SECQ Test Method and Calibration Improvements

IEEE802.3cd, Geneva, January 22, 2018

Matt Sysak, Adee Ran, Hai-Feng Liu, Scott Schube

In support of comments 82-84

Summary

- We are proposing revising the wording in the description of the stressed receiver sensitivity test in 802.3cd Clause 140 to more clearly bound test conditions for PAM4 optical interfaces
- The current SRS test definition in the standard does not place any bounds on noise, ISI, or other stressors that make up the SRS conformance test signal (reference transmitter). Our analysis indicates that this opens up the real possibility of interoperability failures between "compliant" transmitters and receivers in actual field operation.
- We believe that the proposed changes will address these interoperability cases

Outline

- What's written in the draft standard now regarding stressed receiver sensitivity conformance signal / reference transmitter
- Issues with the draft standard text in its definition of stressed receiver sensitivity reference transmitter characteristics
- Why it matters – interoperability gaps
  - Simulations of Rx BER performance of different types of receivers in the face of different types of SRS conformance signals compliant with the current standard
- Our proposed change to address these gaps
- Other implications and anticipated questions

Disclaimer

- Different types of receive equalizers were used in the simulations shown here. These equalizers were used for the sole purpose of showing the difference in performance of two generic receiver types ("more equalization" and "less equalization") as they relate to interoperability cases, and are not meant as an argument for or against any particular equalizer
- Any resemblance to any commercial equalizer implementation is purely accidental

What's Written in the Draft Standard Now:
Current SRS Test Definition in 802.3cd

- The stressed receiver test outlined for PAM4 PMDs in 802.3cd specifies a stressed receiver conformance test signal (a.k.a. reference transmitter) with a given SECQ
- The reference transmitter is calibrated to the specified SECQ value by adding ISI, sinusoidal jitter (SJ), sinusoidal interference (SI), and Gaussian noise (GN)
- The current reference Tx calibration for this test outlined in 802.3cd+bs defines that ISI should be added until at least 50% of the SECQ value is reached, but does not otherwise define the makeup of the SECQ contributing stressors nor reference Tx characteristics.

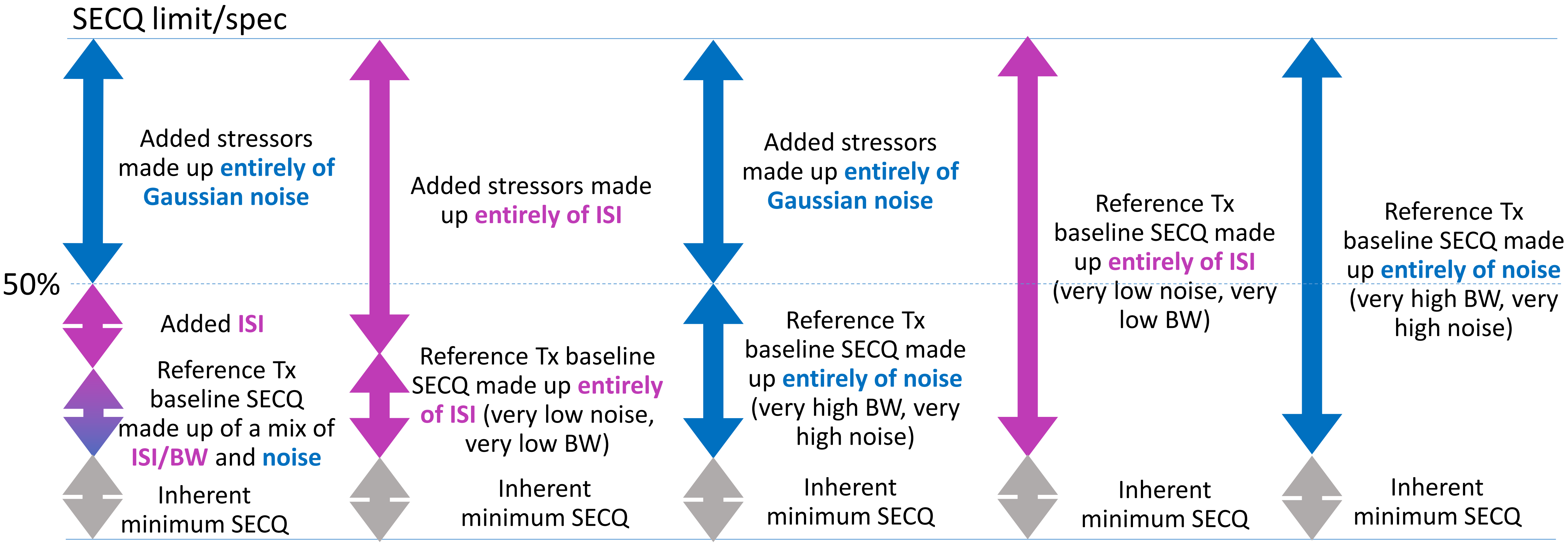
Issues With the Draft Standard Text (1)

- The SRS conformance signal is defined giving the guidance that ISI/BW impairments should be added until "at least" 50% of the SECQ value. This means that up to 100% of the SECQ stress could be from ISI under the current definition.
- There is no guidance/bounds on the baseline characteristics of the reference Tx before stressors are added, so that the baseline reference Tx per the text could be, for example:
  - At 50% of the SECQ limit, meaning that no ISI stressors need to be added
  - At 100% of the SECQ limit, meaning that no additional stressors are added

  Note that the reference Tx SECQ is undefined and could be made up of any combination of stressors, including ones not mentioned in the standard
- The amount of Gaussian noise and sinusoidal interference that make up the remaining 50% (or less, or more – see above) of the SRS test signal SECQ are undefined, as is the ratio between the two stressors
- In combination, these mean that the SECQ makeup/composition of the SRS reference transmitter is essentially undefined, other than the total SECQ value

Issues With the Draft Standard Text (2): Examples

- Under the current SRS conformance signal description in the draft, all of the SRS conformance test signals / reference transmitters shown below would be equally compliant (leaving SJ out for simplicity – small contributor to SECQ). These are just a few of an infinite number of examples that could be considered. **Note: Reference Tx baseline SECQ = SECQ before any outside stressors are added; inherent minimum SECQ is from SECQ filter/algorithm itself (~0.6 dB)**



Why It Matters – Interoperability Gaps (2a):
Simulated Rx Peformance With Different Compliant SRS Ref Tx
Simulation Setup

- Simulation in Matlab
- 75,000 bits run through PAM4 system model
  - Grey coded PRBS31Q
- Data rate: 53 Gbd PAM4
- Oversampling 16/UI
- Waterfall curves generated for three different transmitters into the same receiver.

