Length Dependence of GI-POF BW: update

John S. Abbott, Suresh Donthu
Corning Incorporated

802.3dh 11/30/2022 Task Force ad hoc teleconference

INTRODUCTION -- RECALL KEY POINTS AND CONTEXT

1. Multimode optical fiber bandwidth is a function of **fiber** properties and **transmitter** properties.
2. Fiber bandwidth is typically measured with a well-defined source on a long length (kms) and specified in MHz.km to allow simple calculations on shorter lengths.
3. In many applications using fibers from many vendors, over many years, OM3 fiber has been shown to scale linearly BW[GHz] ~ L^-1[1/km]
4. Published papers suggest mode mixing in GI-POF causes its BW to scale nonlinearly { BW[GHz] ~ L^-g, g<<1 } . This is a documented benefit for longer lengths because it decays more slowly, but a problem in extrapolating back to shorter lengths as in auto links because it overestimates BW(15m).
5. This contribution will highlight the need for additional data to characterize BW length scaling of the specific variety of 55um GI-POF in auto use cases, with automotive transceivers, to guarantee 20GHz @15m for any compliant transceiver

OVERVIEW Length dependence L^γ where γ <1

PREVIOUS:

[1] abbott_3cz_01_150222_GI_POF_BW_length_dependence.pdf summarized measurements of length dependence of 75μm core GI POF samples and an example with length dependence scaling like L^0.67 was presented.

[3] Historical example with AGC 140μm core perfluorinated GI-POF shows L^0.57

THIS PRESENTATION:

Recent example of 60μm core GI-POF shows L^0.597 consistent with reference [3].

CONCLUSIONS

1. Worst case scaling from a large sample of fibers is likely $0.50<\gamma<0.57$
2. Also need data on effect of heat aging on large sample of 100m fibers as well as effect on L^ exponent, and the effect of different launch conditions.
3. BW of 20GHz at 15m needs to be *guaranteed* for any compliant transceiver.

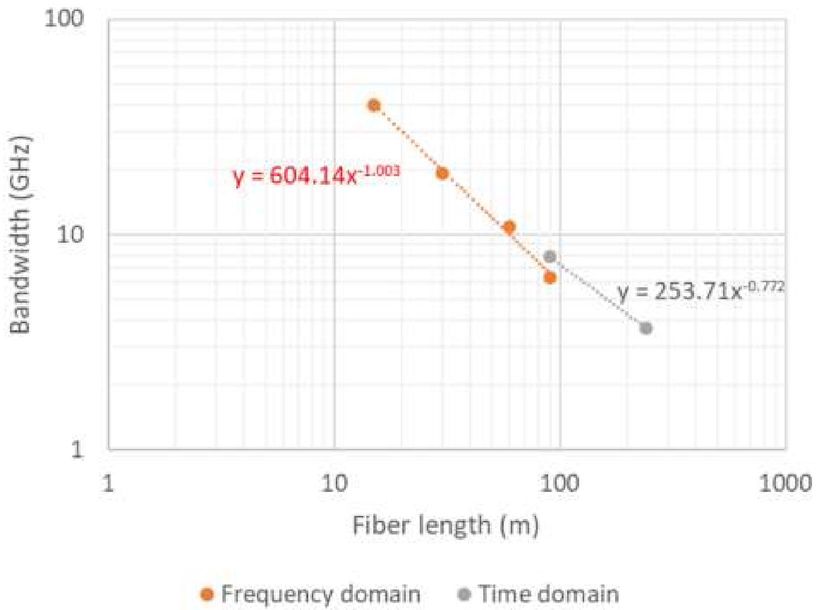
Summary of Length Dependence

[3] 1999 AGC 140μm GI-POF 1/BW ~ L^{γ} $\gamma = 0.57$
[2] 7/2022 Watanabe BW ~ $L^{-\gamma}$ $\gamma = 1.003, 0.772 ; 0.731, 0.758, 0.868$
[1] 2/2022 Abbott 75μm core BW ~ $L^{-\gamma}$ $\gamma = 0.67$
[this ppt] 11/2022 60μm core Abbott BW ~ $L^{-\gamma}$ $\gamma = 0.67, 0.597$

