Moving toward an ERL CC, DC, and CC specification

Addressing unsatisfied d2.1 modal ERL comments 253, 254, 256, 258, 258, 259, 261, 262, 264, 265, 266, 267, 268

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Agenda

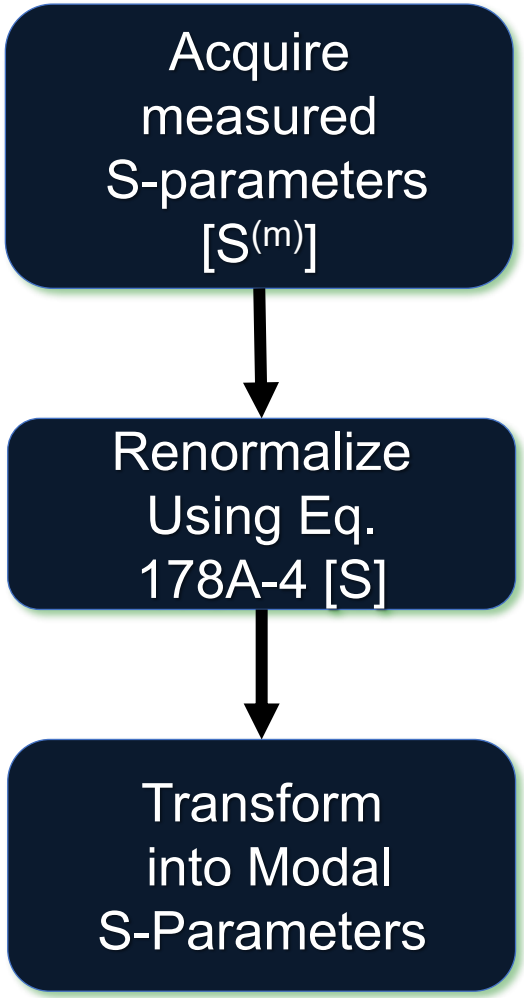
- ❑ Problem Statement
- ❑ Measured s-parameters, renormalization, and modal conversions
- ❑ Modal ERL
- ❑ COM Sensitivity Analysis using modal aware COM
- ❑ Simulation Results: Impact of common modal specification on COM
- ❑ Summary and Recommendation

Problem Statement

- Renormalization is required for modal mask and ERL compliance.
  - Ref 178.9.1, 179.9.3, 176C.6.2, 176D.6.3, and 179B.4.1
- Renormalized modal s-parameter require more clarity
  - In the context of how s-parameter currently expected to be measured or acquired.
- There is a lack of clarity on Modal Specification Impact on COM and Channel Performance
  - This apply to Modal masks and Modal ERL

Precision in Modal Specs Starts with Correct Renormalization

- Accurate renormalization of measured S-parameters is essential for reliable modal mask and ERL compliance.
- Measured s-parameter are single-end transmission and reflections between all single end ports
- Annex 178A currently defines “S” as differential-mode S-parameters and applies Eq. 178A-4, which is appropriate for measured single-ended S-parameters but not for modal S-parameters.
- Equation **178A-4** is correct for renormalizing the measured set of S-parameter measurements, not modal S-parameters.
- Next, define/refine the renormalization and modal conversion method for Annex 178A



Renormalization and Modal Conversion Method for Annex 178A

- ❑ Specify measured 4-port or 2-port s-parameter syntax, $S^{(m)}$
- ❑ Apply renormalization using equation 178A-4 to the measured s-parameters
- ❑ Convert the measured s-parameters to modal s-parameters
  - As in following slide
- ❑ Clarify in 178A.1.3 that references to S or s_{ij} ,and RL, denote differential-mode S-parameters
  - Modal parameters should use syntax such as SDC, SCD, or SCC.

Detail for Modal Conversion

4 PORT EXAMPLE

- Measured 4 port s parameter is denoted $S^{(m)}(i,j)$ or $[S^{(m)}]$
- Choices of indices for i and j are
  - txp, txn = positive and negative terminals of the transmit pair.
  - rxp, rxn = positive and negative terminals of the receive pair.

