

Method for measuring the intrinsic noise and distortion factors NSR_{rx} and EC_{rx} of the ETCC reference receiver

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Background and motivation

- ETCC calculation as per 802.3dj D2.2 clause 185A.2.5.3 demands *“Determine the intrinsic receiver noise power NSR_{rx} and EC_{rx} of the calibrated coherent detector front-end via a measurement or calibration process using a known transmitter.”*
- In this contribution we show a proof-of-concept for measurement the intrinsic receiver noise of two candidate reference receiver implementations in terms of NSR_{rx} and EC_{rx} via two-laser beat signal measurements at various frequencies spread across the analysis bandwidth used for measuring 400ZR and 800ZR

Recap of ETCC calculation

$$ETCC = \Delta RSNR_{tx} = 10 \times \log_{10} \left(\frac{RSNR_{ase,tx}}{ESNR_{ref}} \right) \quad (185A-5)$$

$$RSNR_{ase,tx} = \left((EC_{tx} \cdot ESNR_{ref})^{-1} - NSR_{tx} \right)^{-1} \quad (185A-4)$$

$$EC_{tx} = \boxed{EC_{trx}} \div \boxed{EC_{rx}}$$

$$NSR_{tx} = \boxed{NSR_{trx}} - \boxed{NSR_{rx}}$$

“... measured using a noise loading procedure based on captured waveforms as described in Figure 185A-5”

Focus of this contribution

	BER_{ref}	$ESNR_{ref}$
800GBASE-LR1	1.1×10^{-2}	13.76 dB
800GBASE-ER1	2×10^{-2}	12.71 dB
800ZR	2×10^{-2}	12.71 dB
400ZR	1.25×10^{-2}	13.55 dB

ETCC: Extended transmitter constellation closure

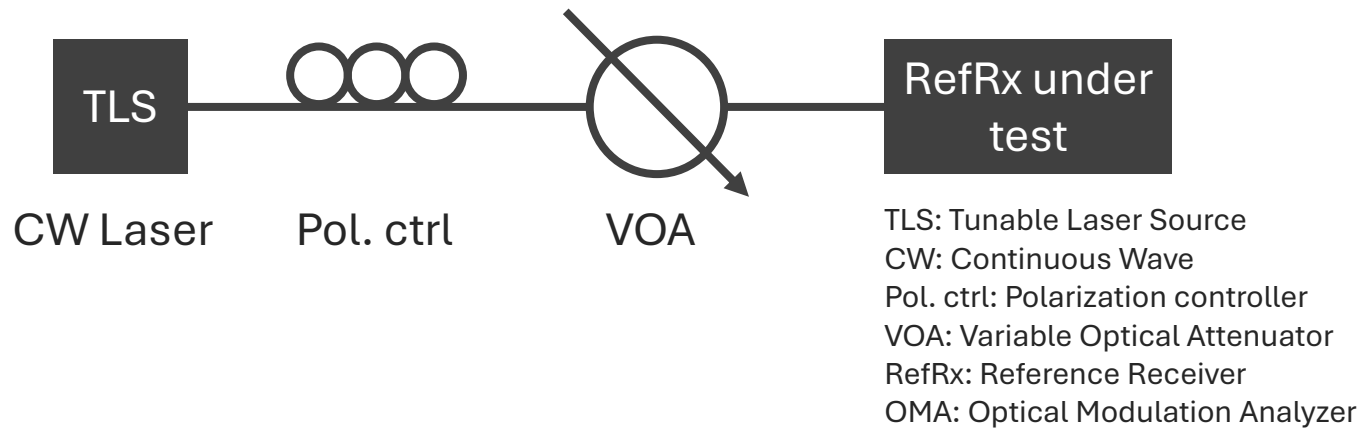
RSNR: Required signal-to-noise ratio

$ESNR_{ref}$: Theoretically required SNR for BER_{ref}

EC: Eye Closure

NSR: Noise-to-signal ratio ($NSR = SNR^{-1}$)

