Validation of using measured DMD from long fiber spools to characterize the installed base

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Questions Requiring Answers

- OFS and Georgia Tech presented coverage results in Vancouver based on measured DMD from a large scale set of 1998 FDDI fibers. Only spools greater than 5km length were included in the study.

1. Nick Weiner asked what was bandwidth detector was used in the 1998 DMD test set, and whether this would artificially broaden IPRs and lead to inflated PIE-D values.

2. Jonathan King asked whether mode coupling effects could make DMD worse for an intermediate distance range?
   - There is agreement that complete mode-mixing would lead to better improved DMD in the very long length regime.
   - However it is conceivable that incomplete or partial mode mixing would make DMD worse in an intermediate length regime.
   - In the latter case, DMD data from 8.8km spools could possibly be overly pessimistic compared to direct measurements of ~300km spools.

3. Review OSL-BW distribution for OFS 1998 legacy fiber set to see what it tells us about the validity of using measured fiber DMD data

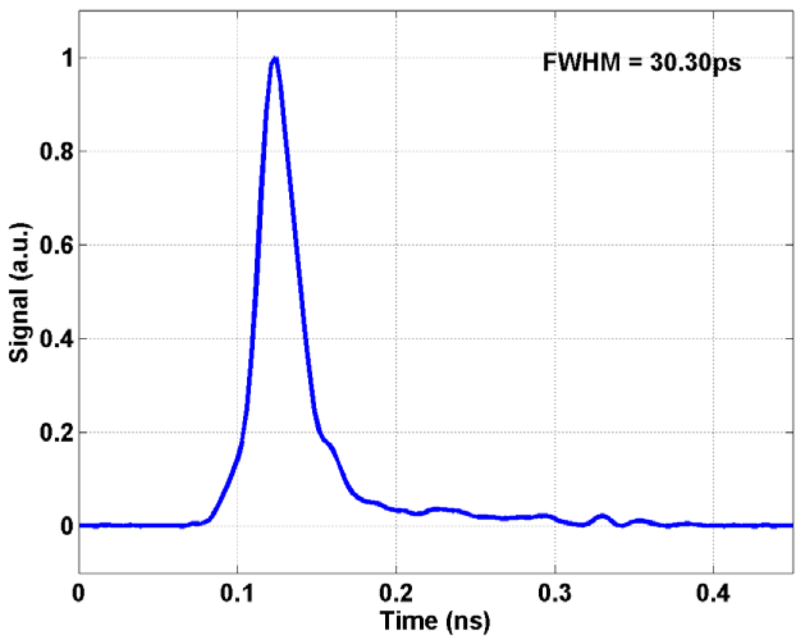
Conclusions and Summary of What Follows

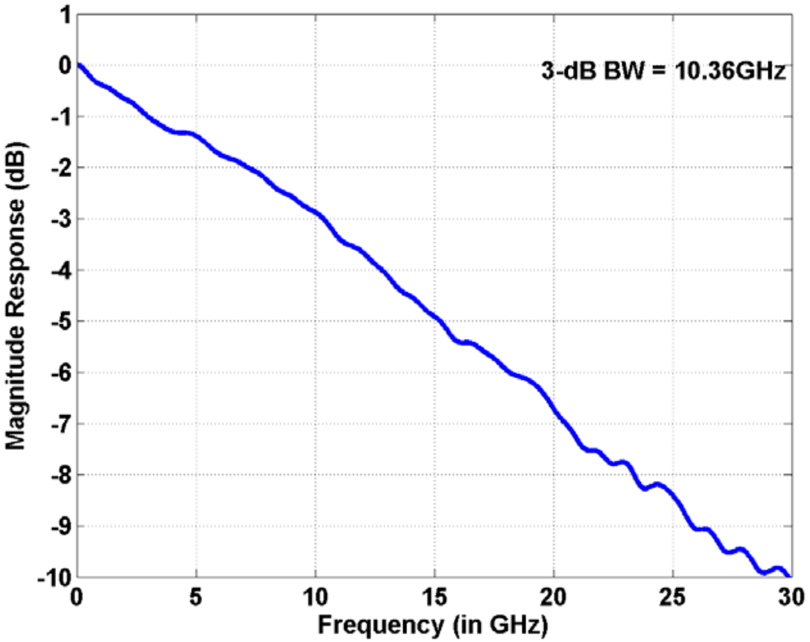
- The use of spool data >5km satisfies concern about the 1-2GHz detector bandwidth used in measuring 1998 fiber DMD (with possible exception of the highest bandwidth fibers affecting the lower %tiles of a coverage curve).
- Analyses of 1) cutback gamma values and 2) OFL-BW data versus length indicate that – on average – mode-mixing improves bandwidth when going from 1.1km to 8.8km lengths. The 1998 OFS dataset used only fibers > 5km. By itself, this effect might lead to an overly optimistic prediction of coverage when we assume linear length scaling. At minimum, we can say there is no evidence that use of long length data is pessimistic w/r to coverage.
- The OSL-BW values for the OFS 1998 fiber set are in line with and not pessimistic w/r to past expectations from GbE assessments of the installed base.
- All fiber models are subject to assumptions and non-idealities.
- The use of measured data on a large set of real fibers is at least as valid as other approaches used.
- Therefore the 5.2dB estimate of 99%tile PIE-D coverage point must be taken seriously as one of the valid estimates of the installed base.

