ERL (Effective Return Loss) Proposal
Addressing comments i71 to i77 (and others) for IEEE P802.3cd D3.0:

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Agenda

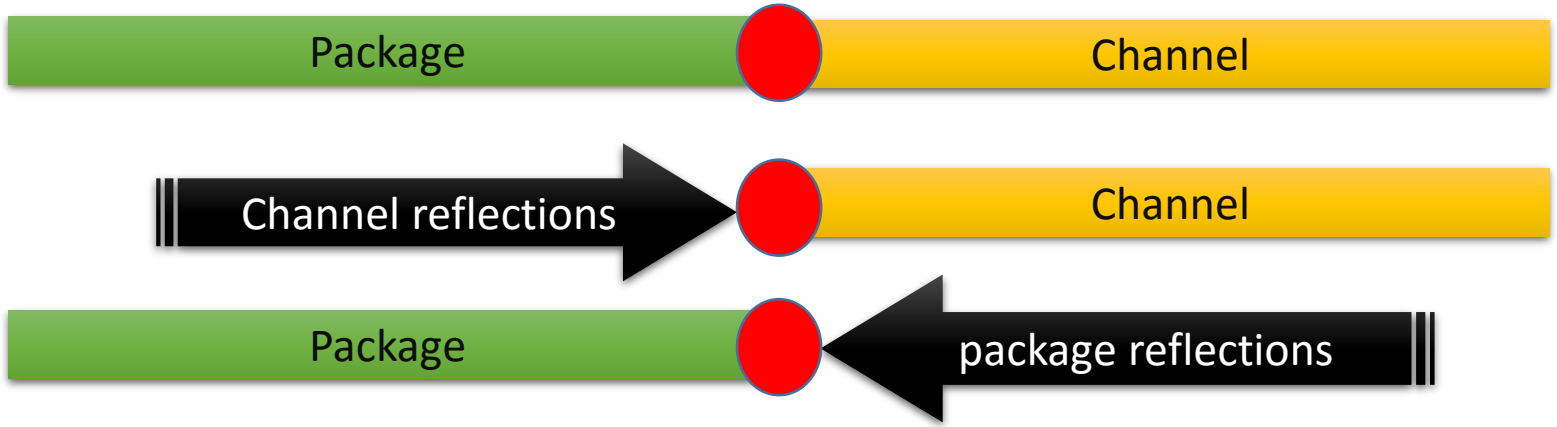
- ❑ History
- ❑ What is ERL
- ❑ Replacing SNR_{ISI} and Return Loss (RL)
- ❑ Computing ERL
- ❑ Refresher on SNR_{ISI} and correlating to ERL
- ❑ ERL of Actual Packages
- ❑ ERL of posted Cable Assembly and Backplane Channels
- ❑ Proposals for comments
  - New Annex or Annex addendum
  - 137 Tx, Rx, Channel
  - 136 Tx Host, Rx Host, Cable Assembly

History

- Before sponsor ballot there has been a pattern of presentations and comments regarding issues with
  - measuring SNDR and SNR_{ISI}
  - test fixture variability impacting measurements
  - Return loss tracking COM (i.e. performance)
    - short packages perform better than long packages but have worst return loss
  - Frequency domain not representative of time domain PHY requirements
    - Strict RL masks may make the link work
    - But also may be overly prohibitive
- In just D3.0 there about 20 or so comments on the above
- ERL provides relief for the above
  - ERL is a time domain analysis and so is COM
  - More details on ERL computation and illustration of how ERL correlates to COM may be found at:
    - http://www.ieee802.org/3/cd/public/Nov17/mellitz_3cd_01b_1117.pdf

Essence of ERL

- ERL is a direct measure of pertinent reflections
  - Using pulse time domain reflectometry (PTDR) …more in future slided
- In the context of
  - Package loss
  - Reference receiver
  - Re-reflections considered from the “missing side” of the channel
    - For a package they are, the channel ERL
    - For a channel they are, the package ERL

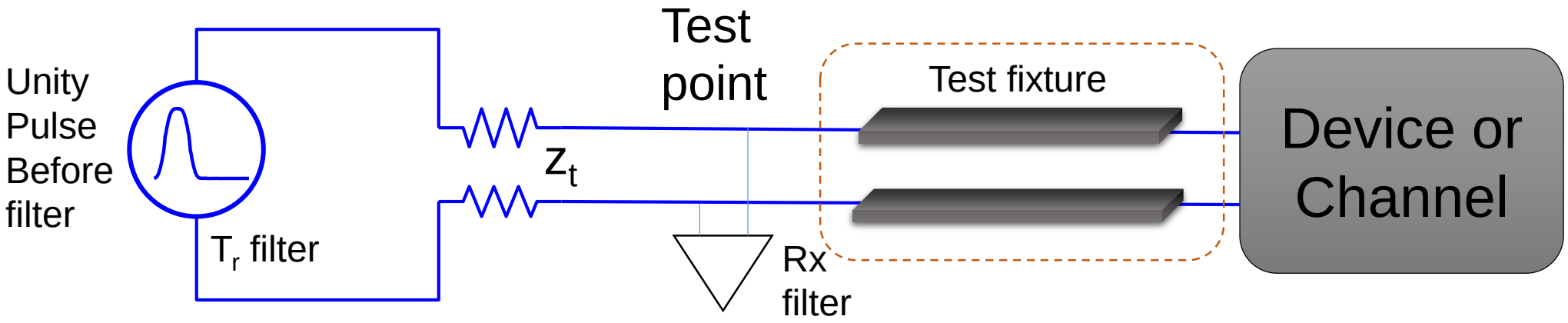


This is proposal to replace SNR_{ISI} and Return loss for Clause 136 and 137

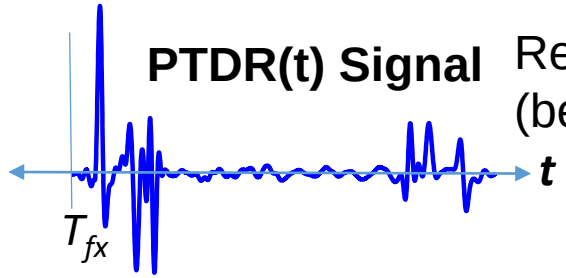
- Unlike current return loss specifications ERL is
  - A single value
    - simplifies compliance and decisions
  - Suited for grading designs
- ERL can correlate to COM
  - For a given reflective channel
    - More reflections in the context of a reference receiver result in
      - Lower COM and ERL
    - Less reflections in the context of a reference receiver results in
      - Higher COM and ERL
  - Return loss has not been shown to track performance
    - Except when RL limits are very strict
- SNR_{ISI} are reflections outside of the reference receiver capability
  - See later slides
- ERL replaces SNR_{ISI} and Return loss (RL)
- ERL removes the unjustified RL penalty for short packages
- ERL incorporates the effects of reference receiver
- ERL unifies channel and device return loss