Measurement setup for NSR_{rx} and EC_{rx}

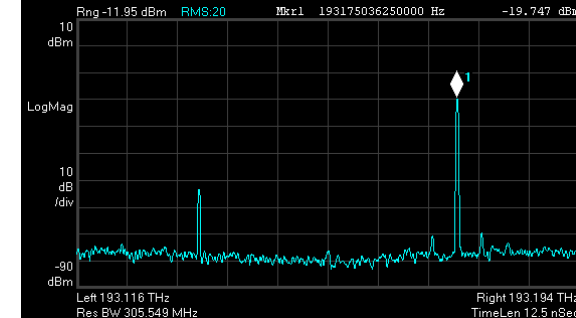
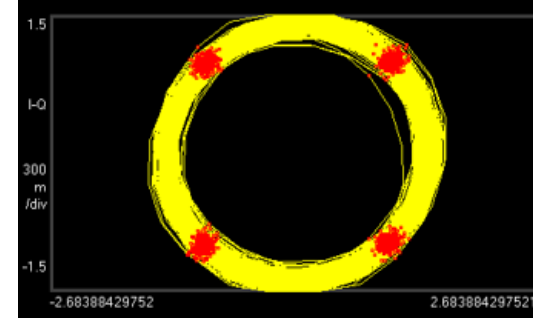


RefRx under test	RTO-Based OMA	Integrated OMA
System bandwidth	110 GHz	39 GHz
Sampling rate	256 GSa/s	92 GSa/s
ADC vertical range setting	80 mV	N.A. (internal autoranging)
TIA	No	Yes

- CW laser with frequency offset from RefRx internal LO stepped from 5 GHz to RefRx max. system bandwidth in 5 GHz steps
 - Note: Initial guesstimate for step size, subject to further investigation
- Polarization controller optimized for equal illumination of RefRx X-Pol and Y-Pol paths
- VOA adjusts input power to RefRx. Target values for initial tests -12 dBm to 0 dBm measured at RefRx optical input (internal power meter)

Processing steps for NSR_{rx} and EC_{rx}

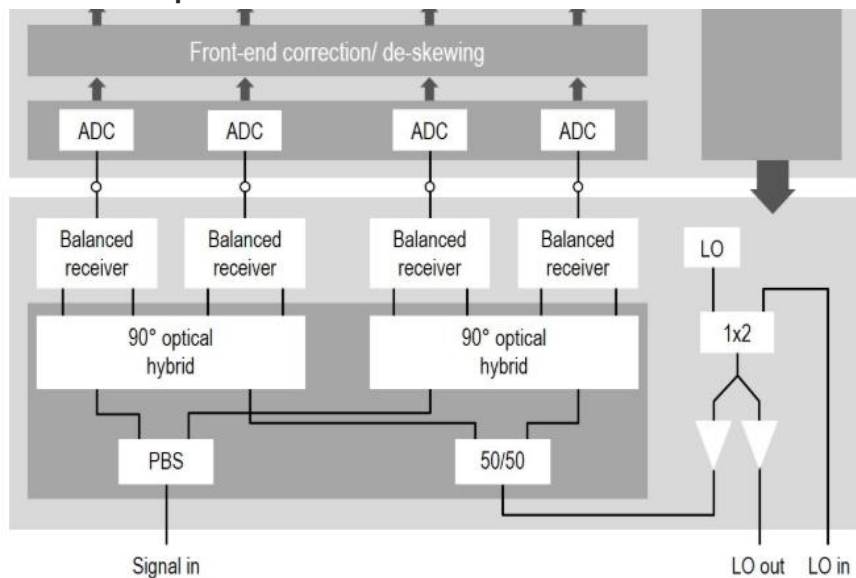
- Beat measurements are recorded sequentially with respective full BW & sampling rate
- Post-processing with
 - Virtual noise loading analog to ETCC methodology
 - Analysis bandwidth and resampling according to target application, in order to get corresponding RefRx noise contribution
 - 78 GHz (156 GHz) if target app is 400ZR (800ZR)
 - QPSK demodulator (“Custom IQ”) with
 - Polarization alignment (using the PolStokesAlign algorithm)
 - Symbol rate: 4x measured beat frequency
 - Result length: 1000 symbols
 - Measurement filter: none
 - Equalizer: Off
 - Read average BER(EVM) over 20 blocks of 1000 symbols
 - Apply fitting procedure analog to ETCC methodology with BER_{ref} according to target application and extract NSR_{rx} and EC_{rx} – assuming noise contribution from CW laser is negligible



