On-die termination model for COM

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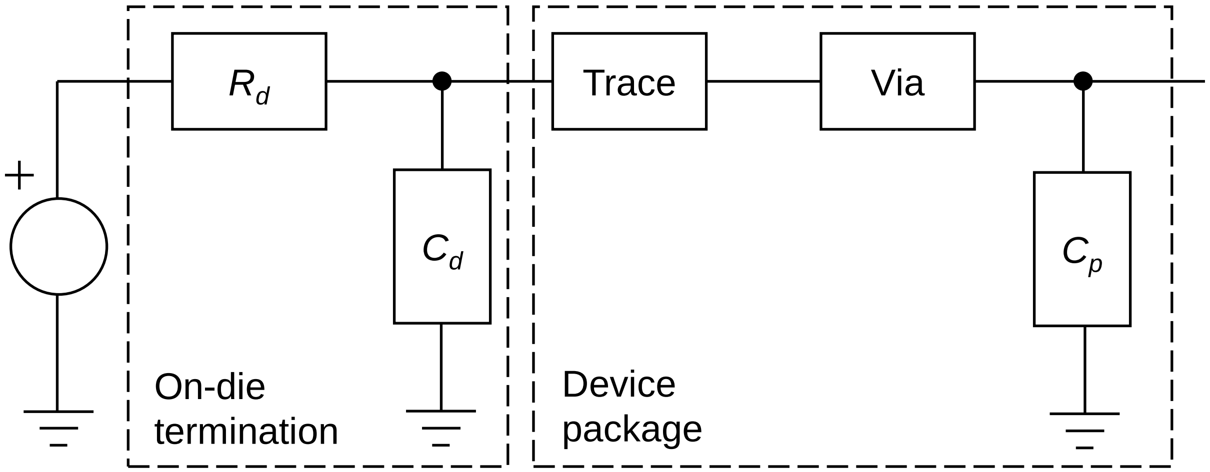
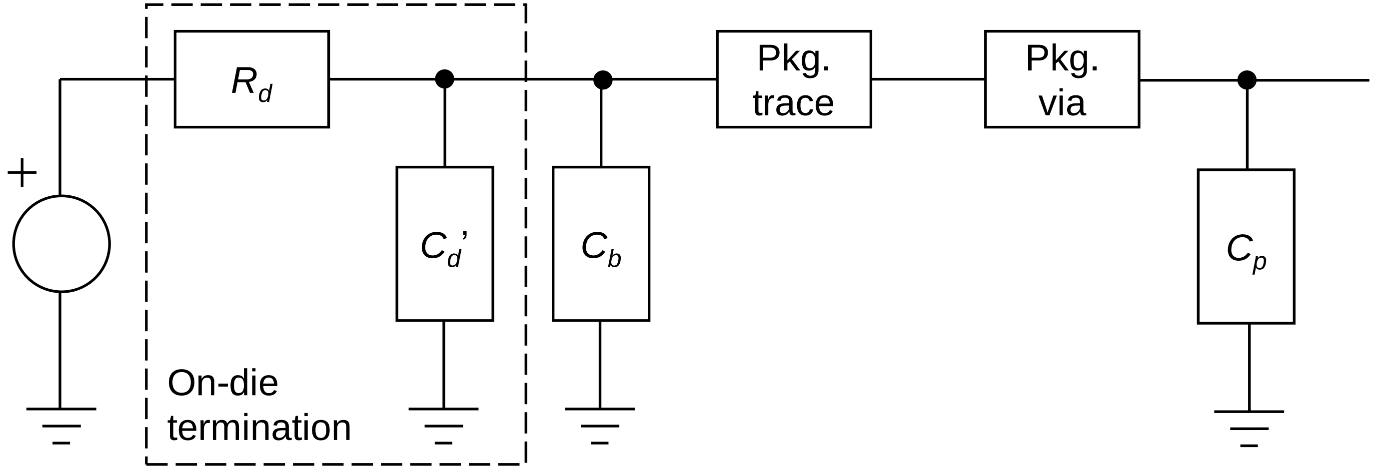
Motivation

- There is interest in improving the performance of the on-die termination model employed in the Channel Operating Margin (COM) calculation
- Earlier work has achieved this improvement via a reduction in the single-ended device capacitance C_d
- This presentation considers another approach to improve termination performance

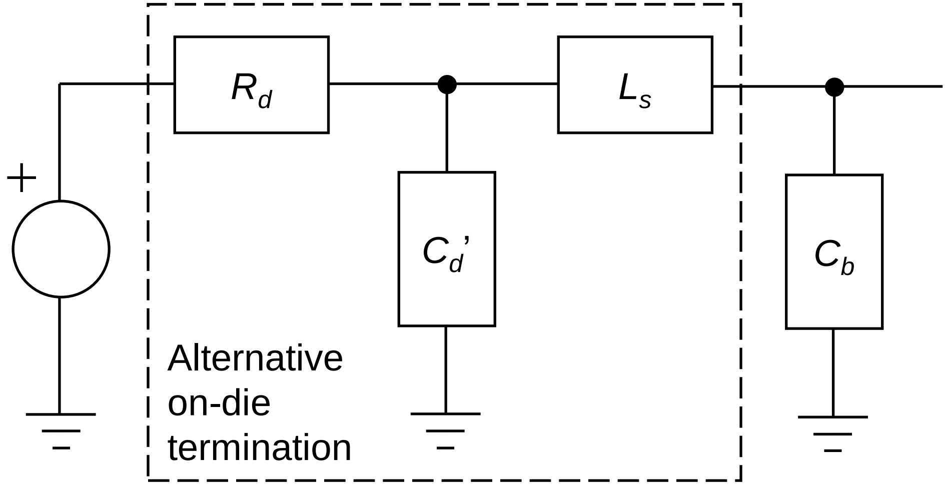


Another approach to improve termination performance



[Step 1](#)

- Recognize that C_d is currently a catch-all term with a number of contributors.
- Split out the fraction of C_d the represents the die-package interface (e.g., the bump and associated package structures).



