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Length Dependence of GI-POF BW and Next Steps

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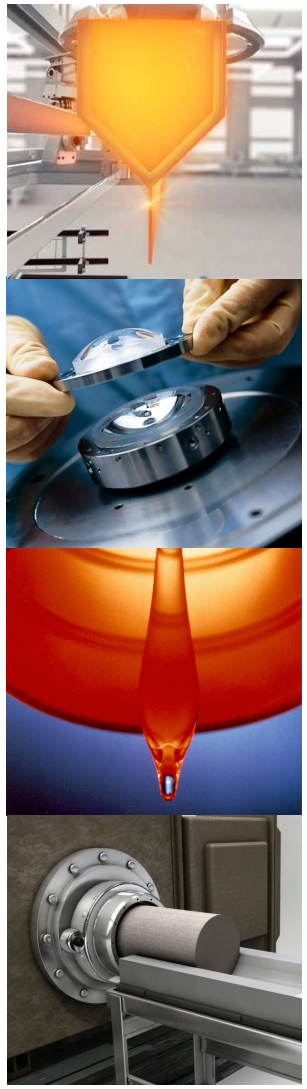
2/22/2022 802.3cz interim TF teleconference



Context of this presentation

This presentation is in support of Swanson August 2021 baseline proposal https://www.ieee802.org/3/cz/public/3_aug_2021/swanson_3cz_02c_030821_AUTO_MDI_Baseline.pdf
And the January interim motion to support comment 173.

This presentation provides further evidence and explanation that the GI-POF option is on a significantly longer timeline than the OM3/VCSEL option and that measurement methodology and specifications still need to be developed to ensure all GI-POF fiber meeting the future revised IEC specifications work with all VCSELs meeting the IEC encircled flux specifications.

The current IEC specification for GI-POF fiber is an OFL BW measurement at 100m which does not support the 40m goal or the 15m proposed link length with all compliant VCSELs. The challenge is that all VCSEL launches look like an OFL launch at 100m of GIPOF due to mode coupling.

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.

Summary of Results and Next Steps

Length dependence of bandwidth of a GI-POF fiber sample (75um core) was measured and found to scale like L^0.67

This is consistent with published results and consistent with the expected **worst-case scaling of L^0.5** from 30m to 100m.

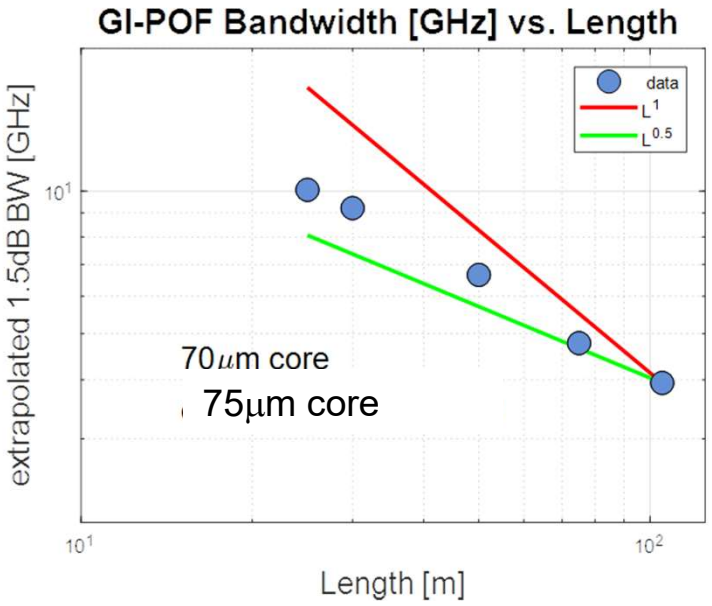
[A] Thus the worst-case BW of a 25m length of GI-POF is expected to be **half** of what is expected from a linear scaling from 100m. This suggests