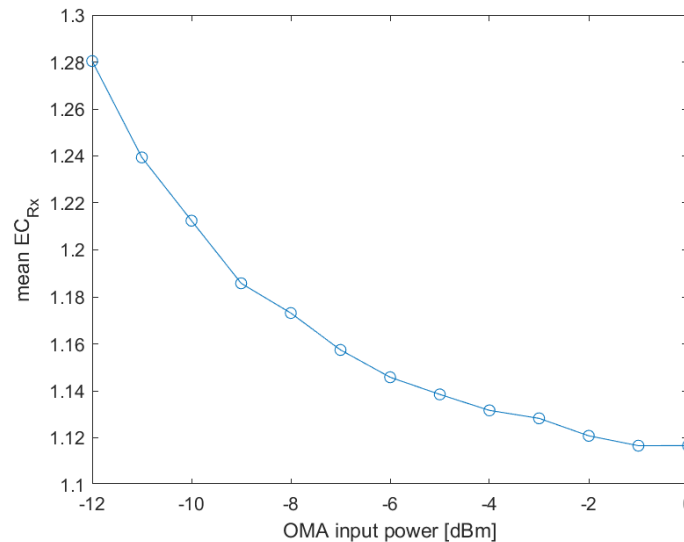
Results with RTO-based RefRx under test

- Results of intrinsic noise measurement applicable for 400ZR signals
 - 78 GHz analysis bandwidth, i.e. ± 39 GHz relative to LO
 - Averaging beat frequencies between 5 GHz and 35 GHz
 - RTO vertical range setting 80 mV