[Step 2](#)

- Recognize that excess on-die capacitance can be compensated in the termination network in order to improve bandwidth and return loss (e.g., T-coil).
- A full-featured T-coil model was proposed in [1] but was deemed to be too complex at the time.

[1] Hidaka, "Comment #18: T-Coil Model for COM", IEEE P802.3bs Task Force, May 2016.

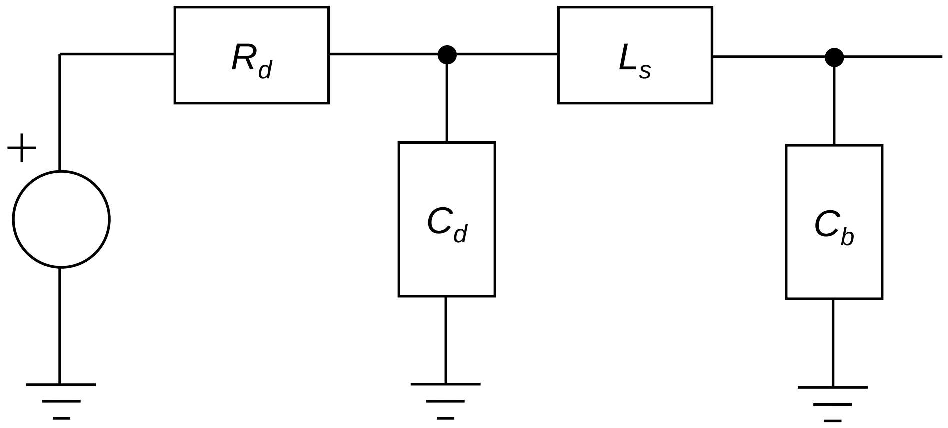
Goals, non-goals, and proposal

Goals

- Improve performance without aggressive reduction in C_d
- Keep the termination model as simple as possible
- Set a minimum performance target

Non-goals

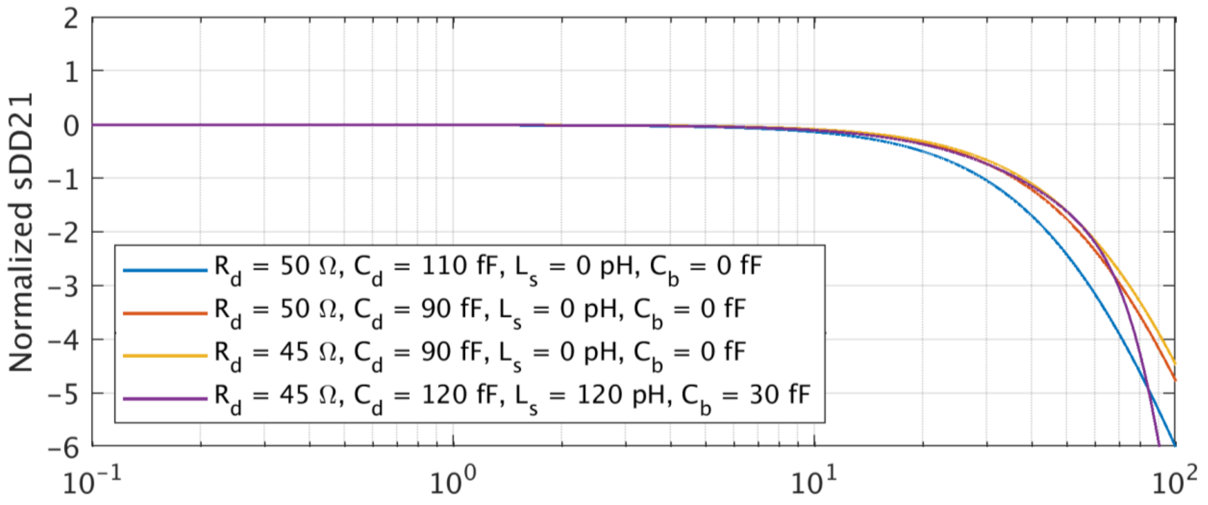
- Represent a specific design
- Provide a complete circuit topology with an extensive design space
- Debate appropriate values for parasitic effects (e.g., interwinding capacitance, equivalent series resistance)