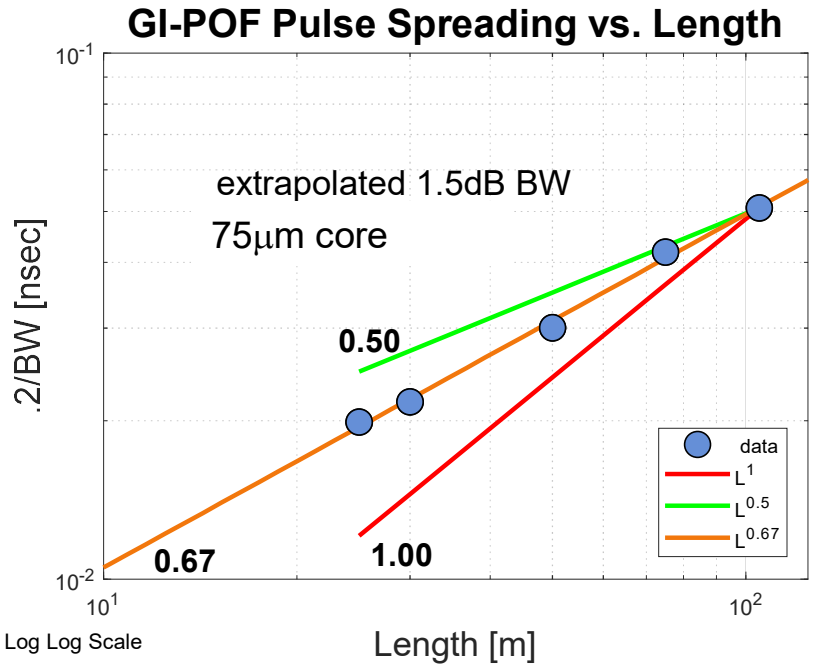
[B] Points to be addressed in moving GI-POF fiber toward a workable IEEE standard for auto links:

1. Develop measurement methodology and specification which guarantees a minimum BW at 40m or 15m for any GI-POF fiber with any “compliant” VCSEL meeting existing IEC encircled flux specifications.
2. Development measurement methodology and specification guaranteeing the attenuation of a 40m or 15m GI-POF link
3. Development of measurement methodology and specification guaranteeing the stability of the GI-POF graded index profile at temperatures specified by automobile OEMs.

Measurement Results : Pulse Spreading vs. Length : L^0.67

A pulse width with units of [nsec] can be obtained by using $\Delta T = 0.2/BW[GHz]$, where ΔT corresponds to RMS sigma for a Gaussian pulse. With no mode coupling ΔT will increase linearly with distance making this easier to visually analyze than BW(length).





Log Log Scale

Log Log Scale

Thank You!

Details and References can be found in backup slides

BACKUP 1. Details of the BW Measurement for Reference

Experimental Results

Measurements of bandwidth of graded-index plastic optical fiber (GI-POF) at Corning suggest that these samples have similar length dependence of multimode bandwidth as suggested in the literature going back as far as 1999.

A **75μm core** sample was measured at lengths 105m, 75m, 50m, 30m and 25m on a measurement bench at Corning's Sullivan Park research lab.

The results suggest that a markdown like 1.5dB BW is important to correctly estimating the BW, with markdowns of 15-35% compared to the 3dB value. This is the guidance in the IEC documentation for EMBc BW measurement of OM3, OM4 fiber.

The 25m-105m 1.5dB bandwidths scale consistent with approximately L^0.67 for this single sample. This supports using L^0.50 as the worst case scaling. Similar measurements need to be done on 55μm A4i samples.

Sourcing the GI-POF sample

We have not been able to purchase any 50-55μm core PF-GI-POF yet, and **would appreciate any help in this area.**

A 75μm core PF-GI-POF was used as best surrogate.