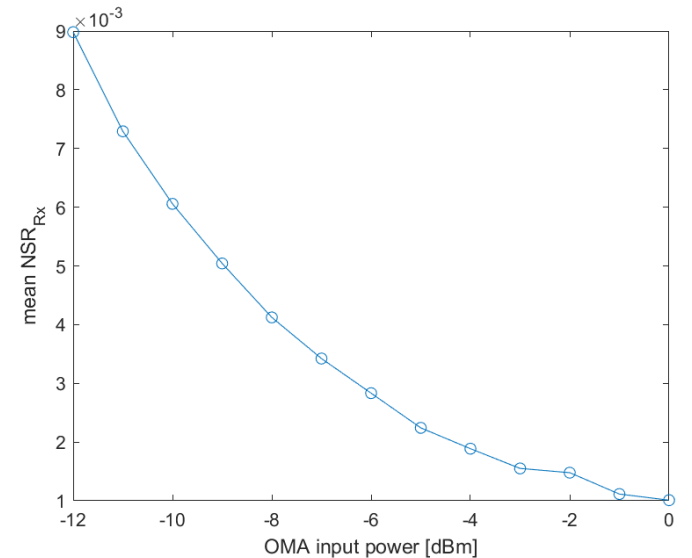
RefRx optical architecture



Mean EC_{rx} vs. optical input power



Mean NSR_{rx} vs. optical input power



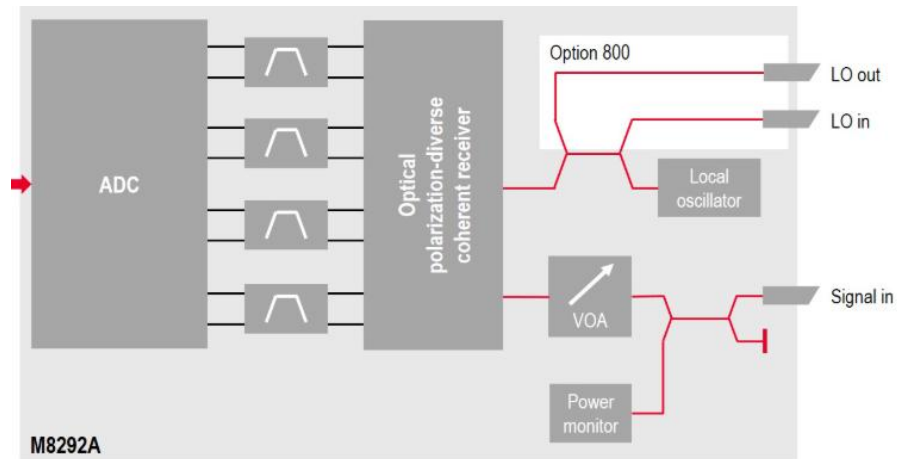
RTO: Real-time oscilloscope

OMA: Optical Modulation Analyzer, here N4391C with 110 GHz, 256 GSa/s RTO

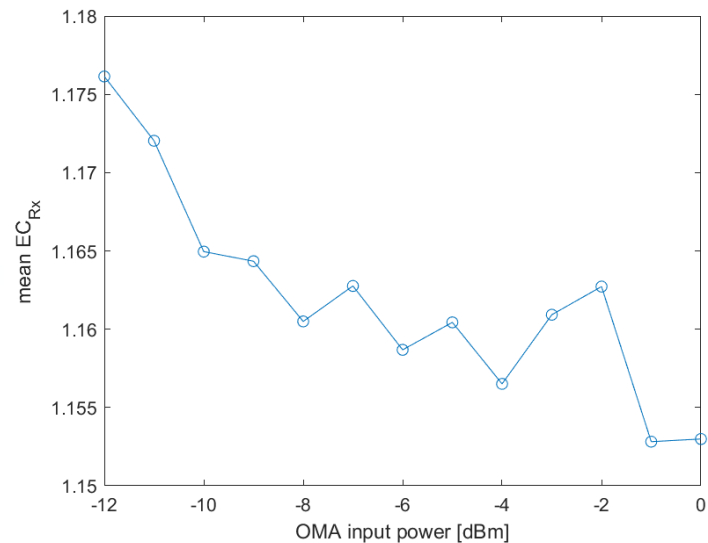
Results with integrated RefRx under test

- Results of intrinsic noise measurement applicable for 400ZR signals
 - 78 GHz analysis bandwidth, i.e. ± 39 GHz relative to LO
 - Averaging beat frequencies between 5 GHz and 35 GHz
 - Integrated RefRx uses autoranging with VOA in signal path

