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Optical Specifications for 10km link

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Proposal Objectives

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Objective

- *To achieve compact and low-power module*
- *To achieve low cost optical modules*

- *In this material only the 10km application will be discussed.*

Size and Complexity: 4λ or 5λ ?

- 4λ is expected to be cheaper and lower power consumption.
- We recommend 4λ to achieve lower cost and lower power consumption (=more compact).

		4λ CWDM	5λ CWDM
Power Consumption	Tx/Rx AC (*1)	1	1
	Tx/Rx DC (*2)	1	1.25
Cost	Total OSA (*3,4)	1	1.25

(*1) Assume 10 Gbit/s AC power=1.0

➔ 4x25 Gbit/s AC power = 2.5: Total AC power 2.5 x 4 =10.0

➔ 5x20 Gbit/s AC power = 2.0: Total AC power 2.0 x 5 =10.0

(*2) Laser bias current, EA bias voltage, etc.

(*3) In case of discrete OSA, a 20Gbit/s OSA is expected to be almost the same cost as a 25Gbit/s OSA

(*4) In case of integrated OSA, cost is expected to scale with number of lanes

FIFO Size: 4λ or 5λ ?

- Skew for 4λ and 5λ scheme are calculated as below and showed no significant difference.
- 4λ 20-nm scheme gives minimum total FIFO bits.

Wavelength dependent skew δ is obtained using the formula below.

$$\delta = L\left(\frac{n_{eff\,4/5}}{c} - \frac{n_{eff\,1}}{c}\right) = \frac{L}{c}\Delta n_{eff}$$

L: transmission distance: 10km,
c: light speed

	CWDM (ITU G.694, ~20nm)		LX4 (~24.5nm)	
	4λ (25G)	5λ (20G)	4λ (25G)	5λ (20G)
Skew, max	0.52 ns	1.36 ns	1.47 ns	2.83 ns
	13 bits	28 bits	38 bits	59 bits
Total FIFO	27 bits	75 bits	82 bits	159 bits

(*1) Based on a measurement. Skew depends on ribbon fiber routing.
(*2) Consider only 64/66B

Transmission Robustness: 4λ or 5λ ?

- There is not significant difference between 4λ and 5λ.
- EA-DFB's have much margin for 10km transmission while today's DM-DFB's have no margin

Simulated result of dispersion limit distances with 4λ and 5λ scheme in the cases of EA-DFB and DM.

	4-λ	5-λ
Optical link configuration	25 Gbit/s x 4λ	20 Gbit/s x 5λ
Wavelength pitch	20 nm (CWDM)	
EA-DFB	Dispersion Limit: 87 km	Dispersion Limit: 92 km
DM-DFB	Dispersion Limit: 10km	Dispersion Limit: 9.6km

Summary: 4λ or 5λ ?

- We investigated 4λ and 5λ.
  - Cost and power consumption of 4λ are better by 25%.
  - Skew of 4λ is 20% smaller.
  - Transmission performance is similar.
- We recommend 4λ for 10-km application.

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Transceiver and Optical Devices

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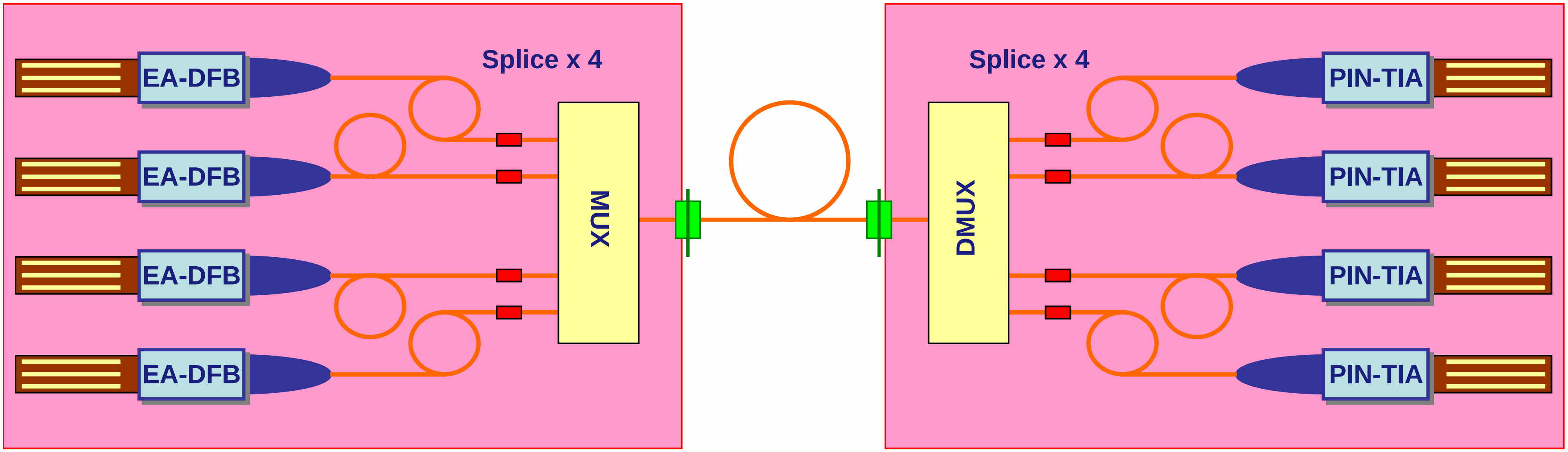
Possible optical devices

