Modal Noise Measurements with 25G VCSELs

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Motivation & Introduction

Recent discussions in 802.3 cm suggest that modal noise (MN) is not negligible. In this document, we experimentally estimate the magnitude of noise produced by lateral misalignment of fibers.

To determine MN from this measurement requires to decouple oscilloscope noise, which is gain dependent, ISI, jitter and RIN.

We will disclose the process employed for the initial data. We invite discussion and suggestions to improve this experiment.

The goal for this work is support current work in 802.3 cm trying to estimate MN penalties.

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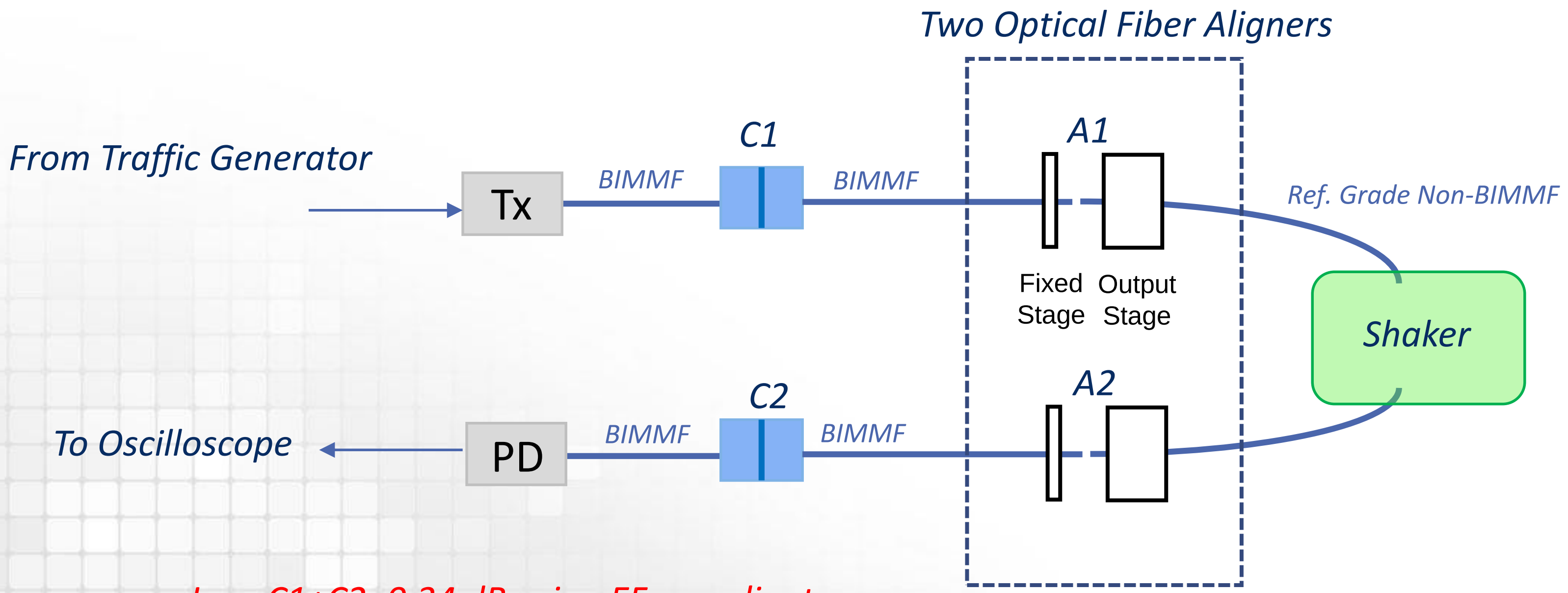
Experimental Setup

The setup intends to represent a four connector channel. It comprises:

- Transceivers, fast photodetectors (large aperture), two connector pairs C1,C2), two fiber alignment systems *A1*, *A2*, and a fiber shaker.
- Short patch cords used to isolate MN from MPN.
- Standard off the self 25G transmitters were used
  - 100GBASE-SR4 from two main manufacturers
  - The EF of each transmitter was measured to assure they meet EF requirements.