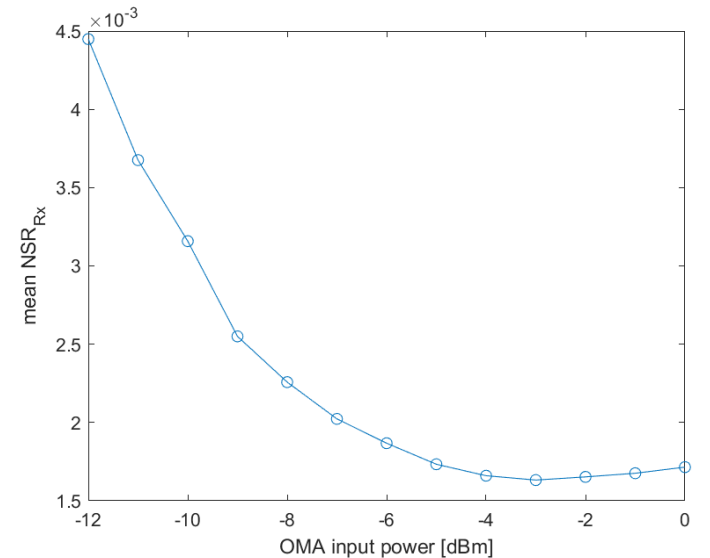
RefRx optical architecture



Mean EC_{rx} vs. optical input power



Mean NSR_{rx} vs. optical input power



RTO: Real-time oscilloscope

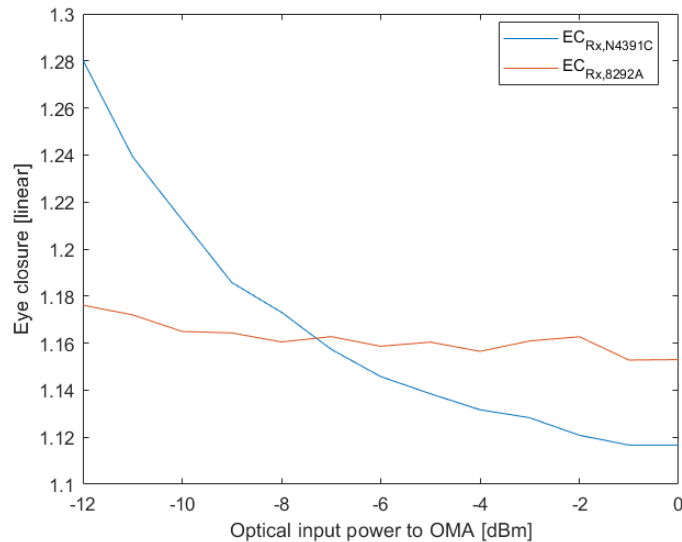
OMA: Optical Modulation Analyzer, here M8292A with integrated coh. Rx and ADC with 92 GSa/s

Comparison

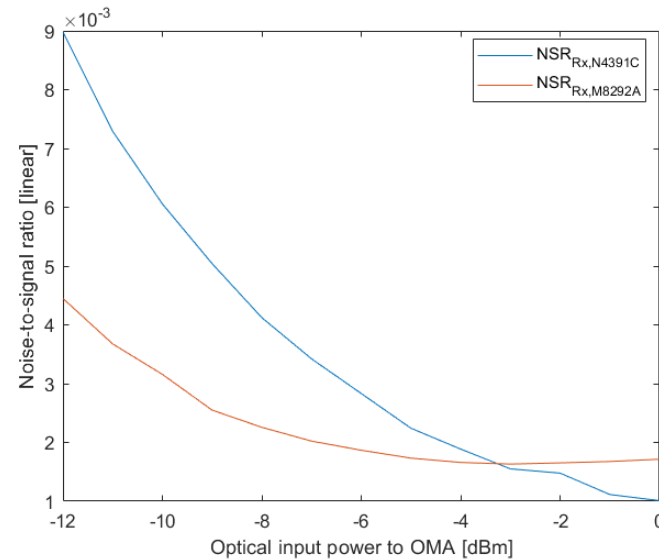
EC_{rx} , NSR_{rx} , $DRSNR_{rx}$ applicable for 400ZR signals, 2 different RefRx hardware implementations

- Stronger power dependence of RTO-based RefRx due to absence of leveling function
- RTO-based RefRx (N4391C) shows a lower penalty at high optical input powers due to better ENOB and no TIA; conversely higher penalty at low optical input power due to bad utilization of ADC inside RTO
- For integrated RefRx (M8292A) at < -6 dBm input power, the leveling reaches its limit and ADC utilization drops