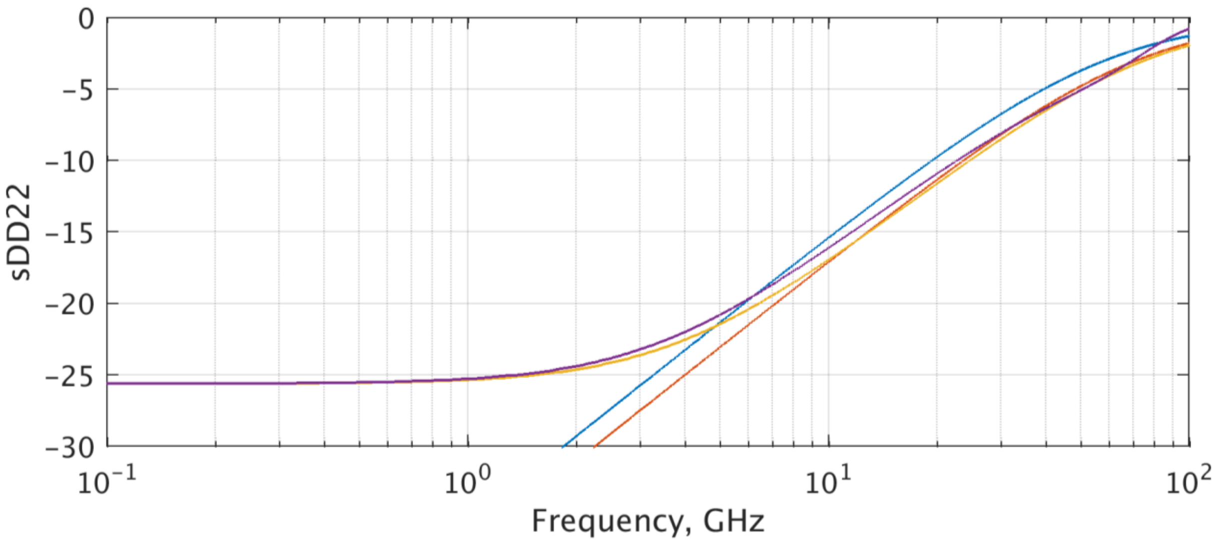
Proposed parameter values

Parameter	Symbol	Value	Units
Single-ended termination resistance	R_d	45 or 50	Ω
Single-ended device capacitance	C_d	120	fF
Single-ended series inductance	L_s	120	pH
Single-ended bump capacitance	C_b	30	fF

Termination model s-parameters



- Series inductance extends the bandwidth to get performance similar to reducing C_d to 90 fF