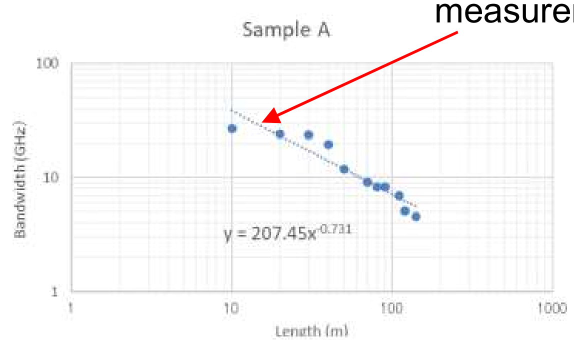
Hypotheses / concerns:

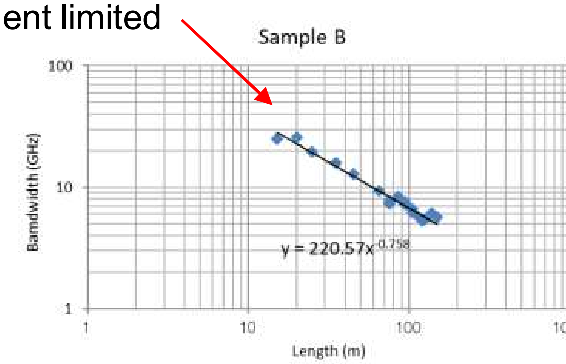
a. Length exponent γ depends on launch condition (the particular VCSEL used; OFL launch leads to different result). Check effect of different launch conditions on γ.
b. Abbott results reflect use of the "1.5dB BW" (SQRT(2) * 1.5dB frequency, not the 3dB frequency) and differences between 1.5dB BW and 3.0dB BW observed.
c. Heat aging experiments [2] should be repeated with more samples, checking if γ changes, as well as the effect of different launch conditions.

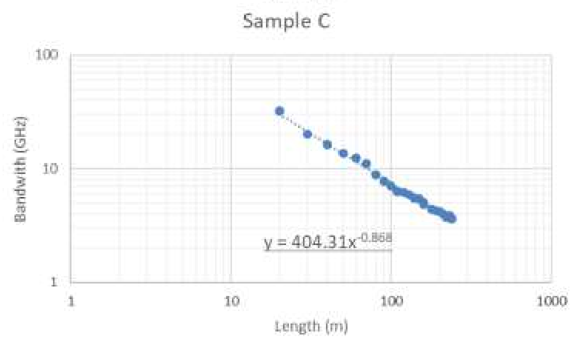
Watanabe_3dh_02_2207.pdf[2] data for reference (55μm core A4i)



Horizontal at short length --> maybe measurement limited







Measured by time domain method

Although GI-POF has high mode coupling, bandwidth of 20GHz over 15m can be achieved.

