Effective Return Loss (ERL): A New Parameter To Limit COM Variability

For Comment Resolution of r02-26, r02-55, and r02-56

Richard Mellitz, Samtec

IEEE P802.3bs Task Force **July2017** **Berlin**

Supporters

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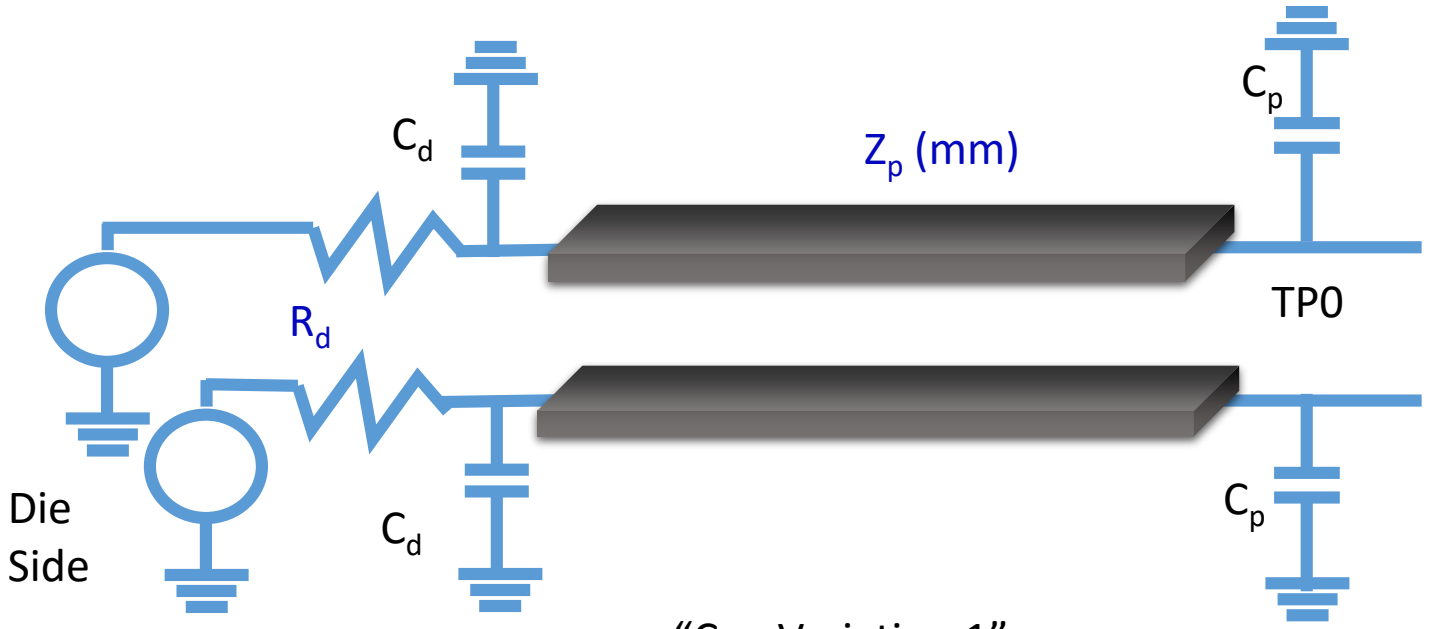
- Howard Heck, Intel
- Upen Reddy Kareti , Cisco
- Rick Rabinovich, IXIA
- Yasuo Hidaka, Fujitsu Laboratories of America, Inc.

TOC

- ❑ Package variant example
- ❑ Compare COM variability to “*dudek_062817_3cd_adhoc*”
- ❑ Introduction to Effective Return Loss (ERL)
- ❑ ERL data for prior package parameter sweeps
- ❑ ERL edit suggestions
- ❑ ERL description
- ❑ Recommendations

There are numbers of ways to get device variations

- Consider a COM like package which meets the Return Loss Mask, SNR_{ISI} , and the V_p/V_f ratio requirements.