Differential Mode (SDD):

$SDD_{11} = 0.5 \times [S^{(m)}(txp, txp) - S^{(m)}(txn, txp) - S^{(m)}(txp, txn) + S^{(m)}(txn, txn)]$

$SDD_{12} = 0.5 \times [S^{(m)}(txp, rxp) - S^{(m)}(txn, rxp) - S^{(m)}(txp, rxn) + S^{(m)}(txn, rxn)]$

$SDD_{21} = 0.5 \times [S^{(m)}(rxp, txp) - S^{(m)}(rxn, txp) - S^{(m)}(rxp, txn) + S^{(m)}(rxn, txn)]$

$SDD_{22} = 0.5 \times [S^{(m)}(rxp, rxp) - S^{(m)}(rxn, rxp) - S^{(m)}(rxp, rxn) + S^{(m)}(rxn, rxn)]$

Common-to-Differential Mode (SDC):

$SDC_{11} = 0.5 \times [S^{(m)}(txp, txp) - S^{(m)}(txn, txp) + S^{(m)}(txp, txn) - S^{(m)}(txn, txn)]$

$SDC_{12} = 0.5 \times [S^{(m)}(txp, rxp) - S^{(m)}(txn, rxp) + S^{(m)}(txp, rxn) - S^{(m)}(txn, rxn)]$

$SDC_{21} = 0.5 \times [S^{(m)}(rxp, txp) - S^{(m)}(rxn, txp) + S^{(m)}(rxp, txn) - S^{(m)}(rxn, txn)]$

$SDC_{22} = 0.5 \times [S^{(m)}(rxp, rxp) - S^{(m)}(rxn, rxp) + S^{(m)}(rxp, rxn) - S^{(m)}(rxn, rxn)]$

Differential-to-Common Mode (SCD):

$SCD_{11} = 0.5 \times [S^{(m)}(txp, txp) + S^{(m)}(txn, txp) - S^{(m)}(txp, txn) - S^{(m)}(txn, txn)]$

$SCD_{12} = 0.5 \times [S^{(m)}(txp, rxp) + S^{(m)}(txn, rxp) - S^{(m)}(txp, rxn) - S^{(m)}(txn, rxn)]$

$SCD_{21} = 0.5 \times [S^{(m)}(rxp, txp) + S^{(m)}(rxn, txp) - S^{(m)}(rxp, txn) - S^{(m)}(rxn, txn)]$

$SCD_{22} = 0.5 \times [S^{(m)}(rxp, rxp) + S^{(m)}(rxn, rxp) - S^{(m)}(rxp, rxn) - S^{(m)}(rxn, rxn)]$

Common Mode (SCC):

$SCC_{11} = 0.5 \times [S^{(m)}(txp, txp) + S^{(m)}(txn, txp) + S^{(m)}(txp, txn) + S^{(m)}(txn, txn)]$

$SCC_{12} = 0.5 \times [S^{(m)}(txp, rxp) + S^{(m)}(txn, rxp) + S^{(m)}(txp, rxn) + S^{(m)}(txn, rxn)]$

$SCC_{21} = 0.5 \times [S^{(m)}(rxp, txp) + S^{(m)}(rxn, txp) + S^{(m)}(rxp, txn) + S^{(m)}(rxn, txn)]$

$SCC_{22} = 0.5 \times [S^{(m)}(rxp, rxp) + S^{(m)}(rxn, rxp) + S^{(m)}(rxp, rxn) + S^{(m)}(rxn, rxn)]$

$RL=RLDD=SDD_{11}$; $RLDC=SDC_{11}$: $RLCD=SCD_{11}$: $RLCC=SCC_{11}$

Specification Supporting Modal ERL

Add section to 179A for modal ERL (suggested wording)

