Multi-Generational Mid-Range Optical Links

Jack Jewell

Next-Gen 100Gb/s Optical Ethernet Study Group
Atlanta, Nov 2011

Background

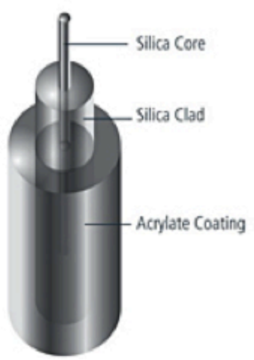
- IDC (Internet Data Center) links need 300-1000m reach
- 850nm MMF for 50-150m @25G/lane
- want “VCSEL-like” - low cost, low power, small size
- want to extend to e.g. 400GbE, T+GbE
- 850/MMF reach limited by:
  - modal bandwidth, spectral width, rise/fall, … , temp, reliability…
- SMF makes modal bandwidth very high, single-mode laser makes spectral width low
- 1310nm VCSELs difficult, edge-emitters consume power
- 950-1200nm VCSELs outperform 850nm VCSELs

- 950-1200nm single-mode VCSELs and SMF attractive

Link elements

SMF w/ shorter cutoff wavelengths

Item # F9232, CL 980 14 Photonic Fibers



CL 980 14 Photonic Fibers

These fibers operate primarily at the 980 nm wavelength (but are also suitable for use at 1550 nm) and vary by numerical aperture. A reduced-diameter version is available for applications where size is critical. Tight geometrical tolerances are maintained for low lot-to-lot variability and low splice loss. The high proof test level helps ensure extended lifetime in high-stress and submarine applications.

From OFS
Cutoff wavelength <970nm
NA 0.14 (might desire lower NA for larger mode size)
Mode Field Diameter 5.9um at 980nm,

MT Ferrules for SMF (US Conec)

	MM MT Elite® Multimode MT Ferrule	Standard Multimode MT Ferrule	SM MT Elite® Single-mode MT Ferrule	Standard Single-mode MT Ferrule
Insertion Loss	0.1dB Typical (All Fibers) 0.35dB Maximum (Single Fiber)[2,3]	0.20dB Typical (All Fibers) 0.60dB Maximum (Single Fiber)[2,3]	0.10dB Typical (All Fibers) 0.35dB Maximum (Single Fiber)[1]	0.25dB Typical (All Fibers) 0.75dB Maximum (Single Fiber)[1]
Optical Return Loss	> 20dB	> 20dB	> 60dB (8° Angle Polish)	> 60dB (8° Angle Polish)

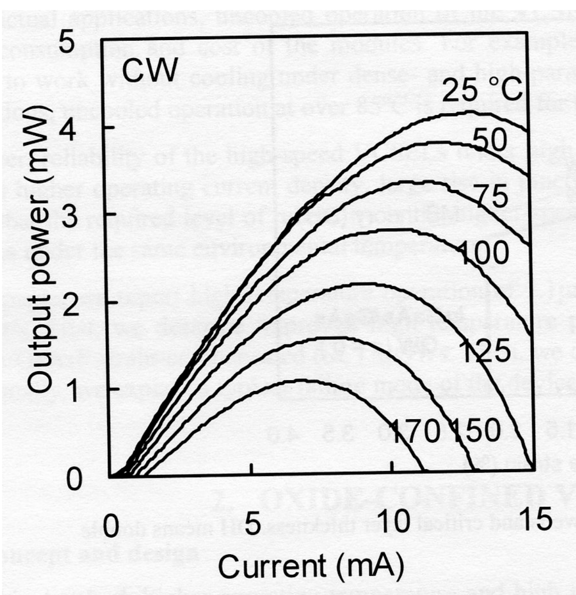
Relative costs (US Conec) ➔ (rough) 1.0X >2X* 1.2X*