Introduction Pulse Time Domain Reflectometry (PTDR)

- PTDR is time domain reflectometry using a pulse as a source
- T_{fx} is the time associated with the end of the test fixture
- Test fixture is only used for devices



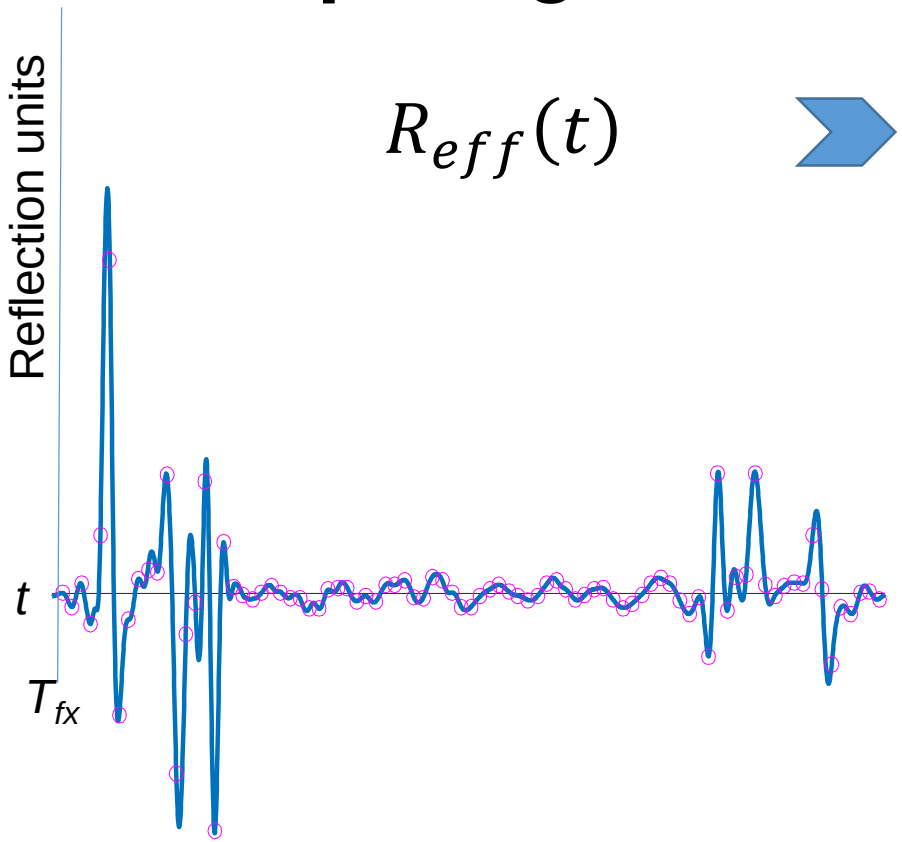
Use T_r=18.9 ps
Rx filter is Butterworth filter as in *IEEE Std 802.3-2015 93A.1*



Reflection units
(between +/- 1)

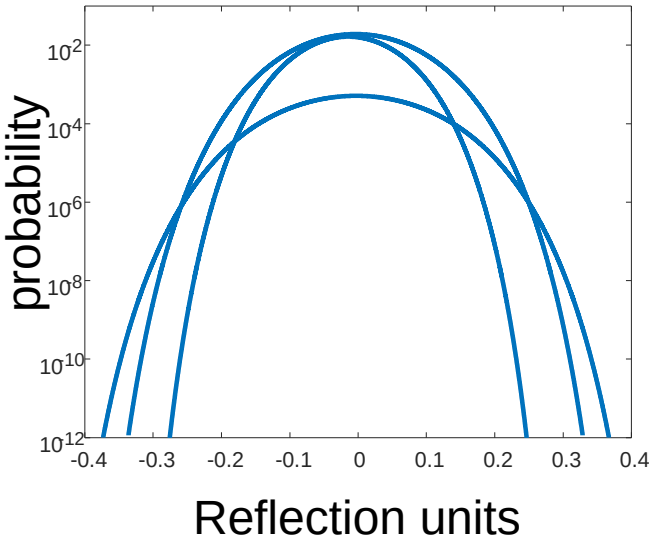
→ Determine ERL from PTDR

Computing ERL



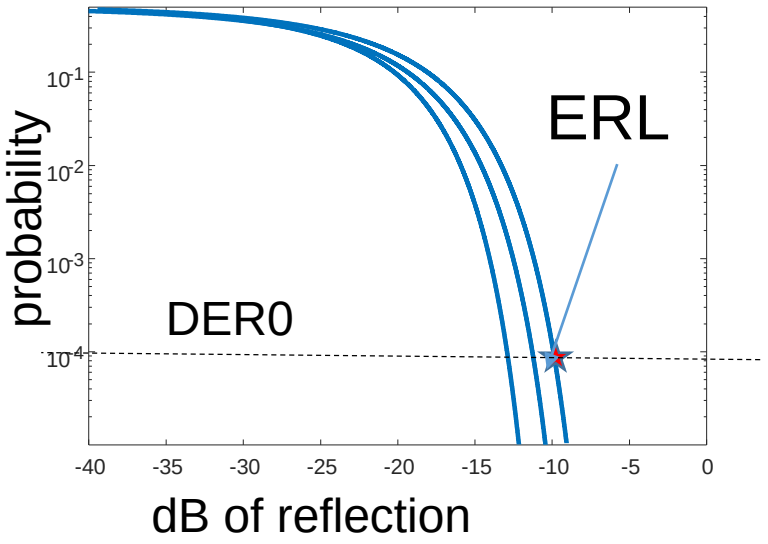
Gated pulse reflection
i.e. for a single bit
Each magenta circle is a sample in each UI (circles are 1 UI apart)