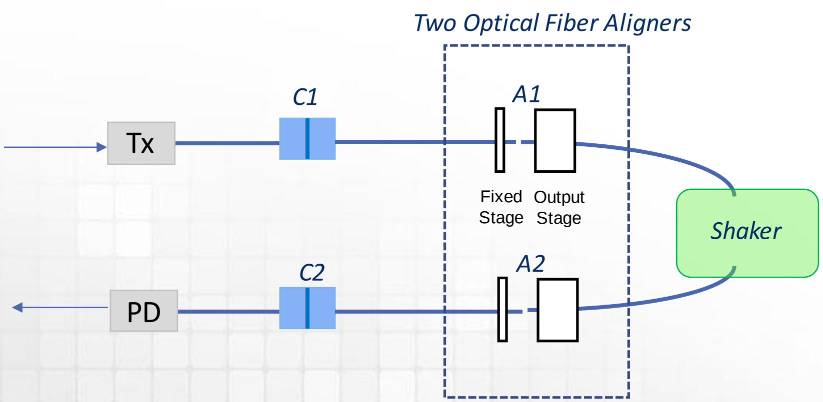


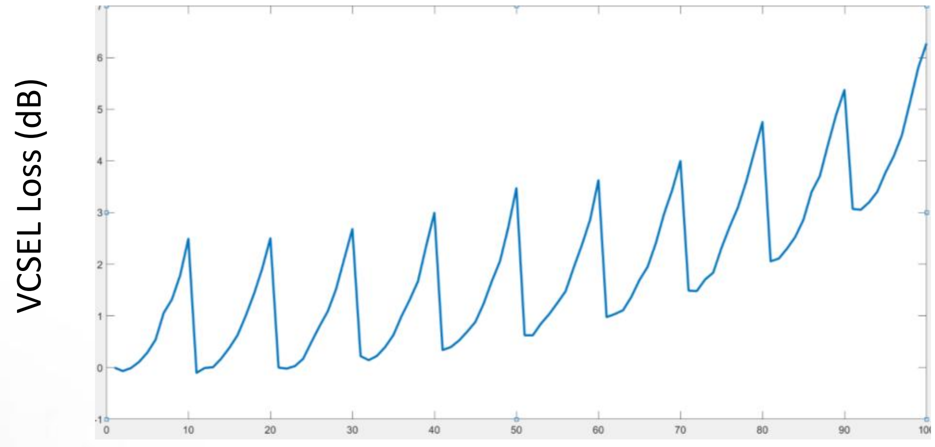
Loss C1+C2=0.34 dB using EF compliant source

Measured Losses vs Offsets

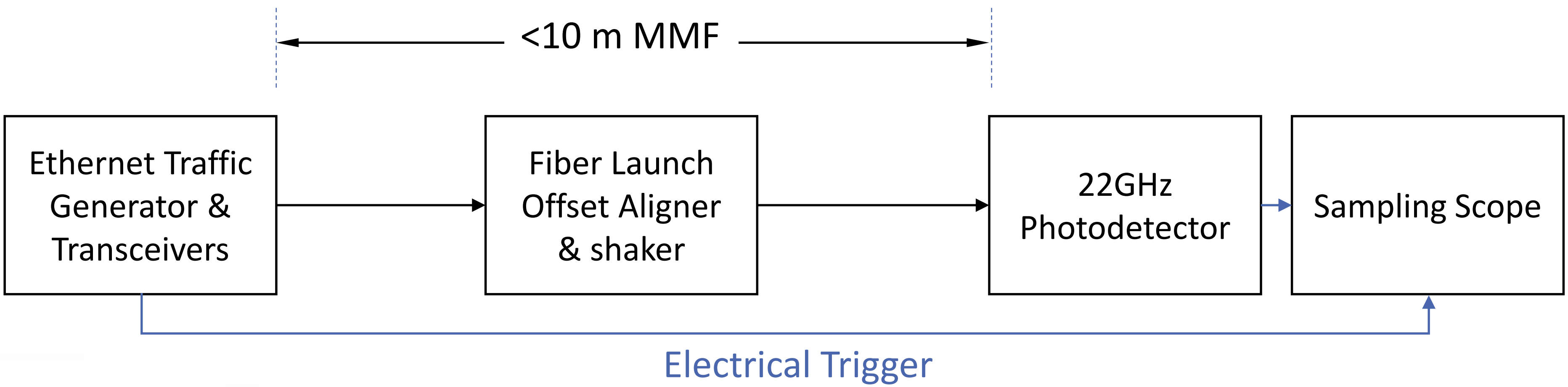
Each aligner covered a large range of lateral offsets (from zero to 18 microns in steps of 2 microns).

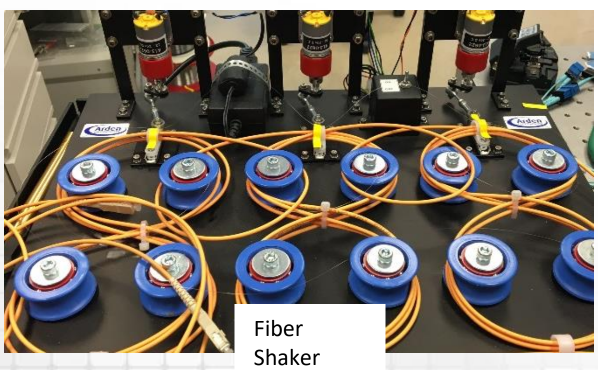
- 10 x 10 combinations of offsets
- Fiber gap < 10 microns