* in MMF-like volume

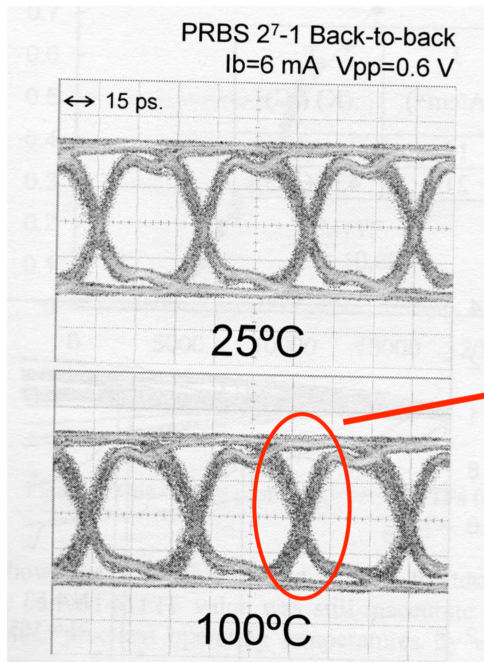
1.1µm VCSELs take the heat

From NEC, strain-compensated InGaAs-GaAsP VCSEL
- presented January 2009; limited but encouraging reliability data
- 6µm diameter should be borderline single-mode, but MMF used
- 1060nm, 980nm VCSEL development at Furukawa, VI Systems

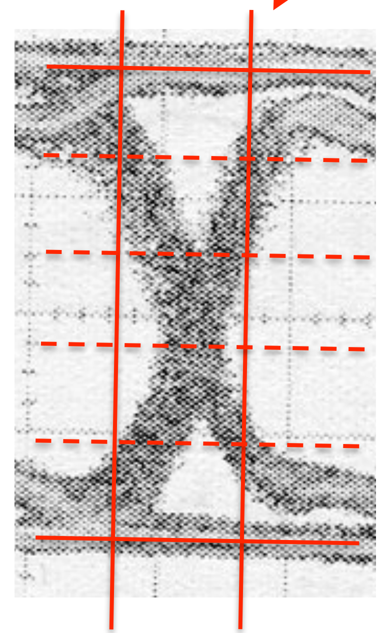
25Gb/s



>2mW @ 100C



15ps fall @ 100C
6mA bias



[H. Hatakeyama, et al., “Highly reliable high speed 1.1um-InGaAs/GaAsP-VCSELs,” in Vertical-Cavity Surface-Emitting Lasers XIII, edited by Kent D. Choquette, Chun Lei, Proceedings of SPIE Vo.. 7229 (SPIE, Bellingham, WA, 2009) 7229 02.]

Link simulations

3.1.16a-based (link model spreadsheet used for 10GbE 802.3ae)

http://grouper.ieee.org/groups/802/3/ae/public/index.html 10Gb/s Link Budget Spreadsheet (Ver. 3.1.16a)

Dispersion Min and Coefficient based on standard SMF

25,781MBd

Baseline wander = 0.015

DCD_DJ = 4.5ps (assumes retiming)

Det. Jitter = [DCD_DJ + 0.3UI] = 16.1ps

Rx Bandwidth = [0.75 x Base Rate] =19,336MHz

SM - RMS Spectral Width = [λ^2*BaseRate/4c] ~0.026nm @1100nm

MM – RMS Spectral Width = 0.5nm

MM – MPN = 0.3; ModalNoisePenalty = 0.3dB

Varied: Rise/fall 14-20ps; RIN -128 and -130 dB/Hz; Wavelength 950-1200nm

The following affect link budget, not signal integrity

Tx Launch OMA = 0.17dBm

Rx Sensitivity OMA = -11.0dBm (est. from 802.3 ae and ba)

