Proposal for 4-channel WDM (WDM4) for intermediate reach 100GbE SMF PMD

Contributors

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Introduction

- One of P802.3bm adopted objectives :
  “Define a 100 Gb/s PHY for operation up to at least 500 m of SMF”

- WDM PMD has been discussed as a cost-efficient solution
  vlasov_01_0312_NG100GOPTX.pdf, martin_01_0712_optx.pdf, weirich_01_0712_optx.pdf
  martin_02_0912_optx.pdf, martin_01_0912_optx.pdf

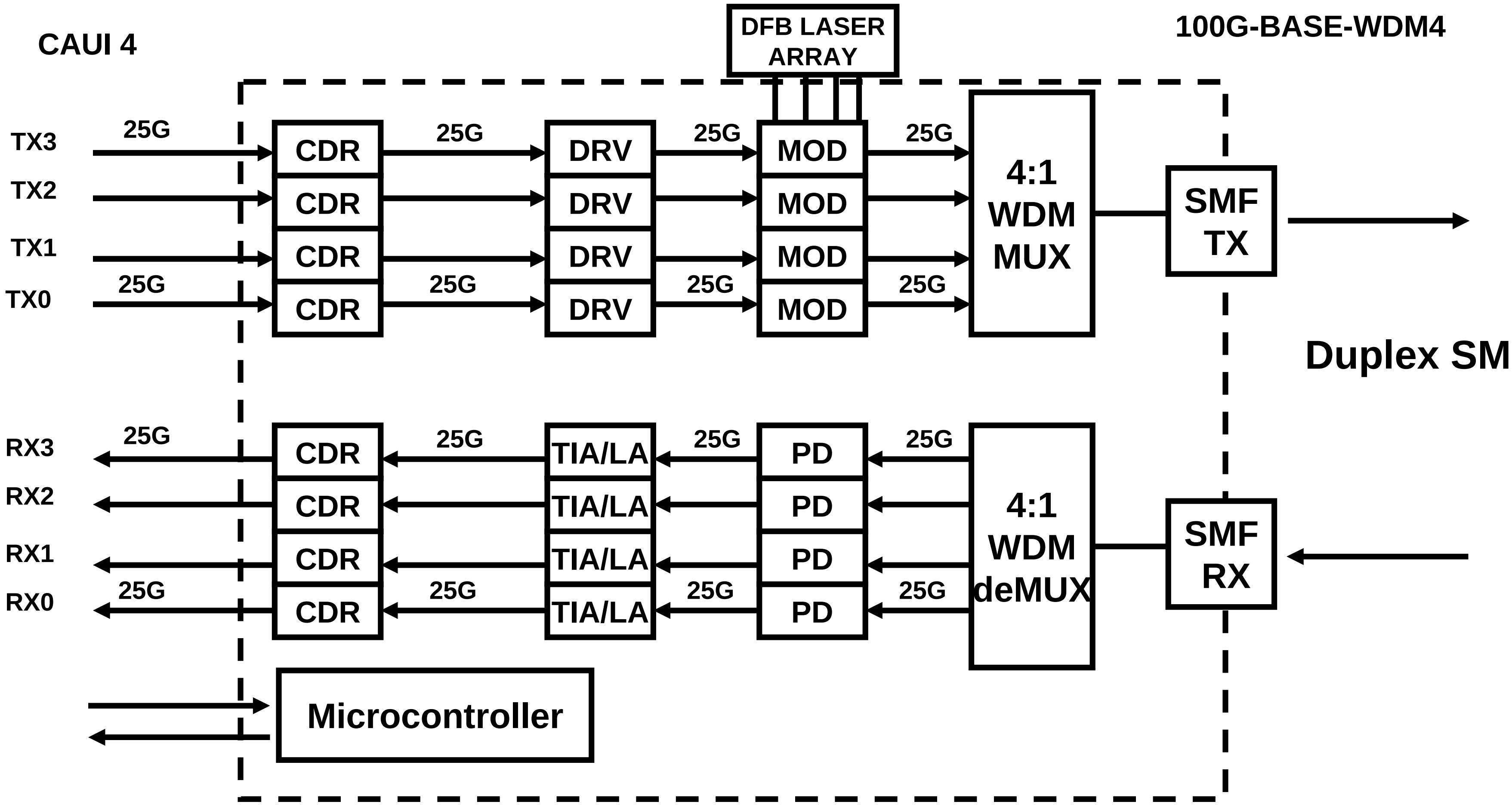
- WDM4 PMD is proposed here

  – 4ch CWDM, Uncooled, Retimed
  – Single die DFB laser array
  – Link budget up to 3.5dB
  – Link reach up to 2km