Mode mixing in GIPOF creates non-linear length scaling of bandwidth

The equation describing the length dependence of BW is given below, where gamma =1 is linear dependence and the worst-case GI-POF gamma is likely 0.5

$$\frac{BW(L_1)[GHz]}{BW(L_2)[GHz]} = \left\{\frac{L_2}{L_1}\right\}^{\gamma}$$

γ in L^{γ}	15m BW [GHz], assume 100m BW=3.5GHz
1	23.3
0.7	13.2
0.6	10.9
0.5	9.0

3.5*(100/15)=23.3;
linear scaling of 350MHz.km

15m BW will be significantly less than the 23GHz expected

Recommended worst case estimate for OFL BW

Measurement Details

The 75μm GI-POF has a non-standard core diameter relative to OM3/OM4.

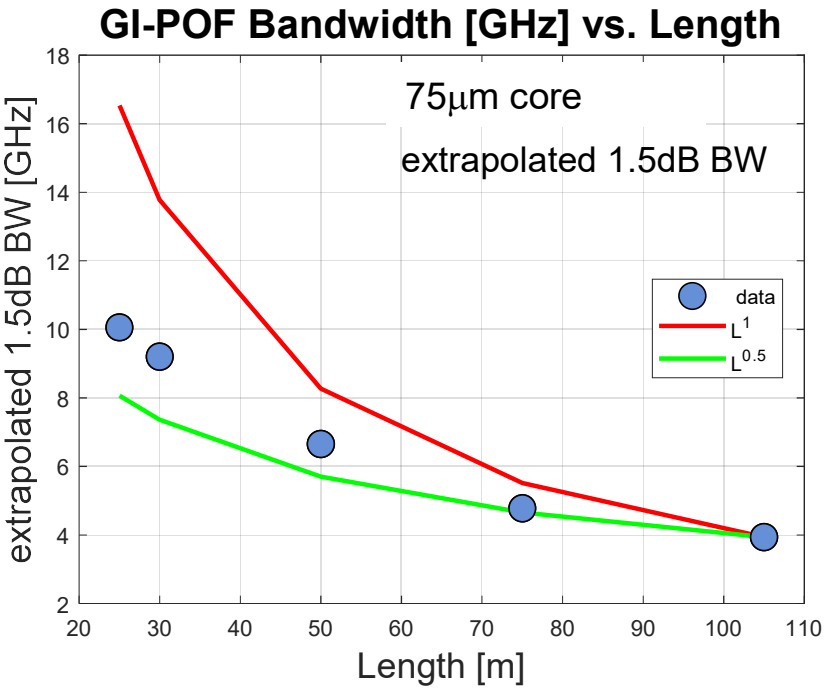
Special connectors were purchased to enable transmit and receive.

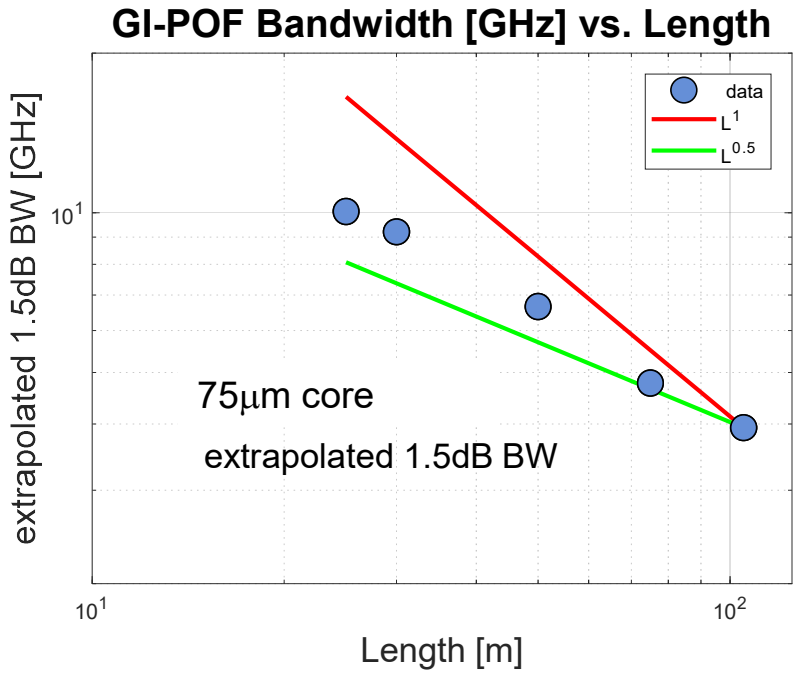
To get a reproducible bandwidth, the launch condition used a ModCon mode conditioner. Launching power approximately matches the encircled flux curve for a MM attenuation measurement. This represents approximately the BW seen with a typical 10Gb/s or 25G/b VCSEL, using a standard detector suitable for 50μm core fiber.

