100GE 10km SMF WDM Grid Alternatives

IEEE 802.3ba Task Force

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10km SMF WDM Alternatives Outline & Summary

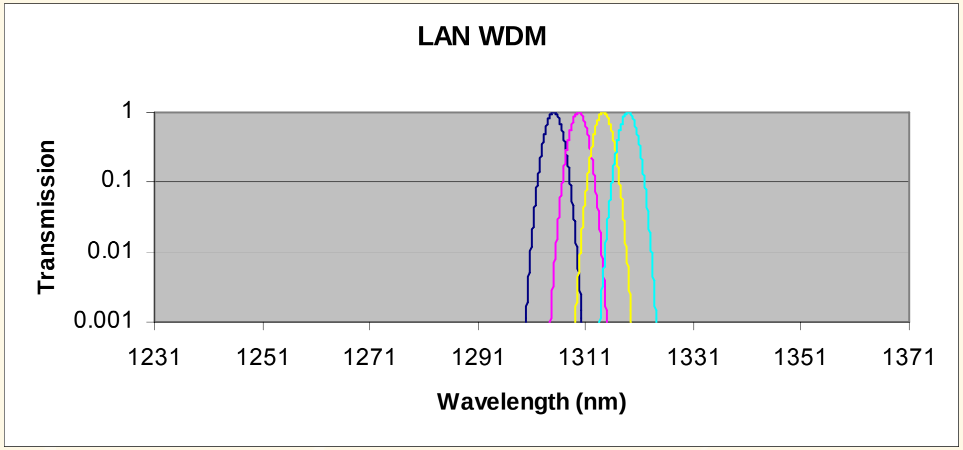
1st Gen LAN WDM PMD	1st Gen CWDM PMD
Uses cooled EML with >90% chip yield on $\geq$4nm grid due to λ tuning only	Uses cooled EML with ~100% chip yield on 20nm grid due to λ tuning only
Lower PMD cost (higher overall EML yield) due to 1.5dB less output power	Higher PMD cost (lower overall EML yield) due to 1.5dB more output power
Lower unit cost by sharing 40km optics development amortization and volume	Higher unit cost because of separate optics from the 40km reach

Next Gen LAN WDM PMD	Next Gen CWDM PMD
Significant cost reduction potential due to use of cooled DML	Limited cost reduction potential due to 10km dispersion preventing DML use
Significant cost reduction potential due to monolithic optics integration	Limited cost reduction potential due to use of discrete optics only

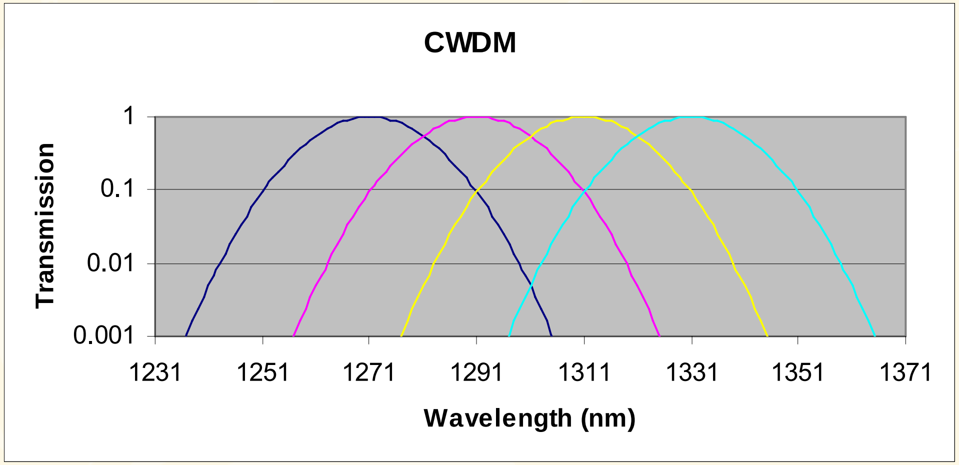
<u>Recommend LAN WDM Grid for 100GE 10km SMF</u>