Receiver details

In all cases:

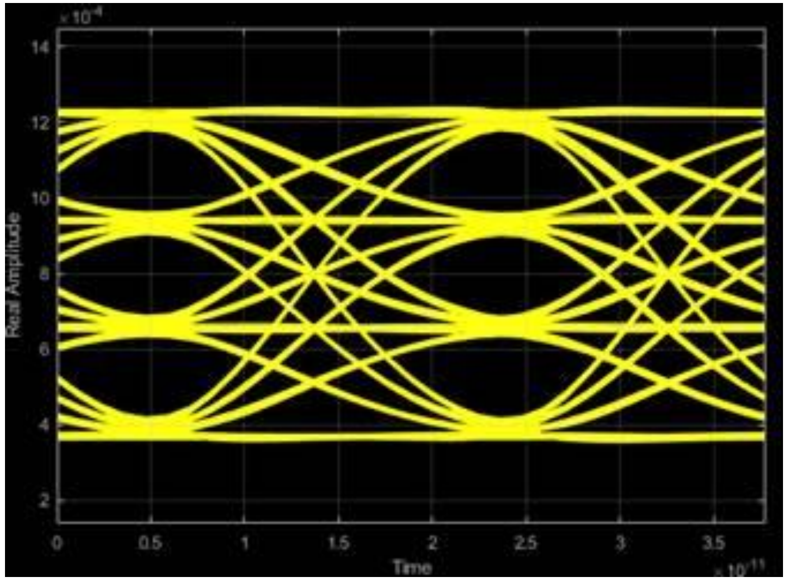
- Bandwidth: 26 GHz
- IRN: 15 pA/rt(Hz)
- Responsivity: 0.5 A/W
- “Receiver 1” has equalizer with 20-tap FFE plus 2-tap DFE
- “Receiver 2” has equalizer with 5-tap FFE

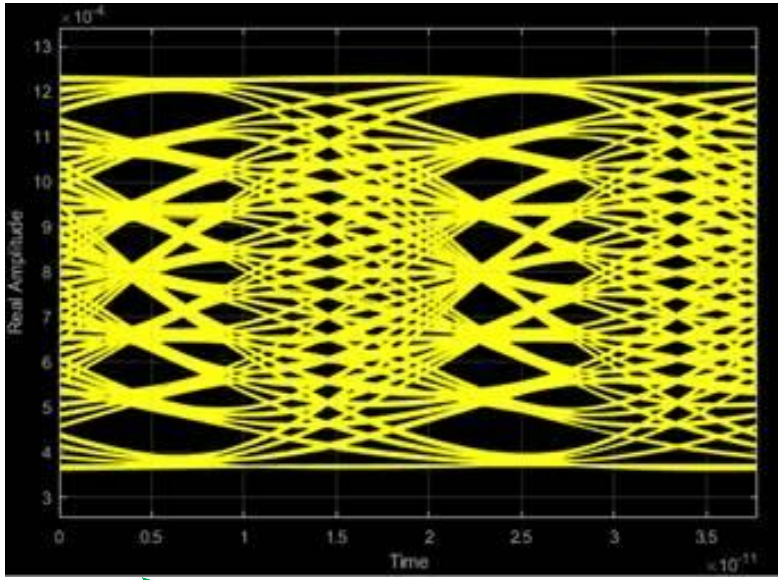
Why It Matters – Interoperability Gaps (2b):
Simulated Rx Peformance With Different Compliant SRS Ref Tx
Simulation Setup: Transmitter Characteristics

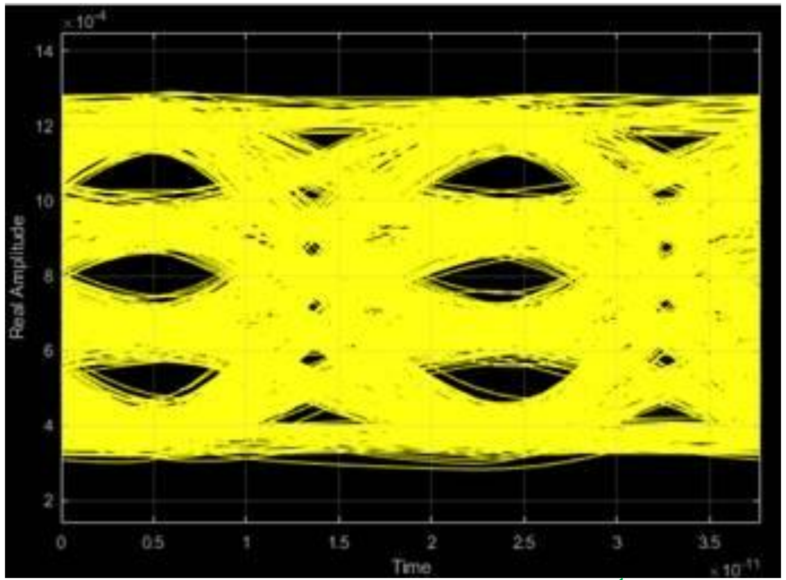
“Ideal” Tx
(high bandwidth, high SNR)
- SECQ not calculated, but probably ~0.5 dB

“ISI-dominated SECQ” Tx
(high SNR, low bandwidth)
- Tx SNR: 50 dB
- Tx BW: 22 GHz
- **TDECQ: 3 dB**

“Noise-dominated SECQ” Tx
(low SNR, high bandwidth)
- Tx SNR: ~22.5 dB
- Tx BW: ~40 GHz
- **TDECQ: 3 dB**

