25 Gbaud PAM-4 transmission and modal noise
RE: comments 4 & 10 against D1.1

Yi Sun (OFS), Earl Parsons (CommScope), Robert Lingle, Jr (OFS)

IEEE P802.3cm 400 Gb/s MMF Task Force
IEEE 802.3 Interim, Long Beach, CA, January 2019

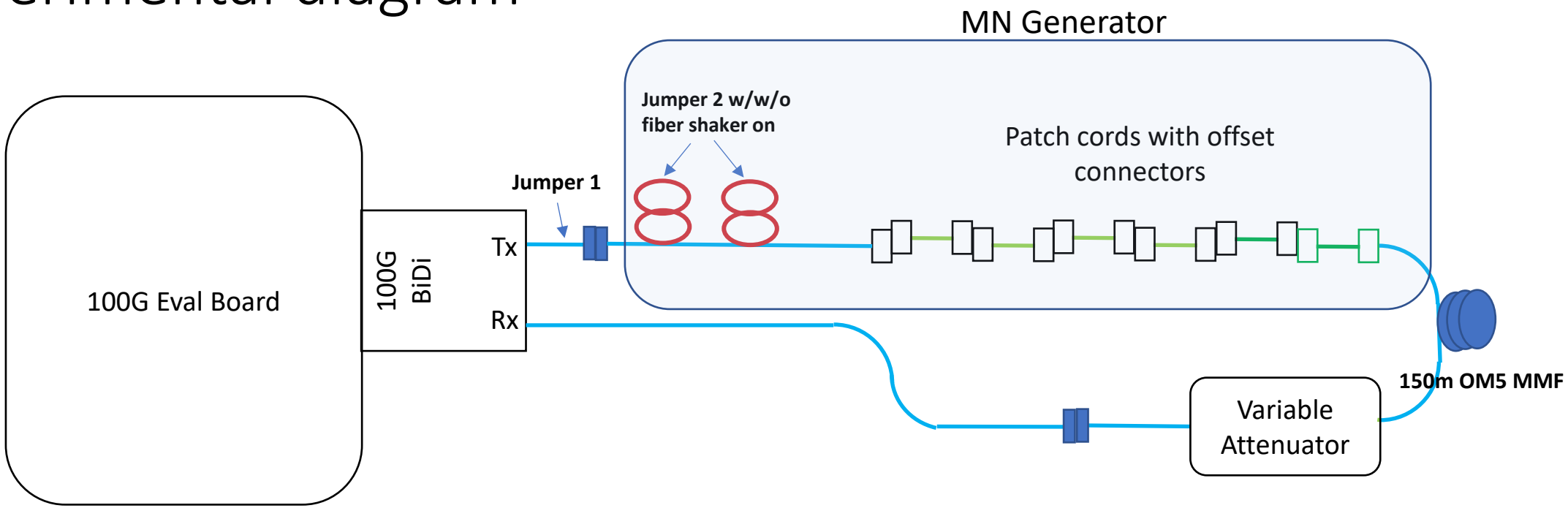
Motivation

- This is not a thorough study of modal noise (MN) with 25 Gbaud PAM-4 VCSELs
- Some arguments from modeling have been presented, raising the question whether the power budget for SR4.2 sufficiently accounts for the MN penalty. http://www.ieee802.org/3/cm/public/adhoc/dawe_3cm_adhoc_01_101118.pdf
- Castro and co-workers showed noise measurements with 25 Gbaud NRZ VCSELs that could be converted into penalties for PAM-4 (http://www.ieee802.org/3/cm/public/November18/castro_3cm_01_1118.pdf)
- A few measurements were performed with a commercial 100G BiDi transceiver to look for MN penalties generated by a fiber shaker launching into a series of offset connections, including a case with 150m MMF in the link.