PDF for each time step



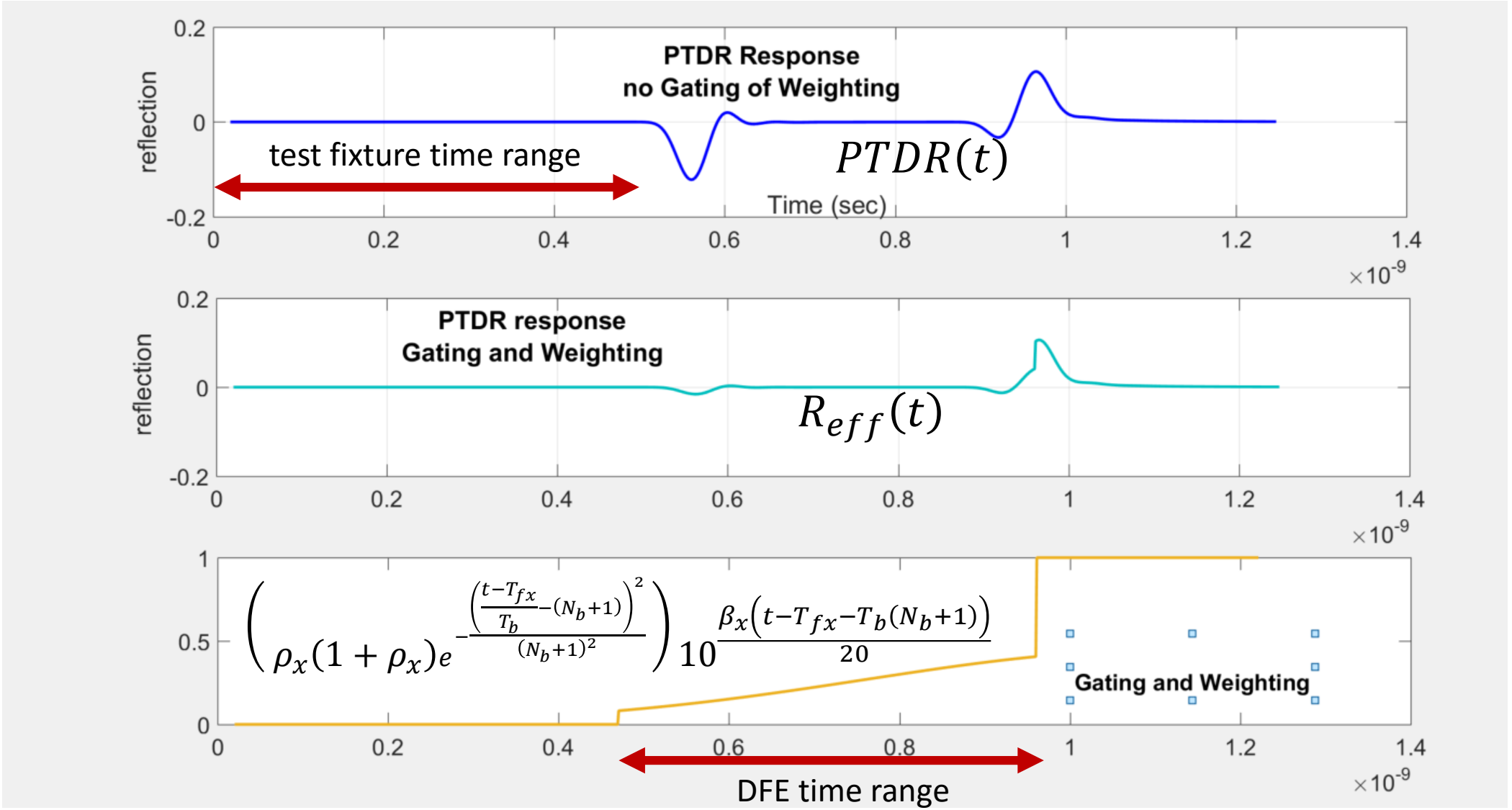
Superposition of reflections from many bits/symbols (PRBS) determines a probability for aggregate reflections

CDF for each time step



Cumulative reflection probability for many bits/symbols (PRBS)

Effective reflection waveform, $R_{eff}(t)$, is used to compute ERL



ERL Computation Parameters

- N_{bx} is the number for DFE taps or set by referencing clause
- T_b is the time for one symbol (aka UI) in ns
- t is time in ns
- T_{fx} is the time in ns associated with the end of the test fixture
- β_x is loss/ratio per unit time derived from the reference package loss in GHz
- ρ_x is the permitted reflection from the "missing side" of the channel
  - ρ_x is a reflection ratio and thus unitless

$$R_{eff}(t) = PTDR(t)\left(\rho_x(1+\rho_x)e^{-\frac{\left(\frac{t-T_{fx}}{T_b}-(N_{bx}+1)\right)^2}{(N_{bx}+1)^2}}\right)10^{\frac{\beta_x\left(t-T_{fx}-T_b(N_{bx}+1)\right)}{20}}$$

DFE re-reflection compensation

Package Loss compensation

Gate and weighing accounting for Loss and DFE and is defined between t < $T_b(N_{bx}+1)$+T_{fx}