- Link transmit and receive characteristics and illustratuve link budget are presented

- Relative Cost Analysis is presented

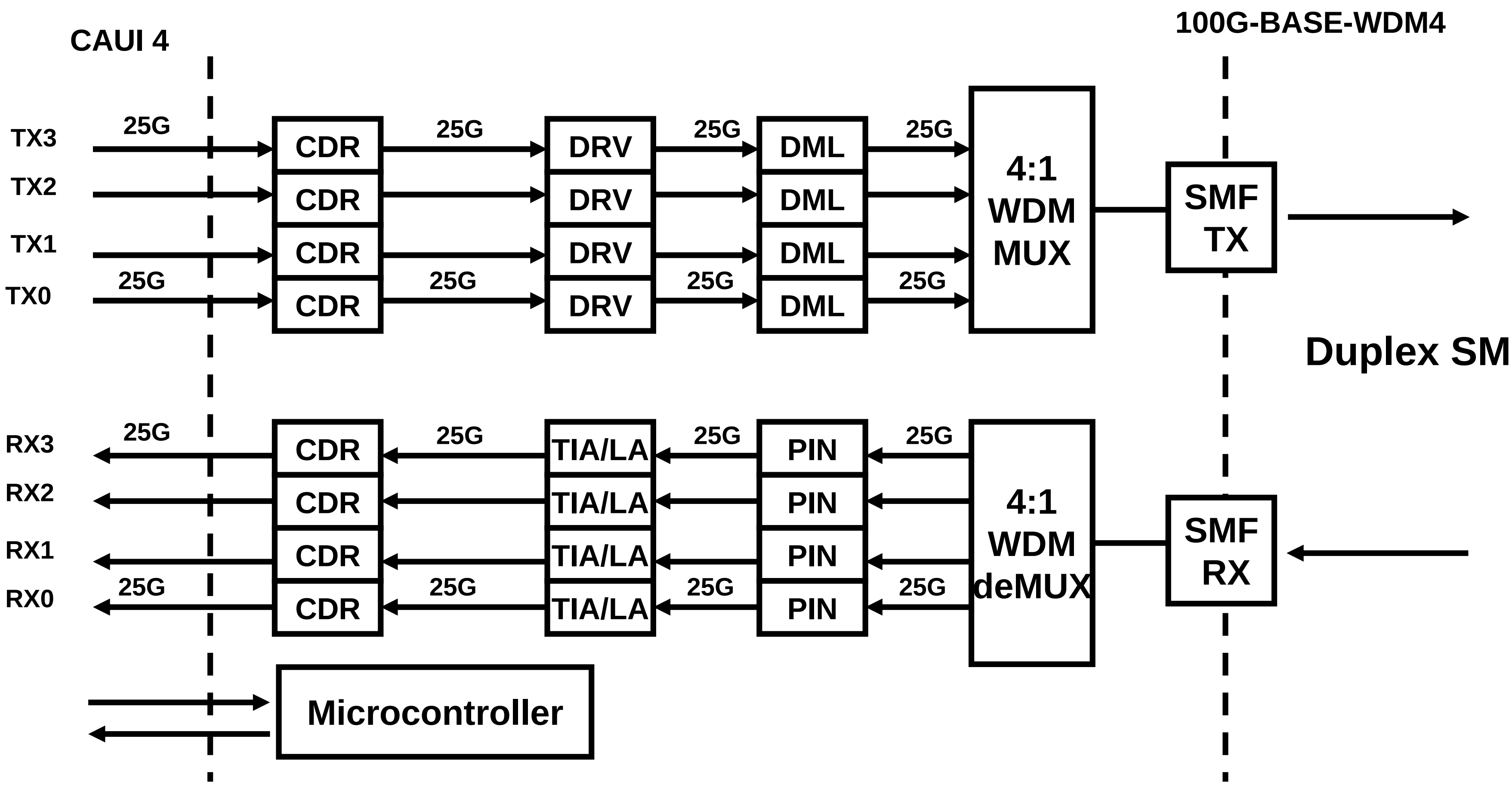
WDM4 block diagram



- All components, except CW DFB laser array, can be integrated monolithically on a single silicon die
- DFB laser array is a single InP die containing 4 CW DFB lasers