1a. Temporal Resolution of DMD Data set

- Requirements to properly assess 300-meter PIE-D performance based on DMD measurements of long fibers
  - Measurement must have an effective bandwidth sufficiently greater than the channel
    - Bandwidth of the ideal channel (no fiber) is <7GHz (Rx has 7.5GHz, Tx has 47ps risetime)
  - The response of longer fibers can be scaled to the equivalent shorter fiber response
  - (The possibility that the fiber response does not actually scale linearly due to mode coupling does not impact the temporal resolution. We address this issue separately)
- Test bench bandwidth assessment
  - The test bench receiver has a bandwidth greater than 1GHz
  - IPR of very good fiber demonstrates a test bench bandwidth must be greater than 350MHz
- Scaling requirement
  - To achieve 7-GHz effective bandwidth using 1-GHz test bench resolution requires a 7-fold increase in length over the 300m fiber channel
  - We choose a scaling factor of 16 to insure excess resolution and thereby eliminating the need to deconvolve
- Therefore test fibers must be greater than 5000m long

1b. Test Bench Response





- Measured impulse response for a very good fiber provides estimate of test bench response (scaled to 300m from 9029m)
  - Time FWHM = 30.3ps
- Corresponding frequency response
  - Has a 3-dB BW = 10.36GHz
  - Unscaled results shows a test bench bandwidth of >350MHz

2a. Occurrence and Impact of Mode-Mixing

- Simple modeling indicates that the initial on-set of mode-mixing during propagation can degrade DMD, but subsequent propagation improves DMD again.
- OFL-BW undergoes a length-scaling effect due to mode-mixing that is typically characterized by the "cutback gamma" parameter.
- Phenomenology: if a longer spool of MM fiber is cut up into shorter segments, the OFL-BW of the longer parent spool will – on average – be higher than the OFL-BW of the shorter offspring spools. A value less than 1.0 indicates that BW improves with length.