178A.3 Modal Effective Return Loss

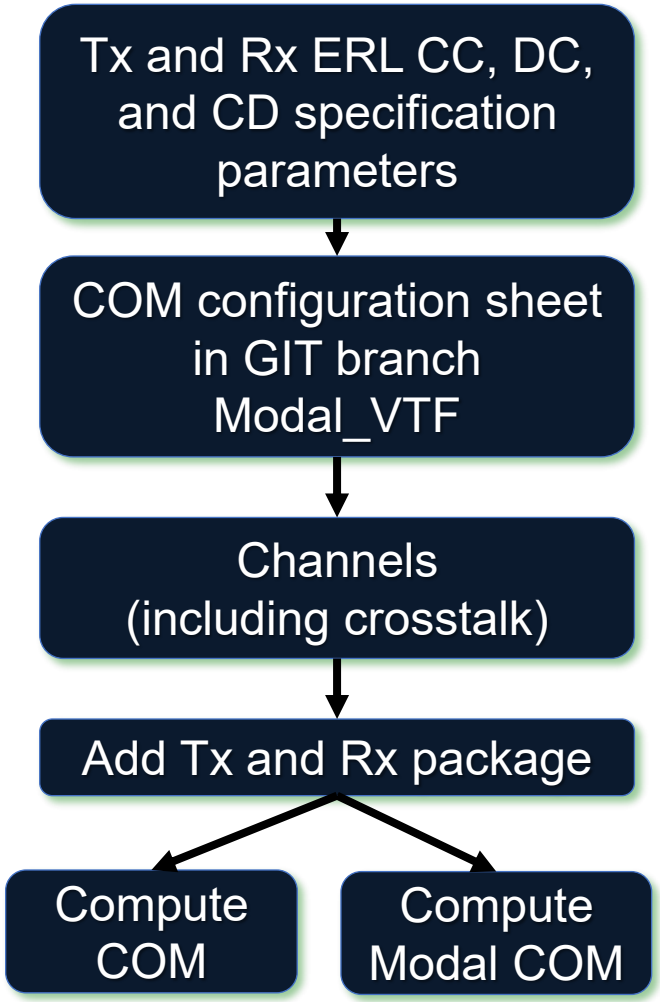
Modal Effective Return Loss (ERL) is a figure of merit that quantifies electromagnetic reflections occurring at the input or output of a device or channel when excited and observed in differential-to-common, common-to-differential, or common-to-common mode signal paths. The modal ERL values—ERL_DC, ERL_CD, and ERL_CC—correspond respectively to common-to-differential, differential-to-common, and common-to-common mode reflections.

The calculation of modal ERL shall be performed using the method defined in this annex, augmenting the ERL methodology described in Annex 93A.5. The parameters required for the computation of ERL_DC, ERL_CD, and ERL_CC are listed in Table 93A–4. The values assigned to these parameters are defined by the Physical Layer specification that invokes the modal ERL method.

When the modal ERL method is invoked, references to ERL shall be interpreted as ERL_DC, ERL_CD, or ERL_CC, as appropriate to the modal context.

COM Simulation Framework for Modal ERL Specification Consideration

- Goal: Determine modal requirement for minimal impact on performance
- COM simulations (modal COM) including crosstalk are used to evaluate impact of modal ERL on channel performance
  - Reference to method in mellitz_3dj_adhoc_01a_250828.pdf
- The simulations use the Modal_VTF GIT branch, which includes
  - Modal ERL values: ERL_DC, ERL_CD, and ERL_CC, representing different mode conversion paths.
  - These values act as proxies for device loading in modal signal paths
- Modal ERL values (ERL_DC, ERL_CD, ERL_CC) are used as proxies for device loading in modal signal paths
  - Device ERL_CC and ERL_DC/CD values swept across simulations
- Framework
  - Uses channels with COM > 3 dB to assess sensitivity.
  - delta COM = modal COM-Ref COM
  - Modal ERLs and SCMR_CH are reported per port and compared to delta COM



Simulation Implementation and Parameter Sweep Details

- Modal COM is implemented in the Modal_VTF GIT branch
  - GIT code pointer
    - https://opensource.ieee.org/richard.mellitz/com_code/-/raw/Modal_VTF/release/com_ieee8023_4p12p0_Modal_VTF.m?ref_type=heads&inline=false
  - Implementation of
    - https://www.ieee802.org/3/dj/public/adhoc/electrical/25_0828/mellitz_3dj_adhoc_01a_250828.pdf
- Configuration Spreadsheet was based on the following in the Modal_VTF GIT branch
  - https://opensource.ieee.org/richard.mellitz/com_code/-/blob/Modal_VTF/config_templates/KR/200G/config_com-4p12p0_Modal_ERL_802p3dj_d2p1_200G_KRCR_PKGA_10_22_25.xlsx?ref_type=heads
- 2 Keywords added for GIT branch Modal_VFT configuration spreadsheet to support modal ERL impact
  - TX_modal_ERL_spec [{ERLcc} {ERLdc} {ERLcd}]
  - RX_modal_ERL_spec [{ERLcc} {ERLdc} {ERLcd}]
- Sweep for modal ERL device parameters include
  - TX and Rx ERLcc = 2, 3, 5
  - TX and Rx ERLdc and ERLcd = 15, 20, 30