vlasov_01_0312_NG100GOPTX.pdf

Alternative WDM4 block diagram



- TOSA with 4 DML lasers + ROSA
- Duplex SMF

Link transmit and receive characteristics

1. CWDM is proposed to avoid cooling and to remove the cost of TEC from the module cost
2. ER=4dB is maintained as in 100GBASE_LR4 to provide capability of driving silicon MZI modulator directly from CMOS 1Vpp driver
3. Minimal launched power (OMA_{min}-TDP) is reduced to -2.5dBm to accommodate additional insertion loss in silicon MZI modulator as well as in WD mux and to decrease the average laser launch power to 20mW.
4. Maximum channel insertion loss is reduced to 3.5dB to accommodate for 0.94dB fiber loss at 1264.5nm and connectors for a double link channel
5. Sensitivity is reduced to -6.0dBm (OMA) to accommodate additional insertion loss on WD demux.
6. Additional savings are expected with optimized WDM grid to decrease the laser cost and increase yield

see also gill_01_1112.pdf

100GBASE-WDM4 transmit characteristics

Parameter	IEEE Std 802.3ba 100GBASE-LR4 10km	vlasov_01_1112_optx 100GBASE-WDM4 2km	Unit
Signaling rate, each lane (range)	25.78125 ± 100 ppm	25.78125 ± 100 ppm	Gbd
Lane wavelength (range) (nm)	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19	**1264.5 to 1277.5** **1284.5 to 1297.5** **1304.5 to 1317.5** **1324.5 to 1337.5**	nm
Single-mode suppression ratio (SMSR), (min)	30	30	dB
Total average launch power (max)	10.5		dBm
Average launch power, each lane (max)	4.5		dBm
Average launch power, each lane (min)	-4.3		dBm
Optical modulation amplitude (OMA), each lane (max)	4.5		dBm
Optical modulation amplitude (OMA), each lane (min)	-1.3		dBm
Difference in launch power between any two lanes (OMA), (max)	5		dB
Launch power in OMA minus TDP, each lane, (min)	-2.3	-2.5	dBm
Transmitter and dispersion penalty (TDP), each lane (max)	2.2		dBm
Average launch power of OFF transmitter, each lane (max)	-30	-30	dBm
Extinction ratio (min)	4	4	dB
$RIN_{20}OMA$ (max)	-130	-130	dB/Hz
Optical return loss tolerance (max)	20	20	dB
Transmitter reflectance (max)	-12	-12	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}	

see also gill_01_1112.pdf

100GBASE-WDM4 receive characteristics

Parameter	**IEEE Std 802.3ba** **100GBASE-LR4** 10km	**vlasov_01_1112_optx** **100GBASE-WDM4** 2km	Unit
Signaling rate, each lane (range)	25.78125 ± 100 ppm	25.78125 ± 100 ppm	Gbd
Lane wavelength (range) (nm)	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19	**1264.5 to 1277.5** **1284.5 to 1297.5** **1304.5 to 1317.5** **1324.5 to 1337.5**	nm
Damage threshold	5.5		dBm
Average receive power, each lane (max)	4.5		dBm
Average receive power, each lane (min)	-10.6		dBm
Receive power, each lane (OMA) (max)	4.5		dBm
Difference in receive power between any two lanes (OMA) (max)	5.5		dB
Receiver reflectance (max)	-26	-26	dB
Receiver sensitivity (OMA), each lane (max)	-8.6	**-6.0**	dBm
Receiver 3dB electrical upper cutoff frequency, each lane (max)	31	31	GHz
Stressed receiver sensitivity (OMA), each lane (max)	-6.8		dBm