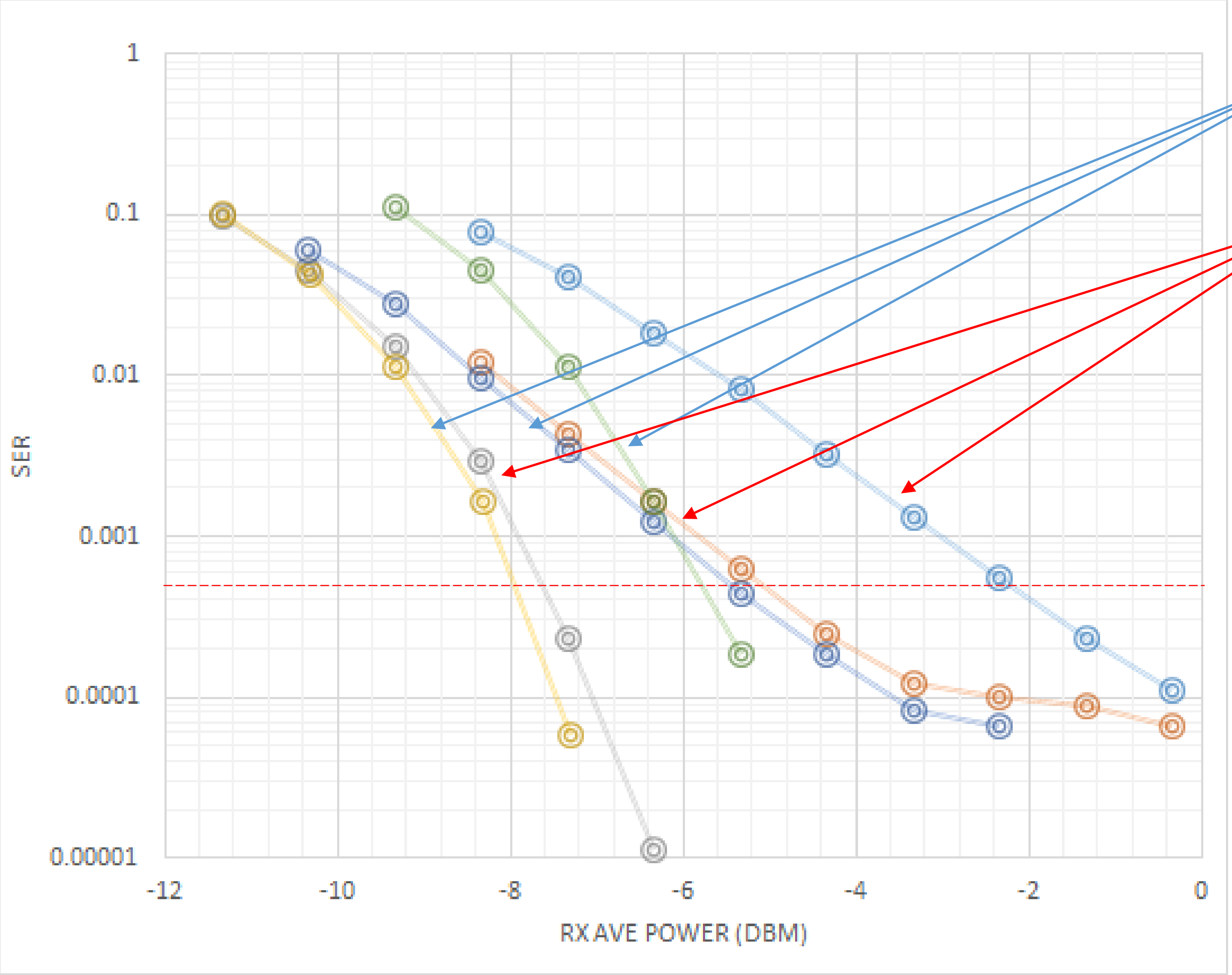






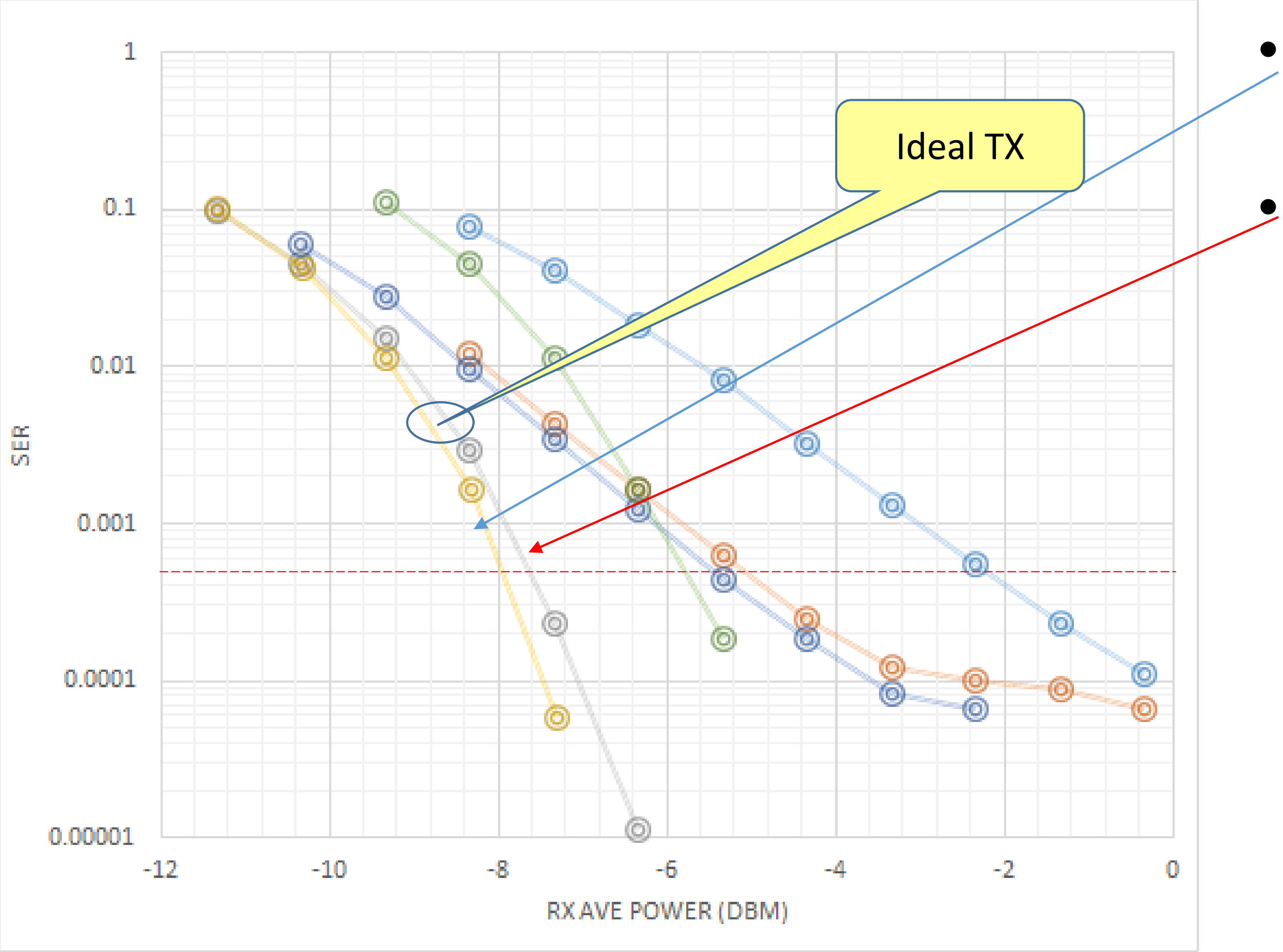
Both compliant SRS conformance signals

Why It Matters – Interoperability Gaps (2c):
Simulated Rx Peformance With Different Compliant SRS Ref Tx