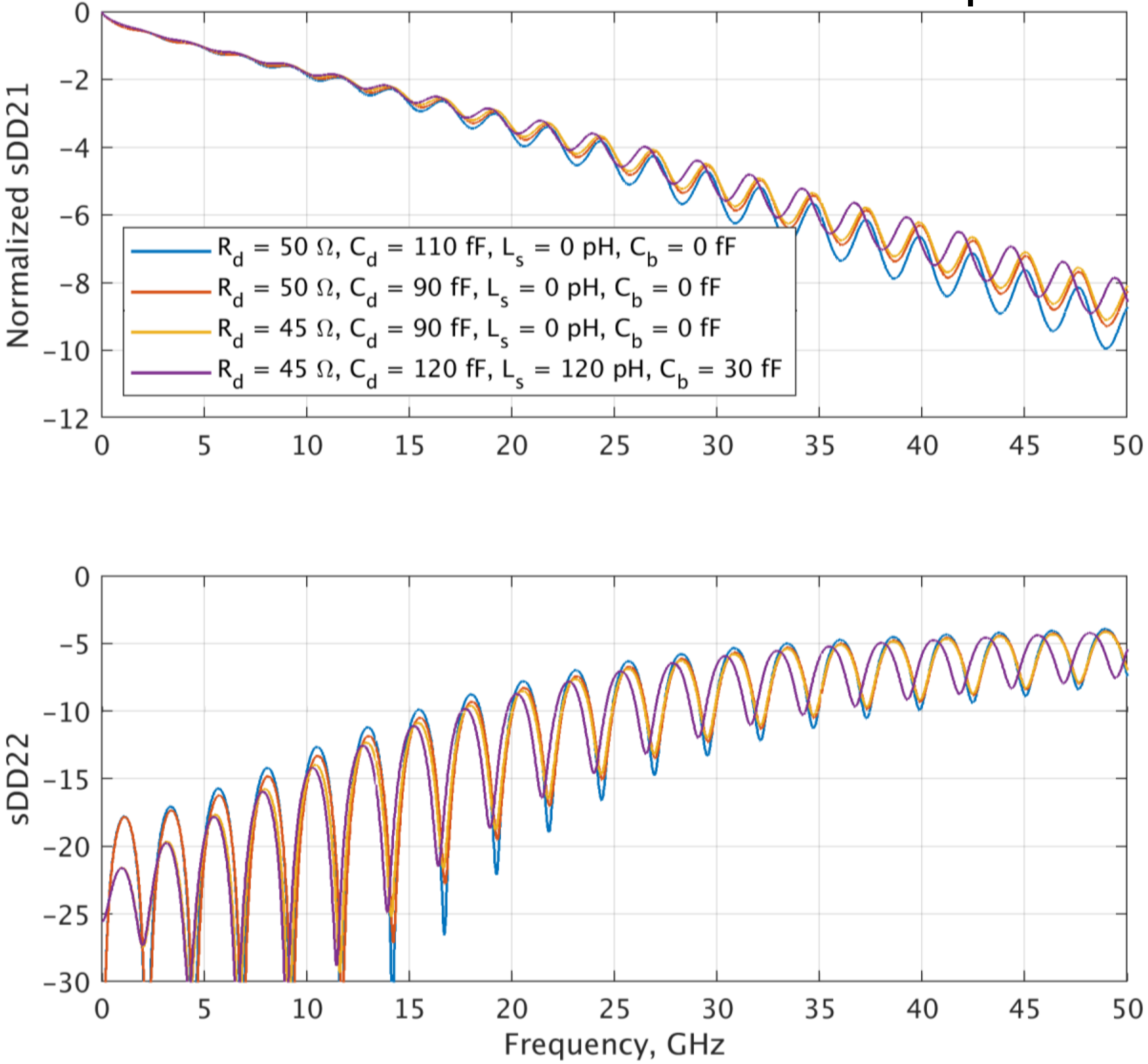


- Also improves return loss to get performance similar to reducing C_d to 90 fF

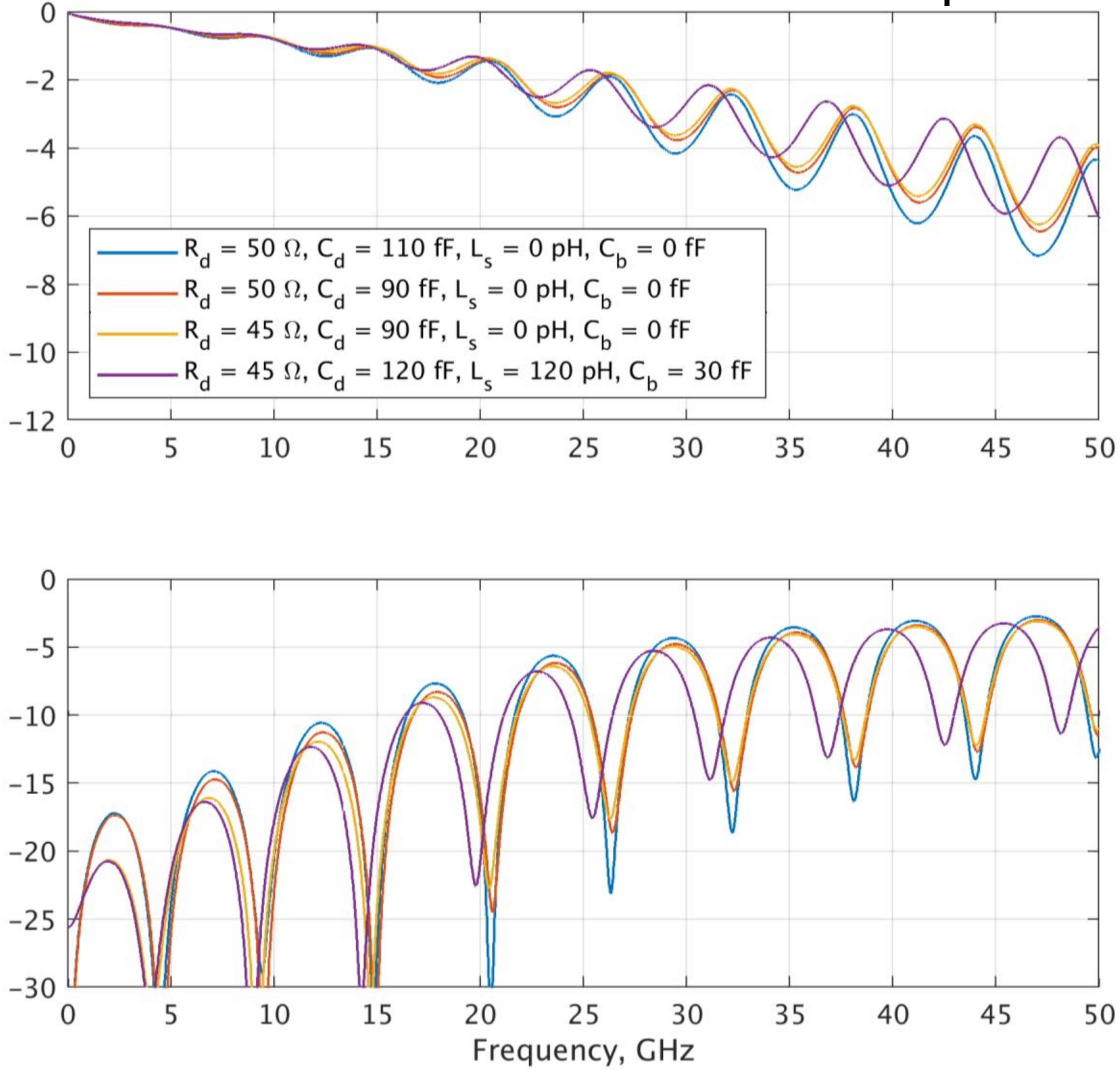
- Improvement with perhaps(?) more palatable parameter values
- Differences in how the performance is achieved may end up being significant