ρ_x Ties Package and Channel ERL

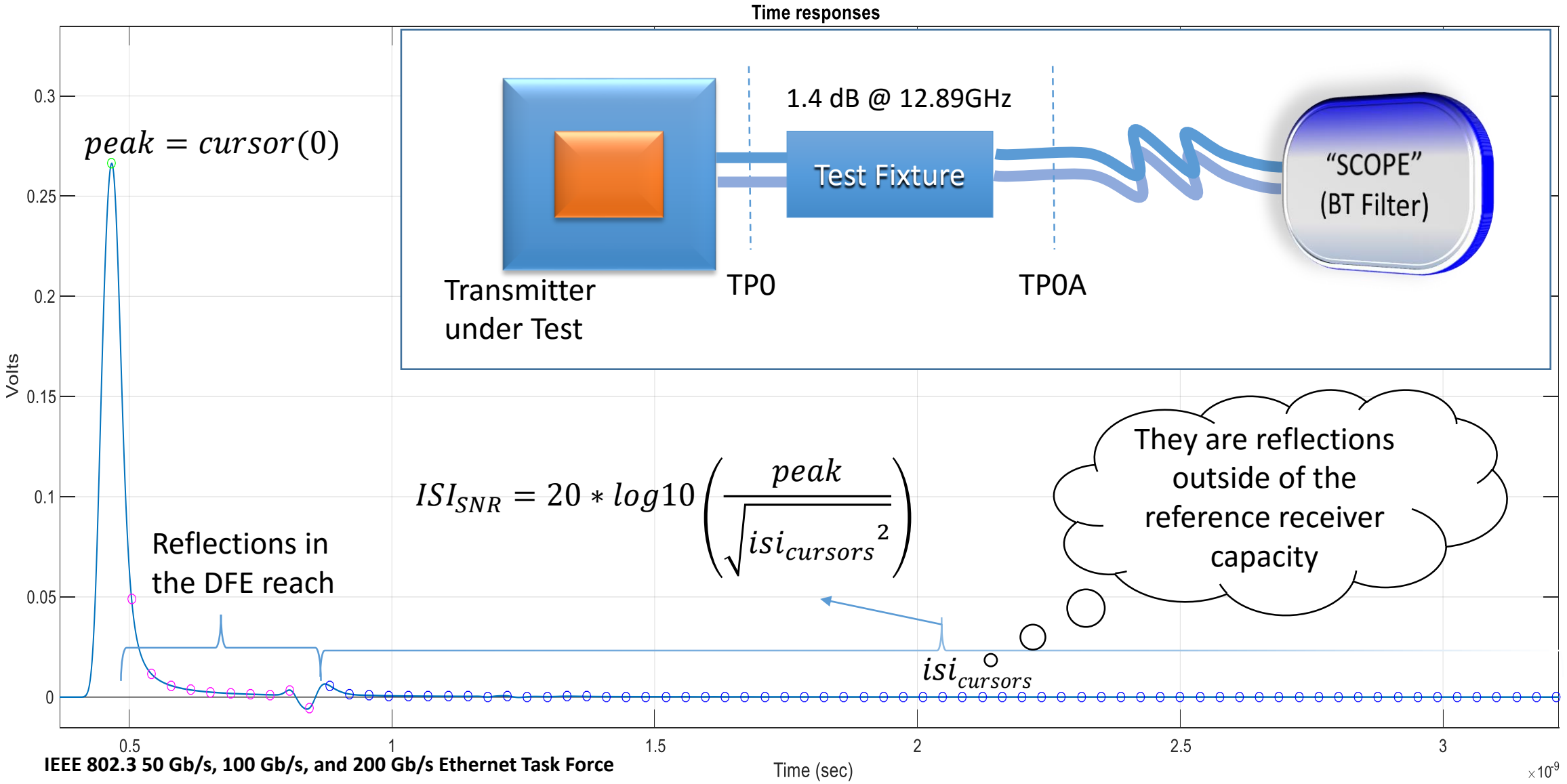
- Define either ERL_x for a channel or package in dB
- The parameter, ρ_x, uses the ERL from the "other side" at the test point in the computation of ERL
  - $\rho_x = 10^{\frac{-ERL_x}{20}}$
  - This caps the re-reflection at the test point

β_x is Loss Weighting for a Signaling Architecture in Relation to Reference Packages

- Assuming a package context for signaling of a short and long package
- Tpδ is the timing difference the two reference package lengths
  - 0.1090 ns
- ΔIL is the loss difference in dB at the Nyquist frequency between short and long package
- IL_{ref} is a required insertion loss in dB (range from 10 dB to 30 dB)
- The package loss weight, β_x, is:

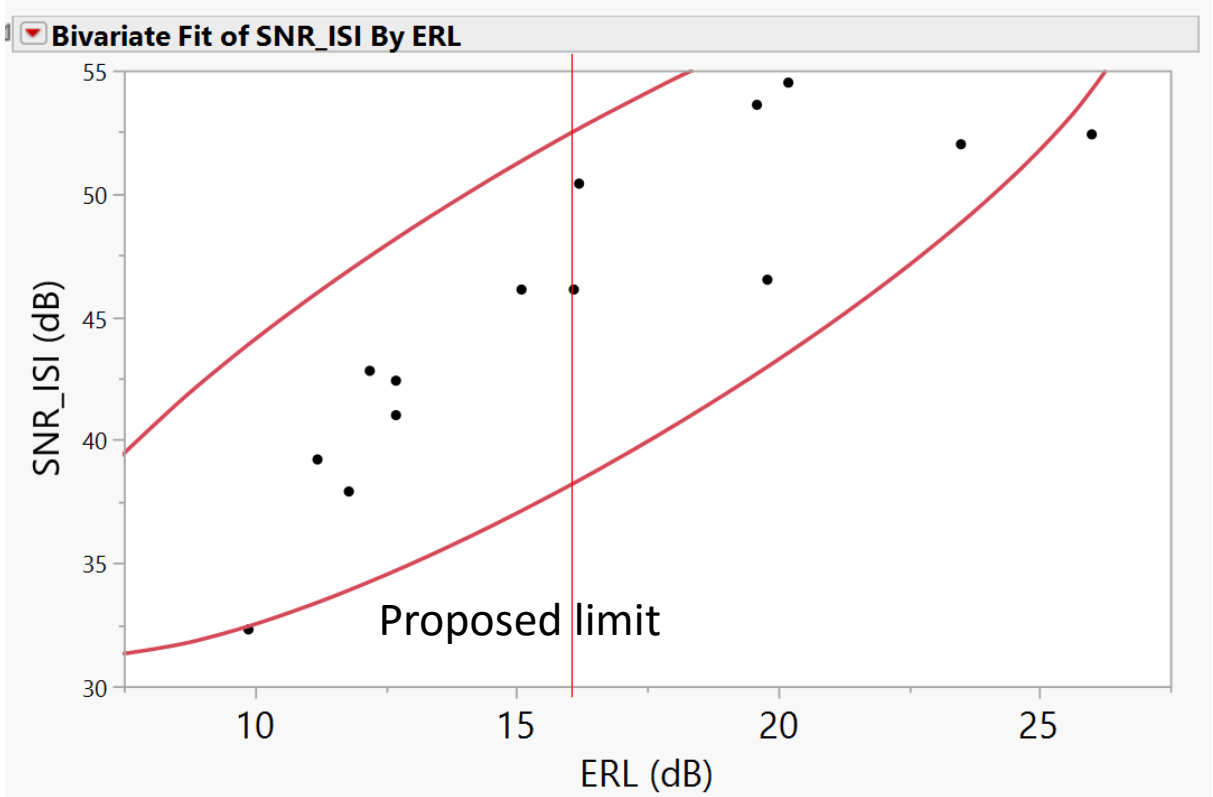
$$\beta_x = \frac{10^{\frac{-(IL_{ref}-\Delta IL)}{20}} - 10^{\frac{-(IL_{ref})}{20}}}{TP\delta\ 10^{\frac{-(IL_{ref})}{20}}}$$

SNR_{ISI} Refresher: Determined From a Fitted Response at Tp0a



ERL is correlated to SNR_{ISI}

- Since
  - SNR_{ISI} are reflections outside of the reference receiver capability
  - ERL is a measure of reflection considering reference receiver capability
- Then
  - SNR_{ISI} should correlate to ERL
- As seen in the graph, correlation appears good
  - Even though ERL also considers re-reflections of canceled cursors.