- <u>Receiver 1:</u> 20-tap FFE plus 2-tap DFE
- <u>Receiver 2:</u> 5-tap FFE

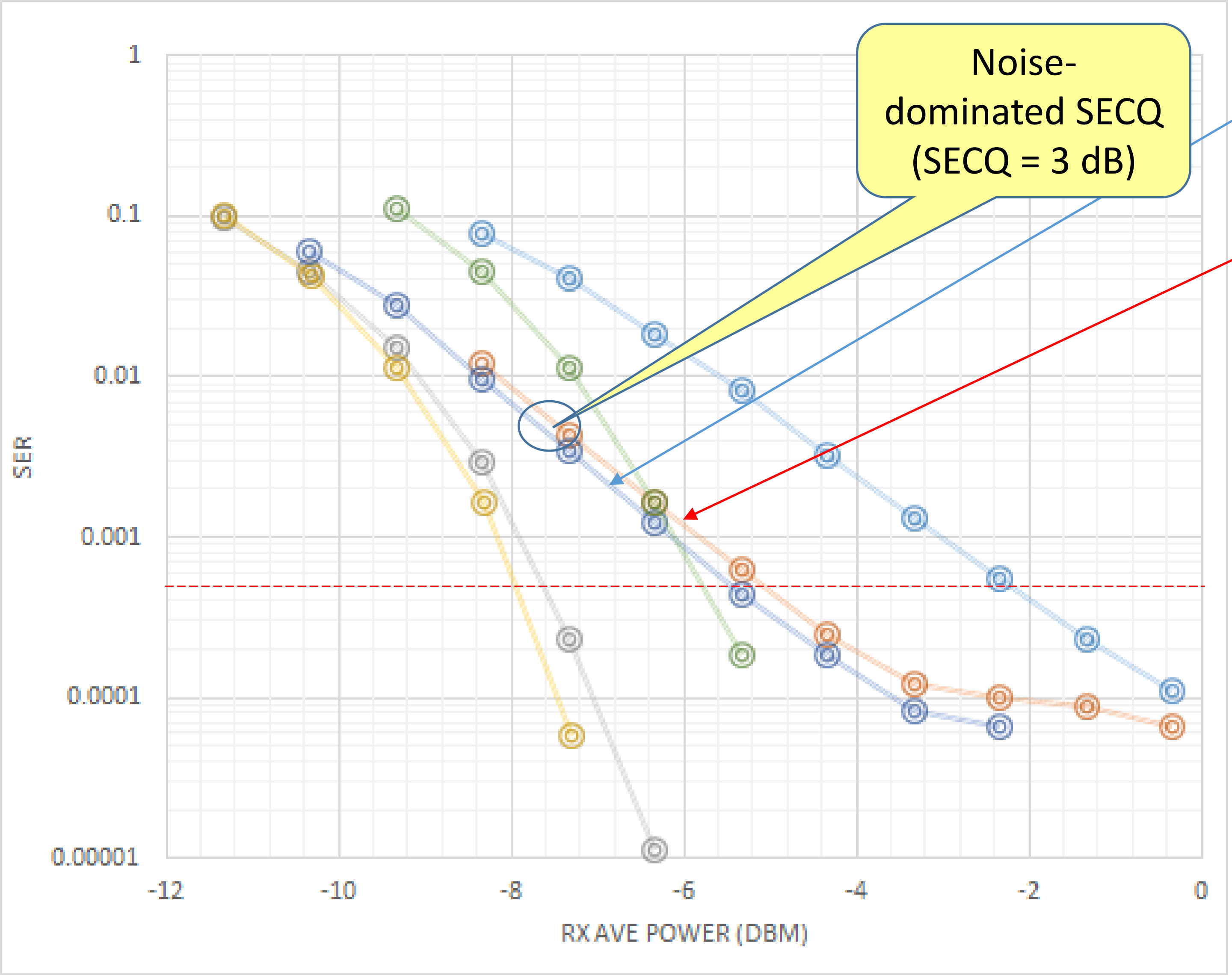
Why It Matters – Interoperability Gaps (2c):
Simulated Rx Peformance With Different Compliant SRS Ref Tx