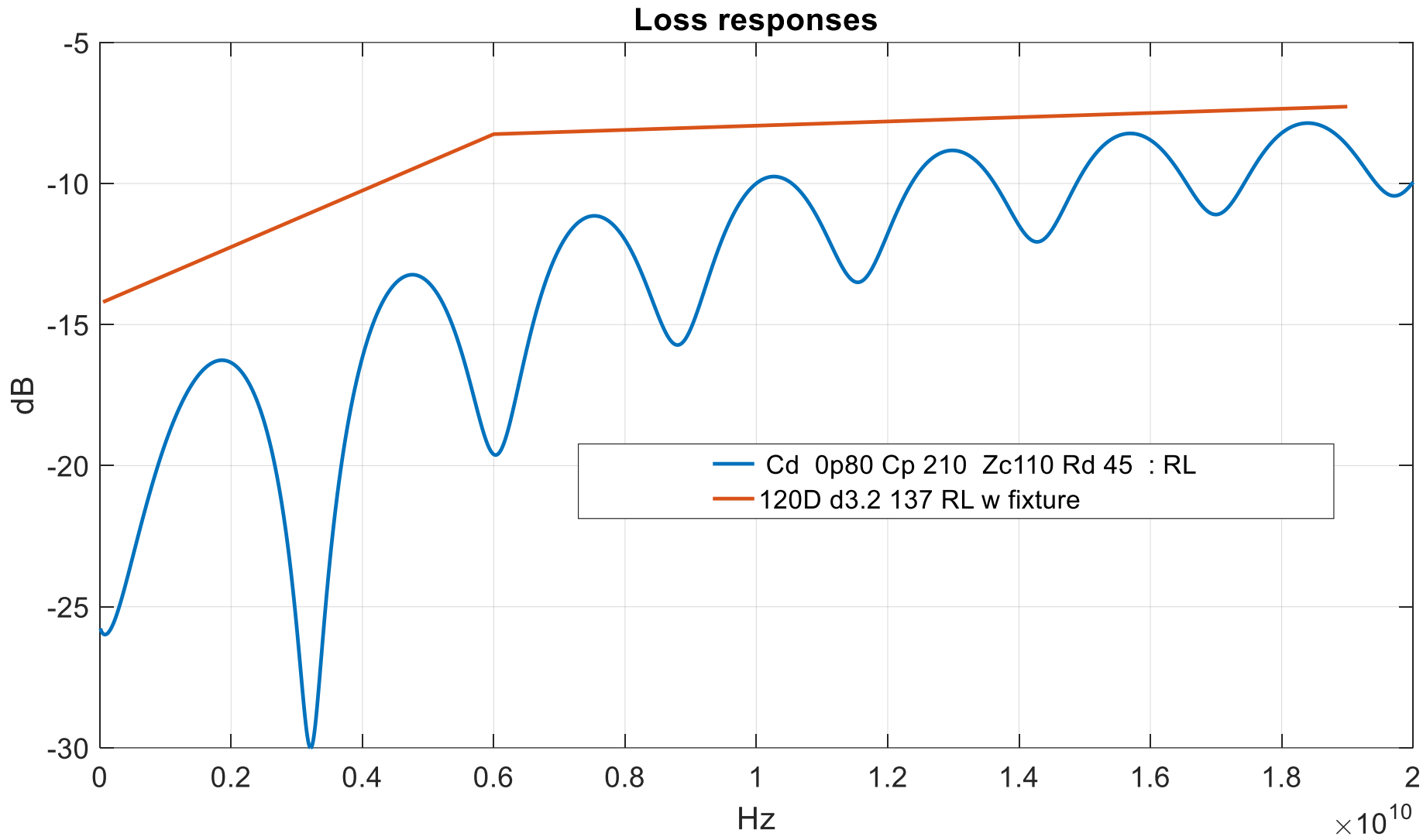


Pkg_Zc (Ω)	110
Cp (nF)	2.1E-04
Rd (Ω)	[45 45]
Cd (nF)	8.0E-05
Zp(mm)	30

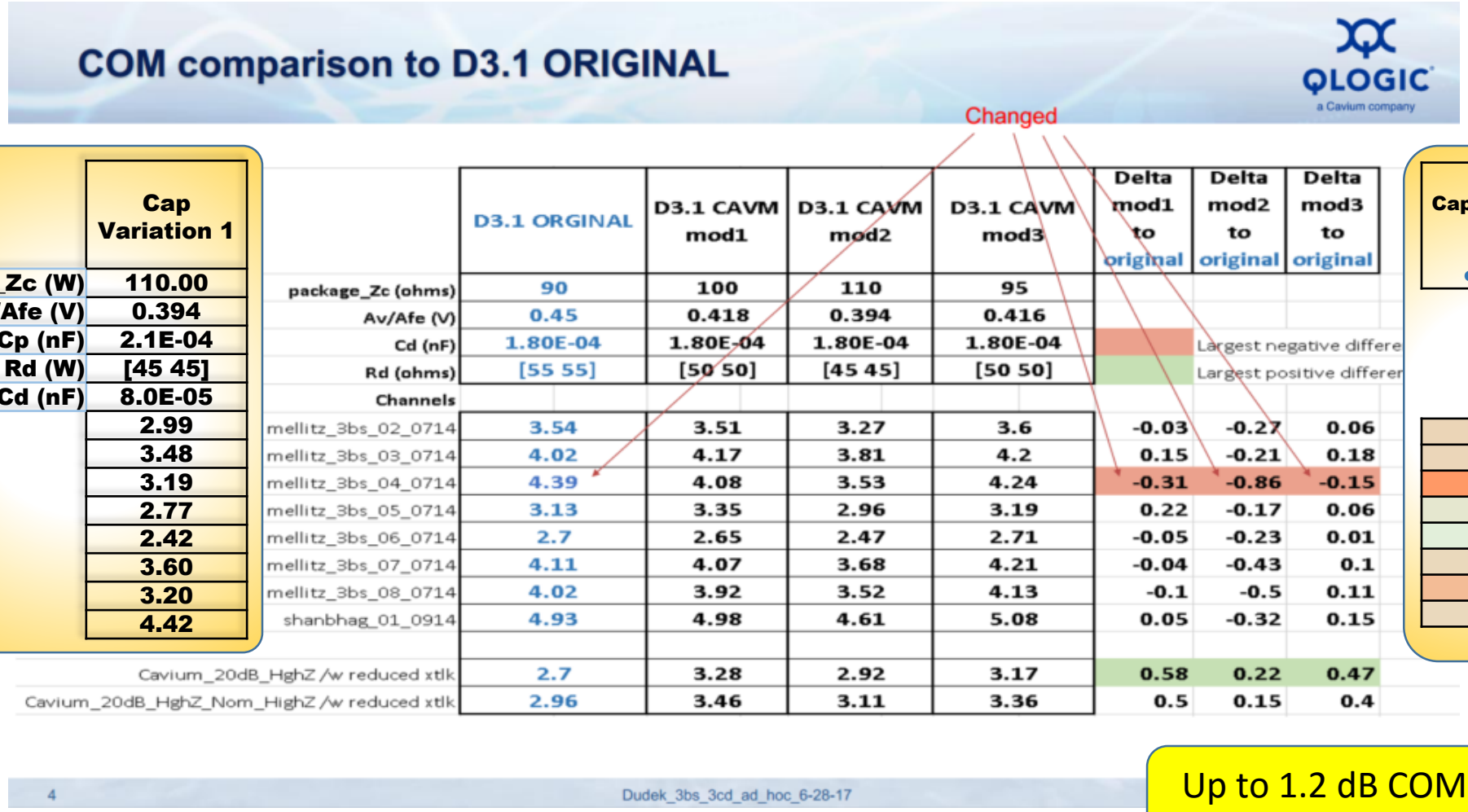
"Cap Variation 1"