Channels

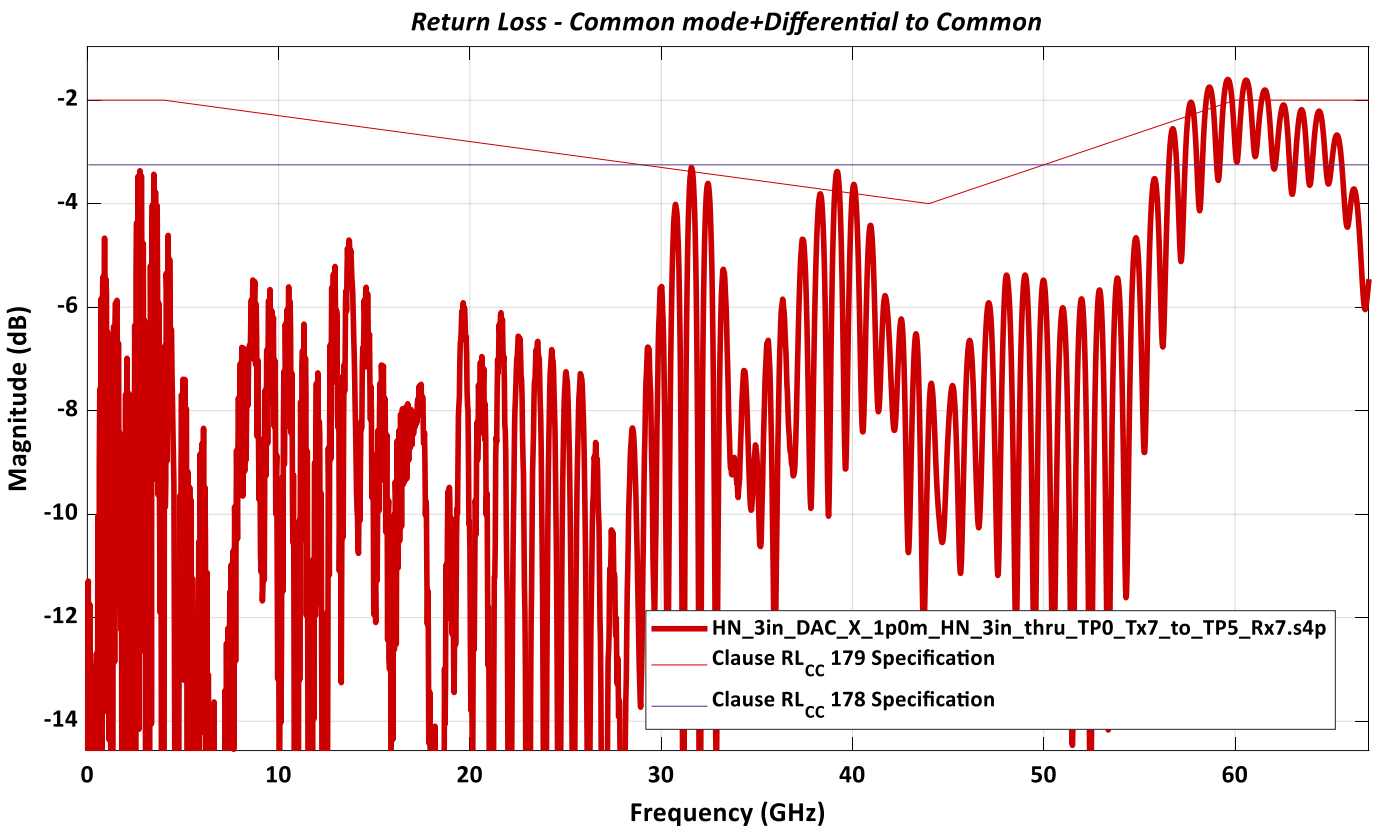
- akinwale_3dj_01_2311
- kocsis_3dj_02_2305
- lim_3dj_03n04_2306205
- mellitz_3dj_02_elec_230504
- weaver_3dj_02_2303
- weaver_3dj_02_2305
- weaver_3dj_02_2311
- weaver_3dj_elec_01_230622a