10km SMF WDM Grid Alternatives

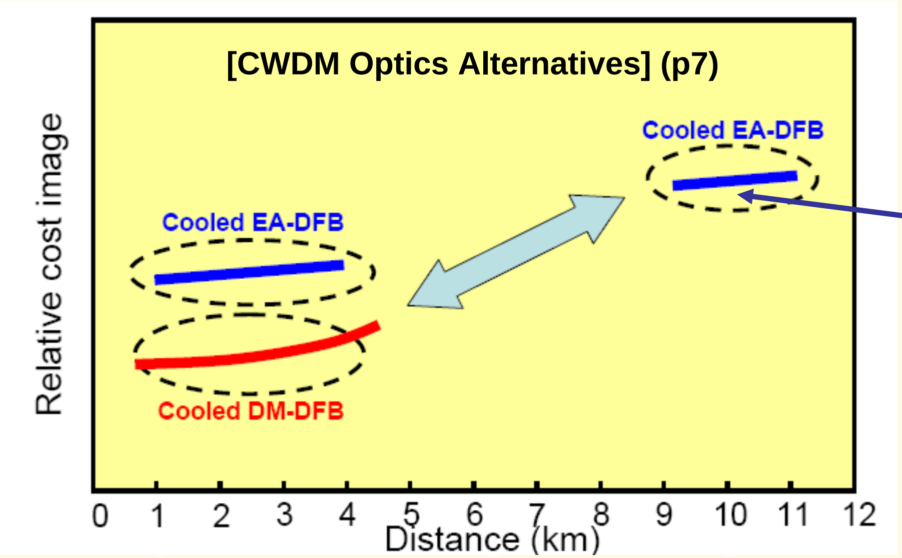
- Alt.1: ITU G.694.1 widely spaced DWDM grid for LAN applications (LAN WDM)
  - 1305 – 1319nm span
  - 193.1THz base
  - 2 - 4nm (400GHz – 800GHz) spacing (800GHz plotted)
  - 1 - 2.5nm width



- Alt. 2: ITU G.694.2 CWDM grid for LAN applications (CWDM)
  - 1264 – 1338nm span
  - 20nm spacing
  - 13nm width