- Has less device capacitance
- But more package capacitance

Return Loss for “Cap Variation 1” Passes



“Cap Variation 1” for Table in *dudek_062817_3cd_adhoc* Shows More Variation

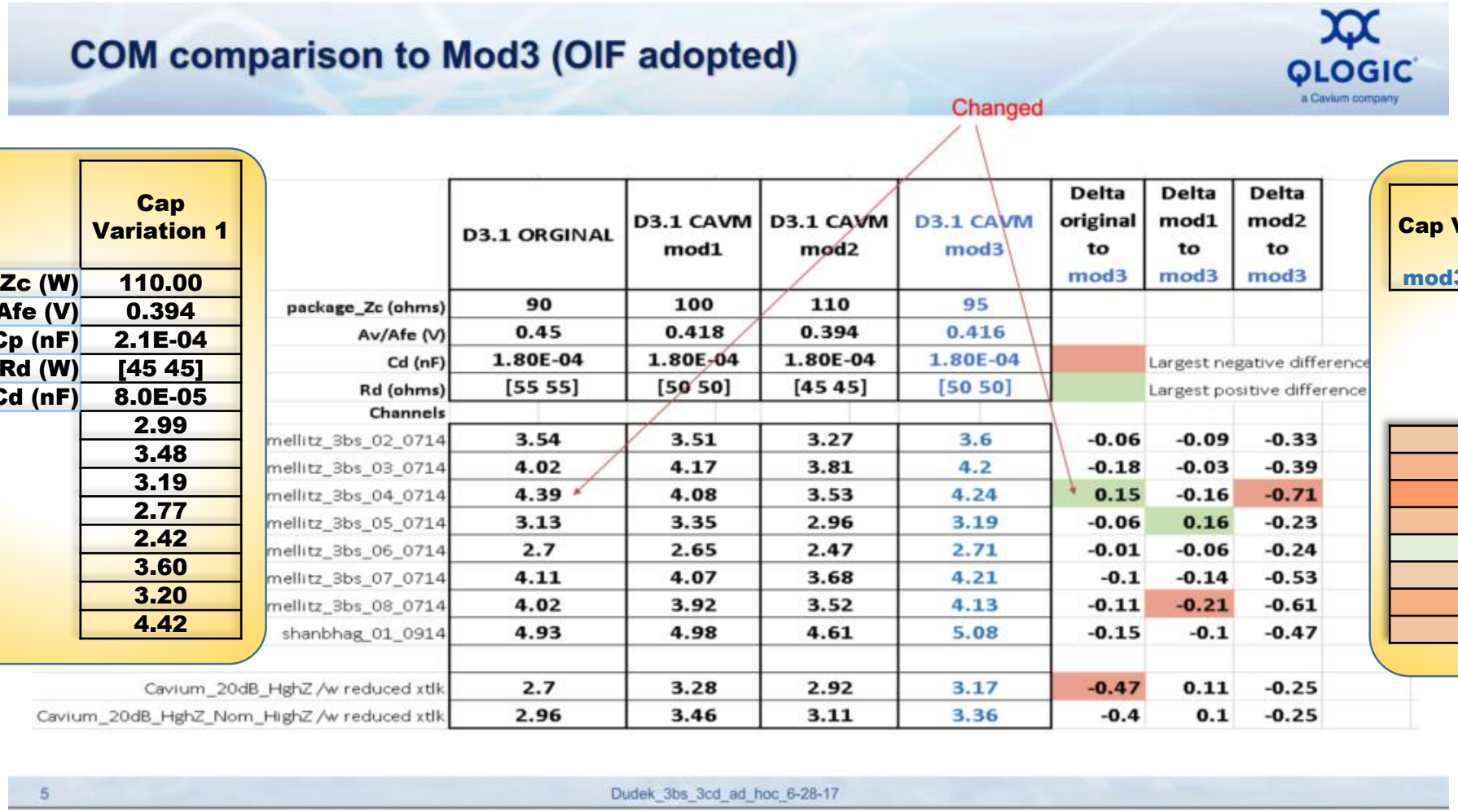


	Cap Variation 1
Pkg_Zc (W)	110.00
Av/Afe (V)	0.394
Cp (nF)	2.1E-04
Rd (W)	[45 45]
Cd (nF)	8.0E-05
	2.99
	3.48
	3.19
	2.77
	2.42
	3.60
	3.20
	4.42

	D3.1 ORGINAL	D3.1 CAVM mod1	D3.1 CAVM mod2	D3.1 CAVM mod3	Delta mod1 to original	Delta mod2 to original	Delta mod3 to original	Delta Cap Variation 1 to original
package_Zc (ohms)	90	100	110	95				
Av/Afe (V)	0.45	0.418	0.394	0.416				
Cd (nF)	1.80E-04	1.80E-04	1.80E-04	1.80E-04				
Rd (ohms)	[55 55]	[50 50]	[45 45]	[50 50]				
Channels								
mellitz_3bs_02_0714	3.54	3.51	3.27	3.6	-0.03	-0.27	0.06	-0.55
mellitz_3bs_03_0714	4.02	4.17	3.81	4.2	0.15	-0.21	0.18	-0.54
mellitz_3bs_04_0714	4.39	4.08	3.53	4.24	-0.31	-0.86	-0.15	-1.20
mellitz_3bs_05_0714	3.13	3.35	2.96	3.19	0.22	-0.17	0.06	-0.36
mellitz_3bs_06_0714	2.7	2.65	2.47	2.71	-0.05	-0.23	0.01	-0.28
mellitz_3bs_07_0714	4.11	4.07	3.68	4.21	-0.04	-0.43	0.1	-0.51
mellitz_3bs_08_0714	4.02	3.92	3.52	4.13	-0.1	-0.5	0.11	-0.82
shanbhag_01_0914	4.93	4.98	4.61	5.08	0.05	-0.32	0.15	-0.51
Cavium_20dB_HghZ /w reduced xtlk	2.7	3.28	2.92	3.17	0.58	0.22	0.47	
Cavium_20dB_HghZ_Nom_HighZ /w reduced xtlk	2.96	3.46	3.11	3.36	0.5	0.15	0.4	

Up to 1.2 dB COM change compared to “original”

The Proposed "Mod1" Reduces the Variability but Still Has up to 0.9 dB COM Change



	Cap Variation 1
Pkg_Zc (W)	110.00
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Cp (nF)	2.1E-04
Rd (W)	[45 45]
Cd (nF)	8.0E-05
	2.99
	3.48
	3.19
	2.77
	2.42
	3.60
	3.20
	4.42

	D3.1 ORGINAL	D3.1 CAVM mod1	D3.1 CAVM mod2	D3.1 CAVM mod3	Delta original to mod3	Delta mod1 to mod3	Delta mod2 to mod3	Delta Cap Variation 1 to mod3 proposal
package_Zc (ohms)	90	100	110	95				
Av/Afe (V)	0.45	0.418	0.394	0.416				
Cd (nF)	1.80E-04	1.80E-04	1.80E-04	1.80E-04				
Rd (ohms)	[55 55]	[50 50]	[45 45]	[50 50]				
Channels								
mellitz_3bs_02_0714	3.54	3.51	3.27	3.6	-0.06	-0.09	-0.33	-0.52
mellitz_3bs_03_0714	4.02	4.17	3.81	4.2	-0.18	-0.03	-0.39	-0.67
mellitz_3bs_04_0714	4.39	4.08	3.53	4.24	0.15	-0.16	-0.71	-0.89
mellitz_3bs_05_0714	3.13	3.35	2.96	3.19	-0.06	0.16	-0.23	-0.58
mellitz_3bs_06_0714	2.7	2.65	2.47	2.71	-0.01	-0.06	-0.24	-0.23
mellitz_3bs_07_0714	4.11	4.07	3.68	4.21	-0.1	-0.14	-0.53	-0.47
mellitz_3bs_08_0714	4.02	3.92	3.52	4.13	-0.11	-0.21	-0.61	-0.72
shanbhag_01_0914	4.93	4.98	4.61	5.08	-0.15	-0.1	-0.47	-0.56
Cavium_20dB_HghZ /w reduced xtlk	2.7	3.28	2.92	3.17	-0.47	0.11	-0.25	
Cavium_20dB_HghZ_Nom_HighZ /w reduced xtlk	2.96	3.46	3.11	3.36	-0.4	0.1	-0.25	