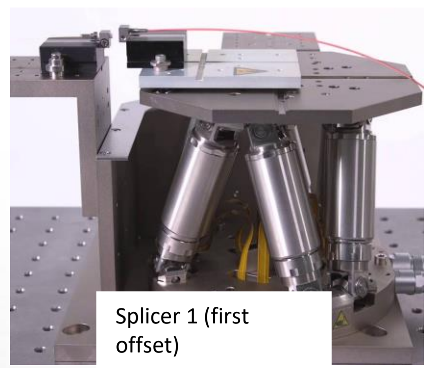


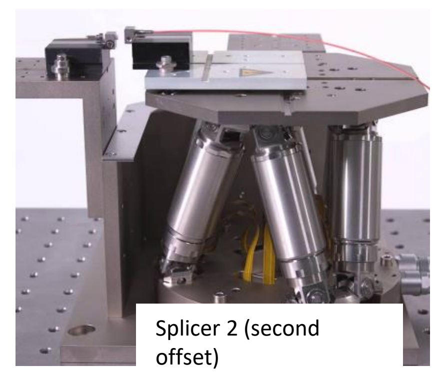


Schematic for the test set-up




Fiber Shaker

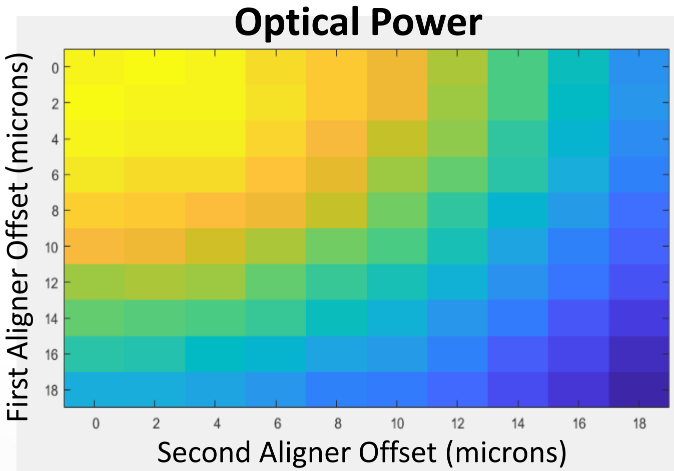

Splicer 1 (first offset)

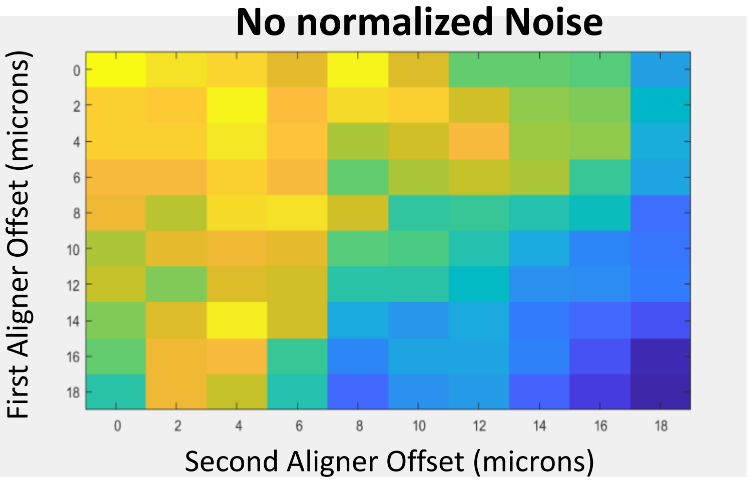

Splicer 2 (second offset)

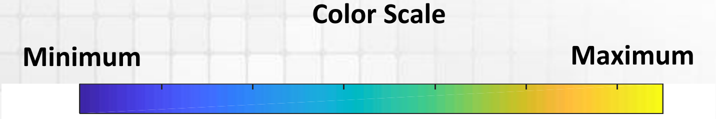
- *Offset aligners on optical tables to isolate vibrations*
- *Fiber shaker placed in another table*

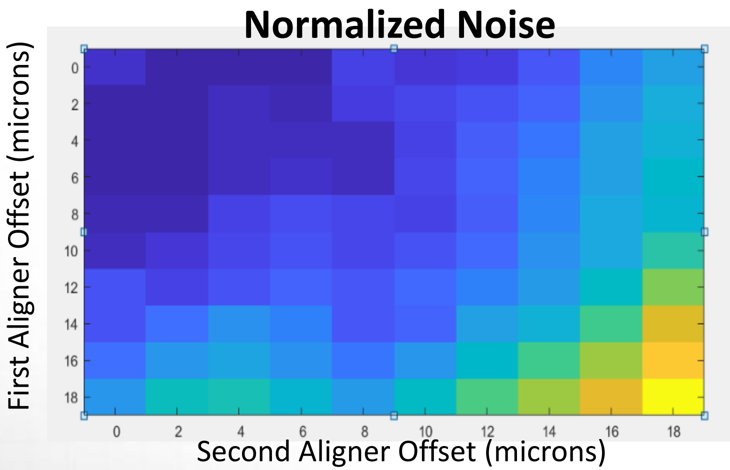
Measured Losses vs Offsets

Images represent normalized power, noise, and normalized loss per offset combination for one VCSEL.