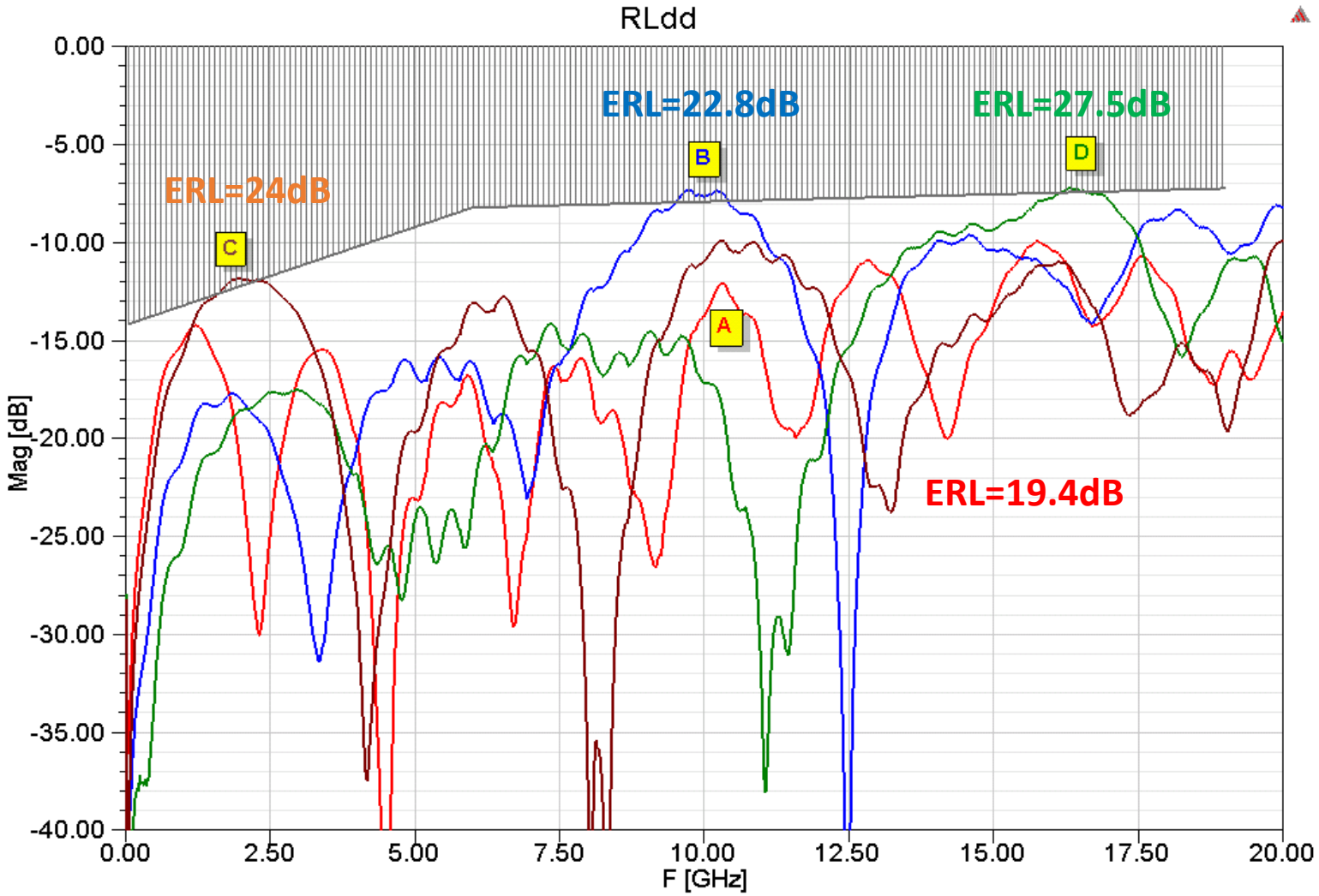
Bivariate Normal Ellipse P=0.900

Variable	Mean	Std Dev	Correlation	Sig
ERL	16.21286	4.92927	0.864723	
SNR_ISI	45.51429	6.627664		

Zp	Zc	Rd	Cd	Cp	SNR_ISI	ERL
30 mm	95 ohms	50 ohms	180 ff	110 ff	46.1	16.1
12 mm	95 ohms	50 ohms	180 ff	110 ff	52	23.5
30 mm	95 ohms	50 ohms	300 ff	180 ff	42.4	12.7
6 mm	95 ohms	50 ohms	300 ff	180 ff	54.5	20.2
6 mm	60 ohms	50 ohms	300 ff	110 ff	53.6	19.6
6 mm	60 ohms	50 ohms	180 ff	110 ff	50.4	16.2
30 mm	60 ohms	50 ohms	300 ff	300 ff	39.2	11.2
30 mm	120 ohms	50 ohms	400 ff	110 ff	41	12.7
30 mm	95 ohms	50 ohms	110 ff	110 ff	46.5	19.8
12 mm	95 ohms	50 ohms	110 ff	110 ff	52.4	26
30 mm	95 ohms	50 ohms	500 ff	500 ff	32.3	9.88
30 mm	95 ohms	40 ohms	200 ff	150 ff	46.1	15.1
30 mm	60 ohms	60 ohms	200 ff	150 ff	37.9	11.8
30 mm	60 ohms	40 ohms	100ff	50 ff	42.8	12.2

RLdd vs. ERL – Actual PKG Design

- 4 packages
  - A, B, C, D
- Actual package design cases with length and impedance variance