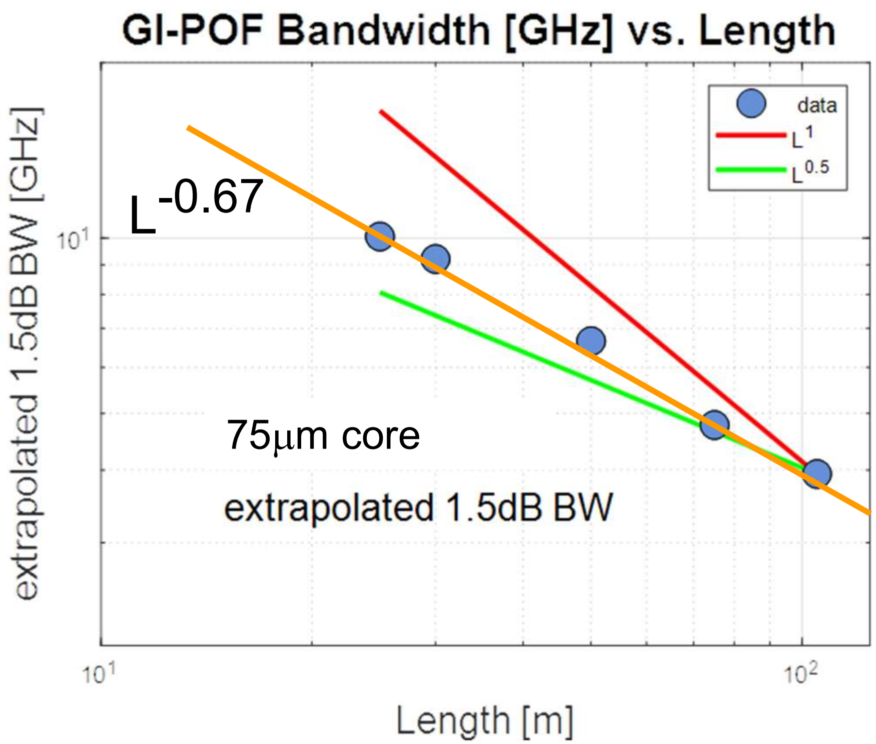
Exponents 1.003, 0.772

Exponents 0.868, 0.758, 0.731

General comments based on these results:

1. The exponent depends on the launch condition. Expect a difference between OFL launch and restricted launch (to be checked).
2. We expect linear (γ=1) at short lengths under 25m, and nonlinear (γ<1 like 0.6 to 0.8) for long distance. However, examples B & C did not transition to linear at short lengths and example A transitioned to γ <<1 (maybe measurement related)

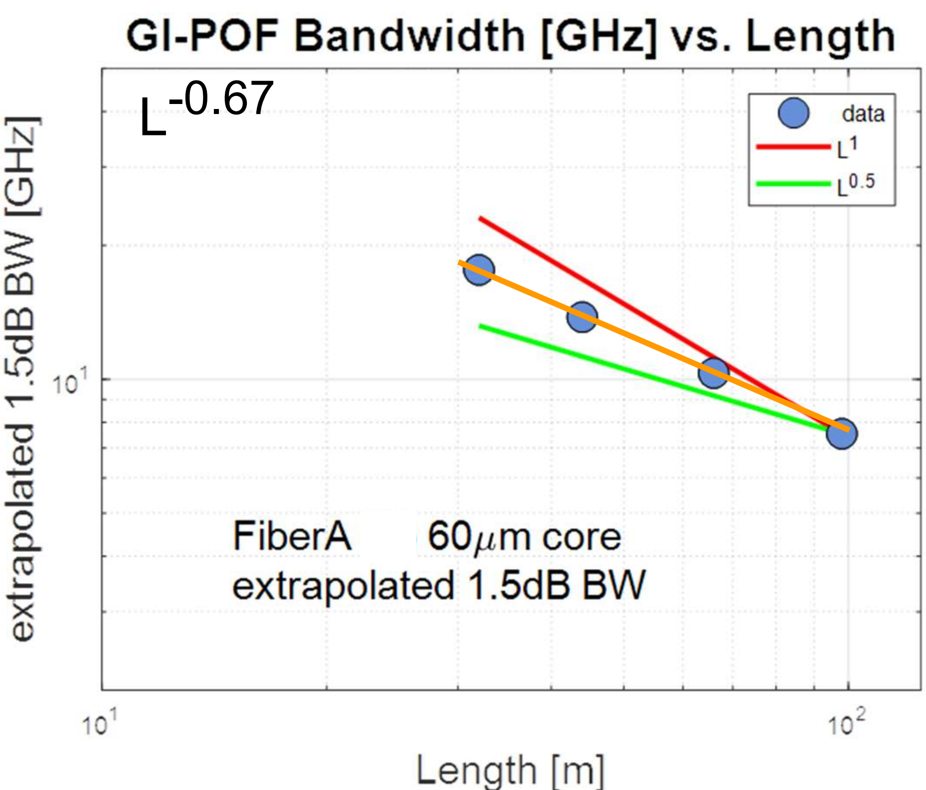
abbott_3cz_01_150222_GI_POF_BW_length_dependence.pdf[1] (75μm core GI-POF)