Summary

- For MMF, we have historically found it difficult to measure penalties smaller than 0.2 dB due to changes when mating & un-mating connectors while swapping out fibers, differences in connector cleaning, jumper layout on the bench, etc.
- Modal noise (MN) data shown here indicates penalties slightly beyond the 0.2 dB inherent resolution, for a set of offset connections totaling 1.5 dB attenuation (measured using encircled flux launch).
- This is similar to the results obtained when noise variances from Castro *et al.* are converted to penalties for PAM-4 transmission.
- Interestingly, the total penalty for the a 150m link at 850nm did not change when modal noise was injected into the fiber.
- Given the uncertainties in measuring penalties of 0.1 dB, and given that the penalty of a 150m link did not change, we recommend further study of MN in the presence of longer lengths of fiber.

Experimental diagram



Errors estimated by FEC decoder
Received power is measured by the power detector built into Rx (also by an external power meter)

Two different sets of offset patch cords
LG: larger offsets patch cord
DG: smaller offsets patch cord
LDG: larger and smaller offset in serial fiber shaker

Worst-case 850nm fiber had EMB of 4875 MHz-km , compared to 4700 MHz-km spec limit

Lowest BW 910nm fiber had EMB of ~3900 MHz-km, compared to ~3100 MHz-km for OM5

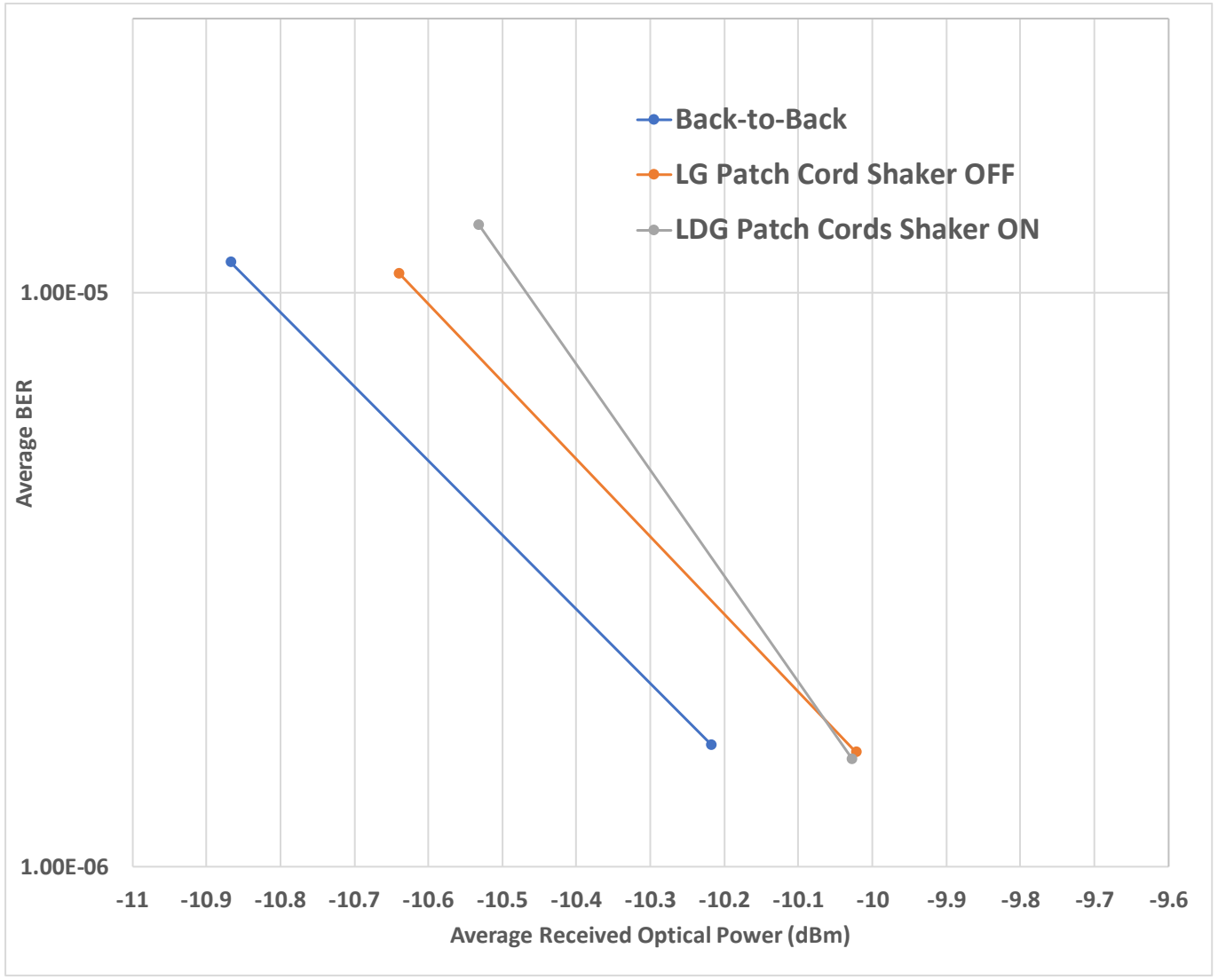
Description of jumpers with offset connections

