WWDM Transceiver Module for 10-Gb/s Ethernet

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Why pursue WWDM for the LAN?

Supports installed bases of MMF (~300m) and SMF (10-20km) with single transceiver.

Lower speeds allow noisier, wider band lasers, slower IC processes, and simpler electrical packaging, reducing cost and adding margin.

Why use Wide Wavelength Spacing?

- **No temperature control required over 0-70ºC operation**

  Laser wavelength varies by 5.0nm @1300nm

- **Much higher laser yield is possible**

  Large interwafer and intrawafer variations in wavelength allowed

- **Smaller, simpler demultiplexing optics**

  Smaller, less collimated beams. Interference filters or gratings.

- **Multimode fiber can be supported**

  Large spatial and angular spread makes fine λ resolution tough.

- **No amplifiers $\Rightarrow$ Narrow spacing unnecessary**

  Entire useful spectrum of fiber can be covered if necessary

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Advantages of 1300nm over 850nm

I. Bandwidth-Distance Product

2.5 Gb/s in 62.5-µm MMF: 110 m @850nm
300 m @1300nm

II. Eye Safety

Class 1 with 4-channel WDM: -10 dbm/channel @850nm
+2 dbm/channel @1300nm

III. Single Mode Fiber Compatibility

850-nm sources are incompatible with standard SMF

IV. Supply Voltage

Lower bandgap means lower forward voltage on lasers

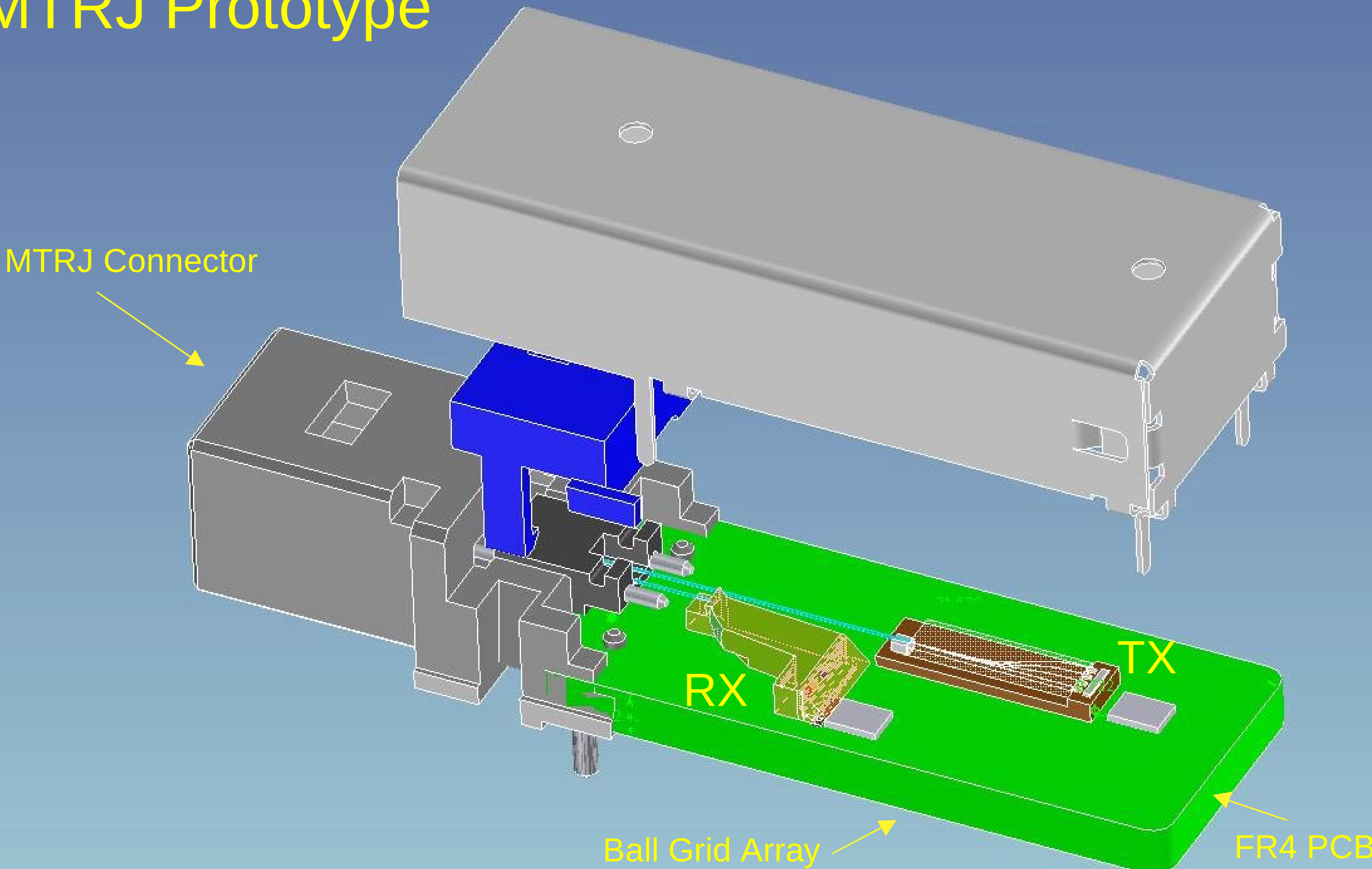
V. Receiver Sensitivity

Lower photon energy $\Rightarrow$ 1.8-dB higher responsivity (A/W)

HP WWDM Proposal

Data	4 duplex channels, 2.5 Gb/s/channel
Fiber	Dual use SMF/MMF (SM TX, MM RX)
Package	MTRJ duplex connector, BGA surface mount
Sources	Uncooled, unisolated DFB, ***No SMSR spec***
Wvlngth	1280,1300,1320,1340 nm
MUX	4-to-1 silica waveguide combiner
Detectors	InGaAs PIN photodiode array
DEMUX	Compact molded plastic “bulk zigzag”
ICs	4-channel TX; 4-channel RX (integrated)

HP Labs WWDM MTRJ Prototype



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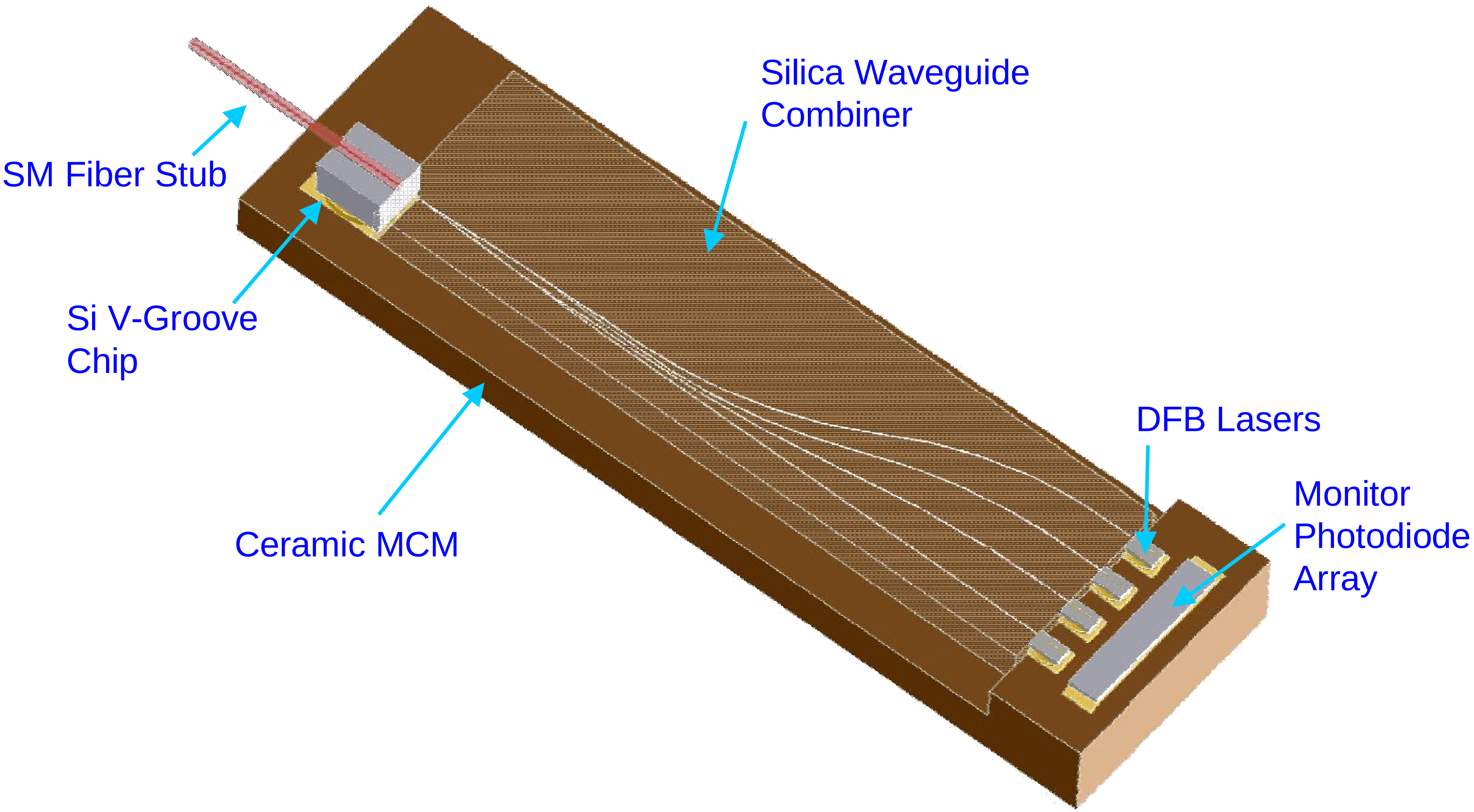
Transmitter Optical Subassembly