- ***EA-DFB (Electro-Absorption modulator with DFB laser)***
  - ***40Gbit/s 1550nm EA-DFB is available in the market***
  - ***25Gbit/s 1310-nm EA-DFB is possible but to achieve higher output power (*1) is challenging***
    - ***(*1) To compensate optical MUX/DMUX losses.***

- ***DM-DFB (Direct modulation DFB laser)***
  - ***10 Gbit/s 1310 nm DM-DFB is available in the market***
  - ***25Gbit/s 1310nm DM-DFB needs a breakthrough to achieve higher resonance frequency and higher output power for commercial use.***
    - ***40Gbit/s DM-DFB waveforms have been demonstrated only at a research level***

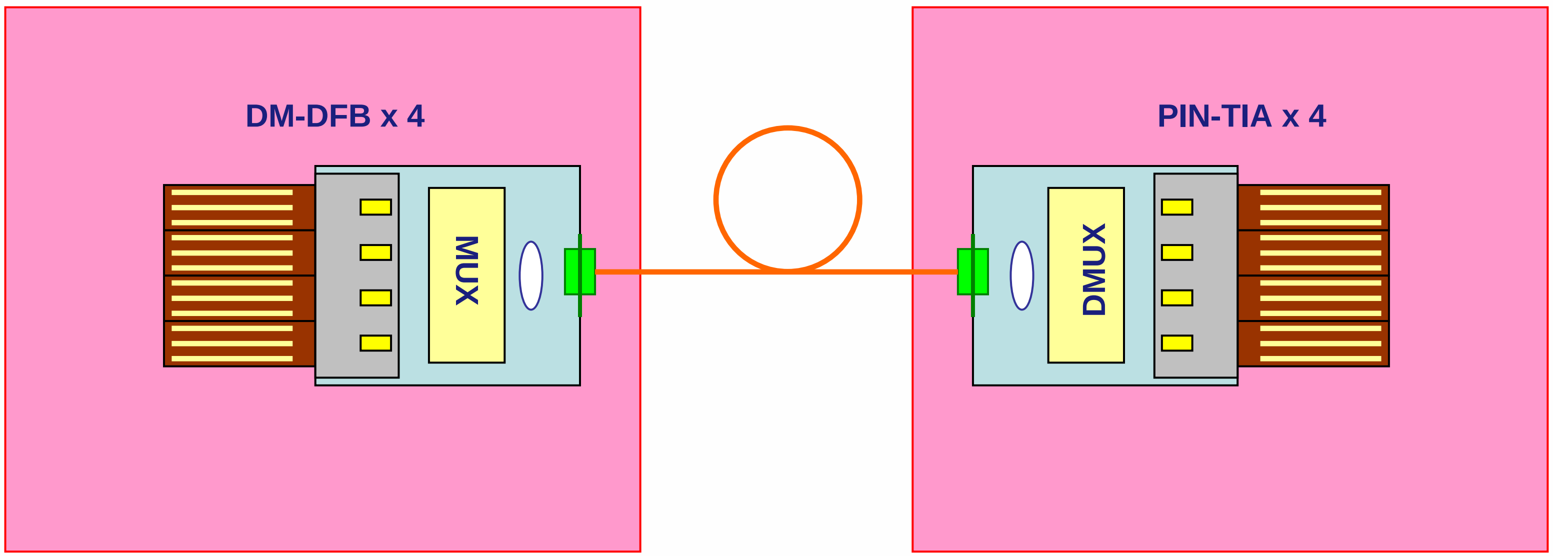
Possible Transceiver

- ***The most commercially available solution today and maybe 2009***
  - ***Use of discrete (separate) 1310nm EA-DFB components***
  - ***Use of discrete (separate) PIN-TIA components***
  - ***Use of Optical MUX/DMUX connected using fiber splicing to optical components.***