- Dark green (DG) patch cord had 10 smaller offsets with total encircled flux loss of 0.6 dB
- Light green (LG) patch cord had 3 larger offsets with total encircled flux loss of 0.91 dB
- Together these give ~1.5 dB loss, at the limit of the power budget for connector loss

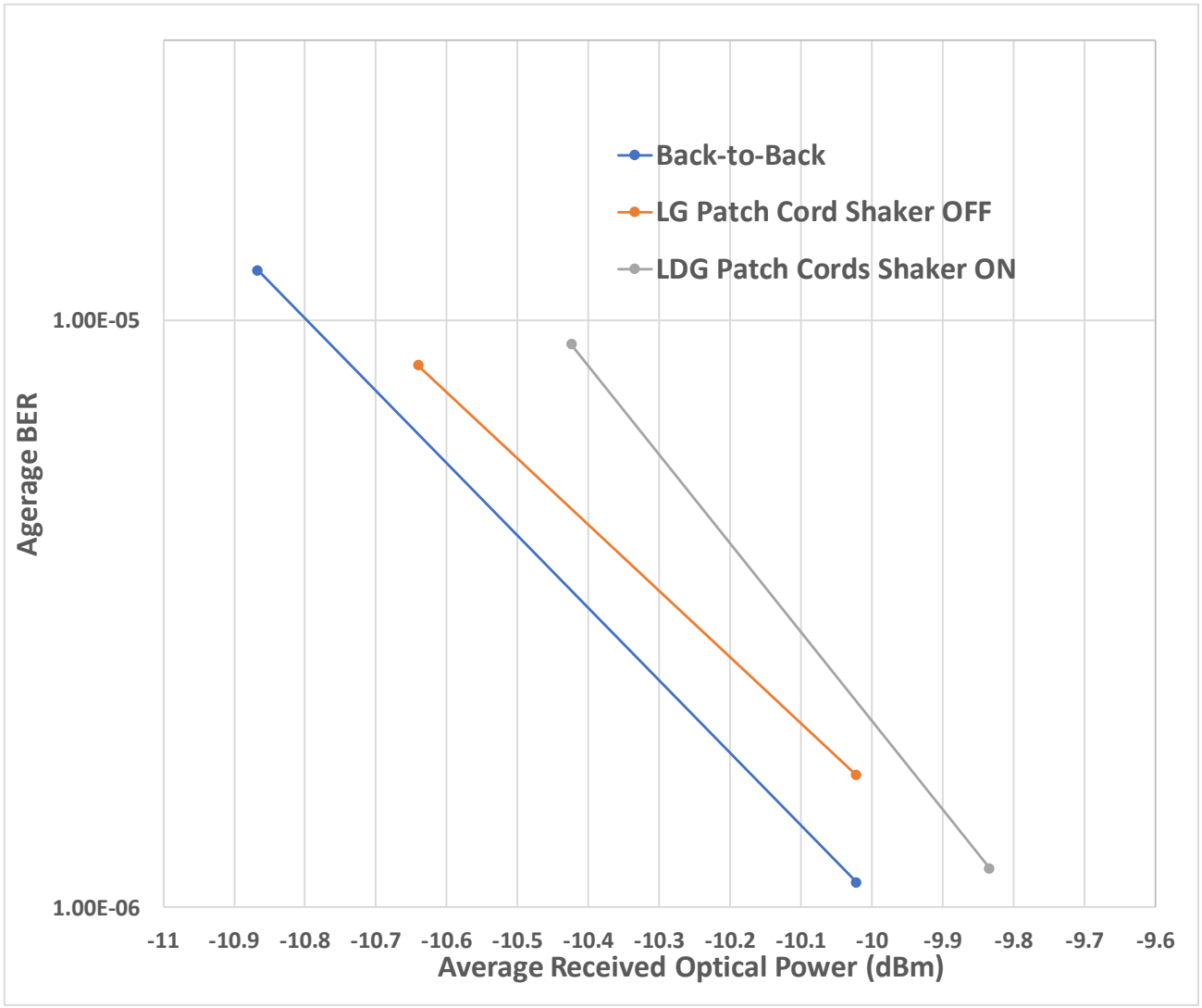
Encircled flux of the 100G BiDi TRx used for MN measurements