No Clear Link Between Modal Mask Excursions and Performance Degradation

Modal Mask References in d2.2	tx			tx			channel tx or rx			
	RLcc	Rldc	Rlcd	RLcc	Rldc	Rlcd	RLcc	Rldc	Rlcd	SCMR
178.9.2 Transmitter characteristics	x									
178.9.3 Receiver characteristics						x				
178.10 Channel characteristics									x	20 dB
179.9.4 Transmitter characteristics	x	x								
179.9.5 Receiver characteristics									x	
179.11 Cable assembly characteristics							x		x	20 dB
176C.6.3 Transmitter characteristics		x							x	
176C.6.4 Receiver characteristics						x				
176C.7 Channel characteristics									x	20 dB
176D.6.4 Host output characteristics	x	x								
176D.6.5 Module output characteristics	x	x								
176D.6.6 Host input characteristics					x					
176D.6.7 Module input characteristics					x					

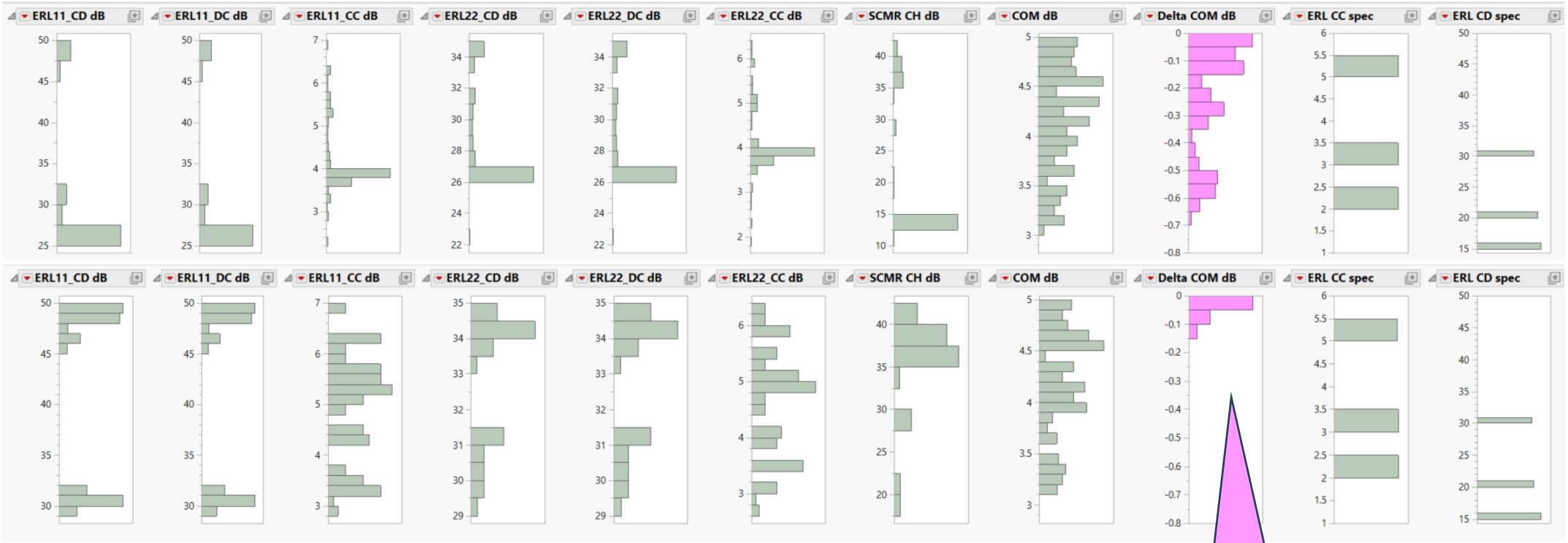
- Modal interactions are complex and multi-path and not represented well with a simple bounce diagram
  - See mellitz_3dj_adhoc_01a_250828 for the explanation
- The existing mask table structure is insufficient to represent these interactions.
- There's no clear method to relate modal mask excursions directly to COM degradation.

Modal ERL Excursions Observed in Full Channel—What Do They Mean?