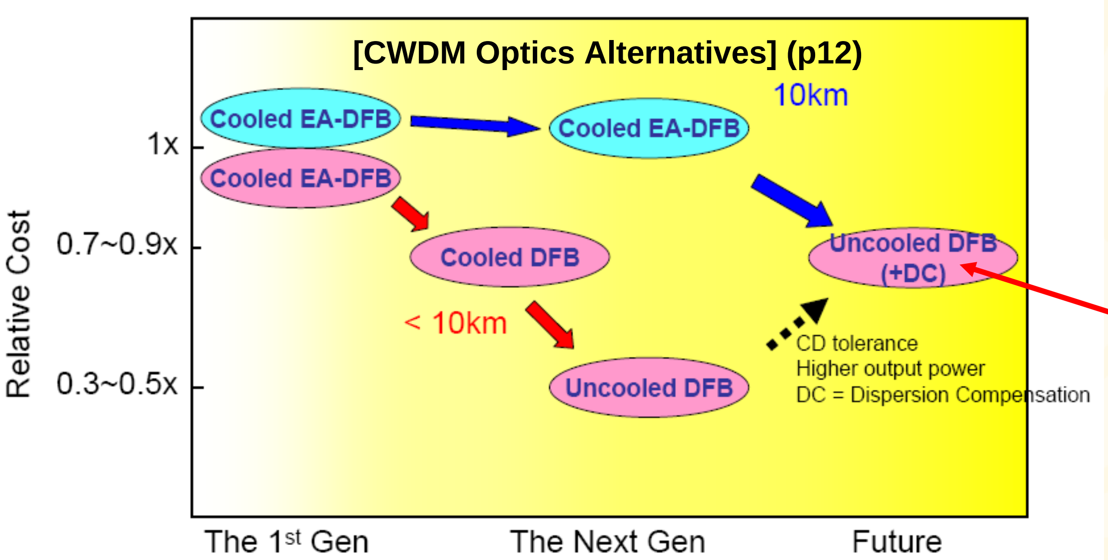


10km SMF WDM Optics Alternatives & Feasibility



traverso_01_1107 (OpNext supported by Eudyna, NEC, Oki, Sumitomo Electric):

"For 10km link, only [cooled] EA-DFB [EML] will be choice due to [too] much dispersion" (p7)



traverso_01_0108 (OpNext supported by Mitsubishi, NEC):

"We recommend to use 4km CWDM link specification" (p15)

[Un-cooled 10km DFB (DML) is only possible in the Future and requires high output power + Dispersion Compensation.]

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10km SMF WDM Cooled EML Yield Comparison

1st Gen 10km SMF LAN WDM or CWDM optics will be cooled EMLs

LAN WDM 10km Optics 1st Gen cooled EML yield due only to wavelength tuning

- johnson_01_0108 (CyOptics):

  [wavelength] " tuning of ±7°C allows laser wavelength range of ±1.8nm or ±2σ of DFB capability **(>90% yield)** " (p7) [quantification based on presented process data and wavelength tuning analysis (p6)]

- traverso_01_0108 (OpNext):

  [qualitatively a yield loss due to wavelength tuning graphically shown, but no process data or analysis presented to quantify the yield loss] (p6)

CWDM 10km Optics 1st Gen cooled EML yield due only to wavelength tuning

- johnson_01_0108 (CyOptics):

  "For CWDM, wavelength tolerance is ± 5nm [± 6.5nm], so yield is close to 100% for wavelength alignment alone" (p6)

- traverso_01_0108 (OpNext):

  "No wavelength yield [loss], … [no] tuning required" [**~100% yield** due to wavelength tuning graphically shown] (p6)

(Same yield comparison applies to WDM DML optics)

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10km SMF Propagation Properties

