Proposal for 8GFC 850nm Links
and
Related SFP+ Comments

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Outline

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  - Option for Further Cost Saving / Risk reduction
- Related Comments on SFP+ Development
- Summary and Future Work
  - Jitter Budget
  - Call for Support

Background

- There is a market need for the finalization of 8GFC and the related SFP+ specifications
- It is important that 850nm 8GFC links be specified in a way which avoids the high costs of 10GBASE-SR (the 850nm 10G Ethernet standard).
- It is possible to design a cost effective 8GFC spec with only minor modifications to the goals of 10GBASE-SR
- A very good first step was made in the August 05 proposal from Jim Tatum of Advanced Optical Components
- Further analysis indicates that adjustments to this proposal would help insure a cost effective standard.

Lessons from 10GBASE-SR

- **A main objective of the 10GBASE-SR standard was to achieve 300m link length on OM3 (2000 MHz•km) fiber**

- **This objective drove two specs which have made the cost of 10GBASE-SR very high**
  - **Spectral Width < 0.45nm**
  - **Minimum TX OMA (specified as a tradeoff with spectral width) which makes Class 1 operation almost unmanufacturable**
    (Non-OM3 links have large unallocated power margin, some in connector budget)

- **Desire to maximize link length on other fiber types resulted in very high ISI (~3.5 dB)**
  - **Early TIAs had difficulty meeting SRS spec. Probably no longer an issue**
  - **SRS test becomes difficult to reproduce accurately at high vertical eye closure.**
    - **Testers may easily have much more closure at low BER contours.**
    - **This may remain a cost driver**
  - **High ISI will translate into more worst case jitter for unequalized limiting receivers.**

10GBASE-SR Spectral Width

- **10GBASE-SR Spectral width specs driven by chromatic dispersion penalty on longer OM3 links**
- **10GBASE-SR defines λ / Spec. Width / Min TX OMA triple tradeoff table.**

	RMS Spectral width (nm)								
Center Wavelength (nm)	**Up to 0.05**	**0.05 to 0.1**	**0.1 to 0.15**	**0.15 to 0.2**	**0.2 to 0.25**	**0.25 to 0.3**	**0.3 to 0.35**	**0.35 to 0.4**	**0.4 to 0.45**
840 to 842	–4.2	–4.2	–4.1	–4.1	–3.9	**–3.8**	–3.5	–3.2	–2.8
842 to 844	–4.2	–4.2	–4.2	–4.1	–3.9	–3.8	–3.6	–3.3	–2.9
844 to 846	–4.2	–4.2	–4.2	–4.1	–4.0	–3.8	–3.6	–3.3	–2.9
846 to 848	–4.3	–4.2	–4.2	–4.1	–4.0	–3.8	–3.6	–3.3	–2.9
848 to 850	–4.3	–4.2	–4.2	–4.1	–4.0	–3.8	–3.6	–3.3	–3.0
850 to 852	–4.3	–4.2	–4.2	–4.1	–4.0	–3.8	–3.6	–3.4	–3.0
852 to 854	–4.3	–4.2	–4.2	–4.1	–4.0	–3.9	–3.7	–3.4	–3.1
854 to 856	–4.3	–4.3	–4.2	–4.1	–4.0	–3.9	–3.7	–3.4	–3.1
856 to 858	–4.3	–4.3	–4.2	–4.1	–4.0	–3.9	–3.7	–3.5	–3.1
858 to 860	–4.3	–4.3	–4.2	–4.2	–4.1	–3.9	–3.7	–3.5	–3.2

- **Practical 10G VCSELs to date have been small aperture MM devices.**
  - **Yield VERY poorly even to largest allowed spectral width**
  - **This is largest single cost driver for 10GBASE-SR**
- **As practical matter, devices are spec'd to >= 0.4 nm**
  - **Results in Min OMA of –3.2 – 2.8 dBm**
  - **Secondary Result is Class 1 Eye Safety Problem**

10GBASE-SR Class 1 Eye Safety Problem

- **Meeting Class 1 Eye Safety Requires Max Avg Power ≤ -1.3 dBm**
  - **Max OMA :**