Proposal: Add a New Requirement for Effective Return Loss (ERL)

ERL is meaningful in the context of signaling architecture

ERL uses a time domain “echo” from a single pulse (symbol)

- Pulse based Time Domain Reflectometry (PTDR)

ERL is computed from the pulse echo response (PER) using methods similar to COM

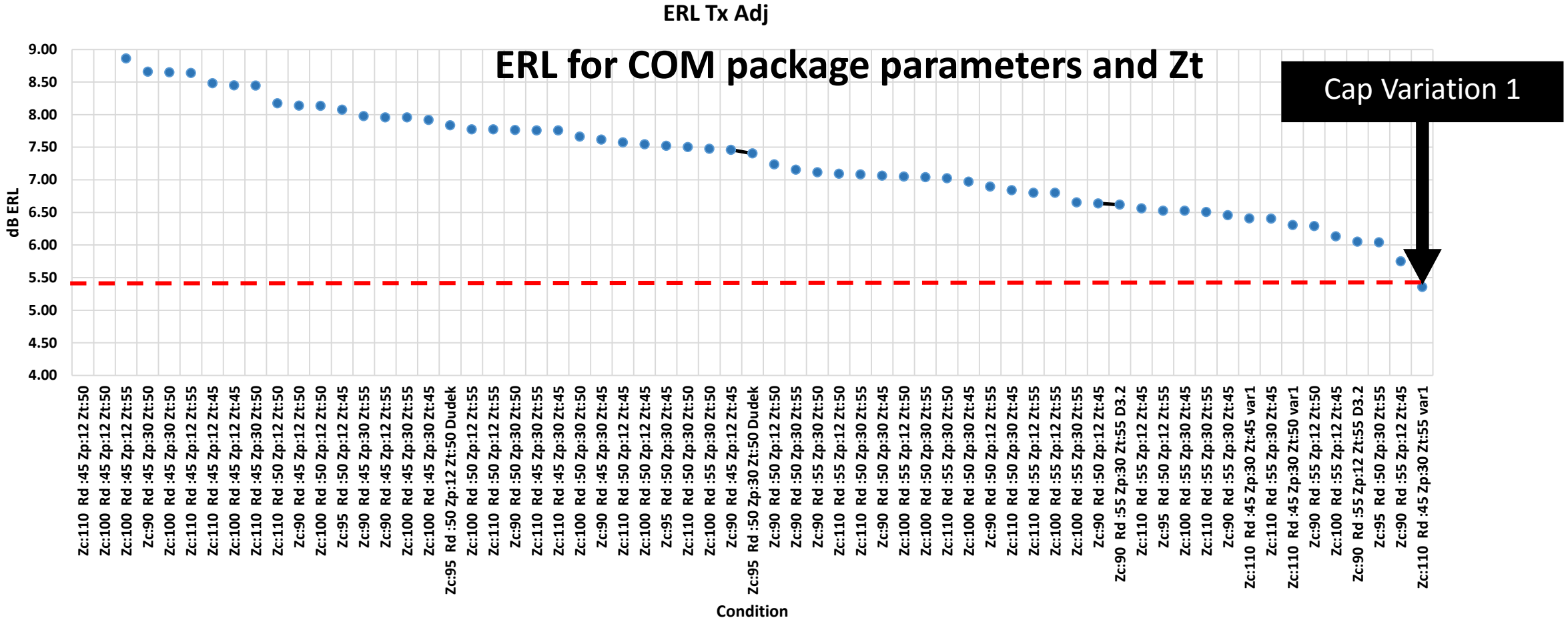
- Statistical noise convolution (mellitz_3cd_02_060717_elect_adhoc)

Compensate ERL for transmitter using V_p/V_f ratio

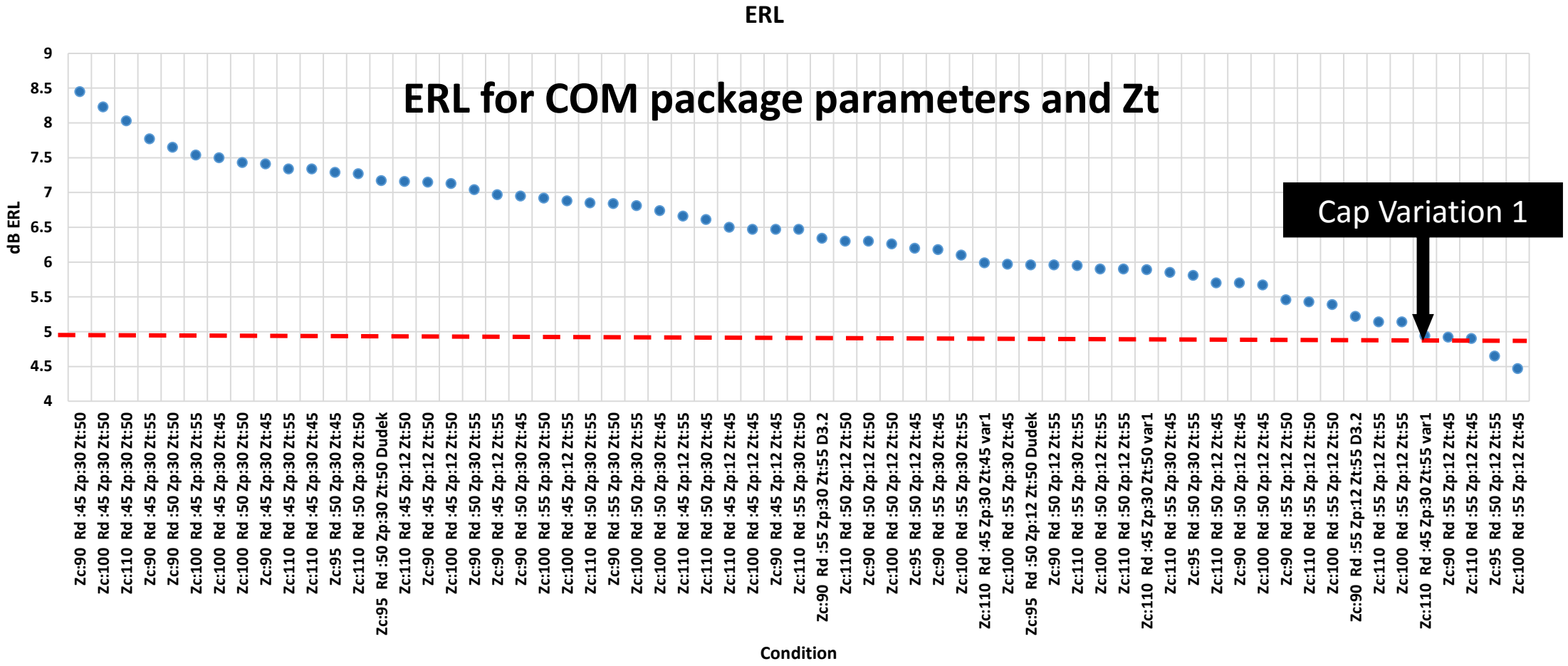
ERL limits

- Package criteria: adjust ERL so that “Cap Variation 1” is unfavorable
- Channel criteria: adjust so ERL channels with the most COM delta are unfavorable