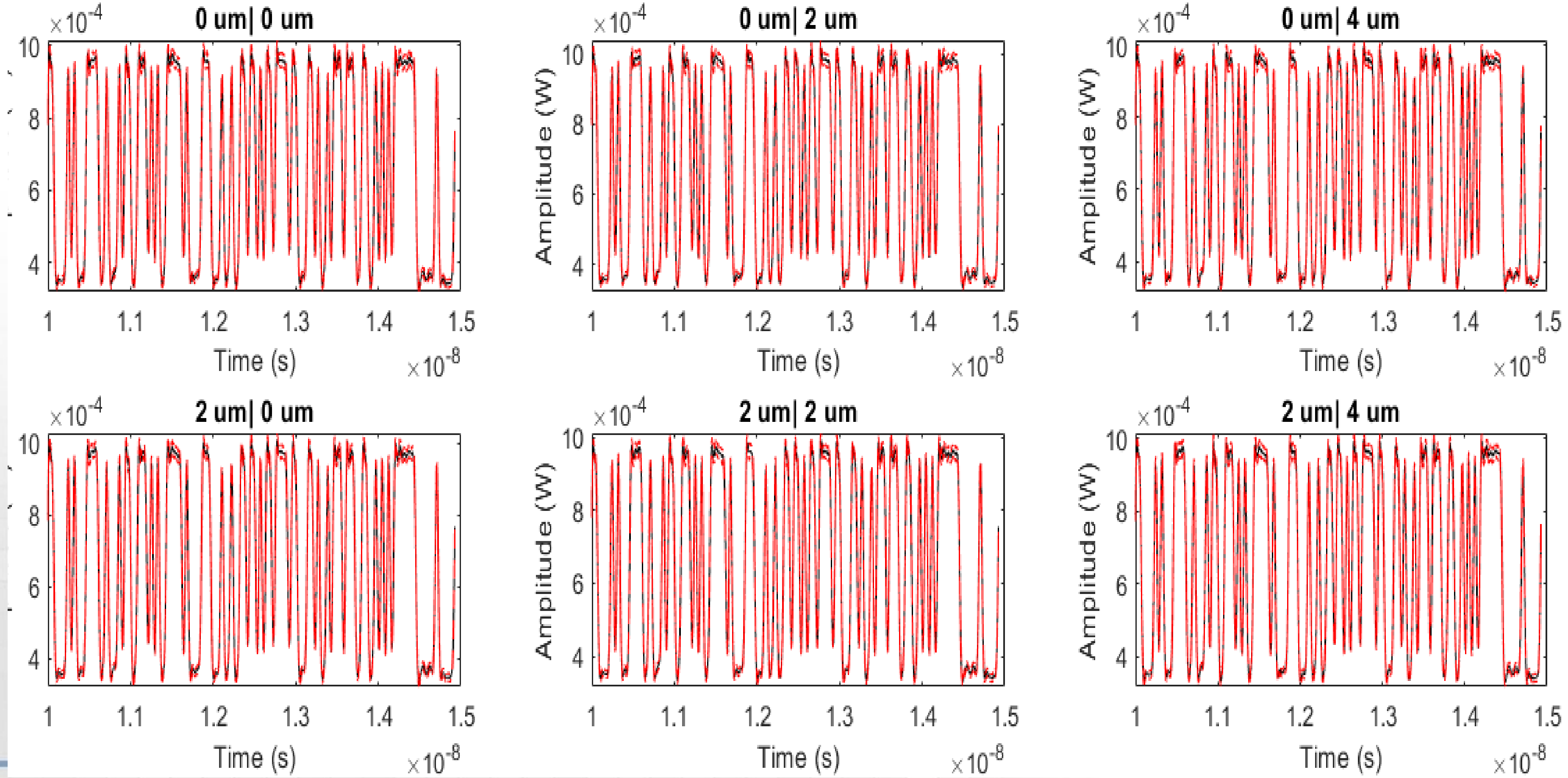


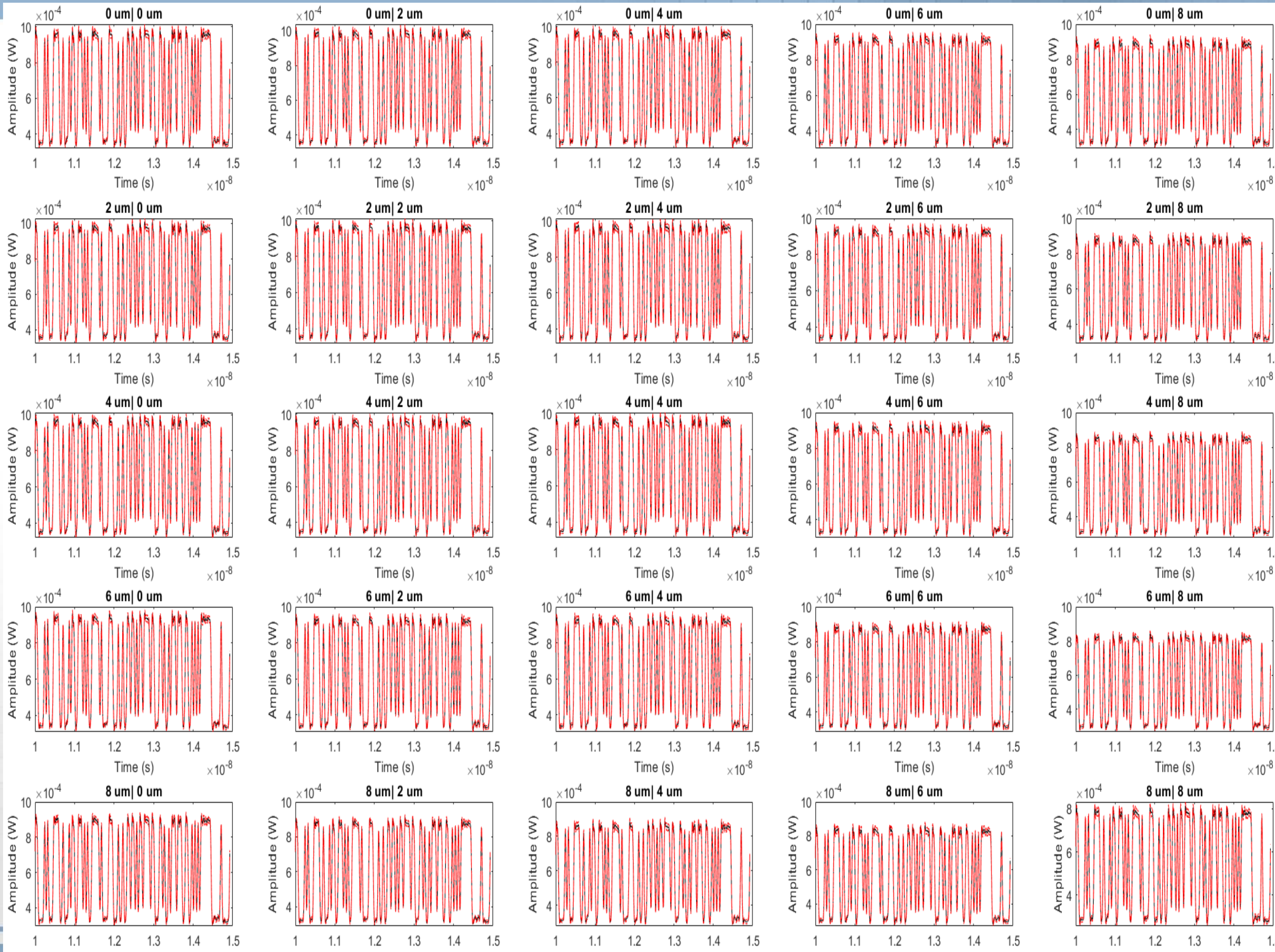




Measured Losses vs Offsets

- Bit Rate 25.78125 Gbps (NRZ).
- Pattern: PRBS7 pattern using 20 points per symbol period.
- Number of Patterns per later offset combination: 50
- Black trace (averaged of 50 waveforms), red trace +/- one STD.