ER	Max OMA
∞	1.71
7	-0.05
6	-0.52
5	-1.13
4	-1.95
3	-3.07

- **Coupling Efficiency:**
  - **Class 1 Eye safety power measured into 7mm aperture @ 14mm**
  - **Min TX OMA is coupled power into 50/125 fiber**
  - **Typical coupling efficiency as low as: -1.5 dB**
- **With Min TX OMA = -3.2 to -2.8, very little margin for practical transmitter**
  - **For ER = 6 dB, only 2.3– 2.7 dB margin.**
  - **This must provide for:**
    - **Typ. Worst Case Coupling Efficiency: 1.5dB**
    - **Power measurement error: ~0.25 dB**
    - **TOSA bore “wiggle” ~ 0.5 dB**
    - **Photodiode tracking error: ~0.25 dB**
- **Practical TX design almost impossible. Requires high ER and expensive yielding and testing**

10GbE Link Model Issues

- **1GbE Spreadsheet used for:**
  - **1000BASE-SX**
  - **1 / 2 / 4 G FC**
- **10GbE Spreadsheet used for 10GBASE-SR**
- **Similarities and differences**
  - **Both use simple model of effective modal BW = OFL BW**
  - **10GbE has some improvements**
    - **Baseline wander**
    - **Cross penalties**
    - **Jitter considerations**
    - **Integrated stressed receiver test calculation**
    - **Different RIN formula**

      (Accounts for much more stringent RIN requirements in 10GBASE-SR)
  - **10GbE Spreadsheet uses rise/fall time**
    - **Resulting 10GBASE-SR and 10GBASE-LR do NOT call out rise/fall time**
    - **Implicit in transmit dispersion penalty test (?)**

OM2 Model Questions

- New model for OM2 (50 um, 500 MHz•km) fiber at 850nm from Abbott
  - Based on Corning measured DMD fiber data
  - Original work at 1300nm for –LRM effort
- Subsequent analysis by Borisch (05-844v0, 12/7/05) shows that modeling EMB = 500 MHz • km would lead to 30% link failure rate
- Roughly would require reduction of existing rated link lengths by 50%
  - Thus, 1GbE, 1/2/4x FC standards are all broken
  - Suggests that Unequalized Links 8GFC on OM2 would be about 50m
  - Would require EDC to meet 100m target of 8GFC users
- Should we adopt this model as basis for this work? - No!
  - Burden of proof is on supporters of a model which shows that previous working standards are broken
  - Show experimental evidence that installed fibers show this performance:
    - High percentage of failing links at predicted lengths
    - Direct measurement of impulse response / bandwidth of links in field

- **Until evidence to contrary, use present model which appears to work fine.**

Considerations for Low Cost 8GFC Links

- Target
  - Achieve 100m on OM2 with specs for lowest cost implementations
  - Choose other link lengths to result in same or easier specs
- Summary of parameters used and motivations
  - Use 10GbE spreadsheet model (rev 3.16.1a), and related SRS test definition
  - Spectral width: 0.65nm max
    - We believe this results in good VCSEL yields and thus low costs
  - Target min OMA < -5 dBm to allow reasonable TX window (4GFC is -6 dBm)
  - If possible, reduce Vertical Eye Closure Penalty of Stress Test
    - Ideally reach ≤3 dB, but in any case, less than 3.5 dB in 10GBASE-SR
  - Use nom. receiver sensitivity no more than 1 dB better than 10GBASE-SR
    - 10GBASE-SR uses -11.1 dBm OMA for unstressed sensitivity
  - 20/80% Rise/Fall = 45 ps
    - Scaled from 4GFC, slower than scaled 10GBASE-SR (35ps scales to 42ps)
    - Used in Spreadsheet, but we should NOT make it a requirement of both rising and falling edges (more on this later).