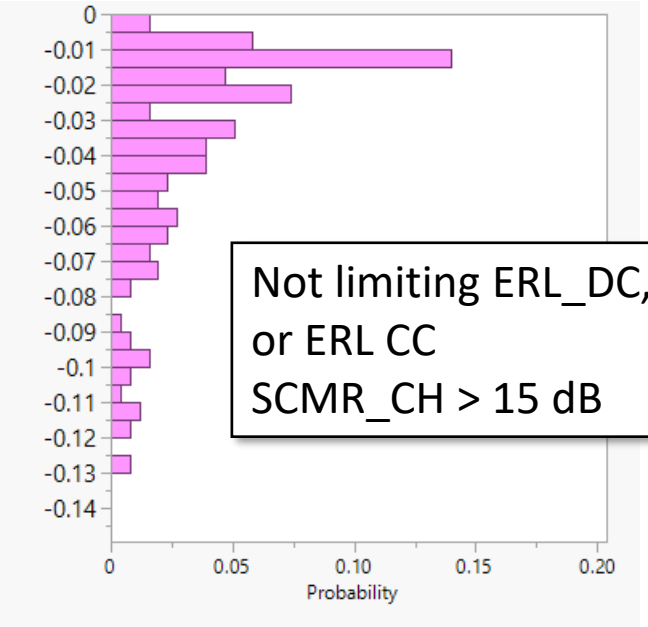
- Observed modal ERL mask excursions in full-channel simulations raise questions about the relevance of strict mask limits, given minimal COM impact
- This channel exhibits delta COM < -0.001 dB for the sweep of ERL specs and packages
  - For this channel ERL_{CC}, ERL_{DC}, and ERL_{CD} = [3.5 22 22] dB

SCMR has a Significant Impact on Modal ERL Sensitivity

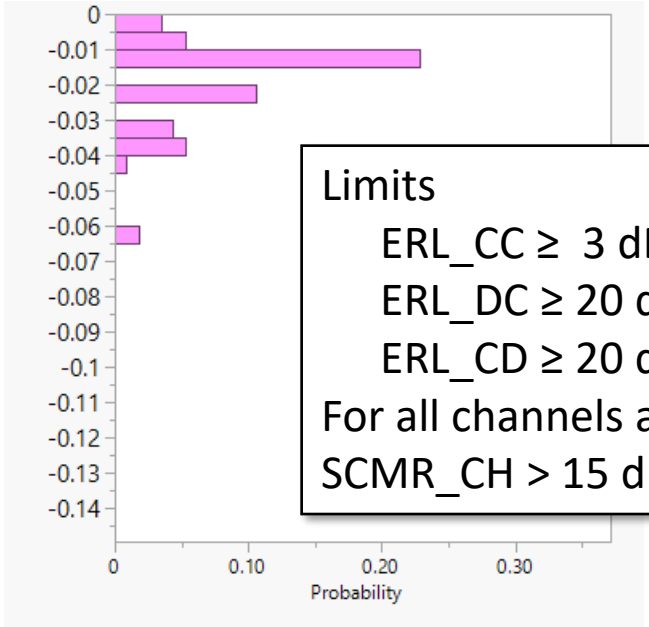


- The magenta histogram is for delta COM
- The other histogram are for the Tx and Rx modal ERL spec sweep and the measured channel Modal reports
- SCMR_CH ≥ 15 dB significantly mitigates the sensitivity of COM to modal ERL variations, supporting relaxed ERL thresholds.

Modal ERL and SCMR Thresholds Effectively Bound COM Sensitivity



Not limiting ERL_DC, ERL_DC or ERL CC
SCMR_CH > 15 dB



Limits
ERL_CC ≥ 3 dB
ERL_DC ≥ 20 dB
ERL_CD ≥ 20 dB
For all channels and devices
SCMR_CH > 15 dB

Delta COM is limited to 6 hundredths of a dB when

- ERL_DC ≥ 20 dB
- ERL_CD ≥ 20 dB
- ERL_CC ≥ 3 dB
- SCMR > 15 dB

Summary and Recommendation

- SCMR_CH strongly influences common mode impact on performance.
- Simulation results confirm that meeting ERL_CC ≥ 3 dB, ERL_DC ≥ 20 dB, and ERL_CD ≥ 20 dB ensures minimal COM degradation across channels and devices.
- Recommended Modal ERL Thresholds for All Tx, Rx, and Channels
  - ERL_CC ≥ 3 dB
    - Ensures acceptable common-mode reflection control.
  - ERL_DC ≥ 20 dB
    - Maintains differential-to-common mode isolation.
  - ERL_CD ≥ 20 dB
    - Preserves common-to-differential mode integrity.

Thank You!