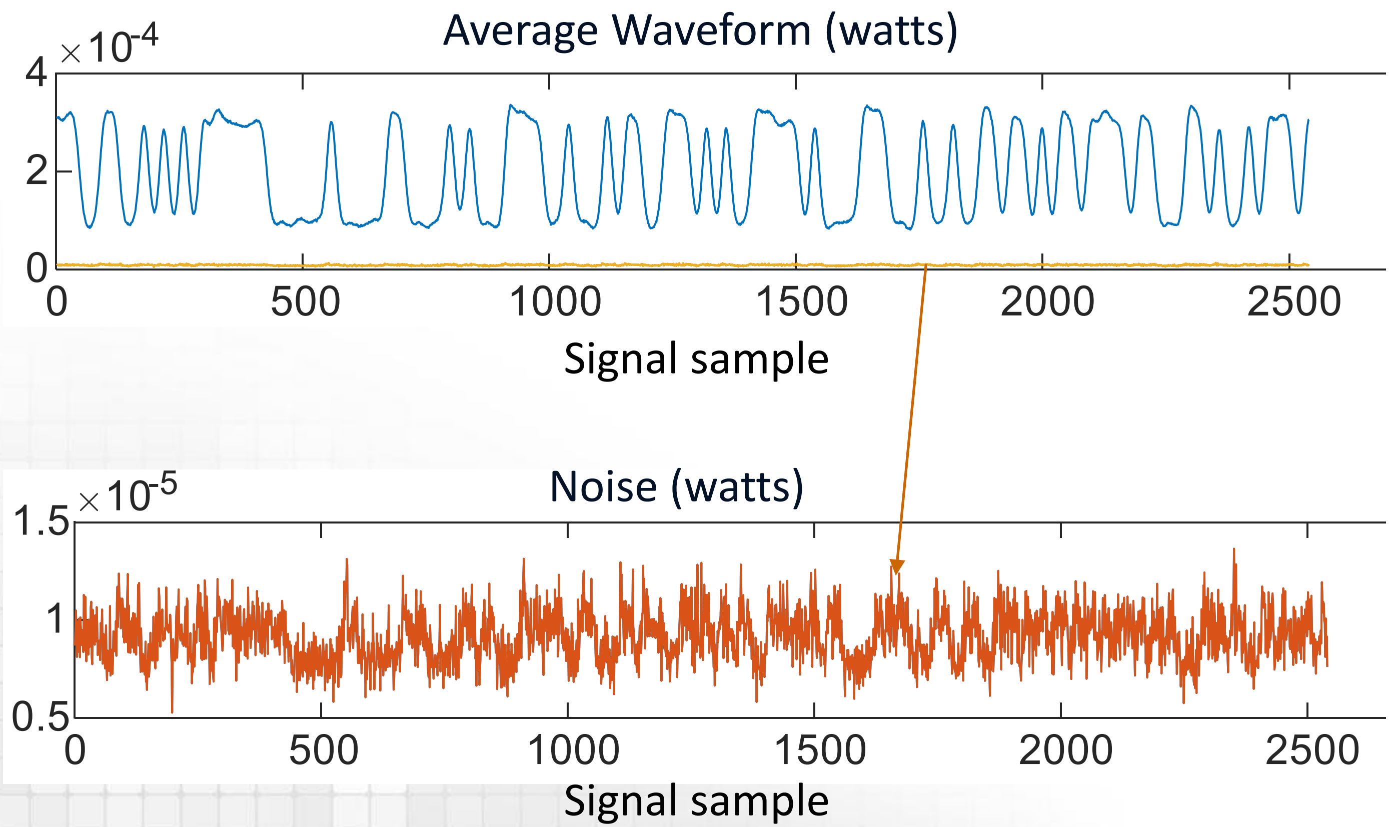




0 um| 0 um
0 um| 2 um
0 um| 4 um
0 um| 6 um
0 um| 8 um
2 um| 0 um
2 um| 2 um
2 um| 4 um
2 um| 6 um
2 um| 8 um
4 um| 0 um
4 um| 2 um
4 um| 4 um
4 um| 6 um
4 um| 8 um
6 um| 0 um
6 um| 2 um
6 um| 4 um
6 um| 6 um
6 um| 8 um
8 um| 0 um
8 um| 2 um
8 um| 4 um
8 um| 6 um
8 um| 8 um
Amplitude (W)
Time (s)
×10^-4
×10^-8