- <u>Receiver 1:</u> 20-tap FFE plus 2-tap DFE
- <u>Receiver 2:</u> 5-tap FFE

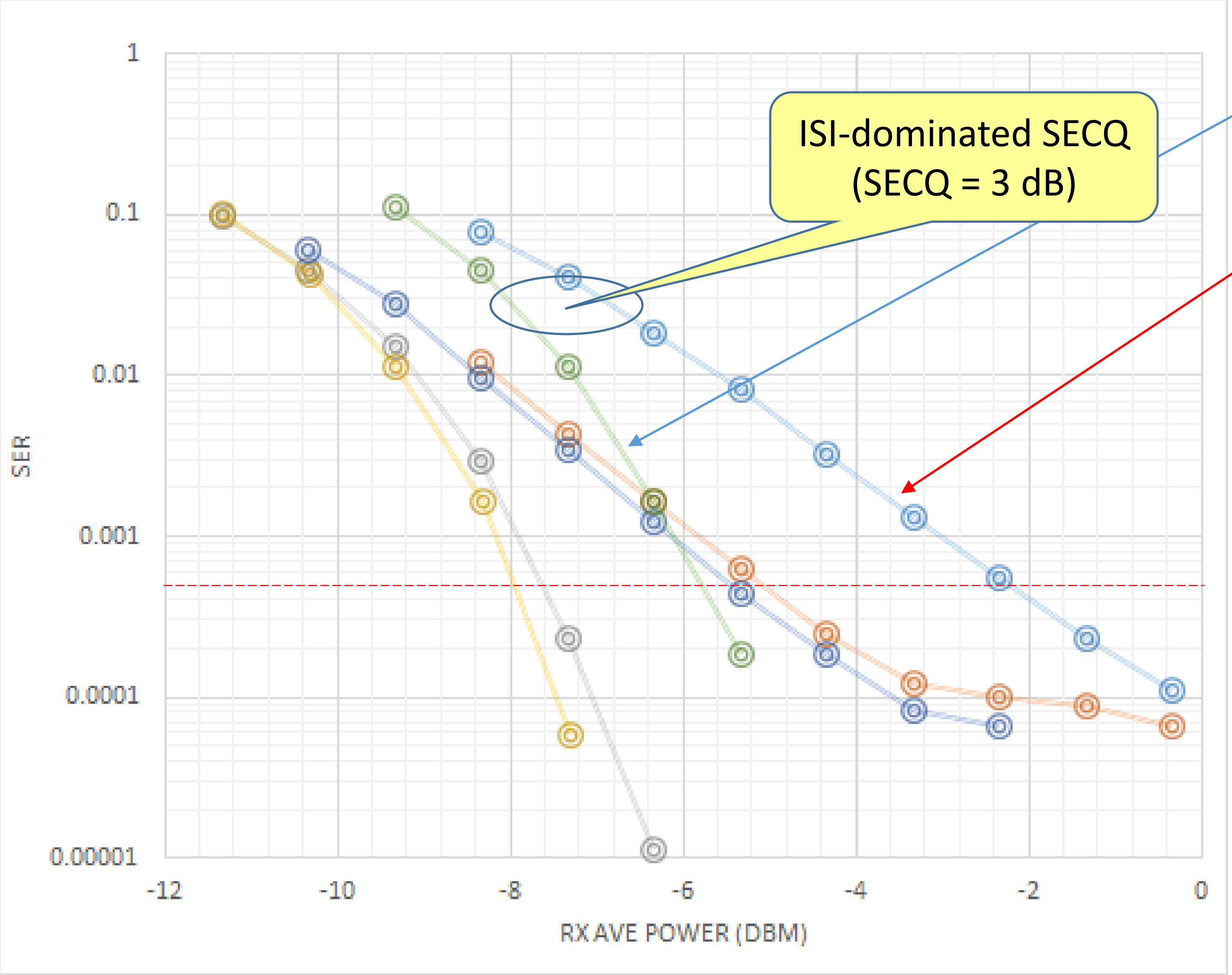
Why It Matters – Interoperability Gaps (2c):

Simulated Rx Peformance With Different Compliant SRS Ref Tx



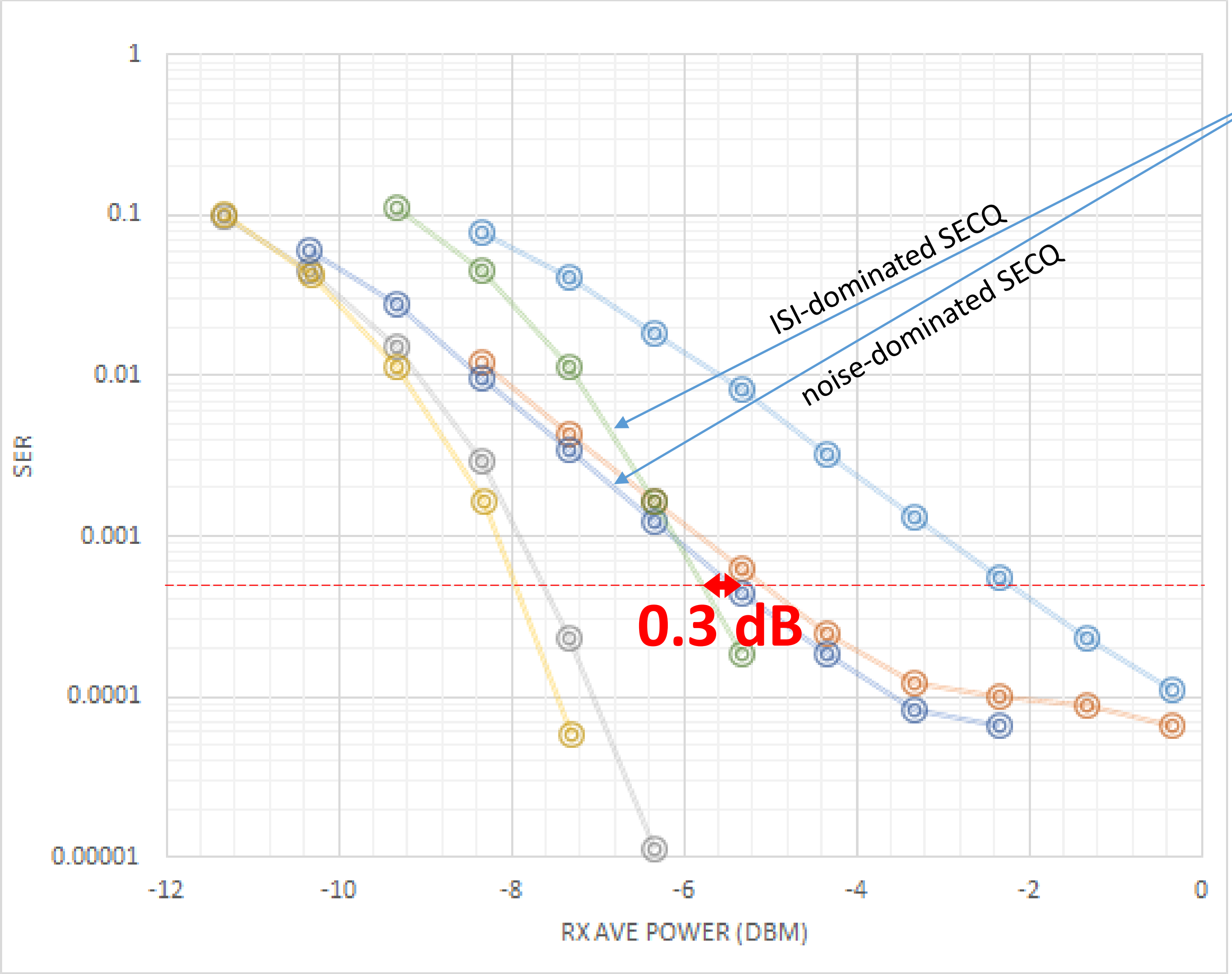
- Receiver 1: 20-tap FFE plus 2-tap DFE
- Receiver 2: 5-tap FFE