Set Tx ERL > 5.5 dB (better than *dudek_062817)*



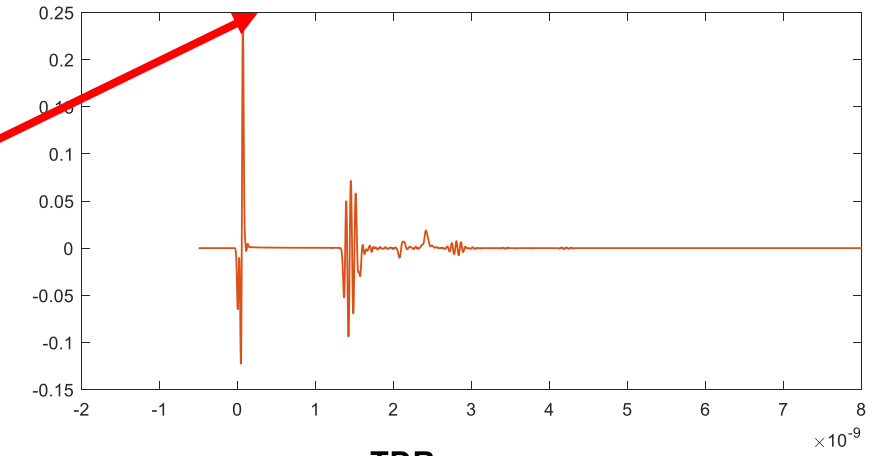
Set Rx ERL > 5.0 dB (better than *dudek_062817)*

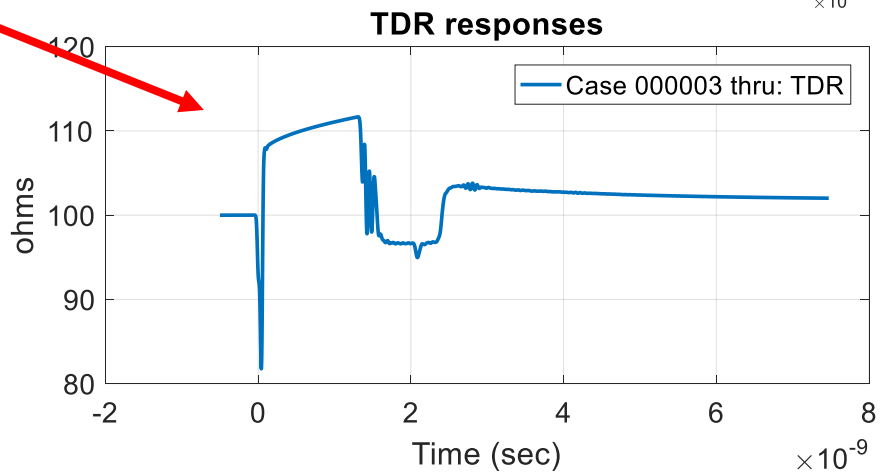


Channel ERL seems to track COM deltas better than package ERL

Channel	Mod 3 COM	Delta Cap Var1 to mod3	ERL
mellitz_bs_02_0714	3.6	-0.55	7.81
mellitz_bs_03_0714	4.2	-0.54	6.88
mellitz_bs_04_0714	4.24	-1.20	4.64
mellitz_bs_05_0714	3.19	-0.36	7.24
mellitz_bs_06_0714	2.71	-0.28	7.4
mellitz_bs_07_0714	4.21	-0.51	6.6
mellitz_bs_08_0714	4.13	-0.82	5.69
shanbhag_01_0914	5.08	-0.51	14.5

This is why





PCB and package interact at boundary.
PCB vias at the package to board connection have low ERL

Suggestion 1: Add ERL Row to Table 120D-1

- Add note for the ERL row
  - use a 18.9 ps (20%-80%) transition time and
  - Use a 4th order Bessel-Thomsen Filter with the 3 dB point at 0.75 f_b
  - $Zt \in \begin{cases} 55 \\ 50 \\ 45 \end{cases}$
- ERL_{tx} min > 5.5 dB

Table 120D–1—200GAUI-4 and 400GAUI-8 C2C transmitter characteristics at TP0a

Parameter	Reference	Value	Units
Signaling rate per lane (range)		26.5625 ± 100 ppm	GBd
Differential peak-to-peak output voltage[a] (max) Transmitter disabled Transmitter enabled	93.8.1.3	 30 1200	 mV mV
Common-mode voltage[a] (max)	93.8.1.3	1.9	V
Common-mode voltage[a] (min)	93.8.1.3	0	V
AC common-mode output voltage[a] (max, RMS)	93.8.1.3	30	mV
Differential output return loss (min)	120D.3.1.8	Equation (120D–9)	dB
Common-mode output return loss (min)	93.8.1.4	Equation 93-4	dB
Output waveform[b] Level separation mismatch ratio R_{LM}(min) Steady state voltage v_f(max) Steady state voltage v_f(min) Linear fit pulse peak (min) Pre-cursor equalization Post-cursor equalization	 120D.3.1.2 120D.3.1.4 120D.3.1.4 120D.3.1.4 120D.3.1.5 120D.3.1.5	 0.95 0.6 0.4 0.736 × v_f Table 120D–3 Table 120D–4	 — V V V — —
Signal-to-noise-and-distortion ratio (min)	120D.3.1.6	31	dB
Transmitter Output residual ISI SNR_{ISI} (max)	120D.3.1.7	38	dB
Output jitter J_{RMS} (max) J4 (max) Even-odd jitter (max)	 120D.3.1.1 120D.3.1.1 120D.3.1.1	 0.023 0.118 0.019	 UI UI UI

[a]Measurement uses the method described in 93.8.1.3 with the exception that the PRBS13Q test pattern is used.
[b]The state of the transmit equalizer is controlled by management interface.