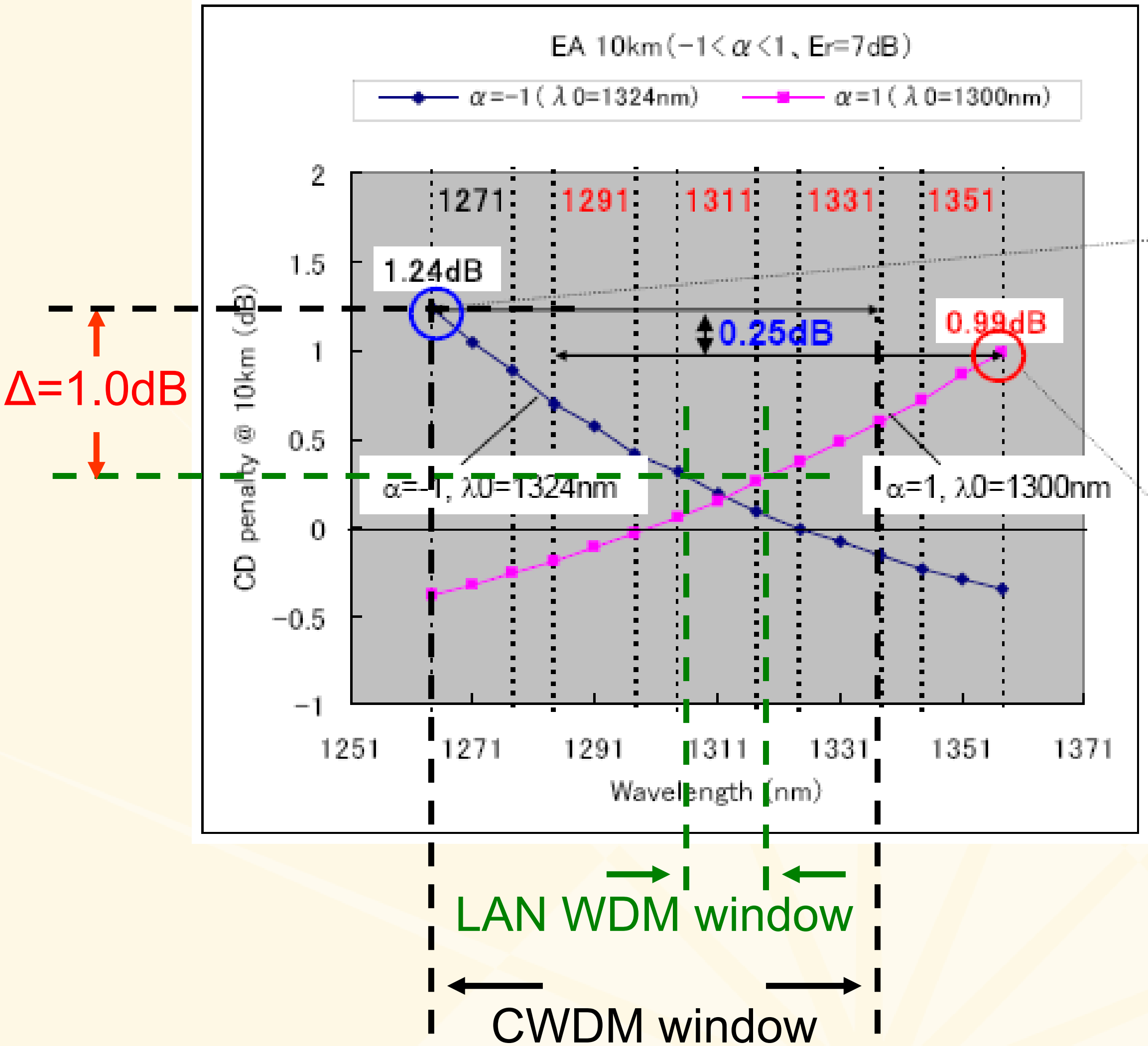
10km G.652 A&B SMF Max dispersion and Max fiber loss

- LAN WDM (4nm spacing) (1306 – 1318nm EML[1] or DML[2] grid)
  λ = 1318nm (worst case EML or DML λ)
  - Max Dispersion (1319nm) = 18ps/nm
  - Max Loss (1319nm) = 4.2dB
- CWDM (20nm spacing) (1271 – 1331nm EML or DML grid)
  λ = 1271nm (worst case EML λ)
  - Max Dispersion (1264.5nm) = -59ps/nm **(330% of LAN WDM)**
  - Max Loss (1264.5nm) = 4.7dB **(0.5dB more than LAN WDM)**

  λ = 1331nm (worst case DML λ)
  - Max Dispersion (1337.5nm) = 33ps/nm **(183% of LAN WDM)**
  - Max Loss (1337.5nm) = 4.3dB (0.1dB more than LAN WDM)

[1] EML: Electro Absorption Modulator (DFB) Laser (= EA-DFB)
[2] DML: Direct Modulation Laser (= DFB)

10km SMF cooled EML Dispersion Penalty



traverso_01_0907 (p10)
[graph only; annotations outside of graph not part of the original presentation]