We did not explore the ‘worst case’ VCSEL like the minEMBc used for OM3

Measurement Results --

The 1.5dB BW data falls between L^0.5 (square root) and L^1.0 (linear) curves. The 850nm data is about L^0.6. On the next slide a least squares fit to all the data gives L^0.67.





Pulse Spreading [nsec] ~ (.2/ BW[GHz])

Bandwidth Length Dependence

$$\frac{BW(L_1)[GHz]}{BW(L_2)[GHz]} = \left\{\frac{L_2}{L_1}\right\}^{\gamma}$$

Approximate Pulse Width
(Gaussian Approximation)

$$\sigma[nsec] = \frac{0.2}{BW[GHz]}$$

Pulse Width Length Dependence

$$\frac{\sigma(L_1)[nsec]}{\sigma(L_2)[nsec]} = \left\{\frac{L_1}{L_2}\right\}^{\gamma}$$

Reference for 0.187/σ

Abbott et al., “Fibers for Short-Distance Applications”, Chapter 7, *Optical Fiber Telecommunications VIA*. New York, Elsevier, 2013.

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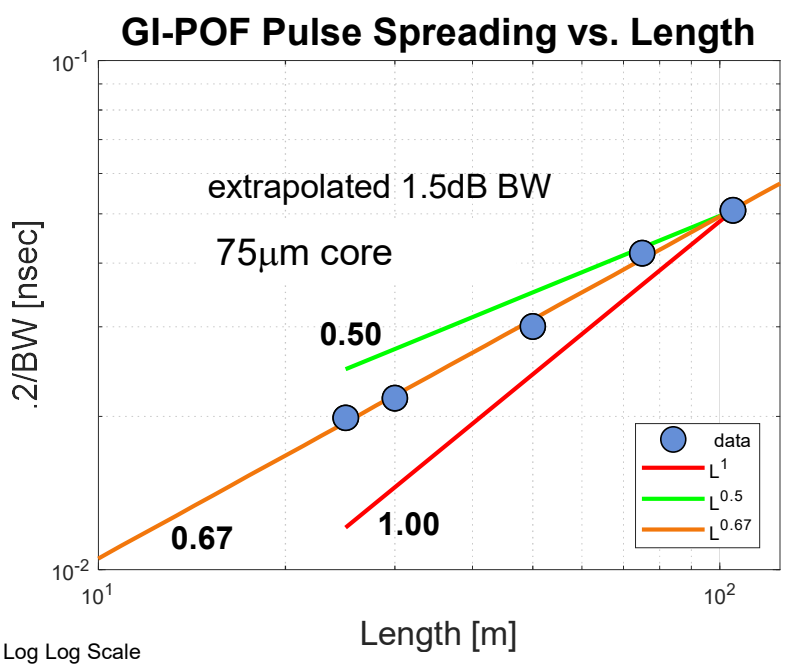
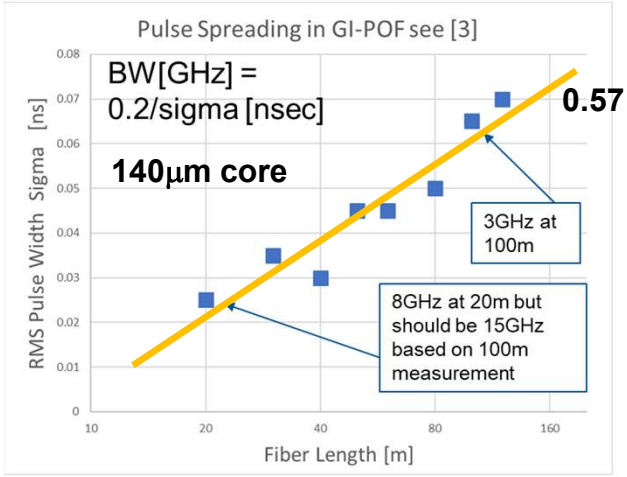
Analysis of results : Pulse Spreading vs. Length : L^0.67