see also gill_01_1112.pdf

100GBASE-WDM4 illustrative link power budget

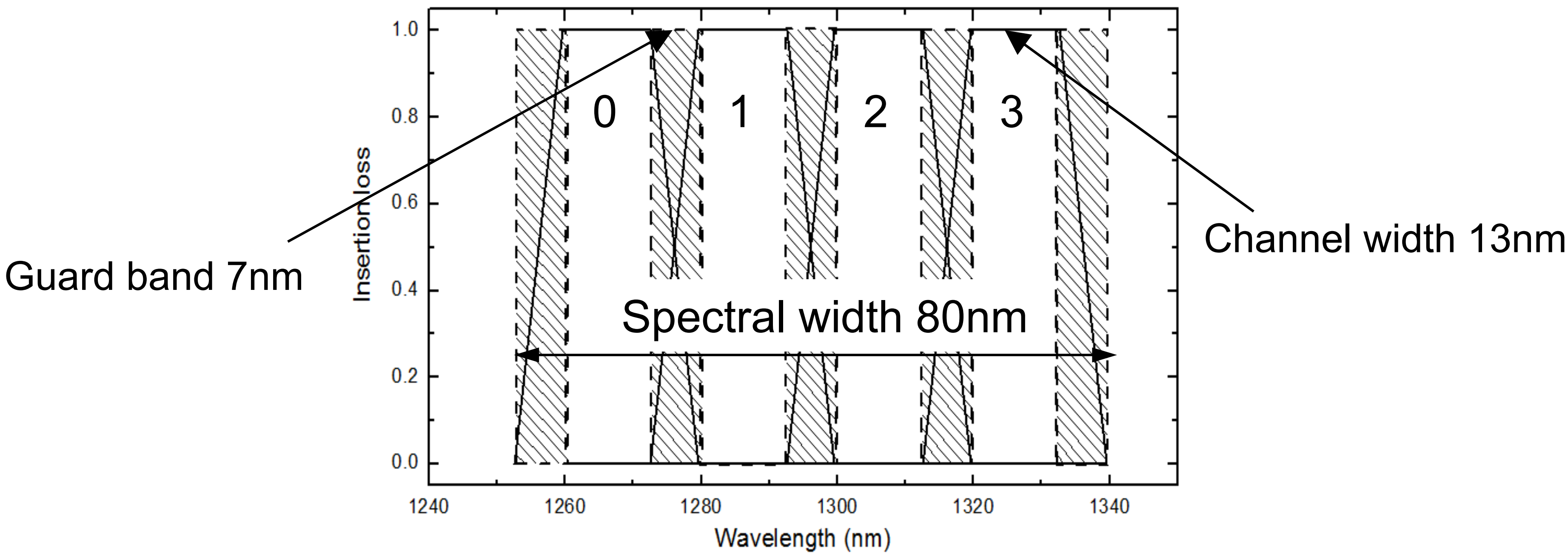
Parameter	**IEEE Std 802.3ba** **100GBASE-LR4** 10km	**vlasov_01_1112_optx** **100GBASE-WDM4** 2km	Unit
Power budget (for maximum TDP)	8.5	**5.7**	dB
Operating distance	10	2	km
Channel insertion loss	6.3	**3.5**[a]	dB
Maximum discreet reflectance	-26	-26	dB
Allocation for penalties (for maximum TDP)	2.2	2.2	dB
Additional insertion loss allowed	0	0	dB

[a] The channel insertion loss is calculated using maximum distance of 2km and fiber attenuation of 0.47dB/km at 1264.5nm plus an allocation for connection and splice loss of 2.5dB

- Link budget implies laser average output power of 13dBm (20mW)
- This looks quite reasonable for CW DFB at 70ºC with 20% slope efficiency
- Total power consumption of a 4 channel DFB laser array is 400mW

Feasibility of WDM4

ITU G694.2 CWDM grid for 100GbE 2km PMD

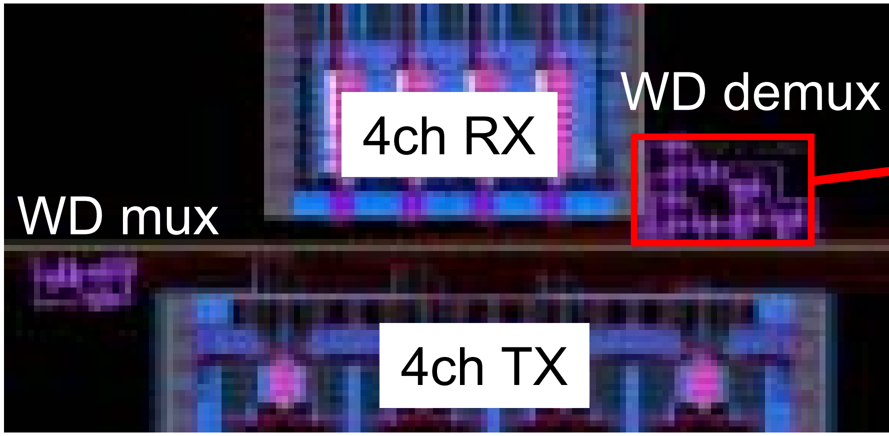


- LAN WDM requires active wavelength locking and tracking
- CWDM is OK, but not optimal
  - → 100% laser yield, no wavelength testing
  - → Up to 130ºC can be accommodated
  - → leverage existing 40GBASE-LR4 components (PLCs or TF filters)
- Further optimization of WDM grid is possible to decrease the laser cost
  - → see gill_01_1112.pdf