50 µm 500 MHz•km MMF

FC-0	Unit	100-M5-SN-I	200-M5-SN-I	400-M5-SN-I	800-M5-SN-I	Note
Subclause		6.4	6.4	6.4	6.4	
Data Rate	MB/s	100	200	400	800	
Nom,inal Signaling Rate	MBaud	1 062,5	2 125	4 250	8 500	
Rate Tolerance	ppm	100	100	100	100	10
Operating Distance	m	0,5 - 500	0,5 - 300	0,5 - 150	0,5 - 100	1
Fiber Core Diameter	µm	50	50	50	50	2
Transmitter (Gamma-T)						
Type		Laser	Laser	Laser	Laser	
Spectral Center Wavelength, min.	nm	770	830	830	840	
Spectral Center Wavelength, max.	nm	860	860	860	860	
RMS spectral width, max.	nm	1,0	0,85	0,85	0.65	
Average launch power, max	dBm					3
Average launch power, min	dBm	-10	-10	-9	-8.5	4
Optical Modualtion Amplitude, min.	mW	0,156	0,196	0.247	0.282	5
Rise/Fall time (20%-80%), max.	ps	300	150	90	45	6
RIN12 (OMA), max	dB/Hz	-116	-117	-118	-128	7
Reciever (Gamma-R)						
Average Received Power, max	dBm	0	0	0	0	
Unstressed receiver sensitivity, OMA	mW	0,031	0,049	0,061	0.066	5, 9
Return loss of receiver, min.	dB	12	12	12	12	
Rx jitter tolerance test, OMA	mW	0,064	0,107	0,154	0,2	
Stressed receiver sensitivity, OMA	mW	0,055	0,096	0,138	0.151	5,9,11,12
Stressed receiver vertical eye closure penalty	dB	0,96	1,26	1,67	3.34	9,12
Stressed receiver DCD component of DJ (at TX), min.	ps	80	40	20	7,7	
Receiver electrical 3dB upper cutoff frequency, max.	GHz	1,5	2,5	5,0	12	8
Receiver electrical 10dB upper cutoff frequency, max.	GHz	3	6	12	18	8

Changes relative to Tatum 8/05 (yellow)

Not analyzed, may require further work. (cyan)

Recommend AGAINST making this explicit requirement of both rising and falling edges (green)

- **New NOTE 12: Stressed receiver specs for 8G assume 10GE defined SRS test.**

62.5 µm 200 MHz•km MMF

FC-0	Unit	100-M6-SN-I	200-M6-SN-I	400-M6-SN-I	800-M6-SN-I	Note
Subclause		6.4	6.4	6.4	6.4	
Data Rate	MB/s	100	200	400	800	
Nom,inal Signaling Rate	MBaud	1 062,5	2 125	4 250	8 500	
Rate Tolerance	ppm	100	100	100	100	10
Operating Distance	m	0,5 - 300	0,5 - 150	0,5 - 70	0,5 - 40	
Fiber Core Diameter	µm	62.5	62.5	62.5	62.5	2
Transmitter (Gamma-T)						
Type		Laser	Laser	Laser	Laser	
Spectral Center Wavelength, min.	nm	770	830	830	840	
Spectral Center Wavelength, max.	nm	860	860	860	860	
RMS spectral width, max.	nm	1,0	0,85	0,85	0.65	
Average launch power, max	dBm					3
Average launch power, min	dBm	-10	-10	-9	-8.5	4
Optical Modualtion Amplitude, min.	mW	0,156	0,196	0,247	0.282	5
Rise/Fall time (20%-80%), max.	ps	300	150	90	45	6
RIN12 (OMA), max	dB/Hz	-116	-117	-118	-128	7
Reciever (Gamma-R)						
Average Received Power, max	dBm	0	0	0	0	
Unstressed receiver sensitivity, OMA	mW	0,031	0,049	0,061	0.066	5, 9
Return loss of receiver, min.	dB	12	12	12	12	
Rx jitter tolerance test, OMA	mW	0,078	0,121	0,164	0,2	
Stressed receiver sensitivity, OMA	mW	0,067	0,109	0,148	0.148	5,9,11,12
Stressed receiver vertical eye closure penalty	dB	2,18	2,03	2,14	3.25	9,12
Stressed receiver DCD component of DJ (at TX), min.	ps	80	40	20	7,7	
Receiver electrical 3dB upper cutoff frequency, max.	GHz	1,5	2,5	5,0	12	8
Receiver electrical 10dB upper cutoff frequency, max.	GHz	3	6	12	18	8