850nm									spec
	Radius	@	30	%	flux	=	8.55	um	>4.5 um
	Radius	@	86	%	flux	=	16.4	um	<19um
	Flux	in	5	um	radius	=	9.2	%	<30%
	Flux	in	19	um	radius	=	95.02	%	>86%
910nm									
	Radius	@	30	%	flux	=	7.38	um	>4.5 um
	Radius	@	86	%	flux	=	15.59	um	<19um
	Flux	in	5	um	radius	=	11.94	%	<30%
	Flux	in	19	um	radius	=	95.76	%	>86%

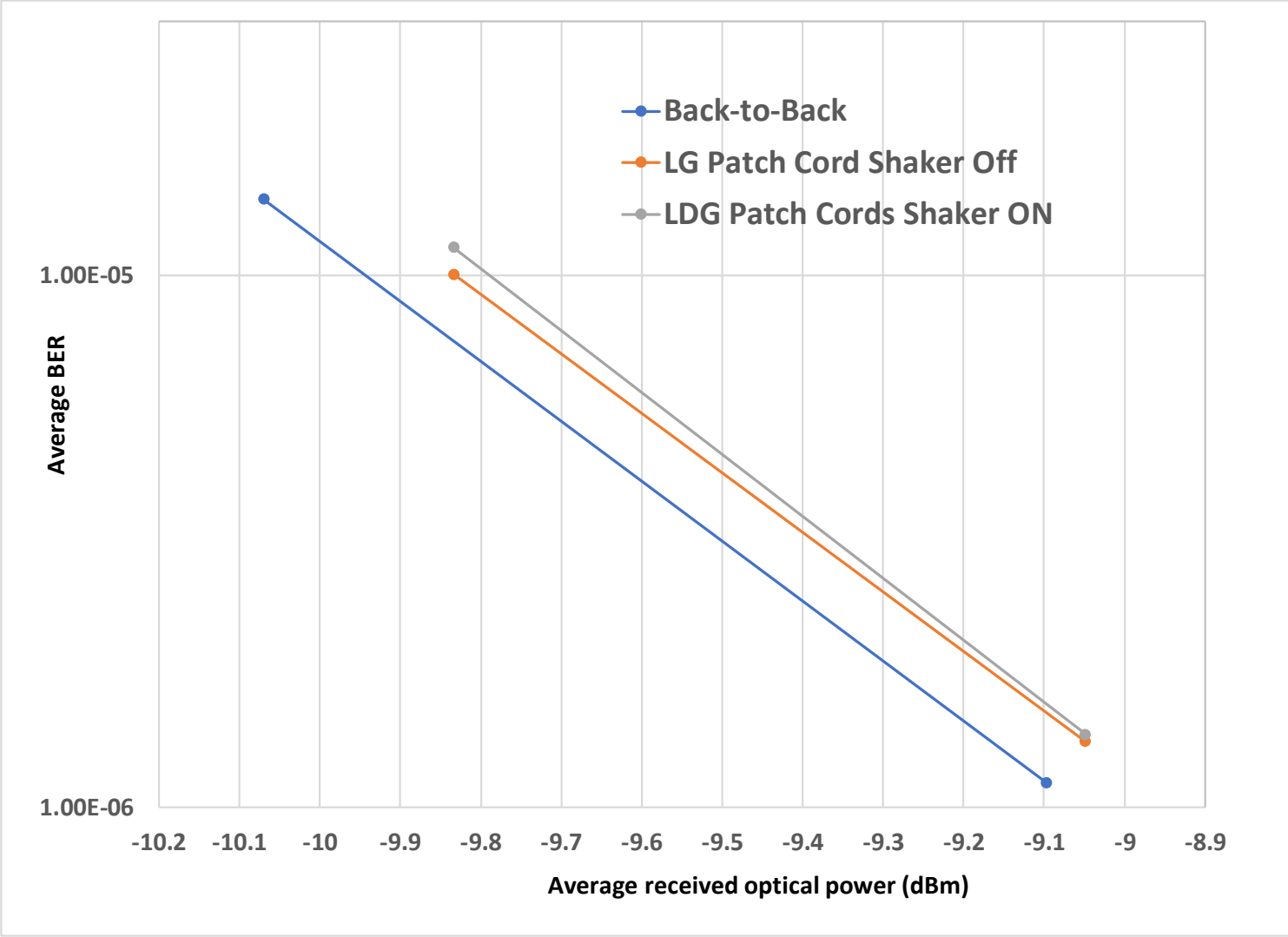
MN measurement #1: 850nm with offset connections w/ 1.5 dB EF loss, penalty ~ 0.35 dB