Resemble 4-year old discussions: traverso_01_0108.pdf, traverso_01_0308.pdf, cole_01_0308.pdf

Feasibility: CMOS WDM4 transceiver 4x25G

Single-die 4x25G WDM4 CMOS transceiver

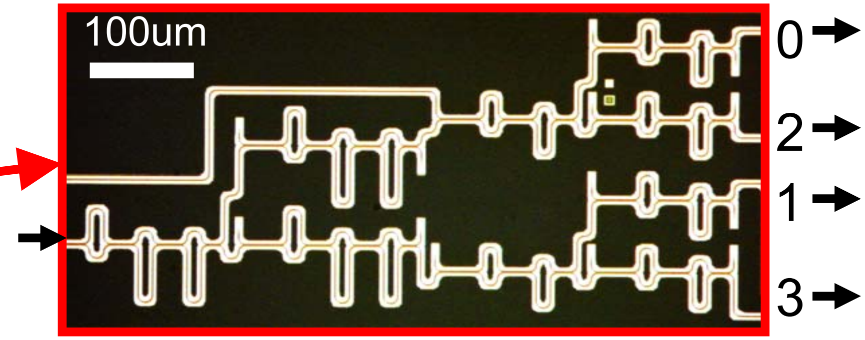


Die size 3.5mmx2mm

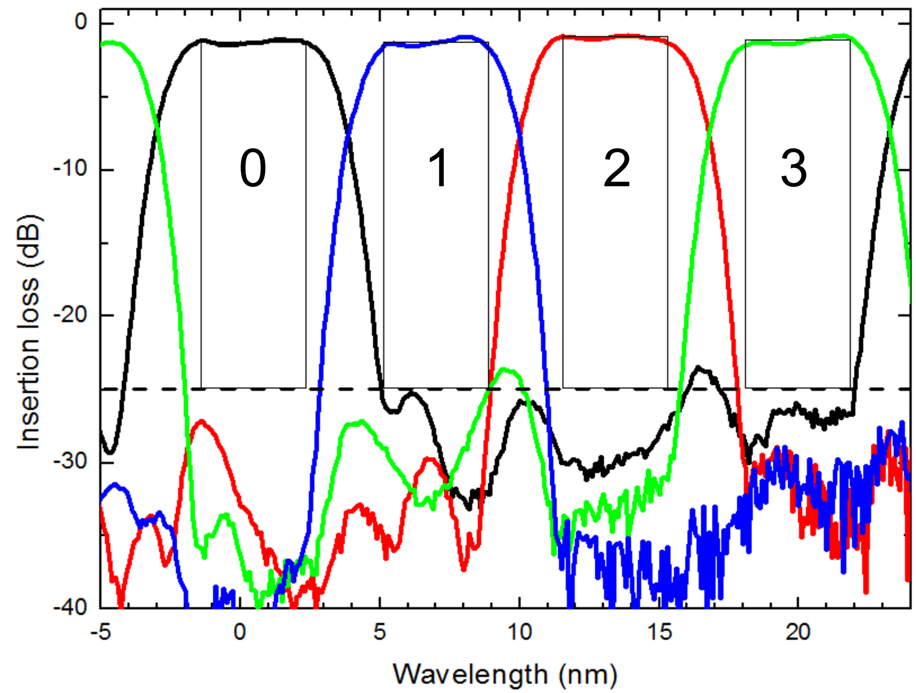
WDM filters at no additional cost:

- No additional mask levels
- No additional processing

Die photo of cascaded 4-stage MZI filter



Design and test by Folkert Horst, IBM Zurich



See also: gill_01_1112_optx.pdf
vlasov_01_0312_NG100GOPTX.pdf

S.Assefa et al, IEDM 2012

Relative Cost Analysis

Laser cost

- Nowell_01_1111 has suggested that number of lasers have direct impact on cost.
- PAM8 and PSM4 utilize 1 laser. WDM4 needs 4 lasers.

Q&A to 3 major laser vendors:

Question: What is cost ratio between 1ch CW DFB die and 4ch CW DFB array die?