Suggestion 2: Add ERL Row to Table 120D-5

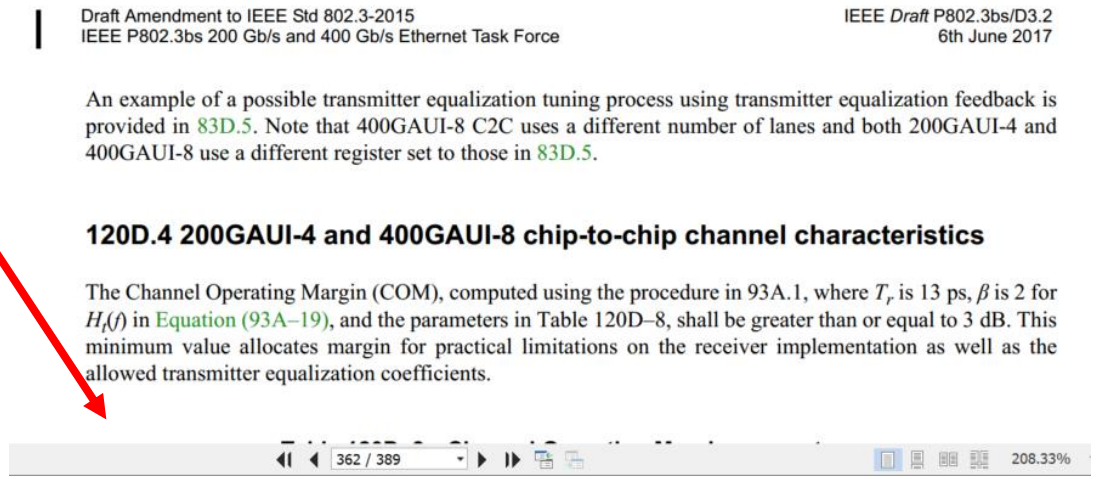
- Add note for the ERL row
  - use a 18.9 ps (20%-80%) transition time and
  - Use a 4th order Bessel-Thomsen Filter with the 3 dB point at 0.75 f_b
  - $Zt \in \begin{cases} 55 \\ 50 \\ 45 \end{cases}$
- ERL min > 4.6 dB Probability

Table 120D–5—200GAUI-4 and 400GAUI-8 C2C receiver characteristics at TP5a

Parameter	Reference	Value	Units
Differential input return loss (min)	93.8.1.4	Equation (93-3)	dB
Differential to common mode input return loss	93.8.1.4	Equation (93-5)	dB
Interference tolerance	120D.3.2.1	Table 120D–6	—
Jitter tolerance	120D.3.2.2	Table 120D–7	—

Suggestion 3: Add ERL to Channel Characteristics

- ERL for the channel is greater than 5 dB.
  - use a 18.9 ps (20%-80%) transition time and
  - Use a 4th order Bessel-Thomsen Filter with the 3 dB point at 0.75 f_b
  - $Zt \in \begin{cases} 55 \\ 50 \\ 45 \end{cases}$

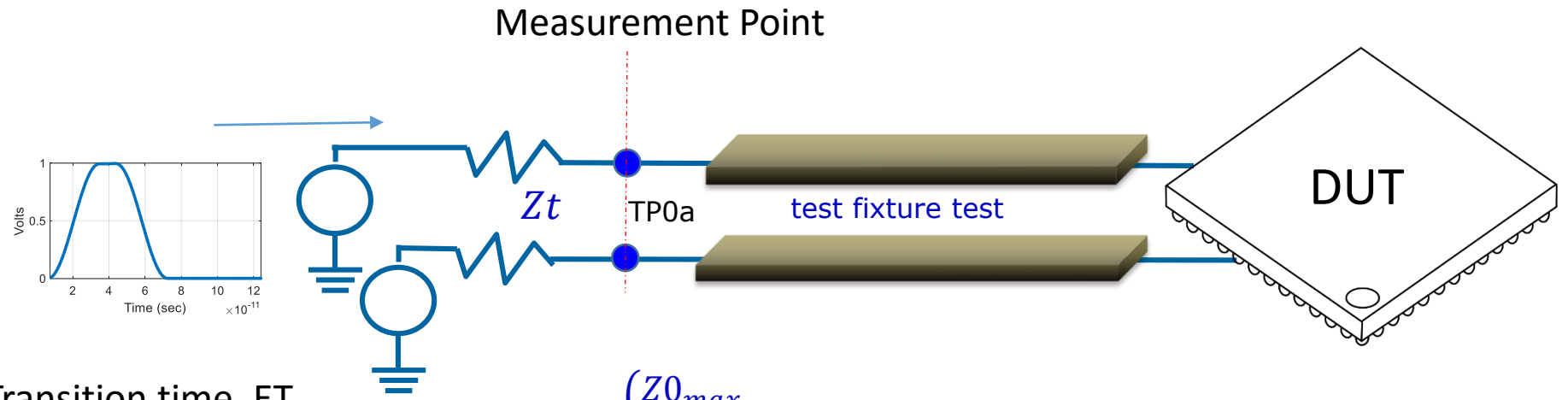


An example of a possible transmitter equalization tuning process using transmitter equalization feedback is provided in 83D.5. Note that 400GAUI-8 C2C uses a different number of lanes and both 200GAUI-4 and 400GAUI-8 use a different register set to those in 83D.5.

120D.4 200GAUI-4 and 400GAUI-8 chip-to-chip channel characteristics

The Channel Operating Margin (COM), computed using the procedure in 93A.1, where T_r is 13 ps, β is 2 for $H_t(f)$ in Equation (93A–19), and the parameters in Table 120D–8, shall be greater than or equal to 3 dB. This minimum value allocates margin for practical limitations on the receiver implementation as well as the allowed transmitter equalization coefficients.