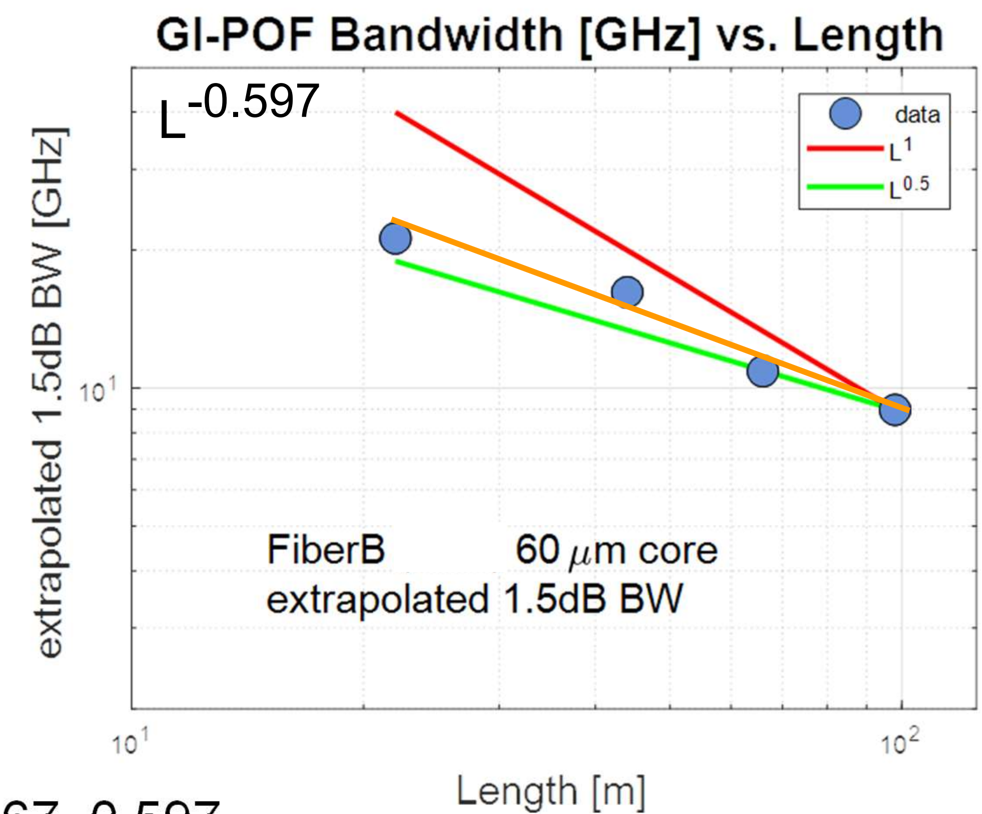


Exponent 0.67

General comments based on these results:
We could not find A4i (55μm GI-POF) Value is below all Watanabe[2] values.

NEW RESULTS (60μm core GI-POF)

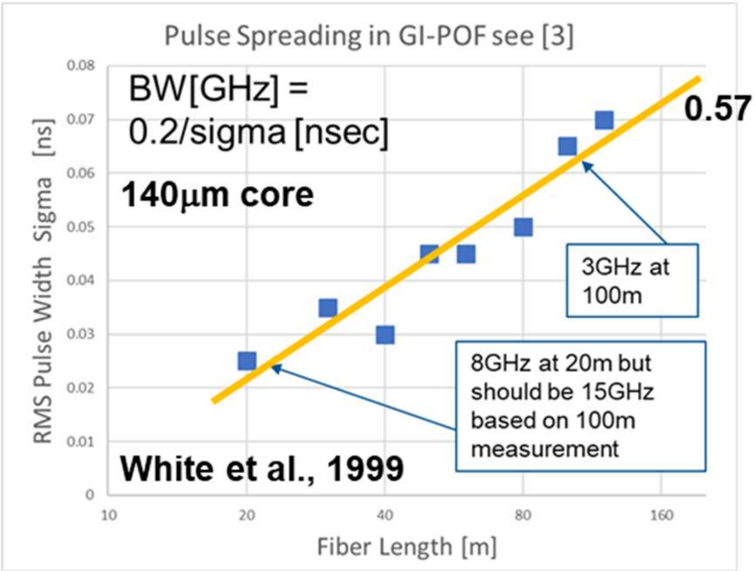




Exponents 0.67, 0.597

General comments based on these results:
We could not find A4i (55μm GI-POF) . Both exponents are below Watanabe[2] values A-B-C