Connector loss = 6dB

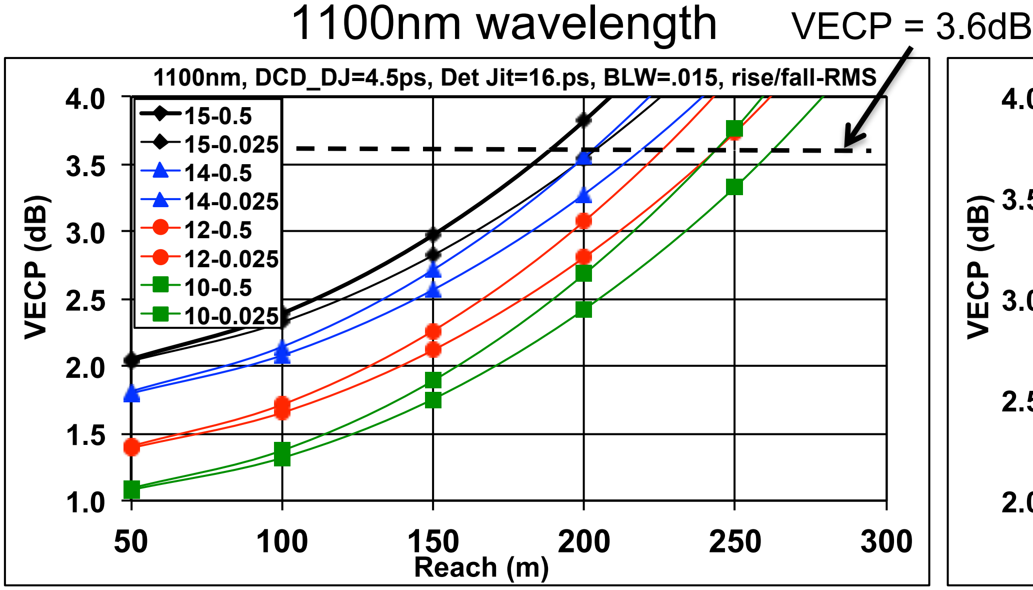
Fiber Attenuation – extended range of spreadsheet calculations, both in SM and MM, through the 1000nm dividing point

Mid-wave VCSELs over MMF

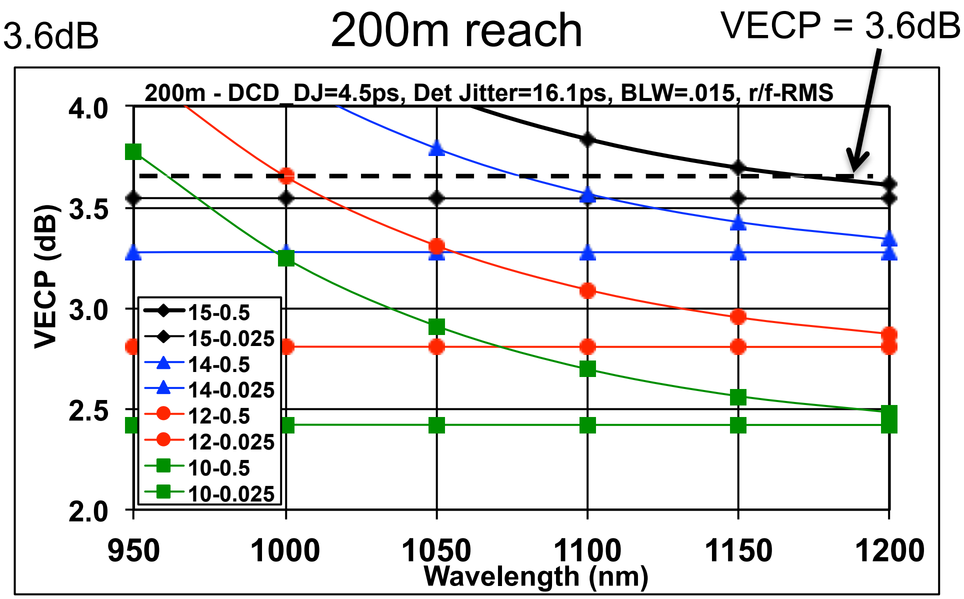
OM4* - 4700MHz-km modal bandwidth *<u>at wavelength</u>
Multimode/singlemode VCSELs (RMS: 0.026nm / 0.5nm)
RIN at -130dB/Hz
Fast rise/fall required
300m would need EDC, FEC, etc
200m w/ MM-VCSEL, 14ps rise/fall, 1100nm

NOT EXTENSIBLE TO WDM OR HIGHER LINE RATES

1100nm wavelength



200m reach



Mid-wave VCSELs over SMF

SM VCSELs, RMS Spectral [λ^2*BaseRate/4c] ~0.026nm @1100nm*

*applied to 1550nm 10GbE yields 0.0206nm rather than 0.0182nm (used in 3.1.16a spreadsheet)