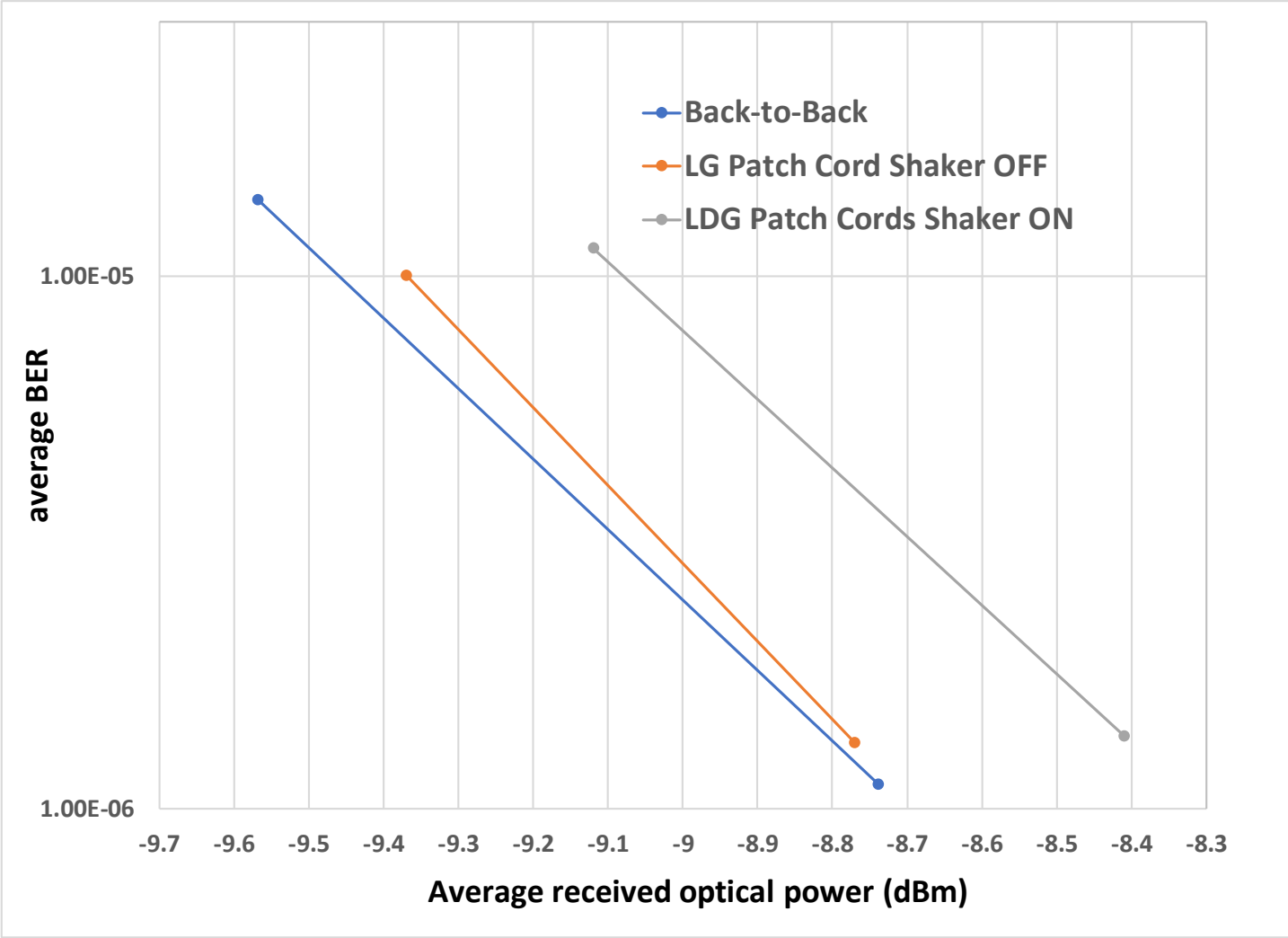
MN measurement #2: 850nm with offset connections w/ 1.5 dB EF loss, penalty ~ 0.35 dB