Changes relative to Tatum 8/05 (yellow)

Not analyzed, may require further work. (cyan)

Recommend AGAINST making this explicit requirement of both rising and falling edges (green)

- **New NOTE 12: Stressed receiver specs for 8G assume 10GE defined SRS test.**

Notes

Notes:
1 The operating ranges and loss budgets shown here are based on MM fiber bandwidth given in table 18. For link budget calculations and other MM fiber bandwidths see annex C.
2 For details see clause 8.2 on page 54
3 Lesser of class 1 laser safety limits (CDRH and EN 60825) or receiver power, max.
4 The value for 100-M5-SN-I is calculated using a 9 dB extinction ratio, consistent with FC-PH2. The values for 200-M5-SN-I and 400-M5 SN-I are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.
5 Optical modulation amplitude values are peak-to-peak. See annex A.5.
6 Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in FC-PI figure 16: Transmitter eye diagram mask. If a filter is needed to conform to the mask the filter response effect should be removed from the measured rise and fall times using the equation: $TRISE/FALL = [(TRISE/FALL\_MEASURED)^2 – (TRISE/FALL\_FILTER)^2]^{1/2}$ The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson Filter. See A.1.2.2
7 See annex A.4.
8 The receiver electrical upper cut off frequency values are informative and may be dependant upon the application and or the design approach of the receiver. See annex A.7.
9 See annex A.6.
10 The data rate shall not exceed +- 100 ppm from the nominal data rate over all periods equal to 200,000 transmitted bits (~10 max length frames).
11 The stressed receiver sensitivity values in the table are for system level BER measurements that include the effects of actual CDR circuits. It is recommended that at least 0.5 dB additional margin be allocated if component / module level measurements are made with laboratory BERT instrumentation that samples in the center of the eye. 0.5dB is a typical value determined by observing the effects on margin when the receiver sampling window is reduced in the link model spreadsheets.Insterad of adding margin, another possibility is to set the BERT to sample the receiver output eye at + and - 0.15 UI from the center.
12. The stressed receiver values for 800 MB/s links refer to the test method described in 802.3ae clause 52.9.9

Worst Case Budget / Parameters

Parameter	Unit	50µm MMF				62,5µm MMF				Note
Modal Bandwidth	MHz*km	500				200				1
Data rate	MB/s	100	200	400	800	100	200	400	800	
Operating Distance	m	0,5-500	0,5-300	0,5-150	0,5-100	0,5-300	0,5-150	0,5-70	0,5-40	
Link Power Budget	dB	7	6	6	6.3	7	6	6	6.3	
Intersymbol Interference	dB	1,85	2,26	2,71	3.38	3,14	3,09	3,21	3.29	
Additional link penalties	dB	1,27	0,96	1,03	1.03	0,86	0,71	0,78	0.97	6
Channel Insertion loss	dB	3,85	2,62	2,06	1.86	3,00	2,10	1,78	1.66	
Unallocated link margin	dB	0,03	0,16	0,20	0.03	0,00	0,10	0,23	0.38	7

Notes:

1	Modal bandwidth at 850 nm.
2	In order to achieve this bandwidth certain launch conditions are required. This bandwidth is currently under study in other Standards bodies. Their future standardization may affect distance and link penalties, specified in this table; or other requirements.
3	See clause 6.3. for other specifications.
4	The reduction in the spectral width specifications reflects the capability of sources that meet the reduced center wavelength range.
5	Optical modulation amplitude values are peak-to-peak. See annex A.5
6	Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [46].
7	The unallocated link margin may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance.