Why It Matters – Interoperability Gaps (2c):
Simulated Rx Peformance With Different Compliant SRS Ref Tx



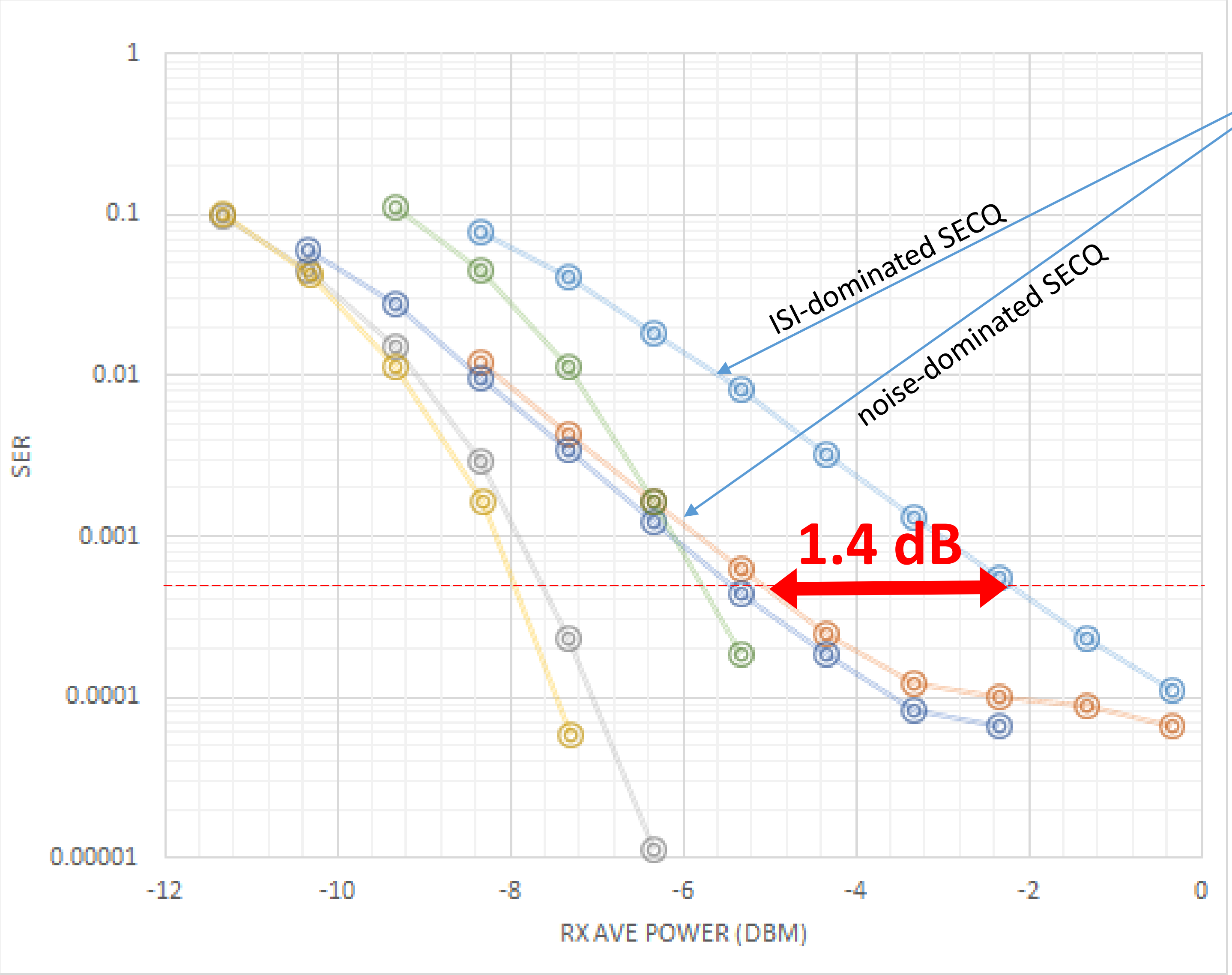
- Receiver 1: 20-tap FFE plus 2-tap DFE
- Receiver 2: 5-tap FFE

Why It Matters – Interoperability Gaps (2c):
Simulated Rx Peformance With Different Compliant SRS Ref Tx



- Receiver 1: 20-tap FFE plus 2-tap DFE
- **0.3 dB difference** in sensitivity when tested with a transmitter with ISI-dominated SECQ case and one with noise-dominated SECQ

Why It Matters – Interoperability Gaps (2c):
Simulated Rx Peformance With Different Compliant SRS Ref Tx



- Receiver 2: 5-tap FFE
- **1.4 dB difference** in sensitivity when tested with a transmitter with ISI-dominated SECQ case and one with noise-dominated SECQ

Why It Matters – Interoperability Gaps (3): What Does This Mean?