Termination and device package model s-parameters

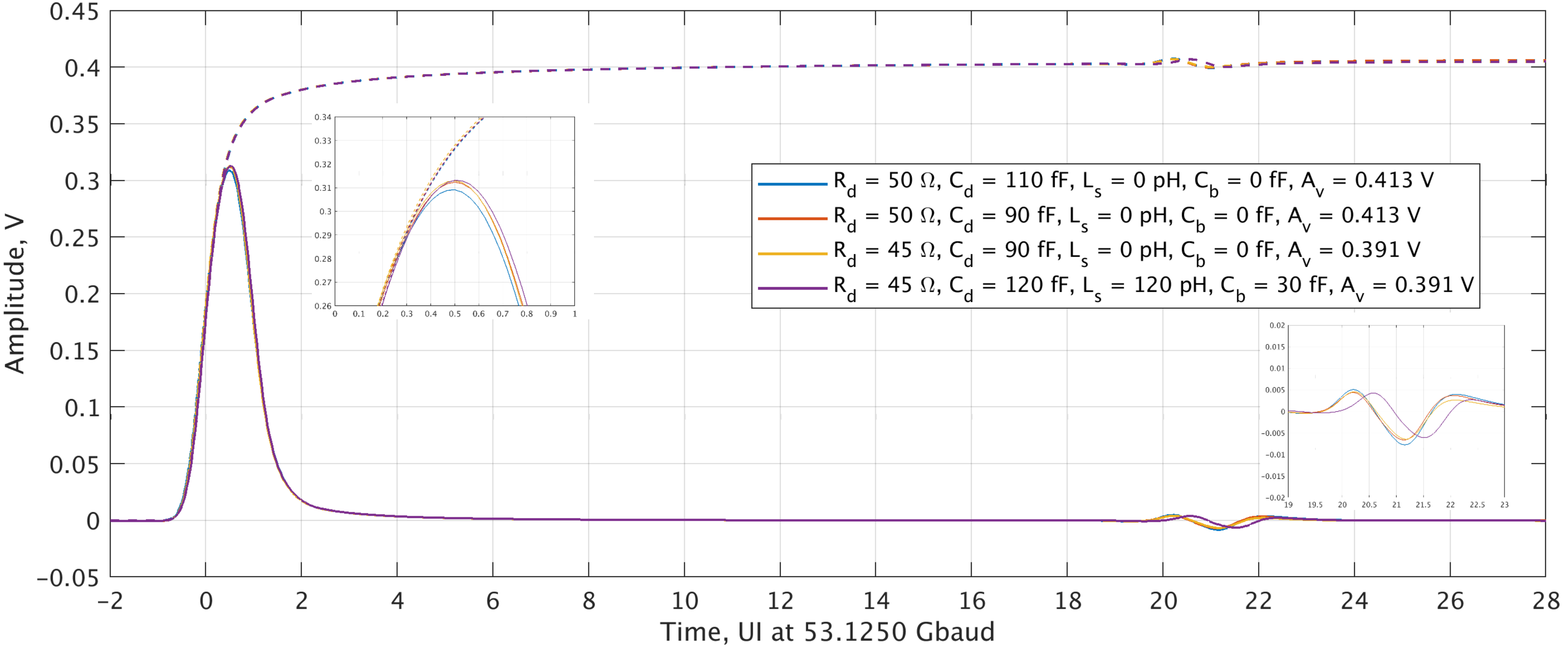
30 mm | 1.8 mm



12 mm | 1.8 mm

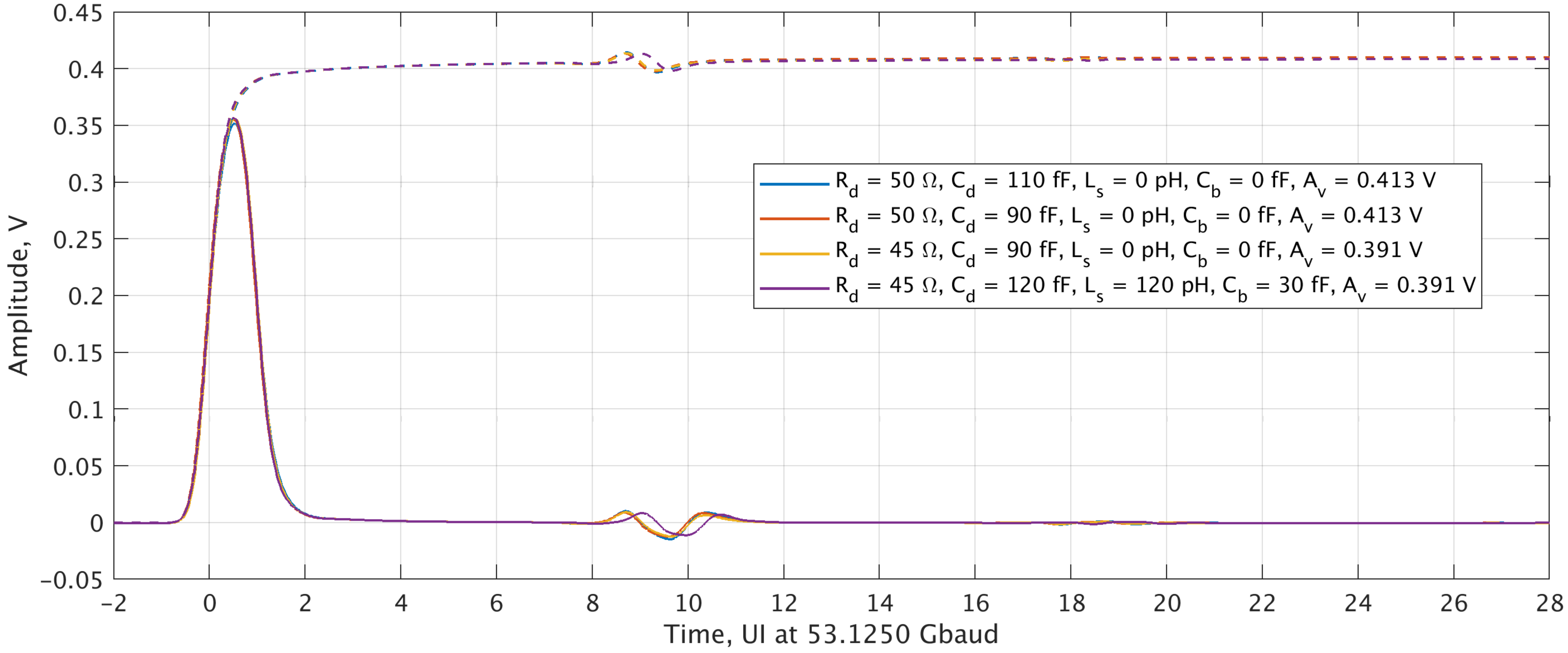


Simulated TP0 output (30 mm | 1.8 mm)



- Includes the Gaussian rise-time filter (T_r = 6.16 ps).

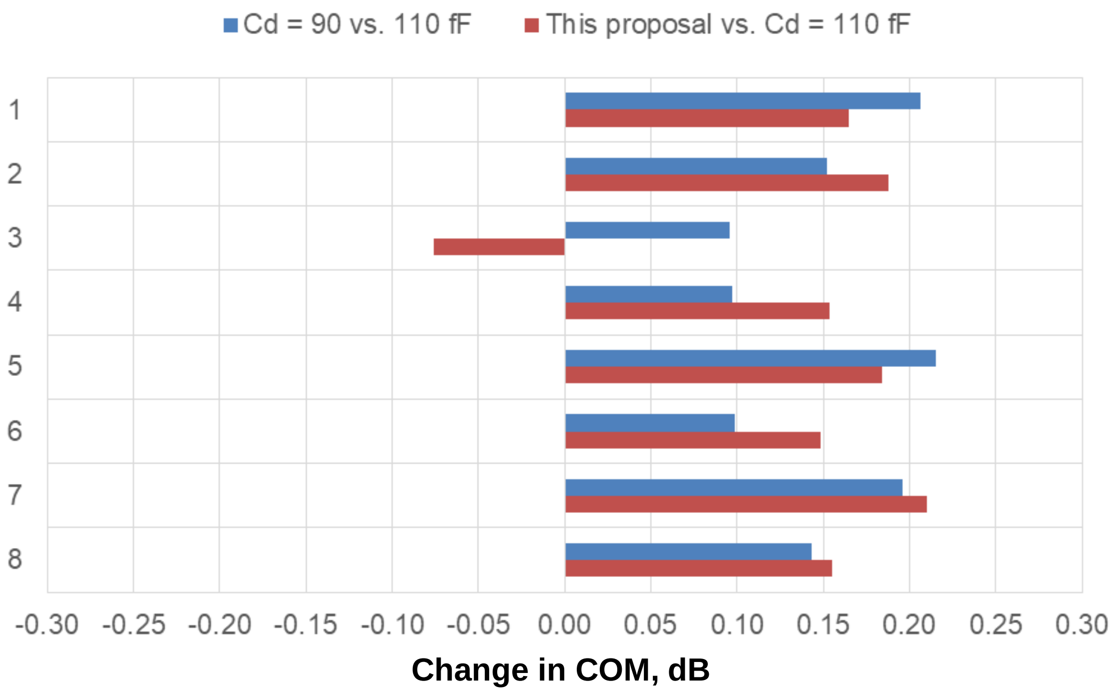
Simulated TP0 output (12 mm | 1.8 mm)



COM results (courtesy of Upen Reddy Kareti)

- Parameters as defined in kareti_3ck_01b_0519 with the following changes
  - Package transmission line length z_p (Tx, Rx) = 31, 29 mm
  - 40 fixed-position feedback taps
  - Other values as noted in the table below