Changes relative to Tatum 8/05

Alternate Low Bandwidth Fibers

		50µm MMF				62,5µm MMF				Note
Modal Bandwidth	MHz*km	400				160				1
Data Rate	MB/s	100	200	400	800	100	200	400	800	
Operating distance	m	0,5-450	0,5-260	0,5-130	0,5-78	0,5-250	0,5-120	0,5-55	0,5-32	3,9
Stressed Receiver Sensitivity	mW	0,058	0,100	0,141	0.145	0,071	0,112	0,150	0.148	3,5,9
Stressed Receiver vertical eye closure penalty	dB	1,2	1,58	2,02	3.17	2,38	2,13	2,14	3.24	
Link Power budget	dB	7	6	6	6.3	7	6	6	6.3	
Intersymbol interference	dB	2,11	2,51	2,97	3.21	3,33	3,08	3,12	3.28	
Addittional link penalties	dB	1,18	0,91	0,98	1.20	0,87	0,70	0,78	0.98	6
Channel insertion loss	dB	3,61	2,47	1,99	1.78	2,76	1,98	1,72	1.62	
Unallocated link margin	dB	0,10	0,11	0,06	0.11	0,04	0,24	0,38	0.42	7

	Notes:
1	Modal bandwidth at 850 nm.
2	In order to achieve this bandwidth certain launch conditions are required. This bandwidth is currently under study in other Standards bodies. Their future standardization may affect distance and link penalties, specified in this table; or other requirements.
3	See clause 6.3. for other specifications.
4	The reduction in the spectral width specifications reflects the capability of sources that meet the reduced center wavelength range.
5	Optical modulation amplitude values are peak-to-peak. See annex A.5
6	Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [46].
7	The unallocated link margin may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance.
8	It is expected that the operating distance for 400 MB/s will increase to at least 300 m with improvements in transmitter or relaxation of laser safety standards.
9	The stressed receiver values for 800 MB/s links refer to the test method described in 802.3ae clause 52.9.9

Changes relative to Tatum 8/05

Alternate High Bandwidth Fiber

Parameter	Unit	50µm MMF				Note
Modal Bandwidth	MHz*km	2000				1,2
Data Rate	MB/s	100	200	400	800	
Operating distance	m	0,5-860	0,5-500	0,5-270	0,5-250	3,8
Wavelength	nm	840-860	840-860	840-860	840-860	3
RMS Spectral Width	nm	0,85	0,85	0,85	0.65	4
Stressed Receiver Sensitivity	mW	0,047	0,083	0,126	0.120	3,5,9
Stressed Receiver vertical eye closure penalty	dB	0,24	0,33	0,75	2.36	9
Link Power budget	dB	7	6	6	6.3	
Intersymbol interference	dB	1,00	1,14	1,66	2.40	
Addittional link penalties	dB	1,36	1,51	1,83	1.26	6
Channel insertion loss	dB	4,62	3,31	2,48	2.41	
Unallocated link margin	dB	0,02	0,04	0,03	0.23	7

Notes:

1	Modal bandwidth at 850 nm.
2	In order to achieve this bandwidth certain launch conditions are required. This bandwidth is currently under study in other Standards bodies. Their future standardization may affect distance and link penalties, specified in this table; or other requirements.
3	See clause 6.3. for other specifications.
4	The reduction in the spectral width specifications reflects the capability of sources that meet the reduced center wavelength range.
5	Optical modulation amplitude values are peak-to-peak. See annex A.5
6	Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [46].
7	The unallocated link margin may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance.
8	It is expected that the operating distance for 400 MB/s will increase to at least 300 m with improvements in transmitter or relaxation of laser safety standards.
9	The stressed receiver values for 800 MB/s links refer to the test method described in 802.3ae clause 52.9.9

Changes relative to Tatum 8/05

Summary of Proposed Specifications

Fiber Type	Max Length (m)	SRS (dBm)	VECP (dB)	Unallocated Margin (dB)
50 um 500 MHz*km	100	-8.2	3.34	0.03
62.5 um 200 MHz*km	40	-8.3	3.25	0.38
50 um 400 MHz*km	78	-8.4	3.17	0.11
62.5 um 160 MHz*km	32	-8.3	3.24	0.42
50 um 2000 MHz*km	250	-9.2	2.36	0.23