For 18ps rise/fall times and 3km reach, VECP < 3.0 for all wavelengths

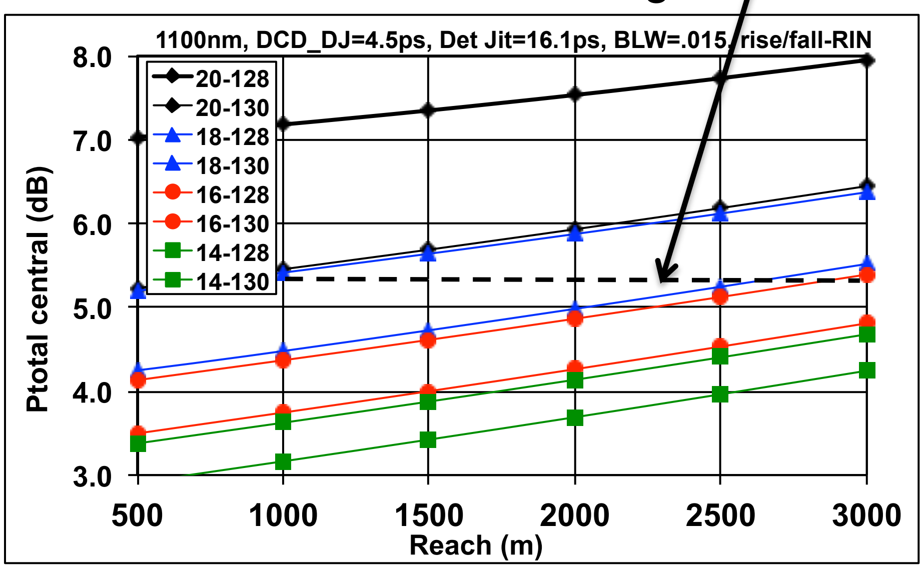
3km is realistic w/o EDC, FEC, etc, even with high connector loss