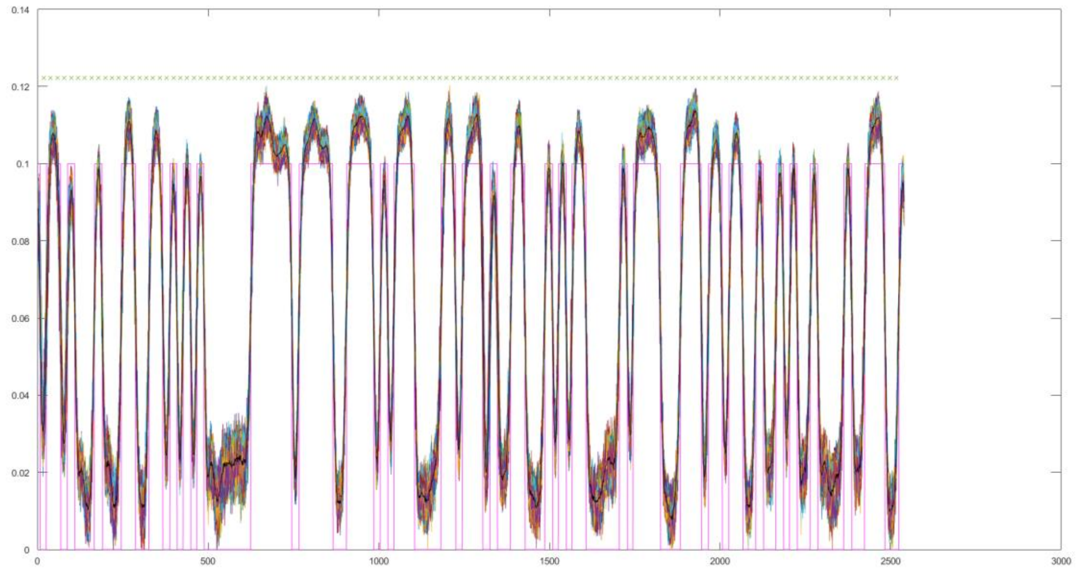
Process (I)

- Per each lateral offset combination the average waveform and noise standard deviation of 50 patterns is computed.
- The oscilloscope noise was estimated and quadratically subtracted.



Process (II)

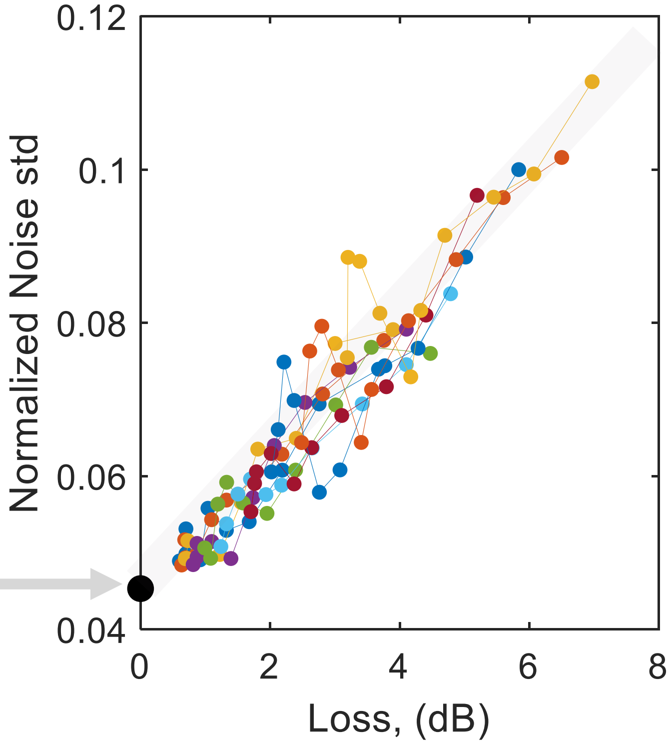
- To decouple ISI from the noise estimation we decode the zeros and ones. Next, the average power and noise standard deviations for all “1s” and “0s” in the pattern were estimated (σ_1 and σ_0).
- To decouple jitter we only considered the noise at the center of each symbol.
- The OMA of the pattern was computed.
- The Q factor with ISI and with decoupled ISI were computed.
- The parameter $(\sigma_1 + \sigma_0)$ /(OMA) was computed. This parameter is shown in the next slide.