Fiber loss is also minimum in the LAN WDM window for Δ=0.5dB

10km SMF OMA Link Budgets

10km SMF 25G TP2 → TP3 Entries in dB	CWDM Cooled EML λ = 1271nm ER = 7dB	LAN WDM Cooled EML λ = 1318nm ER = 7dB	CWDM Uncooled DML λ = 1331nm ER = 3.5dB	LAN WDM Cooled DML λ = 1318nm ER = 4.5dB
Fiber Loss (G.652 A&B)	4.7	4.2	4.3	4.2
Connector loss	2.0	2.0	2.0	2.0
Dispersion Penalty	1.3 [1]	0.3 [2]	3.1 [3]	1.3 [4]
Other Penalties	0.7	0.7	0.7	0.7
Total budget	8.7 ↔ Δ=1.5dB [5]	7.2	10.1 ↔ Δ=1.9dB	8.2

[1] traverso_01_0907, EML: λ = 1264.5nm, chirp α = -1.0, 10km (p10)
[2] traverso_01_0907, EML: λ = 1319.0nm, chirp α = 1.0, 10km (p10)
[3] traverso_01_0907 (p11), isono_01_1107 (p6), DML: λ = 1337.5nm, chirp α = 3.5, 10km
[4] traverso_01_0907 (p13), isono_01_1107 (p6), DML: λ = 1357.5nm, chirp α = 3.5, 4km
[5] EML optimized CWDM grid has Δ=1.2dB (λ = 1351nm)

10km SMF OMA Power Budgets

10km SMF 25G λs Power in dBm (OMA)	CWDM Cooled EML λ = 1271nm [1] ER = 7dB	LAN WDM Cooled EML λ = 1318nm ER = 7dB	CWDM Un-cooled DML λ = 1331nm ER = 3.5dB	LAN WDM Cooled DML λ = 1318nm ER = 4.5dB
TX Min → Max	3.5 → 6.5	2.0 → 5.0	4.9 → 7.9	3.0 → 6.0
TP2 TX Min 2.5dB Mux loss	1.0 ↔ Δ=1.5dB	-0.5	2.4 ↔ Δ=1.9dB	0.5
Link Budget (dB)	8.7	7.2	10.1	8.2
TP3 RX Min 2.5dB DeMux loss	-7.7	-7.7	-7.7	-7.7
RX Min (with 1dB crosstalk penalty)	-10.2	-10.2	-10.2	-10.2

TP2 4λ TX Avrg. Max (= 1λ TX Avrg. Max + 6dB)	8.8	7.3	12.6 [1] (>12.0)	9.7 [1]

[1] Average Power Δ = 2.9dB

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10km SMF CWDM DML Power Budget Problems

Parameter	10km (Ref)	
	Min.	Max.
Tx output power (dBm)	+1.8 (OMA)	P_O limited by Eye Safety
Extinction ratio (dB)	3.5	
Power budget (dB)	9.3	
Connector loss (dB)	2.0	
Fiber loss (dB)	4.2	
Allocation for penalties (dB)	3.1	
Rx sensitivity (dBm)	-7.5 (OMA)	

traverso_01_0108:
DML, λ = 1337.5nm,
chirp α = 3.5, (p14)

- traverso_01_0108 (OpNext supported by Mitsubishi, NEC): CWDM DML power budget (p14) is similar to one on p10 of this presentation and has zero margin for 12dBm Class 1 Eye Safety Limit and requires high output power laser.
- isono_01_0108 (Fujitsu): <u>after addition of 2dB for connector loss</u> CWDM DML power budget (p3) is similar to one on p10 of this presentation and exceeds 12dBm Class 1 Eye Safety Limit and requires high output power laser.

10km SMF LAN WDM & CWDM PMD Costs

- 1st Gen 10km 4x25G cooled 1310nm EML PMD cost (yield) comparison
  - LAN WDM Min TX OMA: 2.0dBm
  - CWDM Min TX OMA: 3.5dBm