$$\frac{BW_1}{BW_2} = \left(\frac{L_1}{L_2}\right)^{1-\gamma}$$

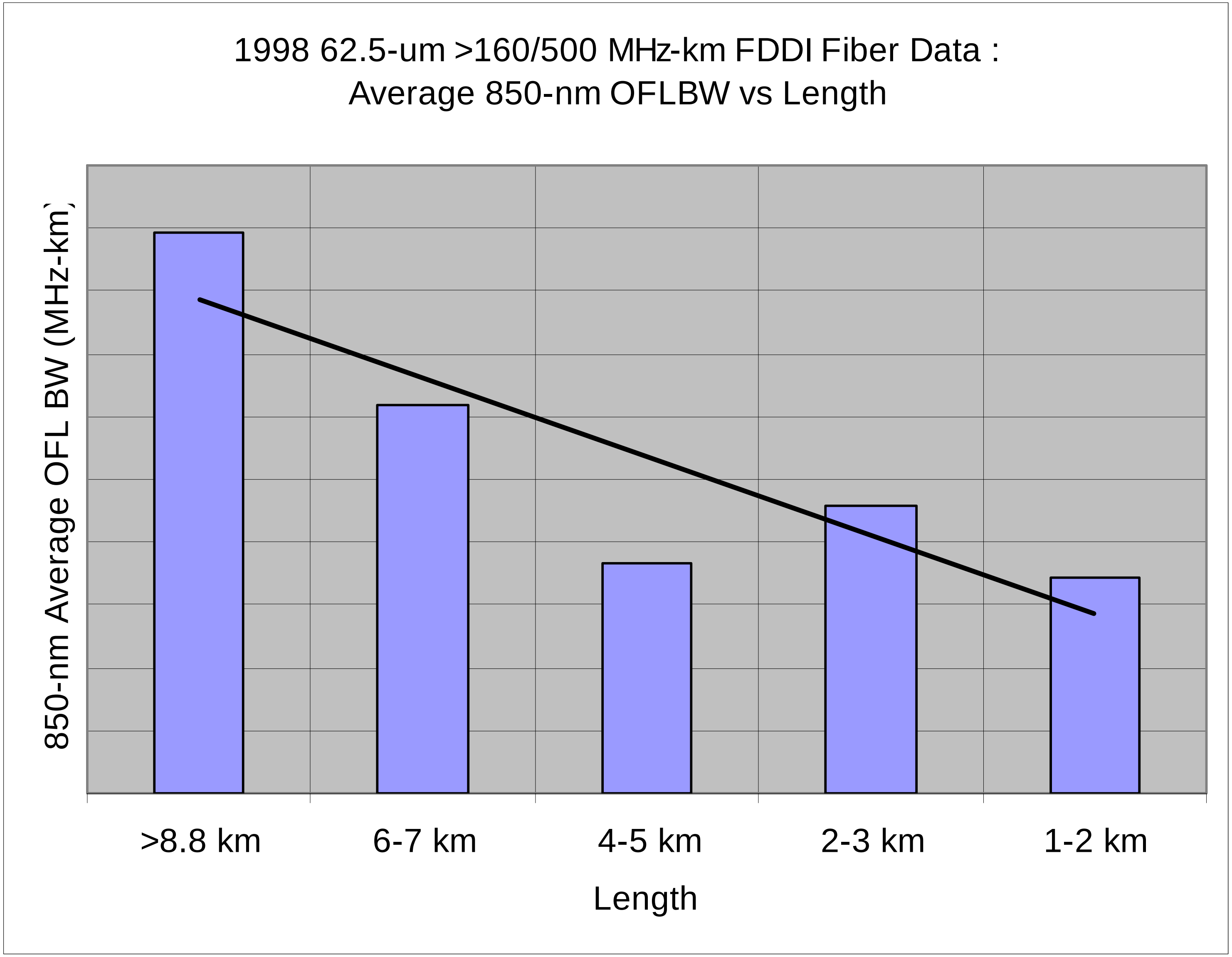
- A value of gamma between 0.8 and 1.0 (precise value usually not disclosed) is applied by manufacturers to provide a guard band so that measurements on long shipping lengths of fiber (e.g. 8.8km) will be reliable when applied to the shorter cabled lengths actually deployed (e.g. 300m).

2b. OFL-BW histograms for 1998 OFS measured fiber data

- Histograms for 850 and 1300nm OFL-BW data for the 1998 OFS measured fiber data set are shown on the following two slides.
- The length scaling between 1.1 and 8.8km spools in both the 850 and 1300nm plots can be described by a gamma value between 0.8 and 1.0, as expected.
- The reasons why fibers get cut into shorter lengths are not related to bandwidth measurements, but various unrelated manufacturing steps.
- Mode-mixing effects that occur between 1.1 and 8.8 km spools lead to higher OFL-BW for the longer lengths, on average, indicating we are in a regime where mode-mixing is *beneficial* (improves BW).
- These date do not directly address the scaling from 300m to 1.1km, since 300m spools are not part of this dataset, and OFL-BW data is not commonly available for spools < 1km.
- However the OFL-BW of spools > 5km length are shown to have higher BW than shorter spools.