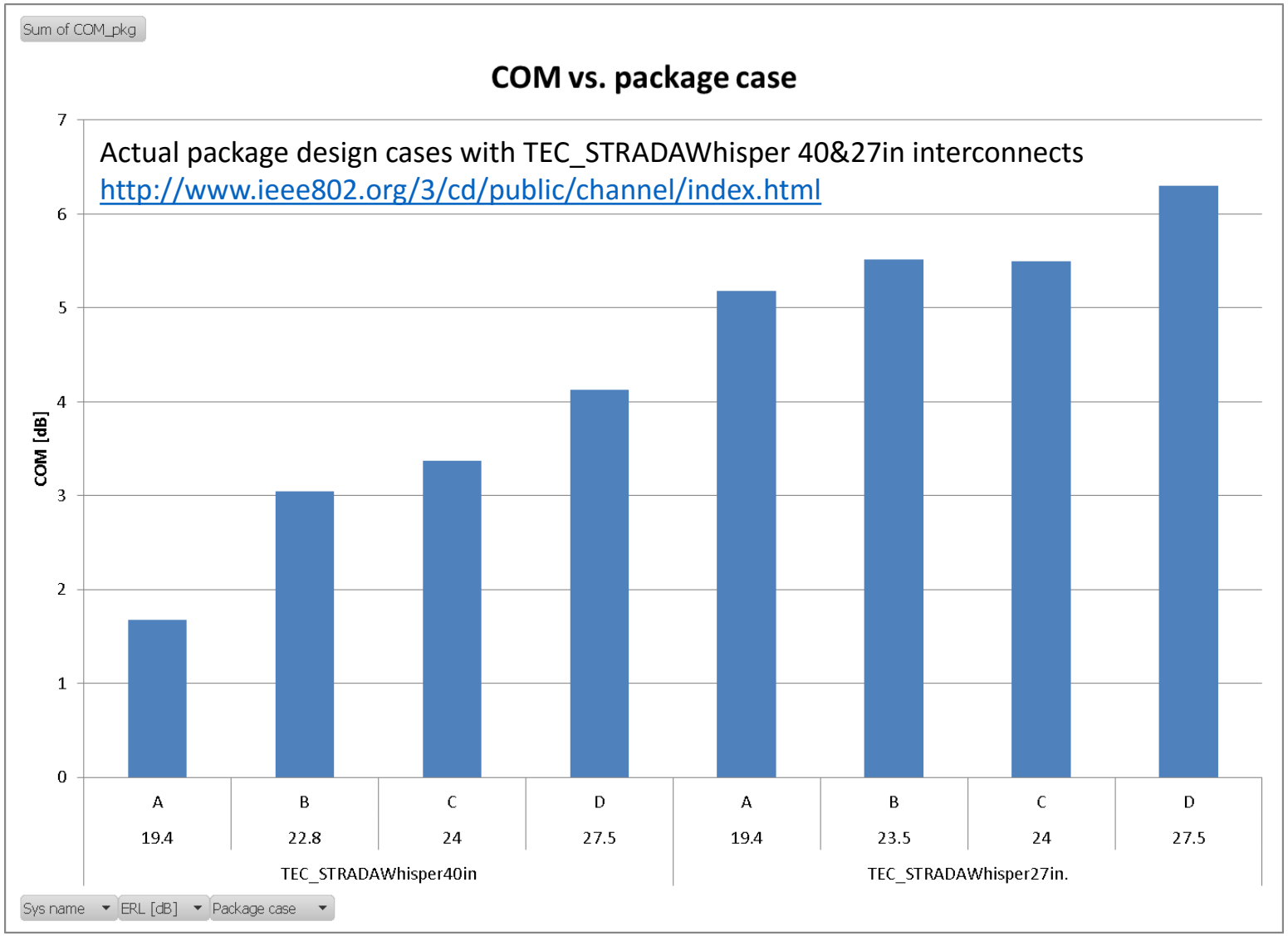


Data from Jacov Brener and Liav Ben-Artsi, Marvell Israel Ltd

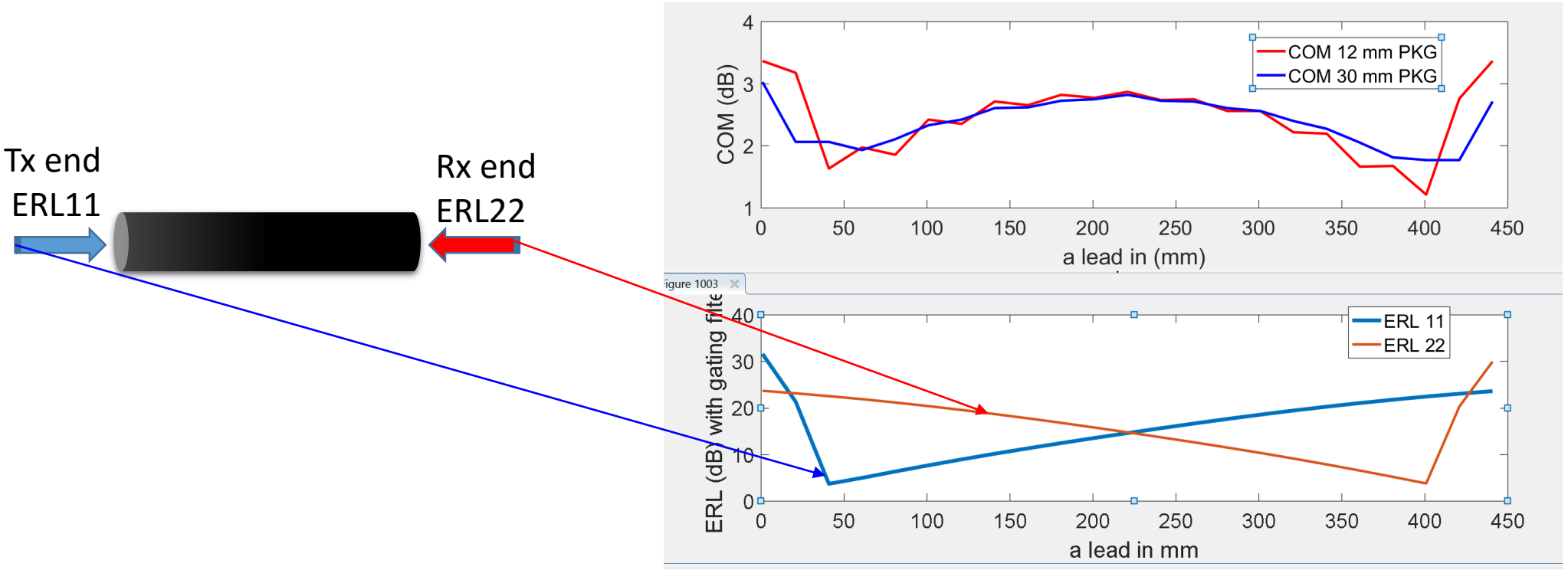
COM vs. ERL – Actual Package Design

- Impressive correlation has been seen between ERL & COM
- Passing RLdd spec doesn't ensure meeting COM target nor correlate to COM results