- These simulation results simply mean that all things being equal, a receiver with less equalization will tend to perform worse in the presence of a lower bandwidth transmitter
  - Both receivers perform about equally poorly in the face of lots of noise, as they are not designed to handle noise (that's the FEC's job)
- If a receiver with less equalization is tested with a reference SRS conformance signal with more noise and higher bandwidth and "passes", there is the strong likelihood that when presented with a real transmitter in the field (compliant and with the same TDECQ as the SRS reference Tx, but with lower bandwidth), at the margins that transmitter and receiver pair will not interoperate
  - <u>Even though both receiver and transmitter passed spec according to the standard</u>

Our Proposed Change to Address These Gaps

- Bound the baseline reference Tx SECQ before stressors are added, to avoid uncontrolled SECQ composition. We propose this value be 1 dB.
- Add language defining that a receiver has to be compliant with **both** a reference Tx including
  - Stressors added to the baseline Tx SECQ up to the SECQ limit comprised of **all Gaussian noise**
  - Stressors added to the baseline Tx SECQ up to the SECQ limit comprised of **all ISI/BW**

  Note that this does not mean that multiple tests need to be run in production – can be qualified by design and/or tested in worst-case condition only for a given receiver design
- Why are we proposing this specific change?
  - This seemed to be the least impactful change to the draft that still ensures interoperability, vs. other options which would also ensure interoperability like bounding the Tx BW and/or SNR (note that in this case the SRS test would still need to be changed to match the worst-case Tx under the new spec)
  - However, if commercial receivers cannot meet SRS in the ISI-dominated-SECQ case, then need to consider bounding TX bandwidth to ensure interop
  - Completely constraining the baseline reference Tx SECQ makeup likely unrealistic

Next Steps

- We are running testing in the lab now to complement the simulation results shown here
- We welcome other efforts to reproduce our analysis either in the lab or in simulations
- We believe our simulation is correct and matches with common sense and intuition, and invite support for our proposed remedy

Other Implications and Anticipated Questions

Doesn't this imply that we would have to propose a change to the Tx specification as well?

- Not necessarily. Either the Rx compliance criteria has to be adjusted to ensure that it can meet spec with all possible compliant transmitters (as proposed here), or the Tx compliance criteria has to be adjusted to ensure that it can meet spec with all possible compliant receivers

Why the "all noise" case as the other extreme?

- This is the other Tx extreme also allowed by the draft spec, and will result in the smallest amount of ISI in the test stressor. If the "all noise" case proves to be the easier of the two, it can be qualified by design and not tested on an ongoing basis
- Note that the "mostly Gaussian noise" case is an allowable transmitter condition per the standard
- [We also believe that the "all noise" case may cause issues of its own in the face of real-world Rx impairments, and definitely leaves less BER margin…]

What implication would the new threshold/RLM proposal have on this change, if that proposal were to be accepted?

- If the threshold/RLM proposal were accepted,
    - SECQ calculation algorithm would be aligned with any new TDECQ algorithm (including threshold adjust)
    - If an RLM spec were added to the Tx, this spec would be required of any SRS reference Tx, before stressors were added

Wouldn't this same issue be there for all PAM4 optical interfaces, including those in 802.3bs?