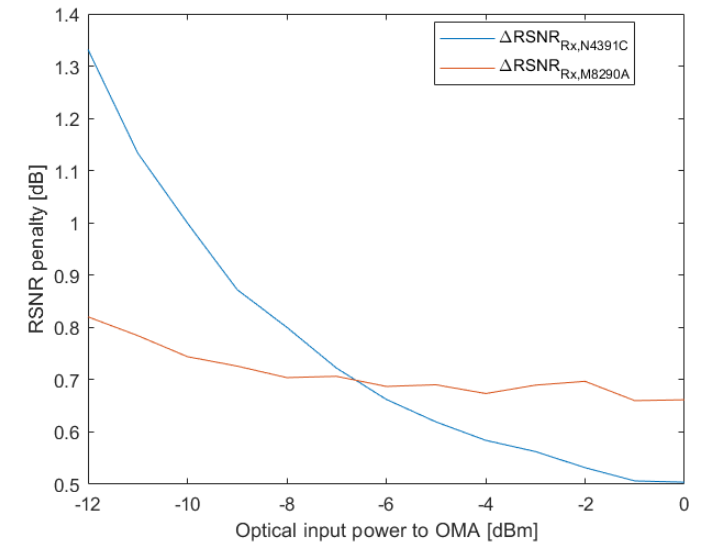
Mean EC_{rx}



Mean NSR_{rx}



Mean RefRx $RSNR$ penalty



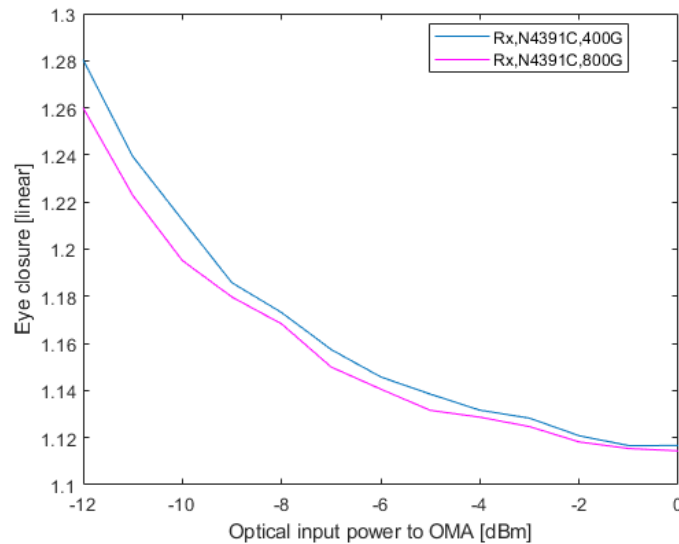
ENOB: Effective number of bits
TIA: Trans-impedance amplifier

Comparison

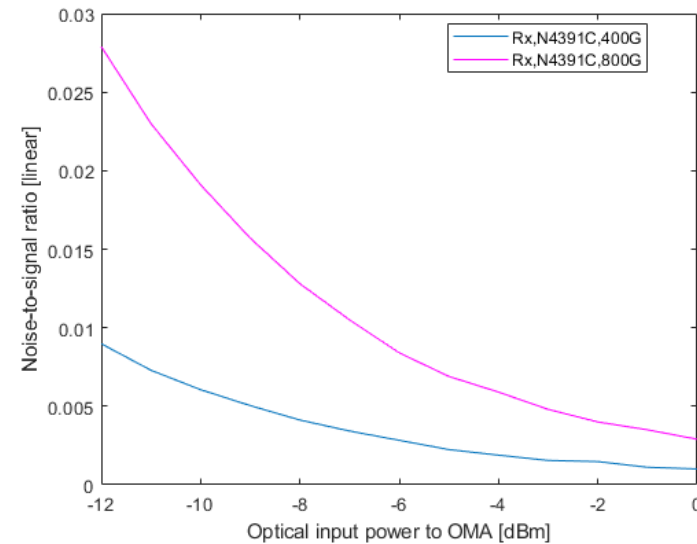
EC_{rx} , NSR_{rx} , $\Delta RSNR_{rx}$ targeted for 400ZR / 800ZR signals, same hardware implementation (RTO-based, N4391C)

Rx penalty analysis applicable for	400ZR signals	800ZR signals
Analysis span	78 GHz	156 GHz
BER_ref	1.25e-2	2e-2
Beat frequencies	5:5:35 [GHz]	5:5:75 [GHz]