  Δ=1.5dB yield margin

  - EML reference 1: 10GBASE-ER 40km Min TX OMA: -1.7dBm [1]
  - EML reference 2: 40G VSR 2km Min TX OMA: 1.7dBm [2]
  - LAN WDM PMD cost (yield) is significantly lower then CWDM PMD cost
- Possible Next Gen 10km 4x25G 1310nm DML PMD cost (yield) comparison
  - CWDM DML is not feasible today (CWDM - LAN WDM OMA = Δ=1.9dB)
  - The only feasible CWDM DML must have properties similar to an EML:
    - low chirp
    - high output power
    - high extinction ratio
    - all the above when hot to enable un-cooled operation
  - No such DML exists today, so there is no process data for cost comparison

[1] IEEE 802.3ae Standard, 10G, 1550nm, ER = 3dB (typical spec: OMA = 2.0dBm, ER = 8dB)
[2] ITU-T G.693 application, 40G, 1550nm, ER = 8.2dB

10km SMF Optics Sharing with 40km

LAN WDM 10km Optics shared development cost and volume with 40km

- cole_01_0907 (Finisar supported by CyOptics, NTT, Oki, Eudyna, Mitsubishi, Sumitomo Electric, NEL)

  "Amortization cost is reduced by sharing development expenses with 40km reach." (p7)

  "Unit cost is reduced through economies of scale by sharing volume between all reaches (… 10km, 40km.)" (p7)

- jiang_01_0507 (JDSU)

  "Increase the total volume base with the combined 10km & 40km market demand." (p10)

- johnson_01_0108 (CyOptics)

  "Developing a single TOSA that can serve all reaches is critical to reducing unit cost and initial time to market

  - Single product development reduces cost and time to market
  - Shared volume for all reaches reduces unit cost" (p12)

CWDM 10km Optics development cost and volume

- 40km optics use LAN WDM (can not use CWDM because of dispersion and noise bandwidth,) so are different from 10km CWDM optics. Require different TOSA and ROSA with no shared development or volume

10km SMF Monolithic Optics Integration

<u>LAN WDM Optics monolithic integration low cost potential</u>

- cole_01_0907 (Finisar supported by CyOptics, NTT, Oki, Eudyna, Mitsubishi, Sumitomo Electric, NEL)

  "LAN WDM 6nm to 12nm band results in significant low cost potential through manufacturing monolithic laser arrays, [and] ultimate low cost potential through monolithic integration of Mux/DeMux." (p7)
- nagarajan_01_1107 (Infinera)

  "To achieve low cost – simple high yield processes are required, >40nm band gap shift (400GHz channel spacing) for optimal performance … " (p5)
- johnson_01_0108 (CyOptics)

  "LAN WDM enables simple, robust DFB and EAM [monolithic] integration" (p8)

<u>CWDM Optics monolithic integration low cost potential</u>

- nagarajan_01_1107 (Infinera)

  "Larger wavelength (e.g. CWDM) are more complex/costly [and] push the limit of integration technology" (p4)
- CWDM requires discrete EML and Mux/Demux optics as integration uses expensive non-standard process steps that do not lead to overall cost savings.

Appendix: LAN WDM 10km & CWDM 4km Dispersion

- 10km G.652 A&B SMF LAN WDM (1306 – 1318nm grid, 4nm spacing)
  - Max Dispersion (1319nm) = 18ps/nm (worst case EML or DML)
- 4km G.652 A&B SMF CWDM (1271 – 1331nm grid, 20nm spacing) [1]
  - Max Dispersion (1266nm) = -23ps/nm (worst case EML)
  - Max Dispersion (1336nm) = 13ps/nm (worst case DML)

SMF Reach (25G) TP2 → TP3 Entries in dB (traverso_01_0907)	EML Dispersion Penalty Worst case λ chirp α = $\pm$1.0 (p10)	DML Dispersion Penalty Worst case λ chirp α = 3.5 (p13)
10km LAN WDM	0.3	1.3
4km CWDM	0.5	0.8

- LAN WDM 10km SMF has similar Dispersion Penalties to CWDM 4km SMF

[1] CWDM 4km + High Loss SMF objective proposed in traverso_01_0108 (p12 -15)