- **Max Spectral Width = 0.65 nm**
- **Min TX OMA = -5.5 dBm**
  - **2.3 – 2.7 dB better than 10GBASE-SR**
  - **Only 0.5 dB worse TX window than 4xFC**
- **Unstressed sensitivity -11.8 dBm (vs. -11.1 dBm at 10.3G in 10GBASE-SR)**
- **Unified SRS = -8.3 dBm with VECP = 3.3dB**
  - **(conservatively rounded to 0.1 dB)**
- **New form of Rise / Fall Time (20/80%) spec**
  - **45 ps used in 10GbE spreadsheet**
  - **10GbE uses TDP test to ensure effective rise fall time.**
  - **Suggest we adopt an easier test, but one not requiring both rise and fall time to be better than 45ps (perhaps some sort of average value)**

Proposed Eye Mask

- **Tatum proposed Scaled 4G FC with increase overshoot**
- **Suggest 'rounded' shape of 10GbE 802.3ae eyemask**
  - **Useful relaxation**
- **Keep proposed relaxed over/undershoot of 40%**
  - **Used in 10GbE**
  - **No demonstrated issues with extra overshoot**

Possible Further Reduction of Cost / Risk

- **Reduce SRS Vertical Eye Closure**
  - **Requires lower link ISI and thus shorter distances**
  - **For VECP = 3 dB, OM2 length becomes ~ 94m**
  - **For VECP = 2.5 dB, OM2 length becomes ~ 82m**
  - **In both cases, can reduce min TX OMA to -6 dBm (4GFC value)**
- **With or without VECP reduction, improve SRS test definition**
  - **Emphasize reproducibility and simplicity over excessive rigor**
  - **Ensure minimum BER = 1e-12 eye opening of test signal**
- **If RIN spec is limiting, re-examine RIN formula in 10GbE spreadsheet**
  - **An experimental measurement of RIN penalty in 8 – 10G 850nm links would be best approach.**

SFP+ Considerations

- **EMI and power dissipation are two most important problems motivating SFP+**
- **Designs proposed using lessons learned in XFP development**
  - **Solid, smooth module body, EMI fingers, gaskets on cage**
  - **Riding heatsink for >1W power dissipation**
- **Proposals**
  - **SFP width for maximum port density (24 vs 16 per line card side/edge)**
  - **No CDRs for lowest cost**
  - **Use of preemphasis / equalization by SERDES for increased host trace lengths**
  - **Require a linear RX chain to enable electronic dispersion compensation of links by host board ICs.**

SFP+ : Linear vs. Limiting

- While enabling future links, practicality of a linear RX SFP+ not yet shown
  - No demonstration of module hardware for linear RX chain
  - No demonstrated linear postamps
  - No demonstration of linear RX performance across pluggable connector
  - No proposed specifications for linearity or S/N at SFP output interface
  - No proposed S-parameters for SFP+ or SERDES to maintain required linearity
- Development of linear SFP+ (both spec and product) will significantly delay time to market for 8GFC
- Cost implications (yield / test) not clear for linear interface

- Recommendations
  - No indication that limiting SFP+ insufficient for 8GFC
  - Develop remaining specs for this approach as quickly as possible
    - S-parameters for interface
    - Jitter specifications
  - Develop linear SFP+ if important market demand warrants
    - 10GBASE-LRM in SFP for example

Summary and Work to do

- **Proposed set of 850nm 8GFC specifications that should enable low costs**
  - **Maintains 100m link length on OM2**
  - **Reduces OM3 length to 250m**
  - **Made suggestions for further cost reductions at expense of OM2 link length**
- **Suggest that SFP+ with limiting interface is adequate**
- **Work to be done**
  - **Others: Confirm that specifications are compatible with low cost or propose modifications**
  - **Decide on modifying SRS test definition for reproducibility**
  - **Decide how to specify effective requirements on rise fall time**
    - **To correspond to 45 ps in the 10GbE link model spreadsheet**
  - **Propose corresponding jitter tables**
  - **Finalize specs for a limiting SFP+**
    - **Settle on mechanical spec**
    - **Settle on S-parameters for SFP+ and SERDES interfaces (use XFP spec?)**