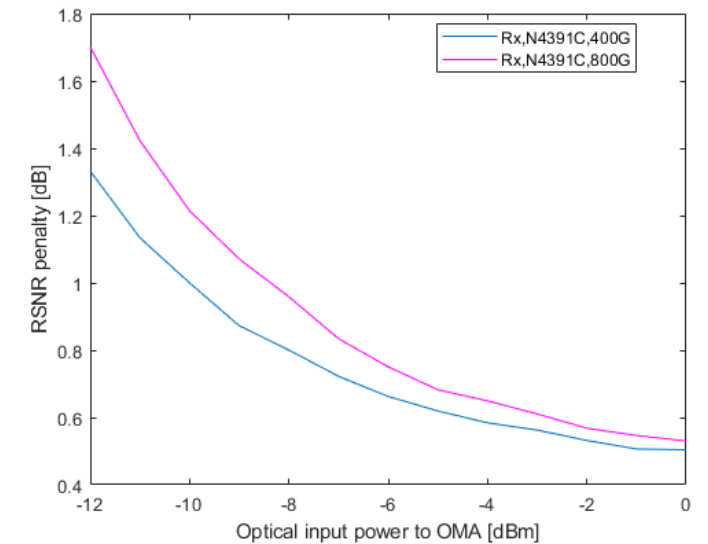
Mean EC_{rx}



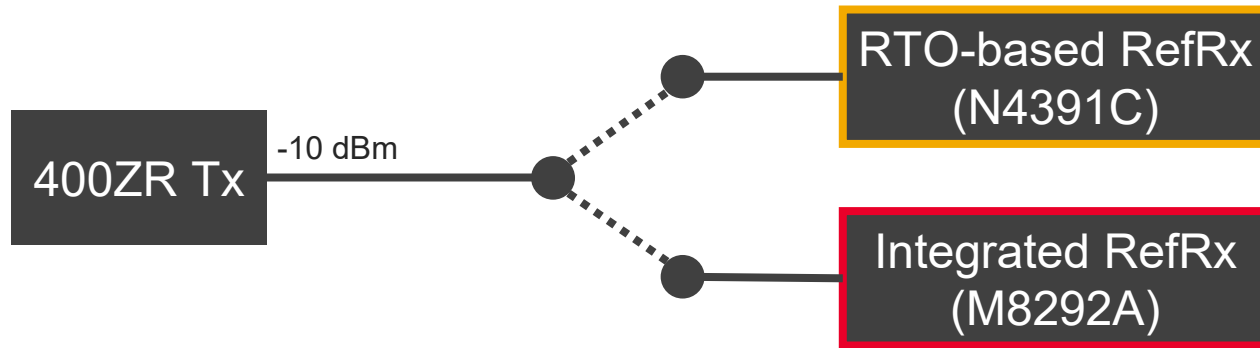
Mean NSR_{rx}



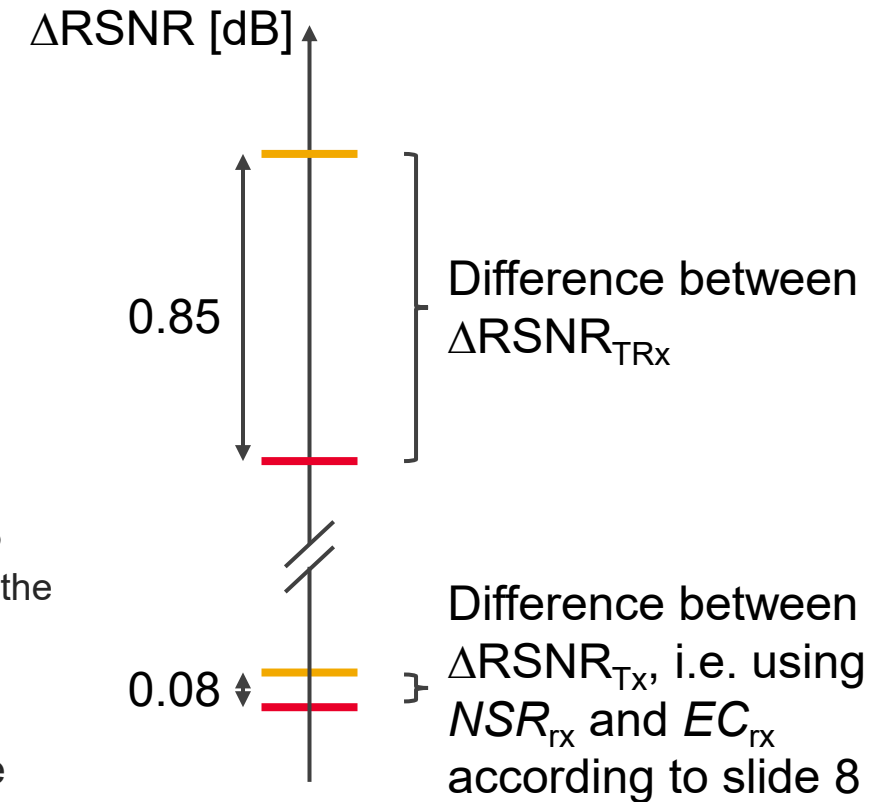
Mean RefRx $RSNR$ penalty



Validation with a commercial 400ZR Tx



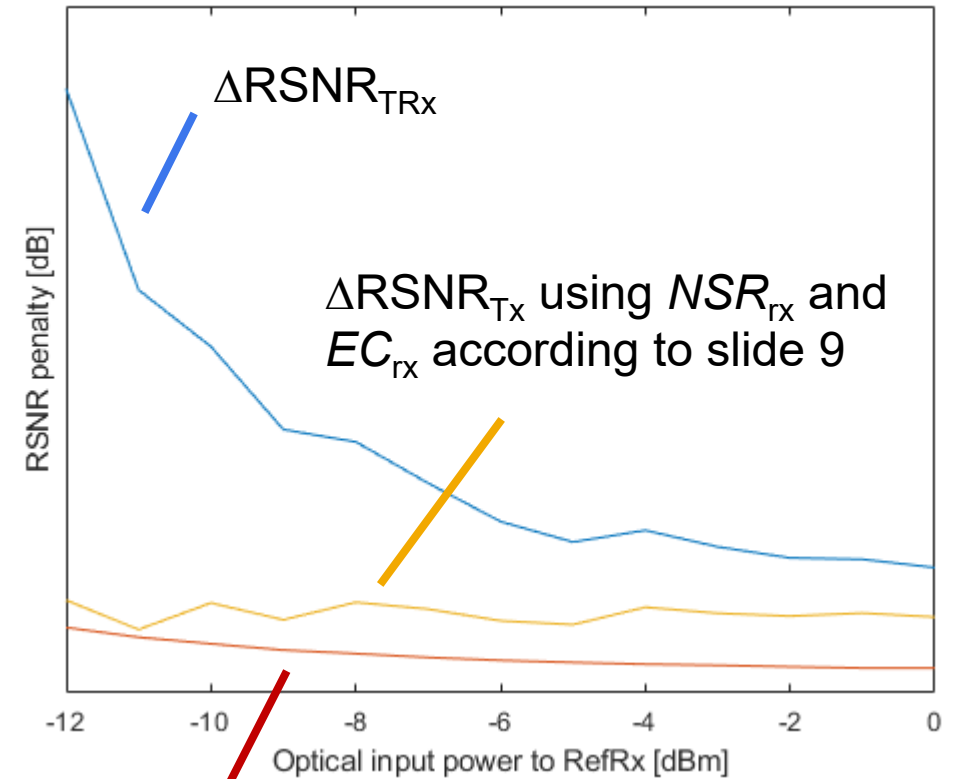
- Same 400ZR Tx waveform is measured with two different RefRx implementations
- The $\Delta\text{RSNR}_{\text{TRx}}$ obtained with the two different RefRx differ by 0.85 dB
 - Result with the RTO-based RefRx is higher than with integrated RefRx (mind the respective power dependencies shown on slide 8)
- Applying the previously measured respective NSR_{rx} and EC_{rx} (values from slide 8) to obtain the $\Delta\text{RSNR}_{\text{Tx}}$, the two measurement results are consistent within <0.08 dB



Validation with a commercial 800ZR Tx



- Same 800ZR Tx waveform is measured with the RTO-based RefRx for different delivered power values as proxy for different RefRx implementations
- The aggregate $\Delta\text{RSNR}_{\text{TRx}}$ shows a strong power dependency due to the different Rx penalties
- This power dependency is removed when applying NSR_{rx} and EC_{rx} (values from slide 9). The residual variation of ETCC is below ± 0.3 dB



$\Delta\text{RSNR}_{\text{Rx}}$, derived from NSR_{rx} and EC_{rx} according to slide 9

Conclusions

- This contribution shows a method to characterize reference receiver penalty in terms of the intrinsic noise and distortion factors NSR_{rx} and EC_{rx}
- Intrinsic receiver penalty and noise results qualitatively show expected behavior relative to different RefRx hardware implementations and operating conditions
- Removal of RefRx penalty is validated for example 400ZR and 800ZR Tx measurements

Special acknowledgement to the two pluggable transceiver vendors that enabled the validation with 400ZR and 800ZR modules