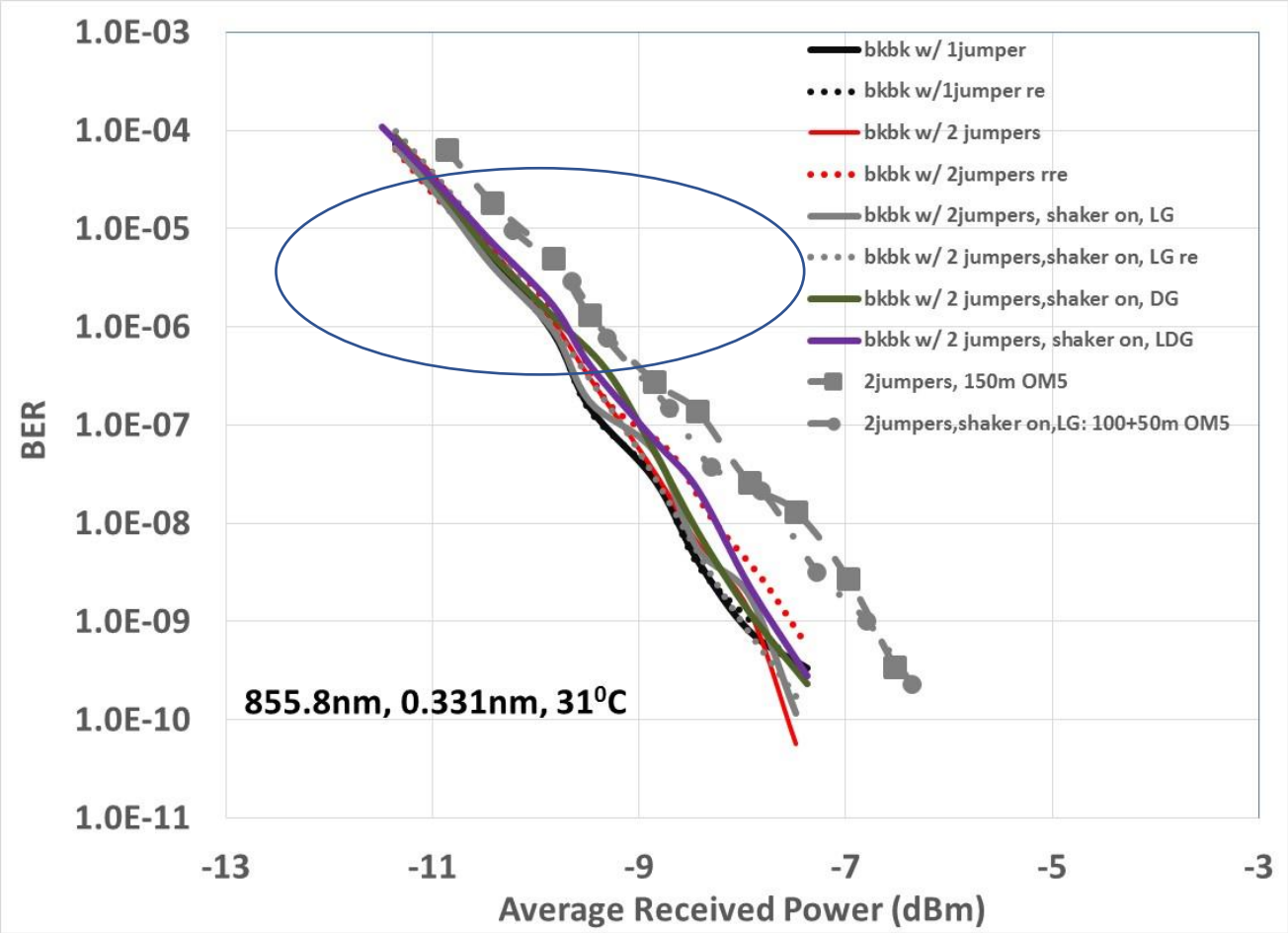
MN measurement #3: 910nm with offset connections w/ 1.5 dB EF loss, penalty ~ 0.15 dB



MN measurement #4: 910nm with offset connections w/ 1.5 dB EF loss, penalty ~ 0.4 dB



MN measurement #5: 850nm with offset connections (w/ 0.6 dB EF loss), 150m worst-case fiber
-- Total penalty ~ 0.5 dB w/ 150m MMF



Same as in a separate measurement, 150m of this fiber showed a 0.5 dB total penalty without the offset patch cords

Conclusions

- Modal noise was generated by offset connections totaling 1.5 dB loss, with a fiber shaker.
- Modal noise penalties were measured with a 25 Gbaud PAM-4 commercial module, in the BER range of 1e-5 to 1e-6, where one would be comfortable operating a link intended for KP4 FEC
- Modal noise penalties were measured from 0.15 to 0.4 dB at 850nm and 910nm. This is similar to MN penalty estimations by Castro et al.
- Since 0.2 dB is approximately the resolution of BER measurements for MMF, this may indicate that launching from a fiber shaker into the offset patch cords generates several tenths of a dB of modal noise.
- The total penalty with 150m of worst case fiber at 850nm was not increased (within error) when a signal carrying modal noise was injected. It was not obvious that the penalties added.
- Further study of 100m and 150m fibers in the link with modal noise generation will be conducted to study if the penalties are additive, prior to making a recommendation on the draft.