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Duplex Coverage Estimates for Selection of TP3 Stressors

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Selection of TP3 Stressors

Correcting the Monte Carlo Model for Mode-Mixing and 1355nm

Purpose: contribute to task force resolution of comments 158, 196, 199, 200, 201, 219-221, 401, and 402

Goal: TP3 compliance test stressors must support coverage vs. maximum rated distance.

Required Improvements to Monte Carlo Model:

- **Mode Mixing Correction:** There has been strong input from the task force that the long-length fiber DMD model (January 2005, 99%tile, single-fiber PIE-D = 5.2dB) must be corrected for mode-mixing. To be consistent, this assertion should be applied as well to the OFL-BW data used to construct Gen67YY.
- **Span Wavelength Range:** The worst case design philosophy (and future applications of LRM) require evaluation at 1355nm with two connectors.
- **Duplex Coverage:** Joint launch PIE-D @ 99% for duplex links = 4.86 dB with two connectors for corrected Gen67YY at 1355nm.

Comment: Relaxing any key link component to <99% and/or relaxing multiple link components to <=99% is abandoning the worst case design philosophy.

Monte Carlo and Measured DMD Results (for 99% Coverage PIE-D)

Model	Joint Launch 99%tile single fiber coverage PIE-D
Gen67YY Monte Carlo set with 2 conn (ewen_1_0105)	4.67 dBo
OFS 1998 Measured DMD model *without* connectors (balemarthy_1_0105)	5.2 dBo
Gen67YY Monte Carlo set with 2 connectors (Ewen, reflector traffic)	4.52 dBo
Gen67YY Monte Carlo set with 2 conn (lingle_1_0305)	4.59 dBo
Corning 1998 Measured DMD model *without* connectors (abbott_1_0305)	5.1 dBo

How do we explain the discrepancy?

Potential Impact	**Possible Factor**
1998 Measured DMD fiber models overly pessimistic	Mode-Mixing in longer lengths, which makes DMD artificially long compared to measurements on the more relevant short lengths?
Gen67 Calculations overly optimistic w/r to center launch	Theoretical single mode launch MPD may not well capture a real launch within tolerances allowed by the encircled flux spec?
Gen67 MC model overly optimistic w/r to Joint Launch	Monte Carlo modeling completed *prior to* adoption of CL • less effort focused on correctly adjusting center region • no effort made to assess correlation between CL and OSL regions
Gen67 MC model overly optimistic	Mode-Mixing in longer lengths, which makes the OFL-BW distribution used to develop the Monte Carlo modeled artificially high?

Necessity of Adjusting the Monte Carlo Model

- To date, the task force has for all practical purposes dismissed the results of the 1998 Measured DMD fiber models, based on the objection that they are pessimistic due to the a degradation of the benefits of single-mode launch by mode-mixing or mode coupling.
- This has proven to be a difficult problem to quantitatively assess.
  - It is rather difficult to model and quantify the impact of mode-mixing on single mode launch.
  - It is prohibitively costly and time consuming to do a meaningful (large-scale, destructive) experimental study
- It is the position of OFS, Corning, and GaTech that the impact of mode-mixing is likely less than that of launching into two connectors (which are NOT included in Measured DMD model; Two connectors add 0.5dB to Gen67yy).
- The Monte Carlo delay sets were developed based on distributions of long length OFL-BW data that did NOT account for mode-mixing.
- If we reject the conclusion of the 1998 Measured DMD models based on concerns about mode-mixing, then we must of necessity adjust the Monte Carlo model for the impact of mode-mixing on the OFL-BW distribution from which it is derived.

Correction of Gen67 MC delays and PIE-D's

- It is well-known that impact of mode-mixing on OFL-BW data can be quantified by the gamma parameter according to a standard equation.

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

- Monte Carlo set (Gen67YY) originally adjusted modal delays to match measured OFL-BW distribution from long fibers
  - Equivalent to assuming $\gamma=1$
- Correct MC set for $\gamma<1$
  - Gamma values as low as 0.85 discussed in reflector traffic. Choose $\gamma=0.95$ as a conservative value, and implement a conservative correction from 5km to 300m. A 15% effect results.
  - The OFL-BWs in the Monte Carlo set are scaled down by 15%, and fibers which move below 500MHz-km after scaling are removed from the set.
  - The modal delays in Gen67YY should be correspondingly scaled up by 15%.
- Evaluate the 99%tile PIE-D for re-scaled MC set (with 2 connectors)