Data from Jacov Brener and Liav Ben-Artsi, Marvell Israel Ltd



COM tracks ERL for a channel with controlled reflections

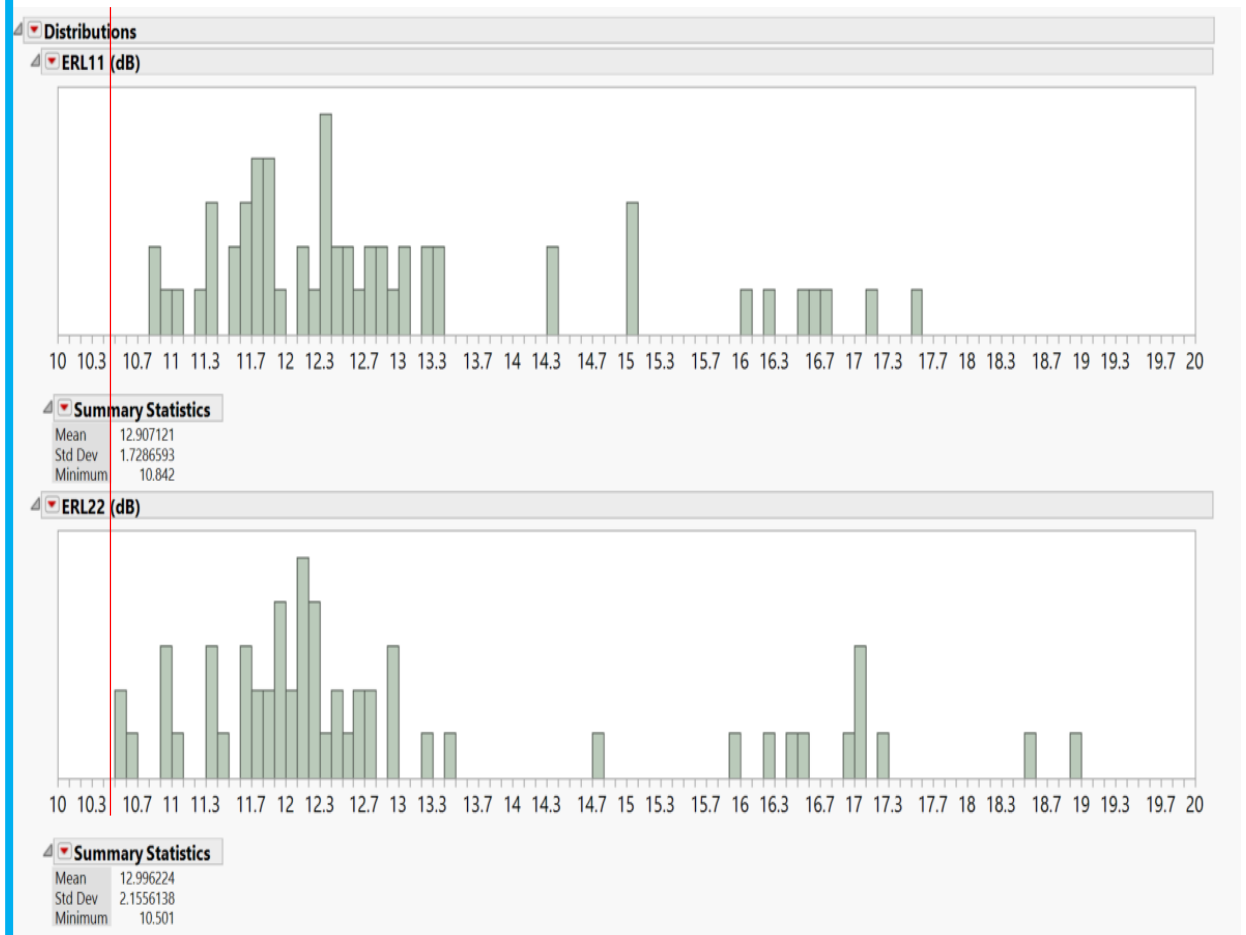


- View the composite of ERL11 and ERL22 in relation to COM
- Details presented in http://www.ieee802.org/3/cd/public/Nov17/mellitz_3cd_01b_1117.pdf

ERL Distribution for:
Posted .3cd and .3by Cable Assembly and Backplane Channels

Proposed limit

Cable Assemblies



Proposed limit

Backplanes

ERL to COM correlation may be found in
http://www.ieee802.org/3/cd/public/Nov17/mellitz_3cd_01b_1117.pdf

Comment # i-74 and # i-75 “Tx Host RL”

- Table 136-11
  - Remove row for "SNR_{ISI} (min.)"
  - Replace row for "differential output return loss (min)" in Table 136-11 with
    - ERL (min) which shall be greater than 9 dB using
      - β_x =10.7 GHz, and ρ_x =0.3 , T_{rp} = 0.0189 ns,
      - N_{bx} is N_b set by this clause.

Table 136–11—Summary of transmitter specifications at TP2

Parameter	Subclause reference	Value	Units
Differential pk-pk output voltage (max.) with Tx disabled[a]	93.8.1.3	30	mV
DC common-mode voltage (max.)[a]	93.8.1.3	1.9	V
AC common-mode RMS output voltage, v_{cmi} (max.)[a]	93.8.1.3	30	mV
Differential pk-pk voltage, v_{di} (max.)[a]	93.8.1.3	1 200	mV
~~Differential output return loss (min.)~~	~~92.8.3.2~~	~~See Equation (92–1)~~	~~dB~~
Common-mode to differential mode output return loss (min.)	92.8.3.3	See Equation (92–2)	dB
Common-mode to common-mode output return loss (min.)	92.8.3.4	See Equation (92–3)	dB
Transmitter steady-state voltage, v_f (min.) Transmitter steady-state voltage, v_f (max.)	136.9.3.1.2	0.34 0.6	V
Linear fit pulse peak (min.)	136.9.3.1.2	$0.49 \times v_f$	V
Level separation mismatch ratio R_{LM} (min.)	120D.3.1.2	0.95	—
Transmitter output waveform abs step size for $c(-1)$, $c(0)$, and $c(1)$ (min.) abs step size for $c(-1)$, $c(0)$, and $c(1)$ (max.) abs step size for $c(-2)$ (min.) abs step size for $c(-2)$ (max.) value at minimum state for $c(-1)$ and $c(1)$ (max.) value at maximum state for $c(-2)$ (min.)	 136.9.3.1.4 136.9.3.1.4 136.9.3.1.4 136.9.3.1.4 136.9.3.1.5 136.9.3.1.5	 0.005 0.05 0.005 0.025 −0.25 0.1	 — — — — — —

Table 136–11—Summary of transmitter specifications at TP2 *(continued)*

Parameter	Subclause reference	Value	Units
Signal-to-noise-and-distortion ratio SNDR (min.)	120D.3.1.6	33.3	dB
~~SNR_{ISI} (min.)[b]~~	~~120D.3.1.7~~	~~36.8~~	~~dB~~

Comment # i-76 “Rx Host RL”

136.9.4 Receiver characteristics

Receiver electrical characteristics are specified at TP3. The receiver shall meet the return loss requirements specified in ~~92.8.4.2~~ and 92.8.4.3. In addition, the requirements in 136.9.4.1, 136.9.4.2, 136.9.4.3 and 136.9.4.4 apply.