Answer: Cost of 4-channel CW DFB laser array die is about 1X-2X (two answers) to 5X (one answer, case of CWDM) the cost of a single channel DFB laser die.

However, all universally agreed that cost of a bare laser die is "insignificant" portion of a final cost.

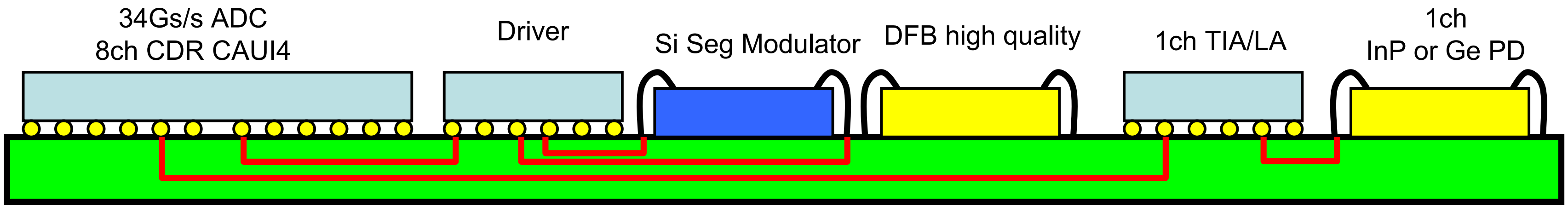
Final cost ratio is predominantly defined by:

- Volumes
- Yield with respect to specs (output power, power variations, wavelength grid, temperature range, RIN, linewidth, SMSR, etc.)
- Packaging

Packaging cost comparison

PAM8

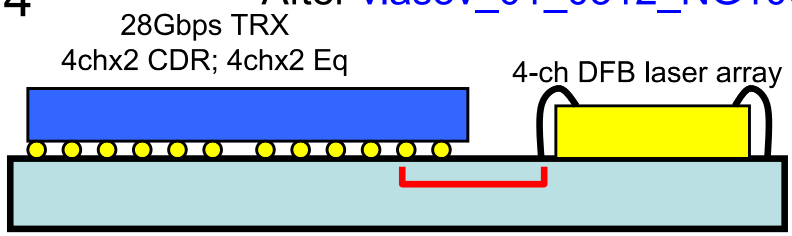
Schematic representation of PAM8 block diagram
e.g. ghiasi_01a_0912_optx.pdf



4-6 chips packaging
Board size larger, RF packaging
34Gb/s signaling, complicated traces
High power laser, RIN = -143dB/Hz

WDM4

After vlasov_01_0312_NG100GOPTX.pdf



2-4 chips packaging
Board size small, amenable for flip-chip
28Gb/s signaling, short traces
Low power laser array, RIN = -130dB/Hz

Observations on relative cost:

Component	PAM8	PSM4	WDM4
Laser	0.5	0.5	1
Chips	2	1.5	1
Board	2	1	1
Assy	2	1.5	1
Total Module	**2**	**1.5**	**1**

Relative cost comparison

Table 1. Module cost

Reference LR4 (CFP4) taken from cole_02_0512_optx.pdf
LR4 (CFP)/LR4 (CFP4) = 1.75; LR4(CFP)/SR4 = 4

	LR4	PAM8	PSM4	WDM4	Notes
Total module cost	3	2	1.5	1	This presentation

Table 2. Fiber cable plant cost

	LR4	PAM8	PSM4	WDM4	Notes
Unity cabling cost	1	1	4	1	cole_01a_0512_optx
Double link channel at CCL	1.75	1.75	7	1.75	kolesar_01a_0512_opt

Channel Cost = Fiber cable + 2×Module

Table 3. Total channel cost

Following example on p.9 of kolesar_01a_0512_optx.pdf

	LR4	PAM8	PSM4	WDM4	Notes
Double link channel at CCL	2.96	1.96	1.54	1	

Conclusion: WDM4 PMD can provide as low cost solution for reaching the 802.3bm TF objective as other proposed PMDs

Summary

- New WDM4 PMD is proposed based on 4-channel CWDM DFB lasers externally modulated with NRZ 25 Gbps signal
- WDM4 utilizes the lowest cost duplex SM fiber cable plant
- Feasibility of silicon integrated WDM filter is verified
- WDM4 PMD can provide a significant cost reduction for reaching the 802.3bm TF objective
- Cost reduction is at least as good as expected for other proposed PMDs (e.g. PSM4 PMD and PAM8 PMD)