Ultimate Future Transceiver

- ***The most aggressive scheme is multi-channel uncooled integrated optical components***
  - ***Challenge (Breakthrough): high power uncooled 1310nm DM-DFB.***
  - ***Challenge (Breakthrough): Low cross-talk multi-channel packaging***



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Optical Specifications Proposal

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Wavelengths

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- There are two related standards: ITU-T CWDM and LX4 wavelengths
- Pitch affects dispersion limited transmission length
  - Narrower pitch preferred. See next page.
- Channel bandwidth affects laser yield
  - The yield difference is not significant with current specifications.
- Pitch and bandwidth affect optical MUX/DMUX cost
  - The cost difference for LX4 and CWDM wavelengths is negligible.
- Conclusion: Recommend ITU-T CWDM wavelengths

Unit = nm	CWDM	LX4	Note
CH1	1291	1275.7	
CH2	1311	1300.2	
CH3	1331	1324.7	
CH4	1351	1349.2	
Channel pitch	20	24.5	
Channel bandwidth	13	13.4	

Dispersion Limit

- Transmission distance using DM-DFB with 1-dB dispersion penalty with CWDM and LX4 based wavelengths are calculated as below.
  - CWDM-base set of wavelengths is preferred because of smaller dispersion with narrower wavelength range.

Wavelength dependent transmission distance L at bit rate of B is obtained using the formula below in the most simple model. D_0: dispersion tolerance at bit rate of B_0.

$$L = \frac{D_0}{D_{CH}} / \left(\frac{B}{B_0} \right)^2$$

	CWDM-base	LX4-base
λ, min	**1283.5 nm**	**1269.0 nm**
Dispersion min	**-3.91 ps/nm**	**-5.40 ps/nm**
λ, max	**1356.5 nm**	**1355.9 nm**
Dispersion max	**4.88 ps/nm**	**4.83 ps/nm**
Distance (*)	**4.59 km**	**4.15 km**

(*) Assumed D_0 = 130 ps/nm for B0=10.7 Gbit/s (ITU-T P1L1-2D1). Actual might be better.

IEEE Related Specification (I)

- Test Point (TP2, TP3) [1] Figure 52-2, "Std 802.3ae-2002"