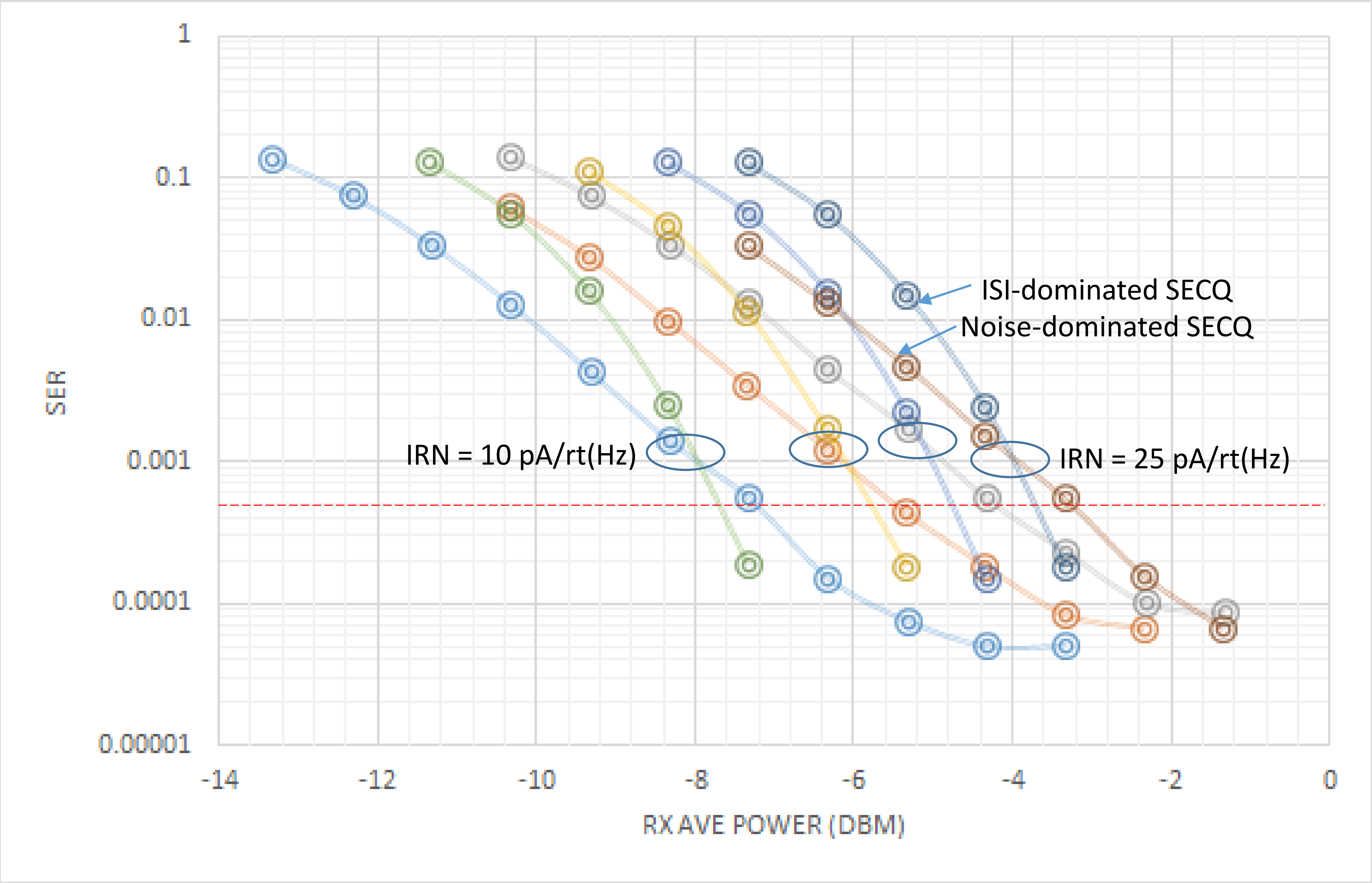
- Yes

Thank You

Backup

Additional Simulations: Impact of Rx Noise / IRN

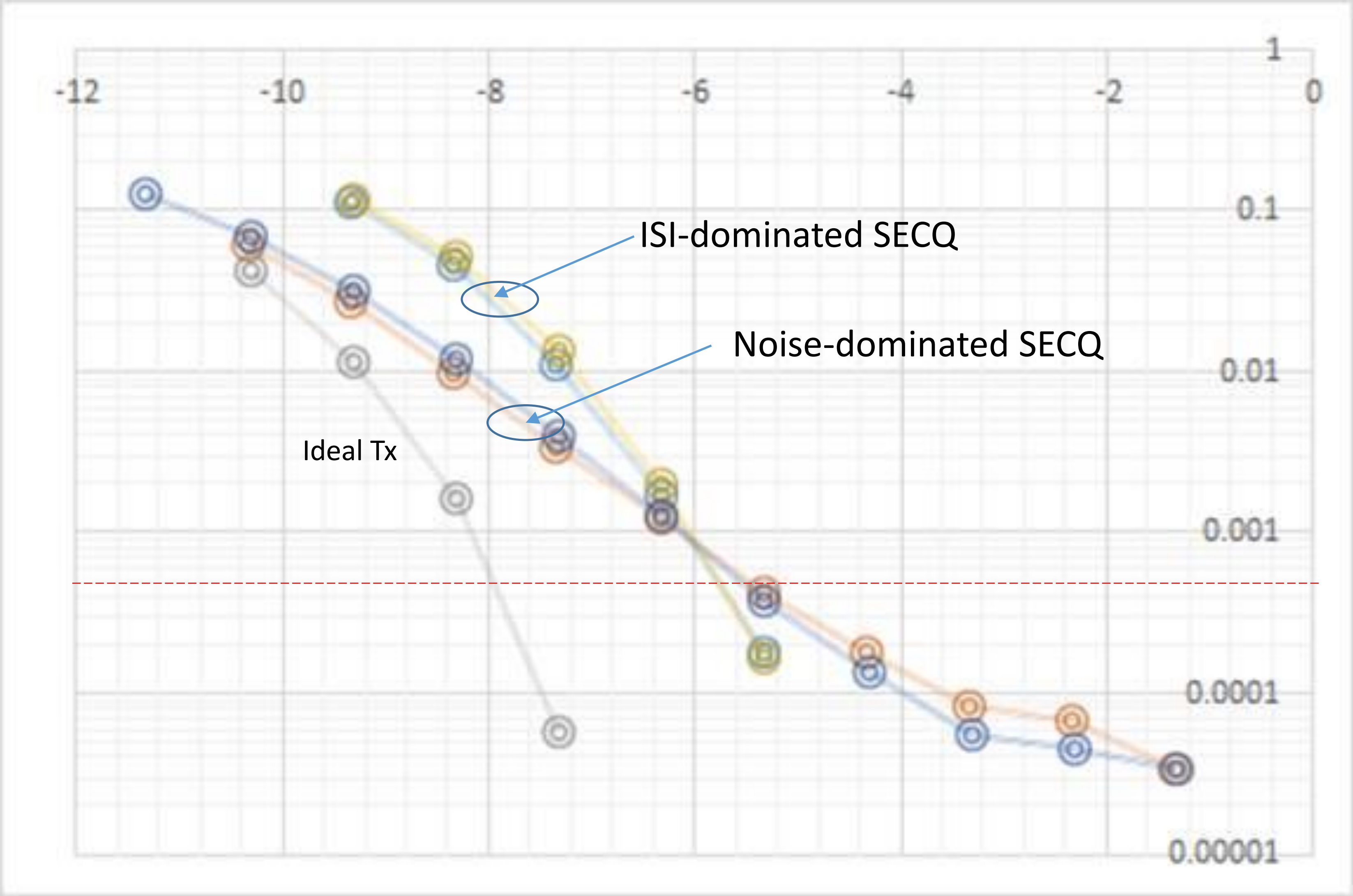
Simulated Rx Peformance



- All simulations done under same conditions as in main presentation, and with “Receiver 1” EQ (20-tap FFE plus 2-tap DFE)
- IRN varied from
  - 10 pA/rt(Hz) (left-most two curves)
  - 15 pA/rt(Hz)
  - 20 pA/rt(Hz)
  - 25 pA/rt(Hz) (right-most two curves)
- While as expected Rx performance is worse with higher IRN, the difference in Rx sensitivity between noise-dominated SECQ and ISI-dominated SECQ that would indicate a possible test/interop issue is not affected significantly

Additional Simulations: Impact of Rx Noise / IRN

Simulated Rx Peformance



- All simulations done under same conditions as in main presentation, and with "Receiver 1" EQ (20-tap FFE plus 2-tap DFE), IRN = 15 pA/rt(Hz) as in original
- Rx BW varied between 25 GHz and 40 GHz, with minimal impact
- Note that lowering Rx BW has the mitigating/counterbalancing impact of reducing Rx noise; the opposite is true for the Tx (at constant SECQ)

Example: Tx SNR / Tx BW relationship @ 1.7 dB SECQ