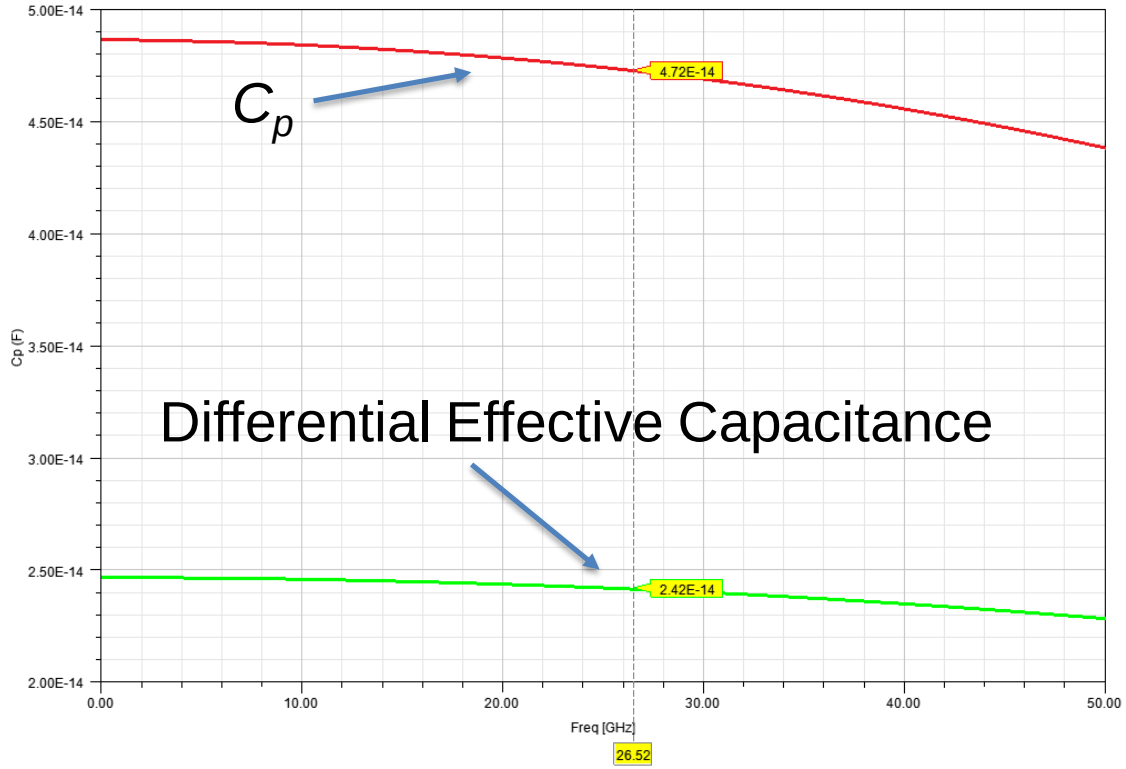
- 600 micron BGA balls
- C_p=61.2 fF at 26.56 GHz
- Effective capacitance of differential mode calculation is slightly greater than C_p/2 due to coupling as expected.

Note: C_p≈60 fF at 28 GHz as reported in other forums.



Results for 0.8mm Pitch

- 500 micron BGA balls
- C_p=47.2 fF at 26.56 GHz
- Effective capacitance of differential mode calculation is slightly greater than C_p/2 due to coupling as expected.



Summary

- Data was provided to lock one of the 11 parameters in the reference package models that can be reliably simulated: one less variable/unknown will be welcome.
- The results are required to have concrete targeted conversations about accuracy and performance of the reference package model.
- As per comment for change request (#115, #116 and #117), C_p to be lowered to $\approx$ 60 fF.
- This study puts a worse case bound on the quantity.
- Serves as a reference for expectation of the module package C_p.