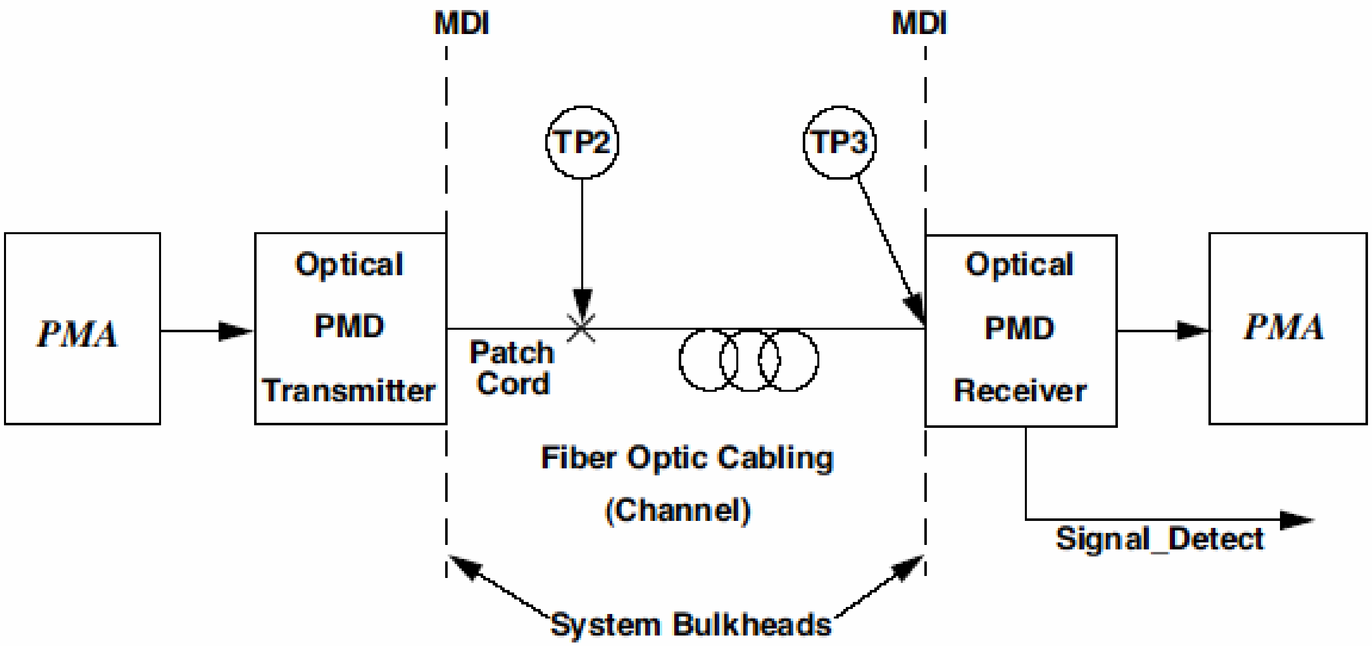


Figure 52–2—Block diagram

IEEE Related Specification (II)

- The Channel insertion loss is 6.0dB for 1310nm 10km link, Cabling in Figure 52-14 and Table 52-24, “Std 802.3ae-2002”

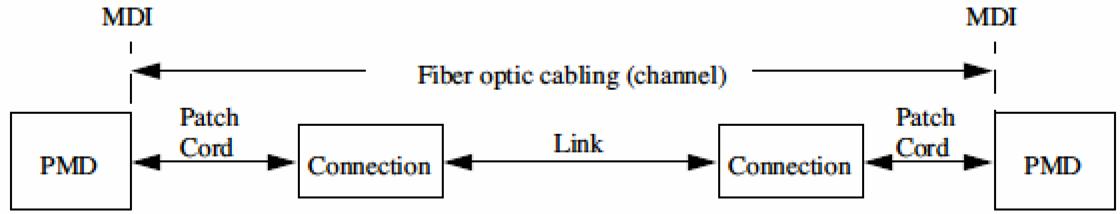


Figure 52–14—Fiber optic cabling model

Table 52–24—Fiber optic cabling (channel)

Description	62.5 µm MMF		50 µm MMF			Type B1.1, B1.3 SMF			Unit
Nominal wavelength	850[a]					1310[b]	1550		nm
Modal bandwidth (min)	160	200	400	500	2000	N/A	N/A		MHz•km
Operating distance (max)	26 m	33 m	66 m	82 m	300 m	10 km	30 km	40 km	
Channel insertion loss (max) [c,d,e]	2.6	2.5	2.2	2.3	2.6	6.0	11.0[f]		dB
Channel insertion loss (min)	0	0	0	0	0	0	5		dB
Dispersion (max)	N/A	N/A	N/A	N/A	N/A	N/A	546	728	ps/nm
DGD_max[g]	N/A	N/A	N/A	N/A	N/A	10	19		ps
Optical return loss	N/A	N/A	N/A	N/A	N/A	N/A	21		dB

[a]Channel insertion loss at 850 nm includes cable, connectors, and splices.
[b]Channel insertion loss at 1310 nm includes cable, connectors, and splices.
[c]These channel insertion loss numbers are based on the nominal wavelength.
[d]Operating distances used to calculate channel insertion loss are those listed in this table.
[e]Maximum attenuation given in Table 52–25.

Receiver Sensitivity

- Hypothesis
  - Commercial available 10Gbit/s receiver *OMA* is around -14.9dBm_{max} (This is equivalent to -17.0dBm average power sensitivity with 10dB extinction ratio. Most commercially available 10Gbit/s receivers have sensitivity ranging from -17.0 to -19.0 dBm)
  - Sensitivity decrease from 10 Gbit/s to 25Gbit/s is calculated to be 4 dB (*1)
  - Commercial available optical DMUX + Splice loss is 2.7 dB_{max}
  - Aging degradation + Accuracy of measurement is 0.5dB_{max} + Interoperability penalty is 1.0 dB

Per lane	*OMA* (dBm)	Loss (dB)	
10 Gbit/s	-14.9		BOL max
25 Gbit/s	-10.9	(4.0)	
DMUX + Splice loss		2.7	
Aging + Accuracy + Interoperability		1.5	
TP3	-6.7		EOL

(*1) Using bipolar TIA that the sensitivity is proportional to the bit rate.