Corrected Gen67 Monte Carlo set 99%tile PIE-D= 4.74 dBo

(John Ewen calculated PIE-D = 4.65 dBo)

Prior Use of Worst-Case Philosophy

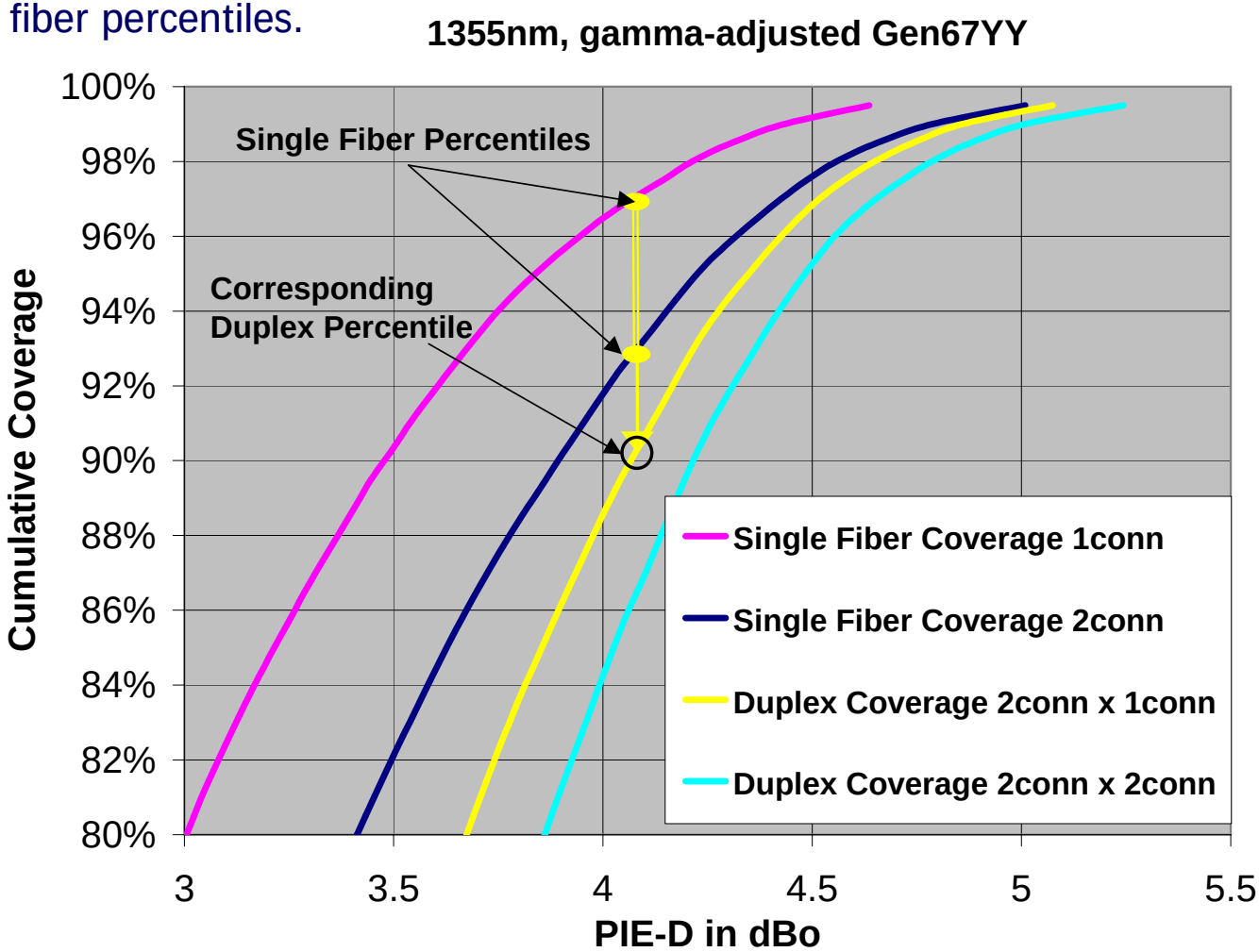
- "It should be kept in mind that to ensure interoperability, IEEE 802.3 standards are specified based on worst case specifications for all the components."

  Nowell, Cunningham, Hanson, and Kazovsky, "Review of the Gigabit Ethernet Model," Opt. Quant. Elect. **32**, p189 (2000).