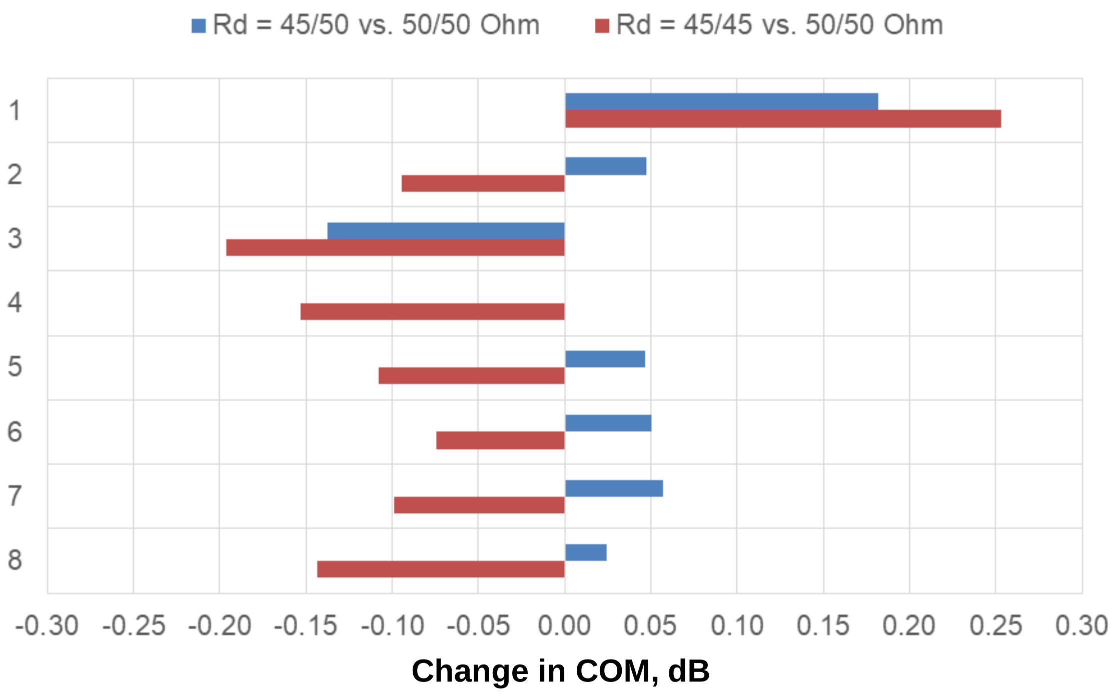
	$A_v = A_{fe}$, V	0.413, 0.608	0.413, 0.608		0.413, 0.608	
	R_d (Tx, Rx), Ω	50, 50	50, 50		50, 50	
	C_d, fF	110	90		120	
	L_s, pH	0	0		120	
	C_b, fF	0	0		30	
#	**Channel name**	**Test case A**	**B**	**B − A**	**C**	**C − A**
1	HH_CABP16	5.832	6.038	0.206	5.996	0.165
2	HH_CABP28	2.510	2.662	0.152	2.698	0.188
3	NT_BP_12in_16	4.069	4.165	0.096	3.993	-0.076
4	NT_OR_12in_28	4.041	4.138	0.097	4.194	0.154
5	RM_CABP28	4.852	5.067	0.215	5.036	0.184
6	UK_28Bch2_b7p5_7	3.012	3.111	0.099	3.160	0.149
7	UK_28CAch3_b2	4.055	4.251	0.196	4.265	0.210
8	UK_28OAch4	2.674	2.817	0.143	2.829	0.155



More COM results (courtesy of Upen Reddy Kareti)

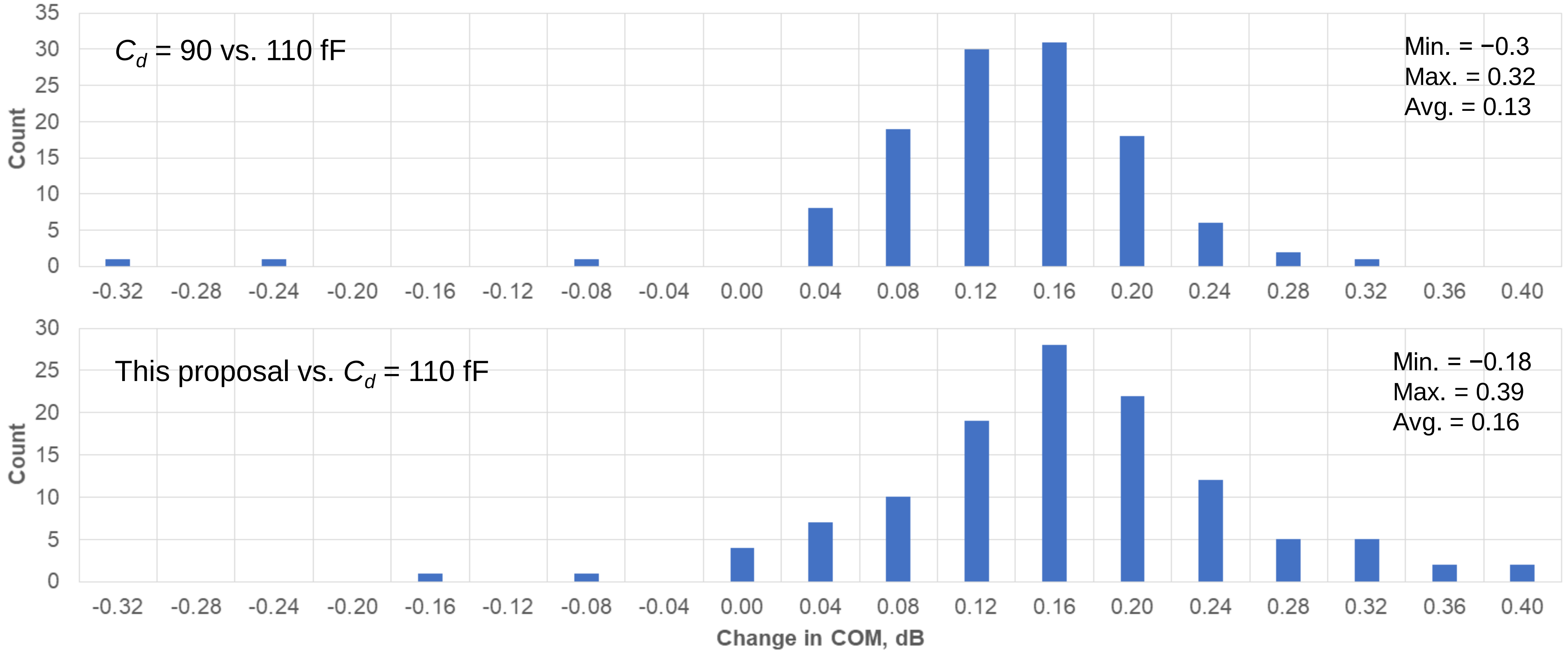
- Evaluate the impact of the choice of R_d
  - Since A_v is scaled to maintain a specific transmitter output amplitude, changing only R_d (Tx) to 45 Ω mostly alters the reflections
  - Changing R_d (Rx) to 45 Ω is possible reduces the amplitude of received signals