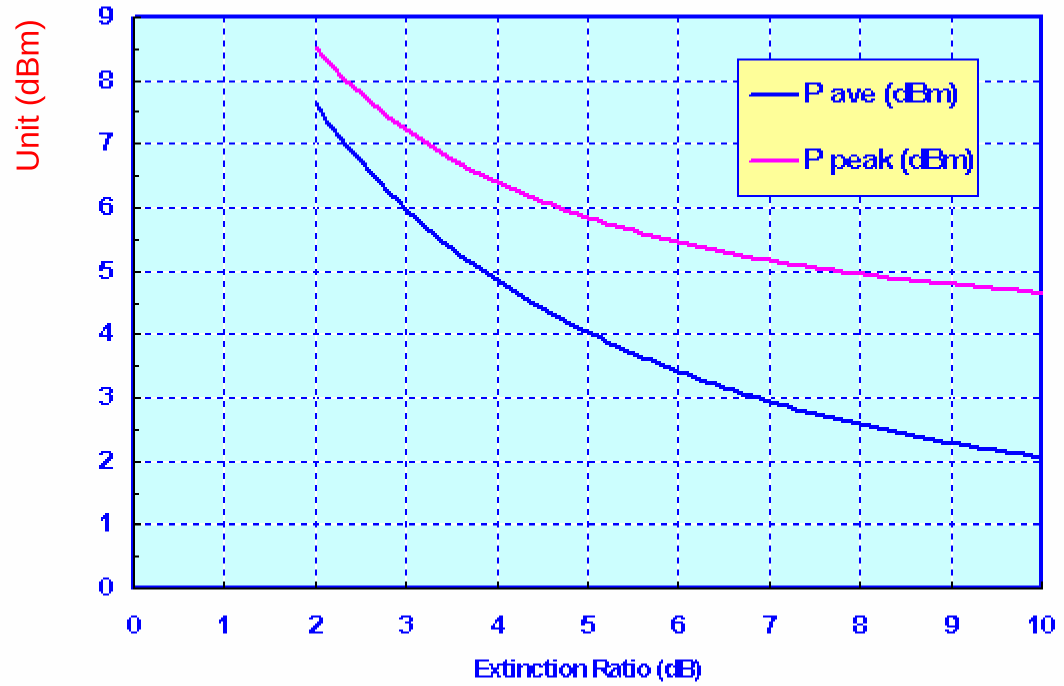
Transmit Power Output

- Hypothesis
  - Receiver sensitivity *OMA* is -3.3 dBm_{max}
  - Link loss is 6.2 dB
  - Dispersion penalty is 1.0dB
  - Commercial available optical DMUX + Splice loss is 2.7 dB_{max}
  - Aging degradation + Accuracy of measurement is 1.0

Per lane	*OMA* (dBm)	Loss (dB)	
TP3	-6.7		EOL
TP2 connector		0.2	
Link loss		6.0	
Penalty		1.0	
TP2	+0.5		EOL
MUX + Splice		2.7	
Aging + Accuracy		1.0	
EML out	+4.2		BOL

Extinction Ratio

- Transmit OMA of +4.2dBm is equivalent to output peak power depending on extinction ratio (Er) shown below.
- Er equal or larger than 7 dB is obtained with realistic output power of BOL=4 dBm with 1dB margin.



Transmit Power Output

- Transmitter

	min	Proposal	10GBASE-L	10GBASE-LX4
T_OMA min , per lane	dBm	+0.5	-5.2	-6.25
T_OMA max , per lane	dBm	+4.5	NA	-1.25
T_Avg max , four lanes	dBm	+9.5 (*1)	0.5	5.5
Er min	dB	7.0	3.5	3.5

- Receiver

	min	Proposal	10GBASE-L	10GBASE-LX4
R_OMA min , per lane	dBm	-6.7	-12.6	-14.45
R_OMA max , per lane	dBm	+4.5	NA	NA
Dispersion Penalty max	dB	1.0	(1.0)	(1.0)

- Link Budget

	min	Proposal	10GBASE-L	10GBASE-LX4
Link Power Budget	dB	7.2	7.4	8.2
Channel Insertion Loss	dB	6.2	6.2	6.2
Margin for Penalty min	dB	1.0	1.2	2.0

Note (*1): Limited by Eye safety (*2) 10km SMF specifications in 10GBASE-LX4 column

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Thank you

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