Measured Noise (norm. standard dev) vs Loss (dB) 1 transceiver

$(\sigma_1 + \sigma_0) / (OMA)$

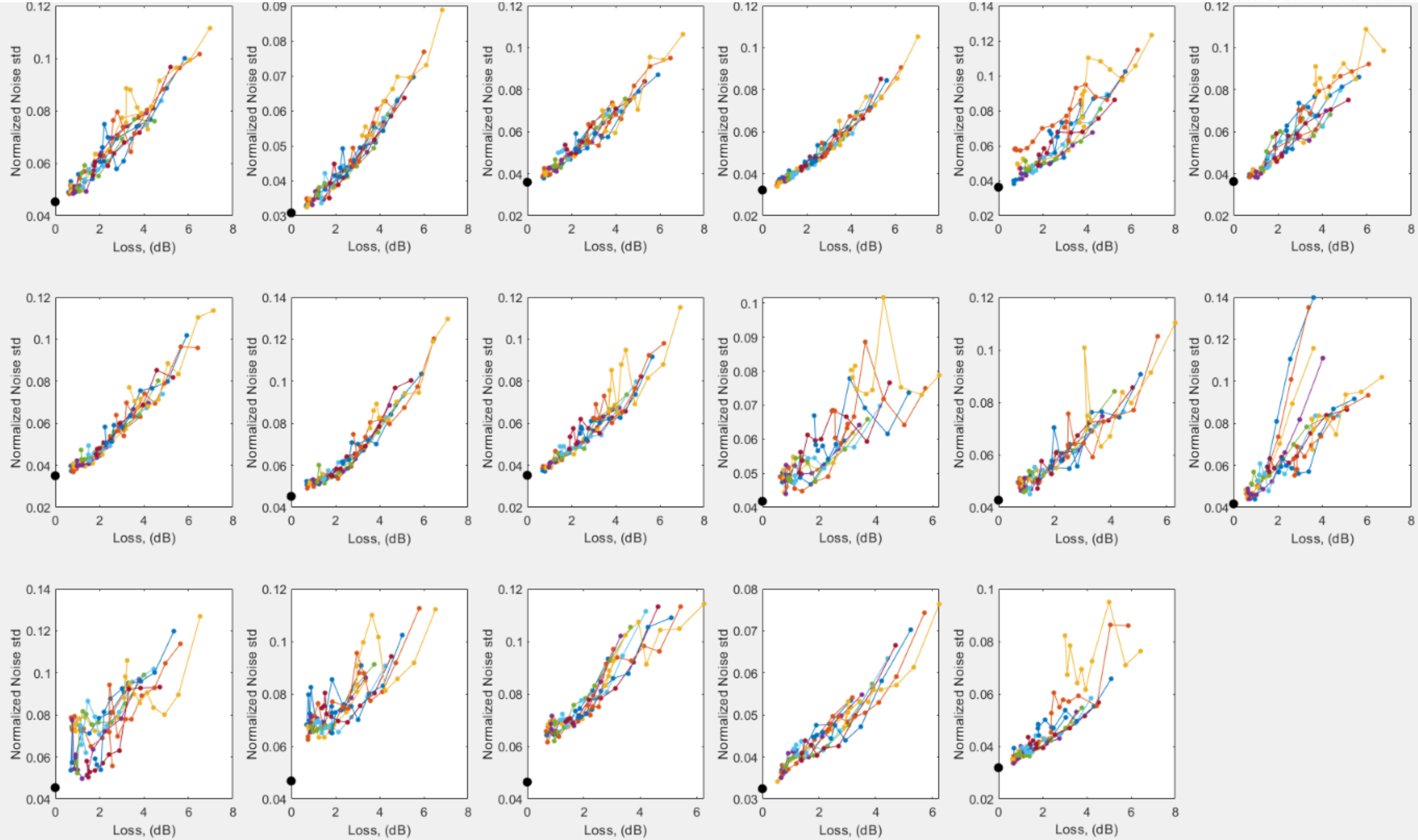
Direct Connection to scope, no aligners or C1, C1 connectors



Colored points represent 100 offset combinations: (*10 offsets position aligner 1) X (10 offsets position aligner 2)*

Colored traces represent the offset of the first position aligner. Each trace have 10 points representing the movement of position aligner 2

Measured Noise (norm. standard dev) vs Loss (dB)



Vertical axis=$(\sigma_1 + \sigma_0)$ /(OMA)

Black dot, direct connection of transceiver to scope

Connector losses in (dB) as produced for each VCSEL (not LED).