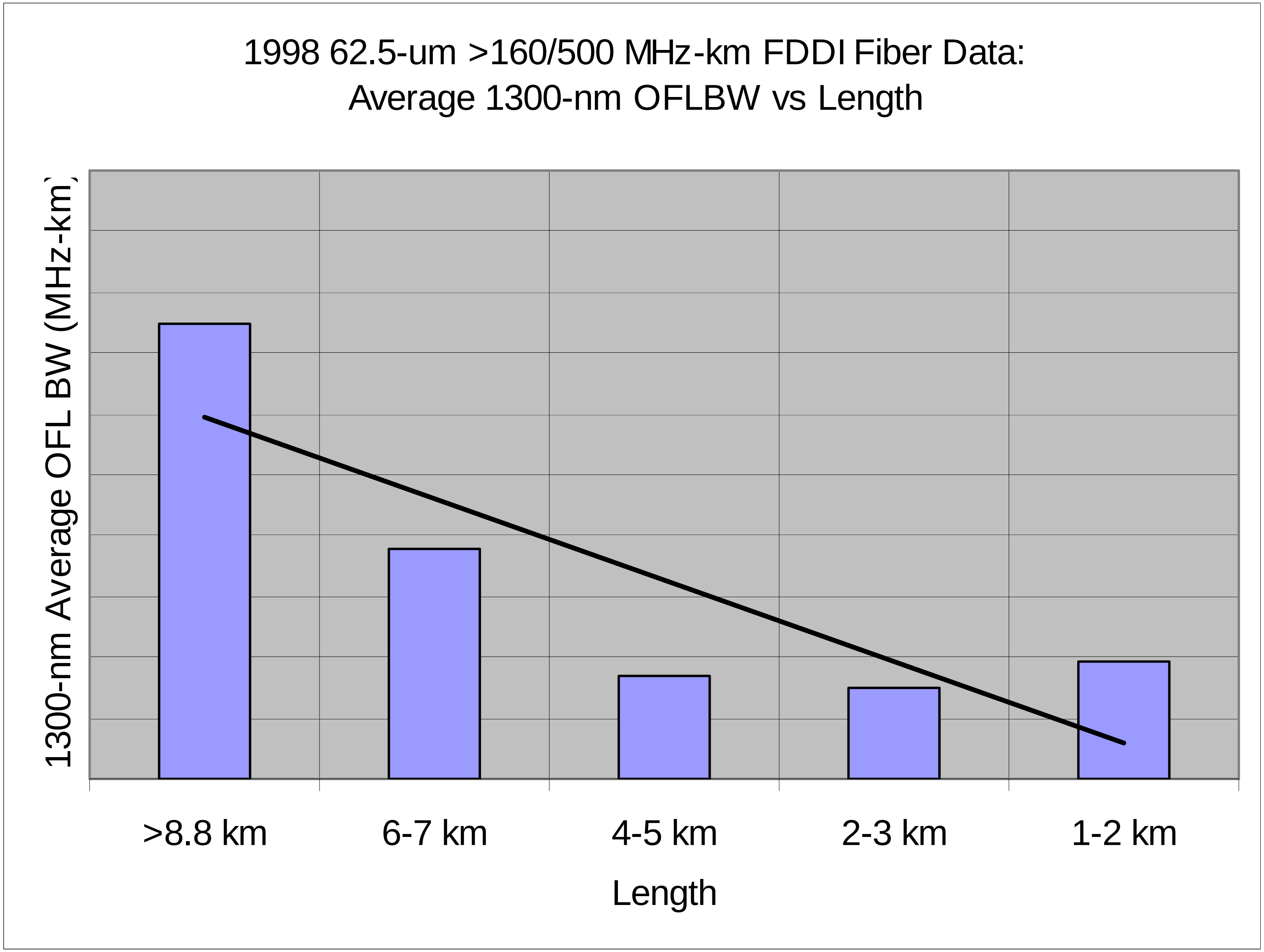
2c. 850nm OFL-BW vs. length histogram for 1998 OFS FDDI fibers