	$A_v = A_{fe}, A_{ne}$ V	0.413, 0.608	0.391, 0.578		0.391, 0.578	
	R_d (Tx, Rx), Ω	50, 50	45, 50		45, 45	
	C_d, fF	120	120		120	
	L_s, pH	120	120		120	
	C_b, fF	30	30		30	
#	**Channel name**	**Test case C**	**D**	**D − C**	**E**	**E − C**
1	HH_CABP16	5.996	6.178	0.182	6.249	0.253
2	HH_CABP28	2.698	2.745	0.047	2.604	-0.094
3	NT_BP_12in_16	3.993	3.855	-0.138	3.796	-0.197
4	NT_OR_12in_28	4.194	4.194	0.000	4.041	-0.154
5	RM_CABP28	5.036	5.083	0.047	4.928	-0.108
6	UK_28Bch2_b7p5_7	3.160	3.210	0.050	3.086	-0.075
7	UK_28CAch3_b2	4.265	4.322	0.057	4.166	-0.099
8	UK_28OAch4	2.829	2.853	0.024	2.686	-0.143



More COM results (courtesy of Rich Mellitz)

- 118 channels considered
  - 12 fixed-position taps plus 3 banks of floating taps (4 taps/bank, 100! UI span)
  - R_d (Tx, Rx) = 45, 45 Ω, z_p (Tx, Rx) = 30, 30 mm, A_v = 0.39 V



Summary

- Considered another approach to improve the performance of the COM on-die termination model
- Proposed model has performance similar to reducing C_d to 90 fF but there are channels-specific differences
- Improvements visible with different reference receivers (note this is not a proposal for a specific reference receiver)
- This proposal could be integrated into the draft with a modest number of changes (see Appendix A)

Appendix A

Changes to Annex 93A to implement this proposal

Changes to Annex 93A to implement this proposal (1 of 3)

Table 93A–1—COM parameters

Parameters	Reference	Symbol	Units
…			
Device package model Single-ended device capacitance Single-ended device series inductance[a] Single-ended capacitance at the device-to-package interface[a] Transmission line length Single-ended package capacitance at package-to-board interface Transmission line characteristic impedance[a]	93A.1.2	 C_d L_s C_b z_p C_p Z_c	 nF nH nF mm nF Ω
…			

[a] Some clauses that invoke this method do not provide a value for L_s, C_b, or Z_c. See 93A.1.2.

93A.1.2.2 Two-port network for a shunt capacitance

The scattering parameters for the device capacitance C_d are denoted as $S^{(d)}(C_d)$, the scattering parameters for the device capacitance C_b are denoted as $S^{(b)}(C_b)$, and the scattering parameters for the device capacitance C_p are denoted as $S^{(p)}(C_p)$. When a value for C_b is not provided by the clause that invokes this method, C_b is set to 0.

Changes to Annex 93A to implement this proposal (2 of 3)

Insert the following subclause after 93A.1.2.2:

93A.1.2.2a Two-port network for a series inductance

The scattering parameters for a series inductance with value L are defined by Equation (93A–8a)

$$S(L) = \frac{1}{2 + j\omega\, L/R_0} \begin{bmatrix} j\omega\, L/R_0 & 2 \\ 2 & j\omega\, L/R_0 \end{bmatrix} \quad (93A–8a)$$

The scattering parameters for the series inductance L_s are denoted as $S^{(s)}(L_s)$. When a value for L_s is not provided by the clause that invokes this method, L_s is set to 0.

Changes to Annex 93A to implement this proposal (3 of 3)

93A.1.2.4 Assembly of transmitter and receiver device package models

The scattering parameters for the transmitter device package model $S^{(tp)}$ are the result of the cascade connection of the device ~~capacitance~~model, package transmission line, and board capacitance as defined by Equation (93A–15) and Equation (93A–15a).

$$S^{(td)} = \text{cascade}(\text{cascade}(S^{(d)}, S^{(s)}), S^{(b)}) \quad \text{(93A–15)}$$

$$S^{(tp)} = \text{cascade}(\text{cascade}(S^{(td)}, S^{(l)}), S^{(p)}) \quad \text{(93A–15a)}$$

Similarly, the scattering parameters for the receiver device package model $S^{(rp)}$ are the result of the cascade connection of the board capacitance, package transmission line, and device ~~capacitance~~model as defined by Equation (93A–16) and Equation (93A–16a).

$$S^{(rd)} = \text{cascade}(\text{cascade}(S^{(b)}, S^{(s)}), S^{(d)}) \quad \text{(93A–16)}$$

$$S^{(rp)} = \text{cascade}(\text{cascade}(S^{(p)}, S^{(l)}), S^{(rp)}) \quad \text{(93A–16a)}$$