500m reach for rise/fall 18ps

EXTENSIBLE TO WDM AND HIGHER LINE RATES

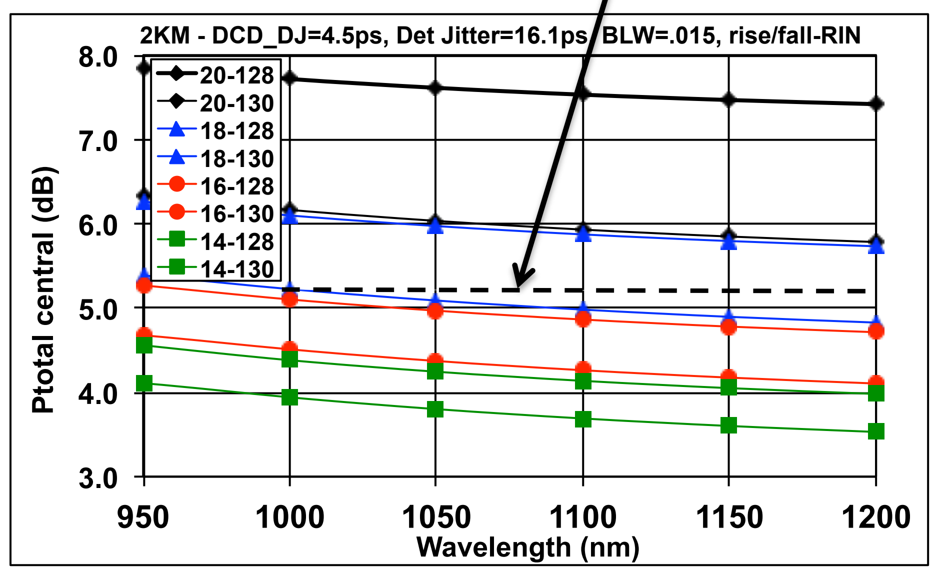
1100nm wavelength

Margin = 0
w/ 6dB connector loss



2km reach

Margin = 0
w/ 6dB connector loss

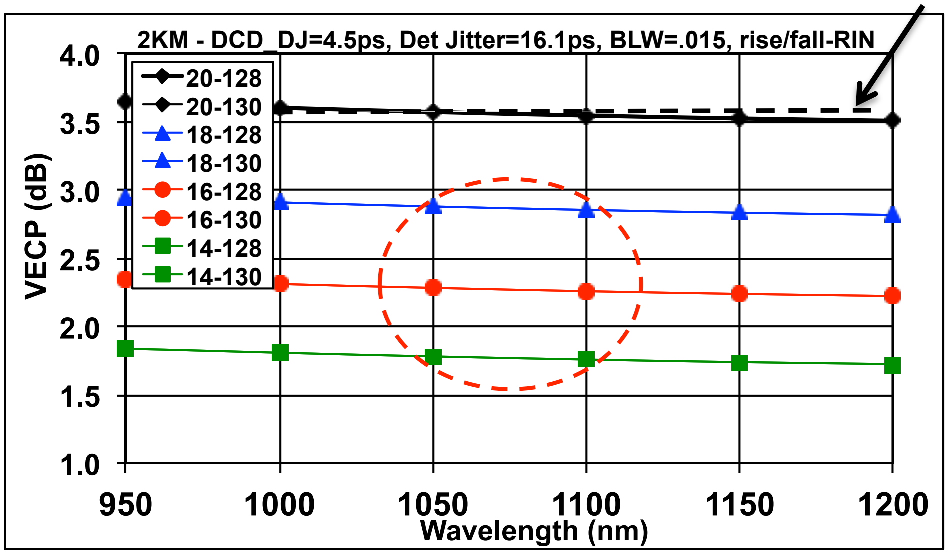


Mid-wave VCSELs over SMF
Extension to WDM

CWDM: 4 channels w/ 20nm spacing ➔ ~80nm range
100GbE over duplex fiber (more laser power needed for CWDM)
Longer wavelengths have more margin
Performance vs wavelength sufficiently uniform for CWDM
SMF also allows DWDM
MMF doesn't allow either CWDM or DWDM
modal bandwidth high only over ~20nm