Classic results [3] (1999 AGC 140μm core GI-POF)



[3] DiGiovanni et al., "Design of Optical Fibers for Communications Systems", Chapter 2 in ***Optical Fiber Telecommunications IVA***. New York: Elsevier, 2002. (Section 5 is "Plastic Optical Fiber").

Gamma exponent 0.57

General comments based on these results:
Gamma value is below all Watanabe [2] values.

CONCLUSIONS -- Summary of Length Dependence

[3] 1997 AGC 140mm GI-POF 1/BW ~ L^{γ} γ = 0.57
[4] 2022 Watanabe 7/22 BW ~ $L^{-\gamma}$ γ = 1.003, 0.772 ; 0.731, 0.758, 0.868
[1] 2022 Abbott 2/22 BW ~ $L^{-\gamma}$ γ = 0.67
[this ppt] 2022 Abbott 7/22 BW ~ $L^{-\gamma}$ γ = 0.67, 0.597

AREAS OF CONCERN / hypotheses.

a. Length exponent γ depends on launch condition (the particular VCSEL used) and the closer to OFL the launch, the closer γ will be to 1.00. Check effect of different launch conditions on γ. WORST CASE VALUE close to 0.50
b. Abbott results reflect use of the "1.5dB BW" (SQRT(2) * 1.5dB frequency, not the 3dB frequency) and differences between 1.5dB BW and 3.0dB BW observed.
c. Heat aging experiments [2] should be repeated with more samples, checking if γ changes and the effect of different launch conditions.

REFERENCES

[1] abbott_3cz_01_150222_GI_POF_BW_length_dependence.pdf
[2] Watanabe_3dh_02_2207.pdf
[3] DiGiovanni, et all, "Design of Optical Fibers for Communication Systems", Chapter 2 in ***Optical Fiber Telecommunications IVA***, New York, Elsevier 2002 (Section 5 is "Plastic Optical Fiber"). This is from an earlier 1999 reference: W. R. White, M. Dueser, W. A. Reed, and T. Onishi, "Intermodal Dispersion and Mode Coupling in Perfluorinated Graded-Index Plastic Optical Fiber", **IEEE Phot. Tech. Lett.,** vol. 11 No. 8 Aug 1999 pp.997-999.

Requirement for an IEEE 802.3 standard

In an IEEE 802.3 standard **every compliant fiber or cable needs to work with every compliant transceiver.** The specifications of both fiber and transceiver need to be designed so that the system works regardless of manufacturer. This requires collaboration between IEEE 802.3 and the TIA/IEC/ISO standards groups providing measurement specifications for transceiver and fiber/cable. This was done with the OM3/VCSEL solution in a process that leveraged multiple labs, included modelling, confirmed through round robin testing. The process took years. It is hoped that this experience can help the GI-POF solution avoid pitfalls.

Bandwidth of 20GHz over 15m must be **guaranteed** with EVERY compliant VCSEL from every manufacturer.

Measured by time domain method

Although GI-POF has high mode coupling, bandwidth of 20GHz over 15m can be achieved.

Next Step – develop measurement technique

A measurement technique which looks promising is to use the “DMD mask” approach originally developed in TIA and IEC for OM3 fiber, which ensures the leading edge and trailing edge of the pulse fit within a ‘window’.

This leads to a “launch independent metric” analogous to what is used for OM3.

Next Step GI-POF fiber samples

Just as in OM3 development, fiber samples of A4i / A4j GI –POF fiber suitable to measurement development need to be made available.