Longer lengths work on average to improve OFL-BW



2d. 1300nm OFL-BW vs. length histogram for 1998 OFS FDDI fibers

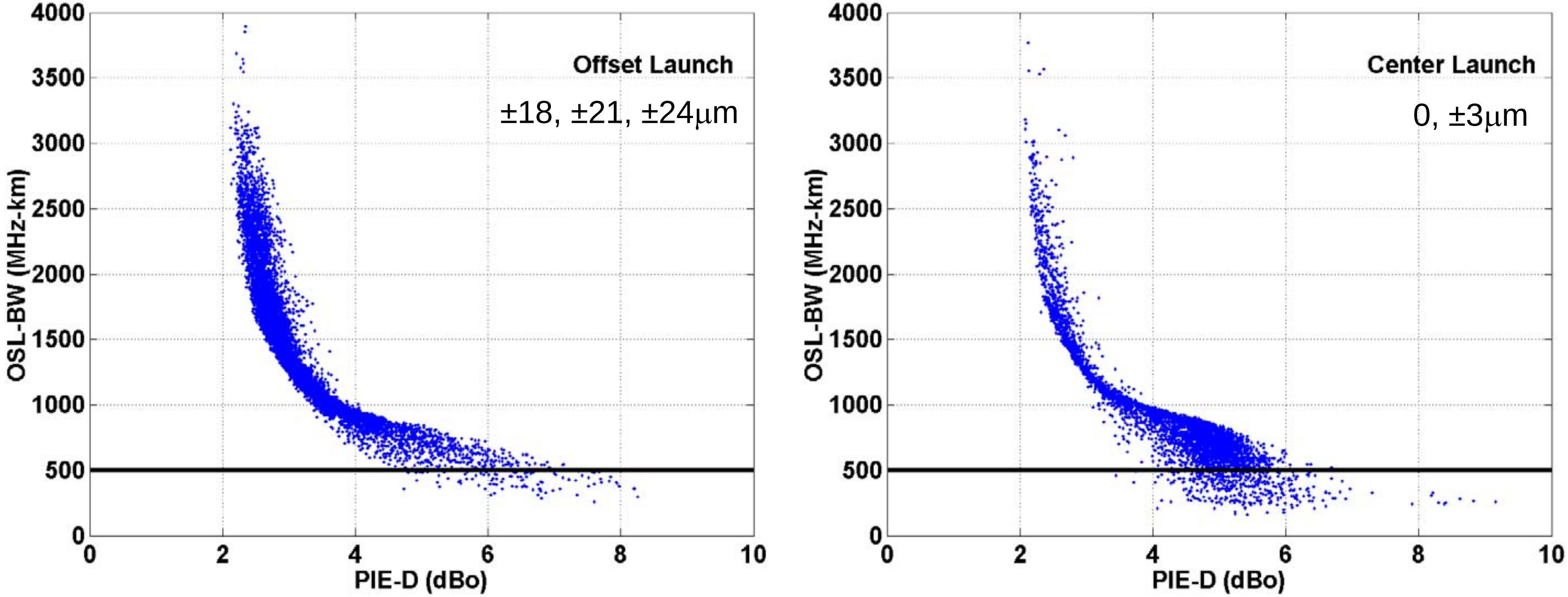
Longer length effects work on average to improve OFL-BW



2e. Implication for use of long spool DMD data to model PIE-D for 300m links

- In modeling PIE-D coverage, the DMD for long spools was linearly scaled from the spool length down to 300m.
- In the case of no mode-mixing effects, this would be correct.
- In a case where mode-mixing leads to narrowing of DMD at 8.8km relative to 300m, then linear scaling would <u>underestimate</u> DMD and thus PIE-D
- The available evidence on length-scaling of OFL-BW provide support for the idea that the procedures used in balemarthy_1_0105 do not systematically overestimate PIE-D using measured DMD data based on mode-mixing phenomena.

3. OSL Bandwidth for 1998 OFS set demonstrates its Validity
- OSL-BW is not pessimistic w/r to past expectations



- 1.3% of fibers have OSL-BW below 500MHz-km
- This is very consistent with past expectations from previous studies
- This fiber set is not pessimistic as characterized by OSL-BW (directly related to PIE-D), but still puts the Joint Launch 99%tile coverage PIE-D penalty on Gen67YY at 5.2 dB.