The receiver specifications at TP5 are provided informatively in 136A.3.

- Remove the reference to 92.9.4.2.
- Add text indicating that ERL (min) for the host input shall be greater than 9 dB using β_x =10.7 GHz, and ρ_x =0.3 , T_{rp} = 0.0189 ns, and N_{bx} is N_b set by this clause.

Comment # i-77
“Cable Assembly RL”

~~136.11.3 Cable assembly differential return loss~~

~~The cable assembly differential return loss shall meet the requirements of 92.10.3.~~

- Rename clause 136.11.3 from “Cable Assembly Differential Return Loss” to ““Cable Assembly Effective Return Loss”.
- Remove all the content of 136.11.3.

Table 136–14—Cable assembly characteristics summary

Description	Reference	Value	Unit
Maximum insertion loss at 13.28 GHz	136.11.2	17.16	dB
Minimum insertion loss at 13.28 GHz	136.11.2	8	dB
~~Minimum differential return loss at 13.28 GHz~~	~~136.11.3~~	~~5.3~~ ~~Equation (92–27)~~	dB
Differential to common-mode return loss	136.11.4	Equation (92–28)	dB
Differential to common-mode conversion loss	136.11.5	Equation (92–29)	dB
Common-mode to common-mode return loss	136.11.6	Equation (92–30)	dB
Minimum COM	136.11.7	3	dB

- Replace with: “The minimum effective return loss of the cable assembly shall be greater than 10.5 dB only when COM is less than 4 dB computed using β_x =10.7 GHz, and ρ_x =0.35 , T_{rp} = 0.0189 ns, and N_{bx} is N_b set by this clause. .
- Replace “Minimum differential Return Loss” in Table 136-15 with an entry for ERL

Comment # i-71 and # i-72 “Device RL”

❑ 137.9.2 Transmitter characteristics

- Remove item 3 in exception list.
- Add exception item indicating that in Table 120D-1 “differential output return loss (min)” is replaced with
  - ERL (min) which shall be greater than 16.1 dB using
    - β_x =10.7 GHz, ρ_x =0.31, T_{rp} = 0.0189 ns
    - N_{bx} is N_b set by this clause.

❑ 137.9.3 Receiver characteristics

- Add exception item indicating that in Table 120D-5 “differential input return loss (min)” replaced with
  - ERL (min) which shall be greater than 16.1 dB using
    - β_x=10.7 GHz, and ρ_x=0.31, T_{rp} = 0.0189 ns,
    - N_{bx} is N_b set by this clause

137.9.2 Transmitter characteristics

The transmitter shall meet the specifications given in Table 120D–1, with the following exceptions:

1) The value of linear fit pulse peak (min) is 0.75 × v_f.
2) The output waveform Pre-cursor equalization and Post-cursor equalization parameters are replaced by the “Transmitter output waveform” specifications summarized in Table 136–11 and detailed in 136.9.3.1.
3) ~~SNR_{TSI} is computed with N_b set to 12 and D_p set to 3. The value of SNR_{TSI} (min) is 43 dB.~~
4) The value of SNDR (min) is 32.5 dB.

137.9.3 Receiver characteristics

Receiver electrical characteristics are specified at TP5a. The receiver shall meet the specifications given in Table 120D–5 with the following exceptions:

1) PCS FEC symbol error ratio (max) values in Table 120D–6 and Table 120D–7 are all 10^{-3}. For 50GBASE-KR and 100GBASE-KR2, RS-FEC symbol error ratio is used instead of PCS FEC symbol error ratio.
2) Insertion loss at 13.2813 GHz values for Test 1 are 14.5 (min) and 15.5 (max).
3) Insertion loss at 13.2813 GHz values for Test 2 are 29.5 (min) and 30.5 (max).
4) RSS_DFE4 value for Test 1 is 0.05.
5) Receiver jitter tolerance (see 120D.3.2.2) is tested using the test channel used for receiver interference tolerance Test 2 (see item 3).

Fixture loss in 137.9.2 and 137.9.3

- ❑ Adjust for fixture loss width de-embedding

Or

- ❑ Loss adjustment can based on replica channel measurements

Basically adjustment is same as we have now. This could be improved.

Comment # i-73
“Channel RL”

~~137.10.2 Channel return loss~~

~~The minimum differential return loss of the channel is given by Equation (137–2).~~

$$RL_d(f) \geq \begin{cases} 12 & 0.05 \leq f \leq f_b/4 \\ 12 - 15\log_{10}(4f/f_b) & f_b/4 < f \leq f_b \end{cases} \quad \text{dB} \qquad (137\text{–}2)$$

where

~~f is the frequency in GHz~~

~~f_b is the signaling rate (26.5625) in GHz~~

~~$RL(f)$ is the return loss at frequency f~~

- Rename clause 137.10.2 from “Return Loss” to “Effective Return Loss”.
- Remove all the content of 137.10.2.
- Replace with: “The minimum effective return loss of the channel shall be greater than 10.2 dB only when COM is less than 4 dB computed using β_x =10.7 GHz, and ρ_x =0.155 , T_{rp} = 0.0189 ns, and N_{bx} is N_b set by this clause”

Summary

- ERL replaces Return Loss and/or SNR_{ISI} for
  1. Devices (KR)
  2. Channels (KR)
  3. Hosts (CR)
  4. Cable Assemblies (CR)

- The above is in the order of supporting data
  - Item 1 has the most compelling data

Clause	ERL Min (dB)
136 Tx Host	9
136 Rx Host	9
136 Cable Assembly	10.5
137 Tx Device	16.1
137 Rx Device	16.1
137 Channel	10.2