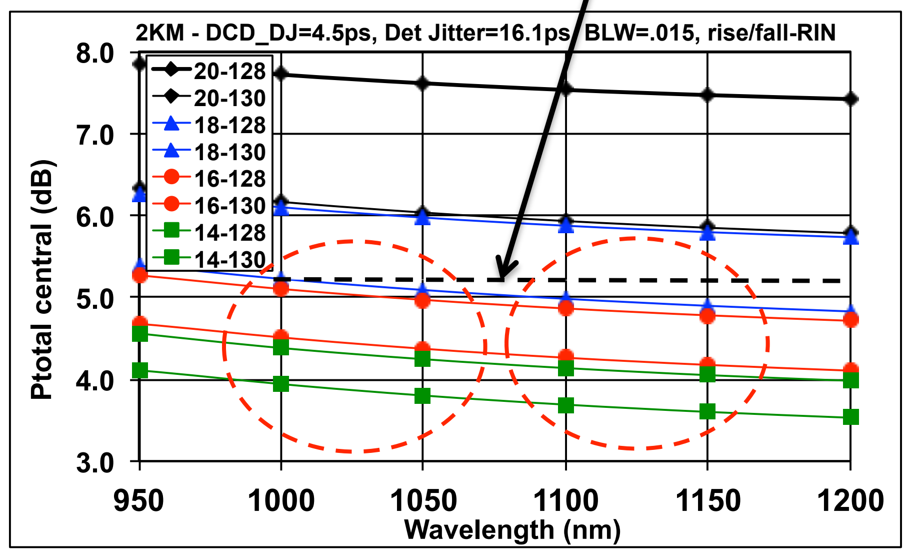
2km reach

VECP = 3.6dB



Margin = 0
w/ 6dB connector loss

2km reach



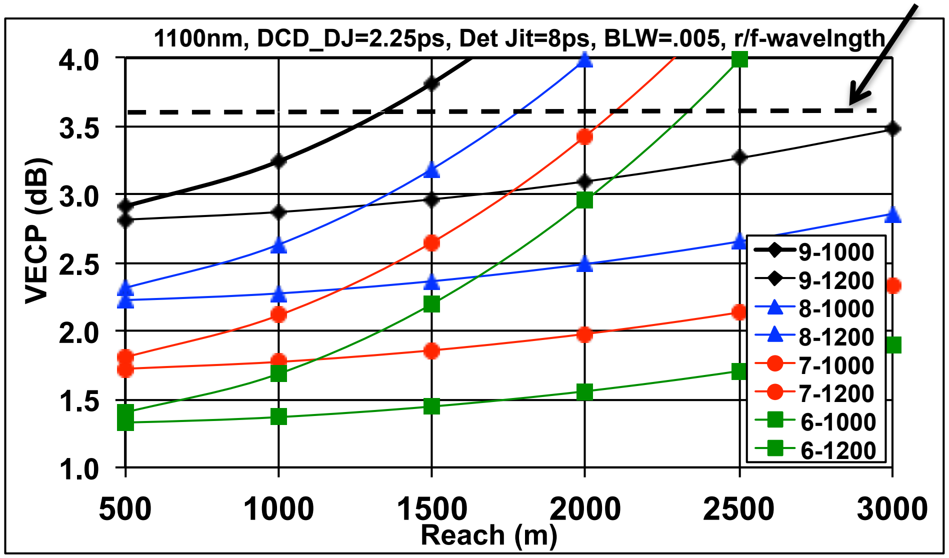
Mid-wave VCSELs over SMF
Extension to 50Gb/s line rate

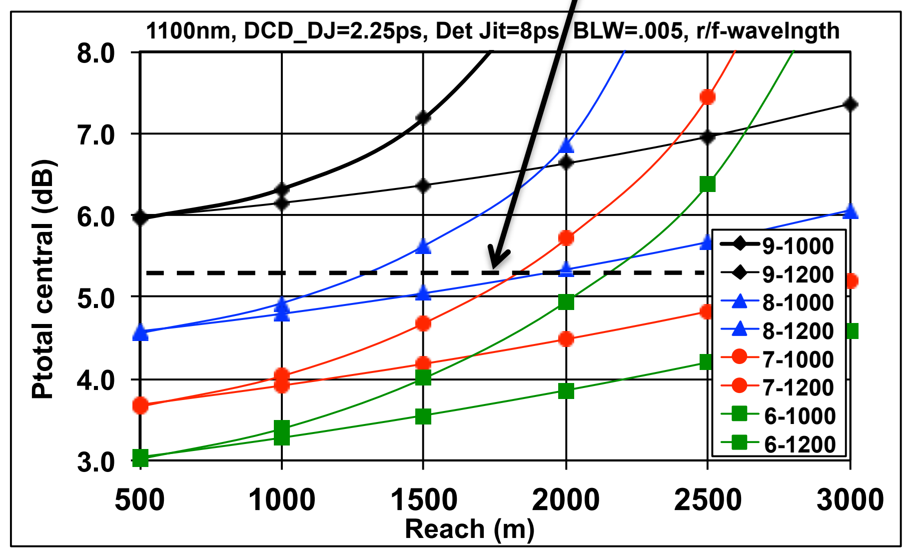
1000nm and 1200nm plotted - longer wavelengths <u>much</u> more margin
RIN set at -130dB/Hz
2km reach, especially for 8ps or faster rise/fall and longer wavelengths
CWDM/DWDM could be added

12 channels X 50Gb/s X 4 wavelengths = 2.4Tb/s!!

Margin = 0
w/ 6dB connector loss

VECP = 3.6dB





It's about

Cost More than 850/MMF

- SM optics, SM connectors

Less than 1310/SMF

- VCSEL mfg

Power Like shortest-reach 850/MMF

Lower than 100-150m 850/MMF

- No EDC, FEC, …

Much lower than 1310/SMF approaches

Size Match 850/MMF form factor(s)

Longevity WDM, higher line rate ➔ 1-2Tb/s

For immediate work

Customer needs

Midwave (InGaAs, 950-1200nm) VCSEL efforts
- especially single-transverse-mode or relevance to such
- chirp under modulation at 25Gb/s and 50Gb/s
  - (chirp not observed in SM 1310nm VCSELs at 10Gb/s)

Available fibers and possible optimization
- cutoff wavelength, mode diameter vs bend radius

Modifications to 3.1.16a, e.g. fiber attenuation/dispersion at 950-1200nm

Conclusions

Midwave VCSEL/SMF viable for links >1km at >25Gb/s

VCSELs, fibers, connectors exist; development (not research) required

Ability to foresee multiple generations of speed increases 1.2-2.4Tb/s

Approach provides lowest power, lowest cost, smallest size