- Thus far, we have made significant concessions for LRM:
  - connector offsets – Rayleigh distribution with mean offset of 3.58μm vs 7μm worst case.
  - center launch modeled a very tight spot, while the standard has looser encircled flux spec
  - Coverage is less than 100% at maximum rated distance
- The Gigabit Ethernet standard was based on worst case λ = 1270nm; following precedent, LRM coverage should be calculated at λ = 1355nm.
- The appropriate channel model should treat the case of two connectors near the transmitter as occurs in practice.
- Further relaxation on key parameters or adoption of statistical treatment must be avoided.

Duplex Link Coverage Calculations

- For the case of 2 connectors between transmitter and fiber in both directions, one should square the single-fiber percentile
- For 2 connectors in forward direction, it is most common to have 1 connector in the reverse direction. Then one should multiply together the 1-connector and 2-connector single fiber percentiles.



The Monte Carlo Model is an Optimistic Representation of the Installed Base

Year	Global Shipments Flatman 03_04 data (FMM)	Cumulative Installed Base	Percentage of Installed Base at Year End	Median OFL BW of fibers shipped (MHz-km)
1990	250	350	2.1%	700
1991	325	675	4.1%	716
1992	400	1075	6.5%	733
1993	500	1575	9.5%	749
1994	600	2175	13.1%	767
1995	750	2925	17.6%	784
1996	875	3800	22.9%	802
1997	1050	4850	29.3%	821
1998	1250	6100	36.8%	840
1999	1500	7600	45.9%	859
2000	1625	9225	55.7%	879
2001	1375	10600	64.0%	899
2002	1250	11850	71.5%	920
2003	1125	12975	78.3%	941
2004	1175	14150	85.4%	962
2005	975	15125	91.3%	985
2006	800	15925	96.1%	1007
2007	650	16575	100.0%	1030
Volume Weighed Installed Base at installed length				**873**
MC67YY Original				**1170**
MC67YY Gamma Adjusted				**1078**

Duplex Coverage with Corrected Gen67 @ 1355nm

	Duplex PIE-D: 2 conn x 1 conn
	GaTech
Duplex Coverage	**Gamma-corrected Gen67**
	1355
	0-0-300 x 0-300
99%	**4.86**
98%	**4.65**
97%	**4.52**
96%	**4.43**
95%	**4.35**
92.5%	**4.19**
90%	**4.07**
87.5%	**3.96**
85%	**3.85**
82.5%	**3.76**

- Duplex coverage for 2 conn x 1conn
  - 99%tile compliance test (green) — stressors set at 4.86 dB
  - 97%tile compliance test (yellow) — stressors set at 4.52 dB
- Recall this is a conservative (small) correction for mode-mixing, and does not address deficiencies in low order modes of Gen67YY
- OFS and Corning measured DMD models would also pull these PIE-D's higher

Implications for Stressor sets

Duplex Coverage	**γ = 0.95** **Corrected Gen67, 2 conn+1 conn, @ 1355nm**
D2.0 stressors 5.1, 4.9, 5.1dB	> 99%tile
Ewen 24,23,23 4.74, 4.92, 4.73	98.5-99%tile
Ewen 23,22,20 4.57, 4.57, 4.56 dB comments 199-201, 401, 402	97.5%tile
Ewen 10,5,15 3.8, 3.8, 4.2 dB Comments 196, 201	83.5–92.5%tile

Ewen stressors given in order
of Precursor, quasi-sym, and post-cursor

Conclusions

- Current D2.0 stressors are approximately correct for 99% duplex coverage of the OFS and Corning Measured DMD models *without connectors*.
- Mode mixing has been raised as issue to be accounted for in fiber modeling. This can best be accomplished by the simple adjustment of the Monte Carlo model described here.
- A *generous* case for LRM coverage calculations, consistent with 802.3 worst case design philosophy, is the gamma-corrected Gen67 using γ=0.95, at 1355nm, with two connectors between Tx and fiber in one direction, and one connector in the reverse direction.

  The duplex coverage for that case indicates 99%tile at PIE-D = 4.86 dB.
  - Ewen stressors 24, 23, 23 are $\leq$ 99%tile.
  - Ewen stressors 23, 22, 20 (comments199-201, 401, 402) are $\leq$ 97.5%tile (0.3 dB below 99%)
- Chipmakers have stated that today's silicon can already equalize a 4.5-4.6dB PIE-D fiber; future improvements are expected.
- LRM should meet customer's reliability/coverage expectations set by previous 802.3 optical PMD standards