ERL Annex or Section:
Basic Concept, pulse TDR (PTDR)

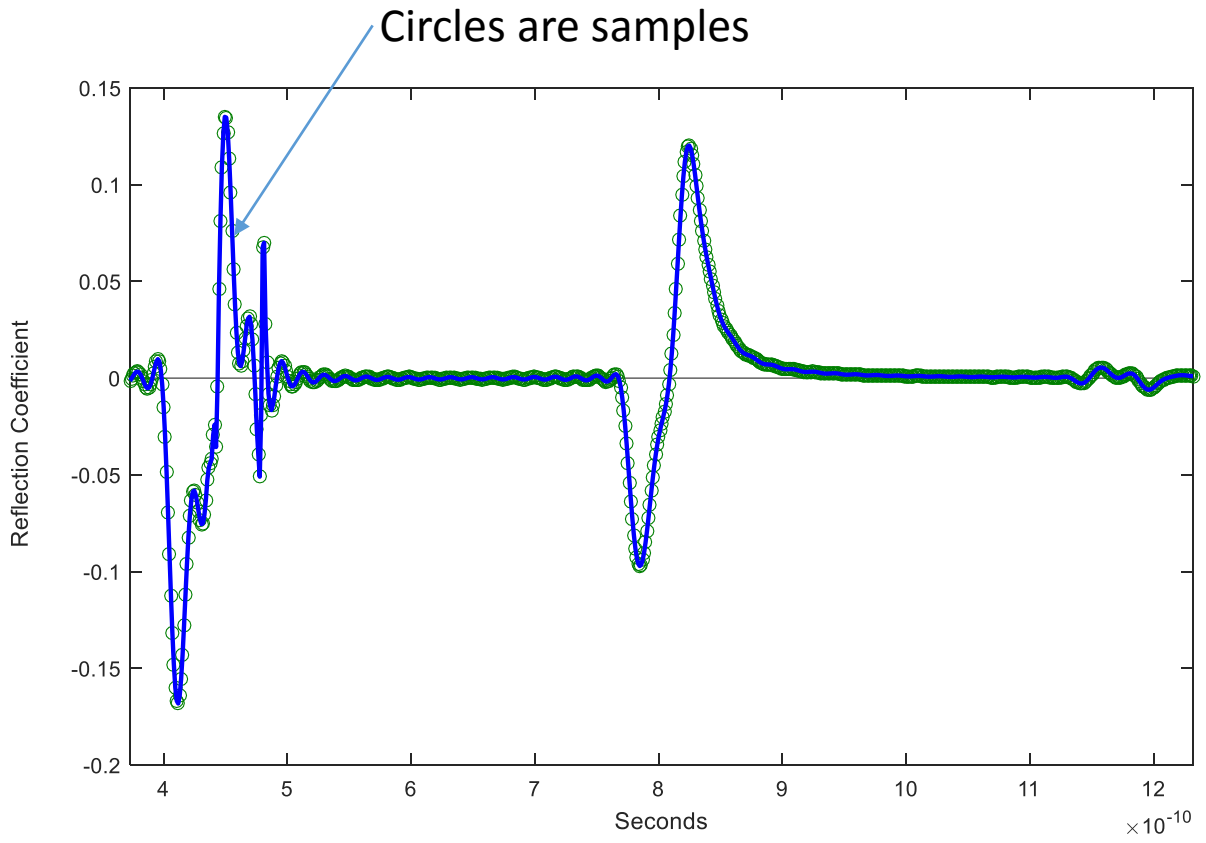


ERL Transition time, ET_r

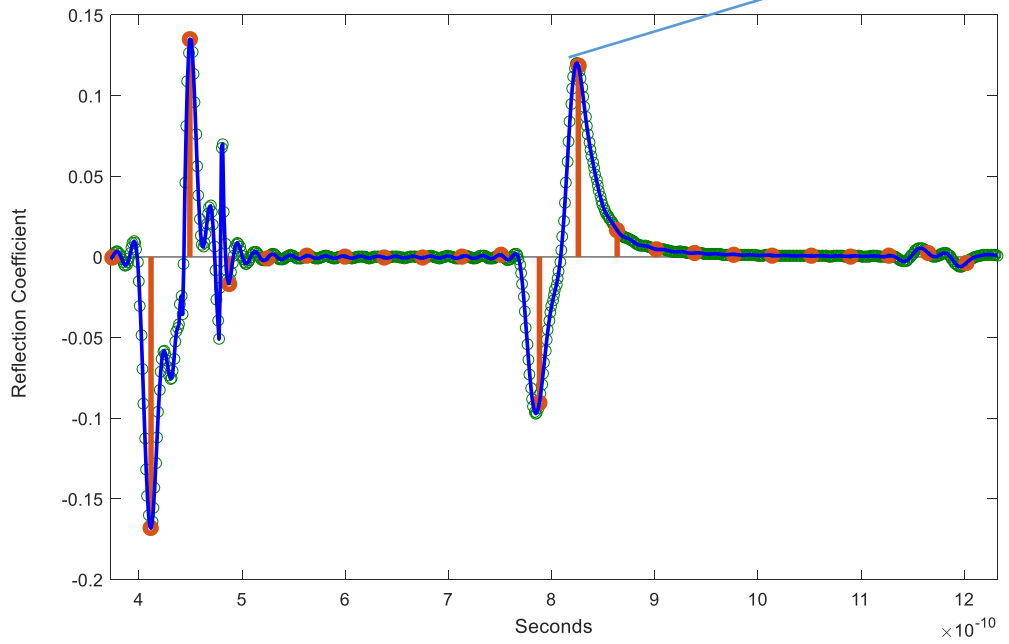
$$Zt \in \begin{cases} Z0_{max} \\ Z0_{mid} \\ Z0_{min} \end{cases}$$

PTDR measurements are in terms of rho (ρ)
PTDR may be computed from s-parameter responses

Determine PTDR response for each Zt



Determine effective reflection coefficient for each sample in a unit interval



S(n,m) where m = 1 to numbers samples per UI, M and n = 1 to number of UI's in response , N

Note: MxN is the number samples response

Compute a Probability Density Function (PDF) and Cumulative Distribution Function (CDF) for the ERL Response

- Referring to equation 93A-39 and 93A-40
  - Commute PDF $p_n(y)$ where h(n) is replaced which S(n,m) for each m
  - And $p_n(y)$ is indexed by $p_{n,m}(y)$
- Determine the CDF (cumulative distribution function) for each $p_{n,m}(y)$
  - This a set of CDF's of the reflection coefficients.
- Choose the worst ERL for all m by
  - Determining the value of P(n,m) where the CDF just equals DER0
    - This value converted to dB is the ERL
- The sample which has the most ERL is chosen for each Zt
- The reported ERL is the one with most ERL for all the Zt values

93A.1.7.1 Interference amplitude distribution

The interference amplitude distribution is computed from the sampled pulse response $h(n)$ with the assumption that the transmitted symbols are independent, identically distributed random variables and that the symbols are uniformly distributed across the set of L possible values. For the purpose of this subclause, $h(n)$ is a general notation that corresponds to $A_{DD}h_f(n)$ (see 93A.1.7.2), $h_{ISI}(n)$, or $h^{(k)}((i/M+n)T_b)$ (see 93A.1.7.3).