Estimation of MN

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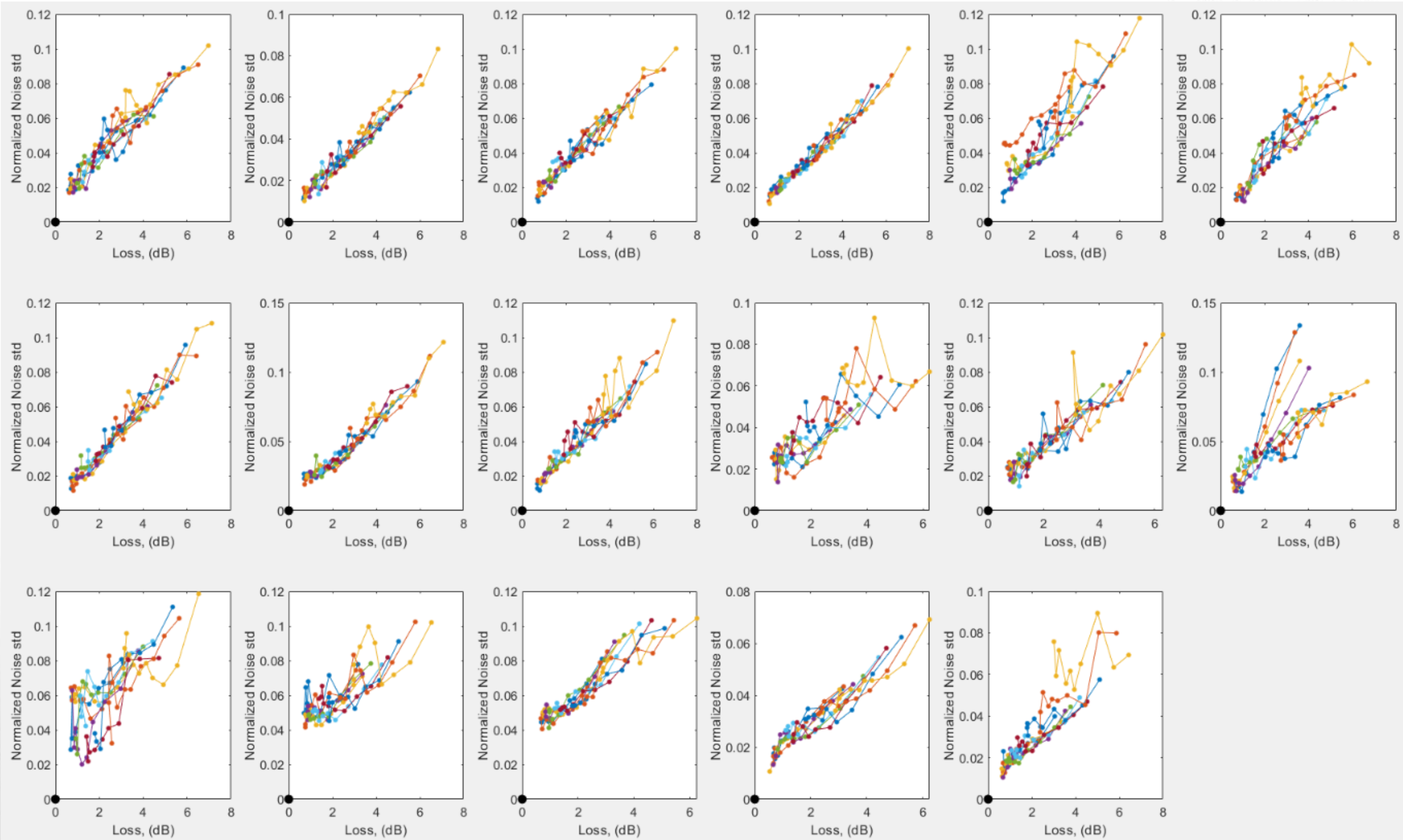
- The noise shown in the previous slide is a combination of MN, RIN, residual jitter, and residual noise of the scope.
- At zero loss (when the VCSEL is connected directly to the photodetector), we estimate the RIN is the most significant noise source.
- We expect that the difference of variances between the total noise and RIN will be an acceptable approximation of MN caused by the lateral offset. Results of this computation are shown in the next slide.

Estimation of MN (standard dev) vs Loss (dB)



Vertical axis=$(\sigma 1 + \sigma 0)$ /(OMA)

Connector losses in (dB) as produced for each VCSEL (not LED).

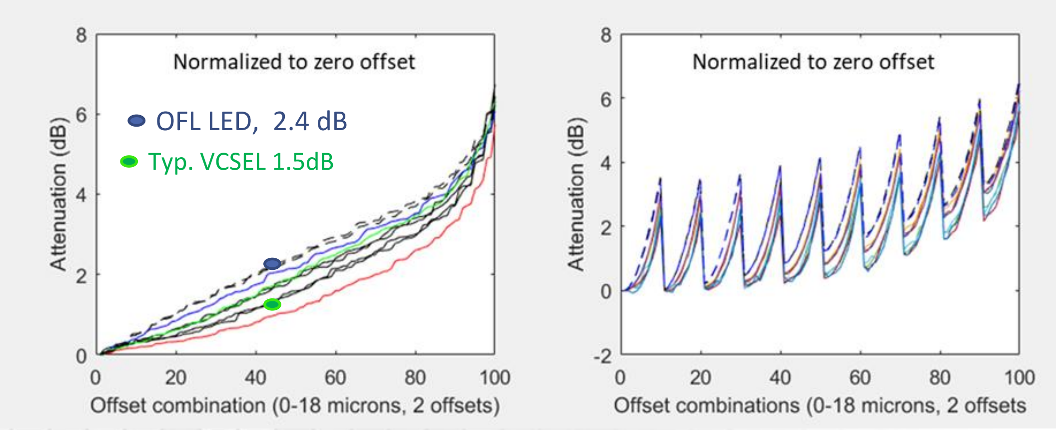
Estimation of MN

- Based on those assumptions described in previous slides, our preliminary MN estimation for the measured VCSELs (still a small sample) shows that for the majority of cases,

MN_std/(OMA/2) < 0.05 at 1.5 dB   (VCSEL loss)

- Since the loss is dependent on the launch condition, the MN is expected to be lower. The figures below show the losses of a LED source and several VCSELs for the same lateral offsets. A loss of 1.5 dB for VCSELs will likely be 2 dB in a channel as measured by EF standard compliant source.
- Since the EF standard compliant is used to measure the loss of the channel (and also used in link models) our estimation of MN need to be corrected . So far our experiments indicates that the dependence of the noise vs connector loss produced by lateral offsets could be estimated using:

$$\frac{\sigma_1 + \sigma_0}{OMA} = 0.02(Connector\_Loss(dB) - 2) + 0.05$$



Summary

- Experimental results for noise produced by lateral fiber offsets was presented.
- A procedure for estimating MN from those measurements was described.
- An initial estimation of MN was shown based on a small sample of VCSELs.
- Results can be used to compute MN penalties for PAM given the required Q factor.
- However, since MN depends on speckle noise and VCSEL mode power fluctuations, we suggest a reevaluation of the penalties for longer reaches.
  - It is possible that MN decreases as the distance increases due to the limited coherence length of the source. Also, the VCSEL mode power fluctuation might manifest as MPN instead of MN.
  - Larger sample population required to validate results shown in this presentation
  - More experiments are needed to avoid over penalizing longer reaches.