A pulse width with units of [nsec] can be obtained by using $\Delta T = 0.2/BW[GHz]$, where ΔT corresponds to RMS sigma for a Gaussian pulse. With no mode coupling ΔT will increase linearly with distance making this easier to visually analyze than BW(length).

A best fit line shows the 70μm sample has a pulse spreading like L^0.67 compared to L^0.57 in 1999 paper. Since these are single fiber samples the spreading is comparable and worst case would be L^0.50



Log Log Scale



x-scale is 10, 20, 40, 80, 160m

[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").

Discussion and Conclusions

These results fully support previous work in the journal literature documenting significant mode coupling in GI-POF optical fibers. The use of a linear scaling from 100m measurements is overly conservative for longer lengths and overly optimistic for short lengths like the 15m-40m lengths being considered by 802.3cz

These measurements of single samples both in 1999 and in 2021 do not establish a lower bound to the 'gamma' parameter in the scaling L^gamma. The lower bound is likely 0.50 corresponding to full coupling, and this should be used in estimating 25m bandwidths from 100m data.

In addition, at short lengths there is no mode coupling and the bandwidth will be very sensitive to the particular launch conditions, just as it is for OM3 fiber. It is not possible to estimate the range of the effective modal bandwidths (EMBs) at short length from the 100m OFL BW alone and additional work is needed to develop a methodology. This might involve measurement of index profiles and modeling, or there may be a direct way to measure or estimate the bandwidth in 15m pieces, for example with a specialized DMD.

It is important to measure 50-55μm fibers.

BACKUP2

1. Literature reference
2. Slides explaining 3dB BW, 1.5dB BW

Previous Work

Some work first published in 1999 provides a pulse spreading (somewhat like this ppt) which scales like L^0.57 .This was work completed by researchers at Lucent and Asahi Glass Company.

W. R. White et al., “Intermodal Dispersion and Mode Coupling in Perfluorinated Graded-Index Plastic Optical Fiber”, *IEEE Photonics Technology Letters*, Vol. 11 No. 8 August 1999

Example technical papers providing support for L^0.5 scaling above a coupling length L_c:

1. CLEO 2007 paper CWM5 Polley, Balemarthy, Ralph, “Mode coupling: Why POF supports 40Gbps” and Polley Georgia Tech thesis https://smartech.gatech.edu/bitstream/handle/1853/31699/polley_arup_200812_phd.pdf

See also
NIST Symposium on Optical Fiber Measurements 1998 SOFM_1998_GI_POF_Lucent_AsahiGlass.pdf

Optical Fiber Telecommunications Volume IVA (2002) Chapter 2 “Design of Optical Fibers for Telecommunication Systems” DiGiovanni et al. figure 28 p.62

IEC informative guidance

IEC 60793-2-10:2019 p.33
Annex E (informative)

System, modal bandwidth, and transmitter considerations

To generate a robust bandwidth estimate when the impulse response is non-Gaussian, the 3dB bandwidth is replaced by an extrapolation of the 1.5dB bandwidth