Equation (93A–39) defines the nth component of the interference amplitude distribution function where $\delta(y)$ is the Dirac delta function.

$$p_n(y) = \frac{1}{L}\sum_{l=0}^{L-1}\delta\left(y-\left(\frac{2l}{L-1}-1\right)h(n)\right) \quad (93A\text{–}39)$$

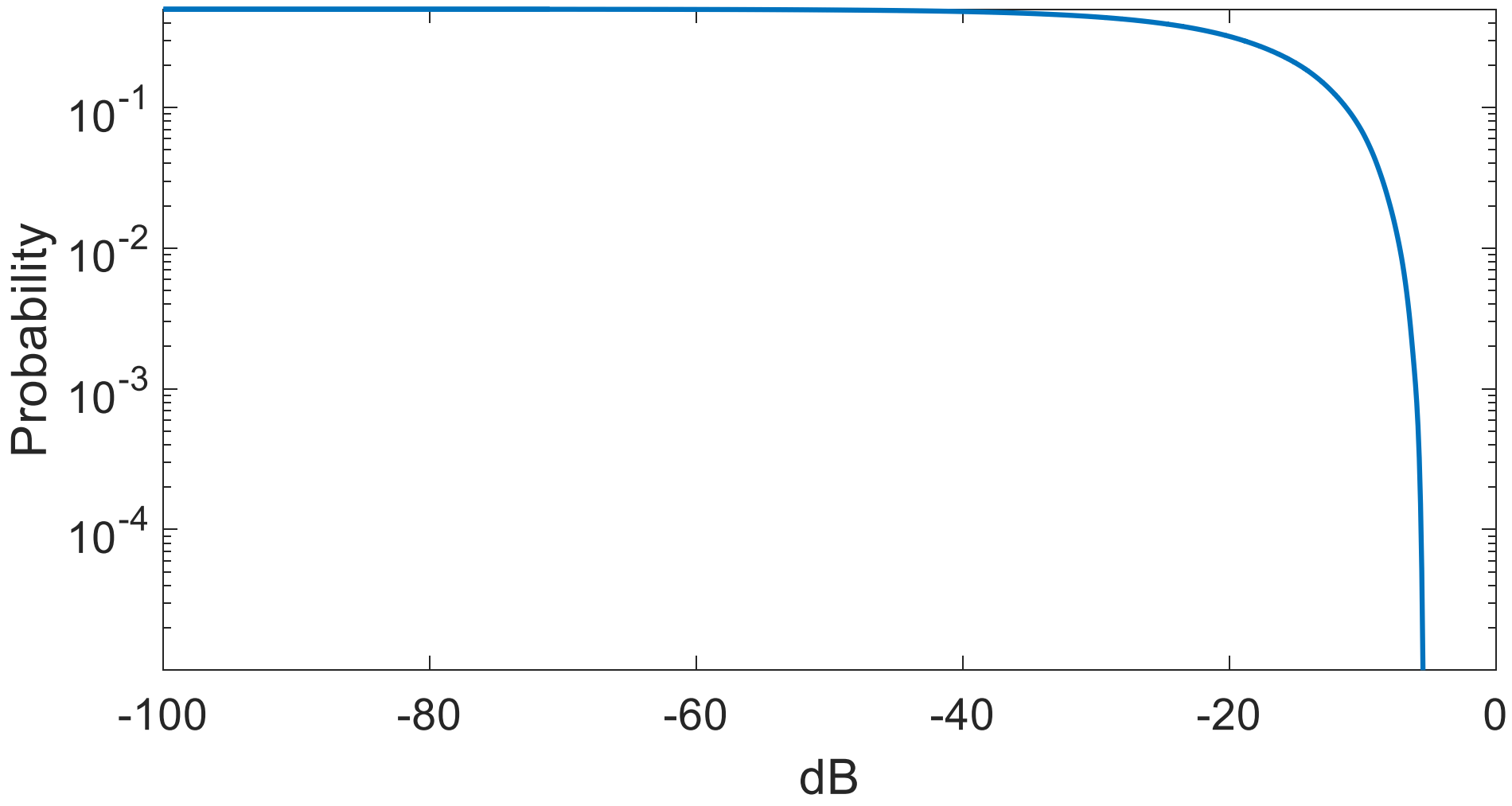
The set of N such components are combined via convolution to obtain the complete interference amplitude distribution. Initialize $p(y)$ to $\delta(y)$ and then evaluate Equation (93A–40) sequentially for n=0 to N–1.

$$p(y) = p(y) * p_n(y) \quad (93A\text{–}40)$$

NOTE 1—COM is expected to be numerically computed using a quantized amplitude axis y. The amplitude step Δy introduces quantization error in the calculated distribution function that is compounded by subsequent convolutions with other quantized distribution functions. It is recommended that Δy be no larger than 0.1% of A_s or 0.01 mV, whichever is smaller.

NOTE 2—It is recommended that components of the pulse response whose amplitude is less than 0.1% of A_s be ignored as they likely correspond to measurement noise or numerical artifacts.

Illustration of CDF for “Cap Variation 1” with Zt=55Ω



Package Loss Compensation for Transmitter

- ERL is adjusted by removing the insertion loss contributor
- ERL_{tx}= ERL- 20*LOG10(0.736/(V_p/V_f))*2

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AC common-mode output voltage[a] (max, RMS)	93.8.1.3	30	mV
Differential output return loss (min)	120D.3.1.8	Equation (120D–9)	dB
Common-mode output return loss (min)	93.8.1.4	Equation 93-4	dB
Output waveform[b] Level separation mismatch ratio R_{LM}(min) Steady state voltage v_f(max) Steady state voltage v_f(min) Linear fit pulse peak (min) Pre-cursor equalization Post-cursor equalization	 120D.3.1.2 120D.3.1.4 120D.3.1.4 120D.3.1.4 120D.3.1.5 120D.3.1.5	 0.95 0.6 0.4 0.736 × v_f Table 120D–3 Table 120D–4	 — V V V — —

ERL Benefit

- Quantify what might really matter for packages and channels
- Remove disadvantage of short transmitter package return loss
- Improve suitability of devices and reduce required margin left on the table for COM

Recommendations

- To minimize impact of from comments r02-55 to 58
  - Add an ERL_{tx} row to Table 120D-1 where the min entry is 6.0 dB
  - Add an ERL_{rx} row to Table 120D-5 where the min entry is 5.5 dB
  - Add an ERL requirement for channels > 5 dB
  - Add an Annex or subsection describing the measurement of ERL
  - Consider ERL for the RITT channels (r0-25)
- Keep COM limits the same for RITT and channel compliance

  Or
- Only add line to 120D.4 for channel COM
  - If ERL of channel is less than 5.0 dB then sweeping package parameters is recommended.

  Or
- Keep status quo: Do not change draft 3.2 for to accommodate COM computation variability
  - Addressing variability is really complicated at this point in the project
- Defer exploration of ERL and COM variability to .3cd and future standards