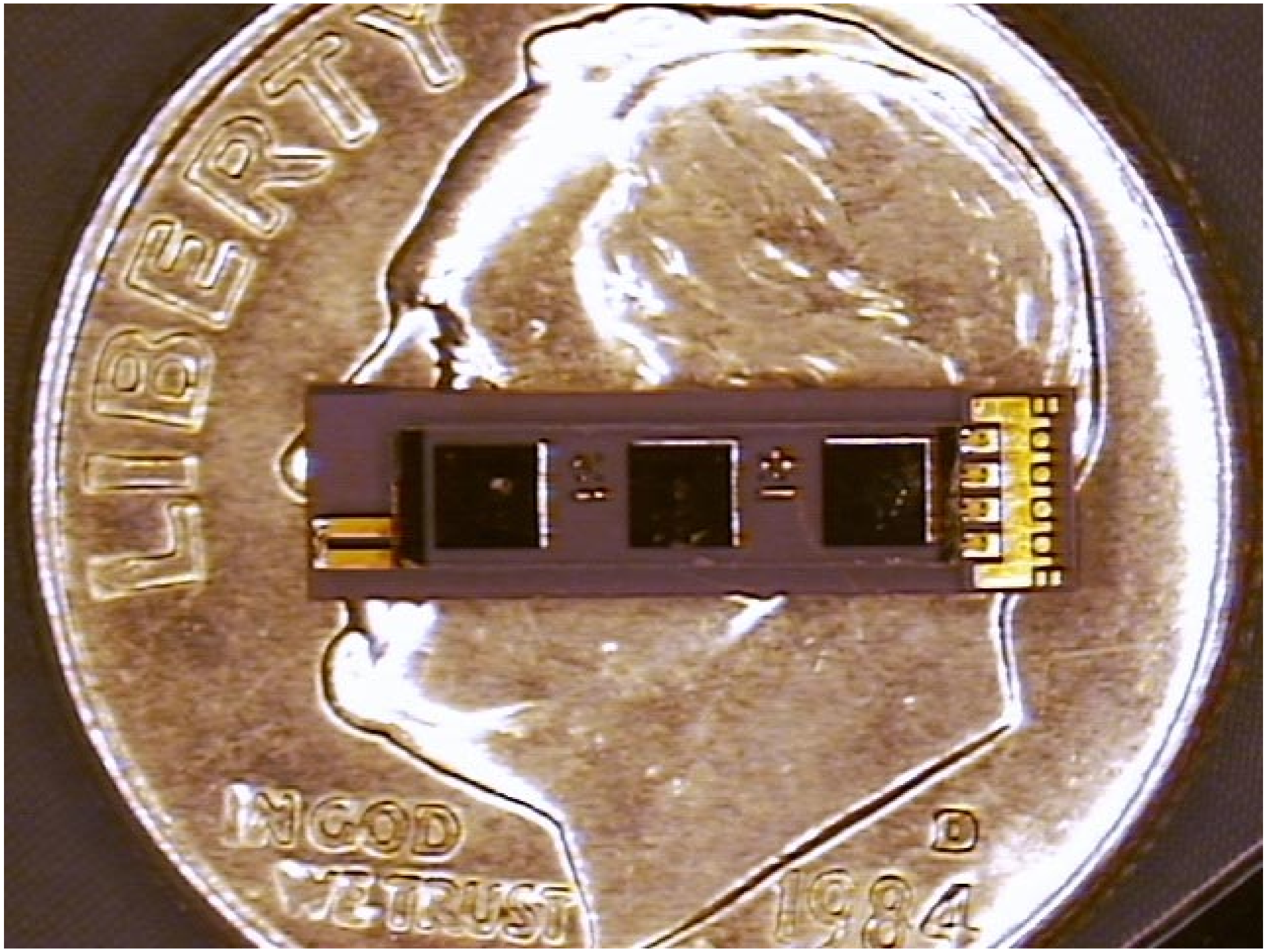


Transmitter Subassembly

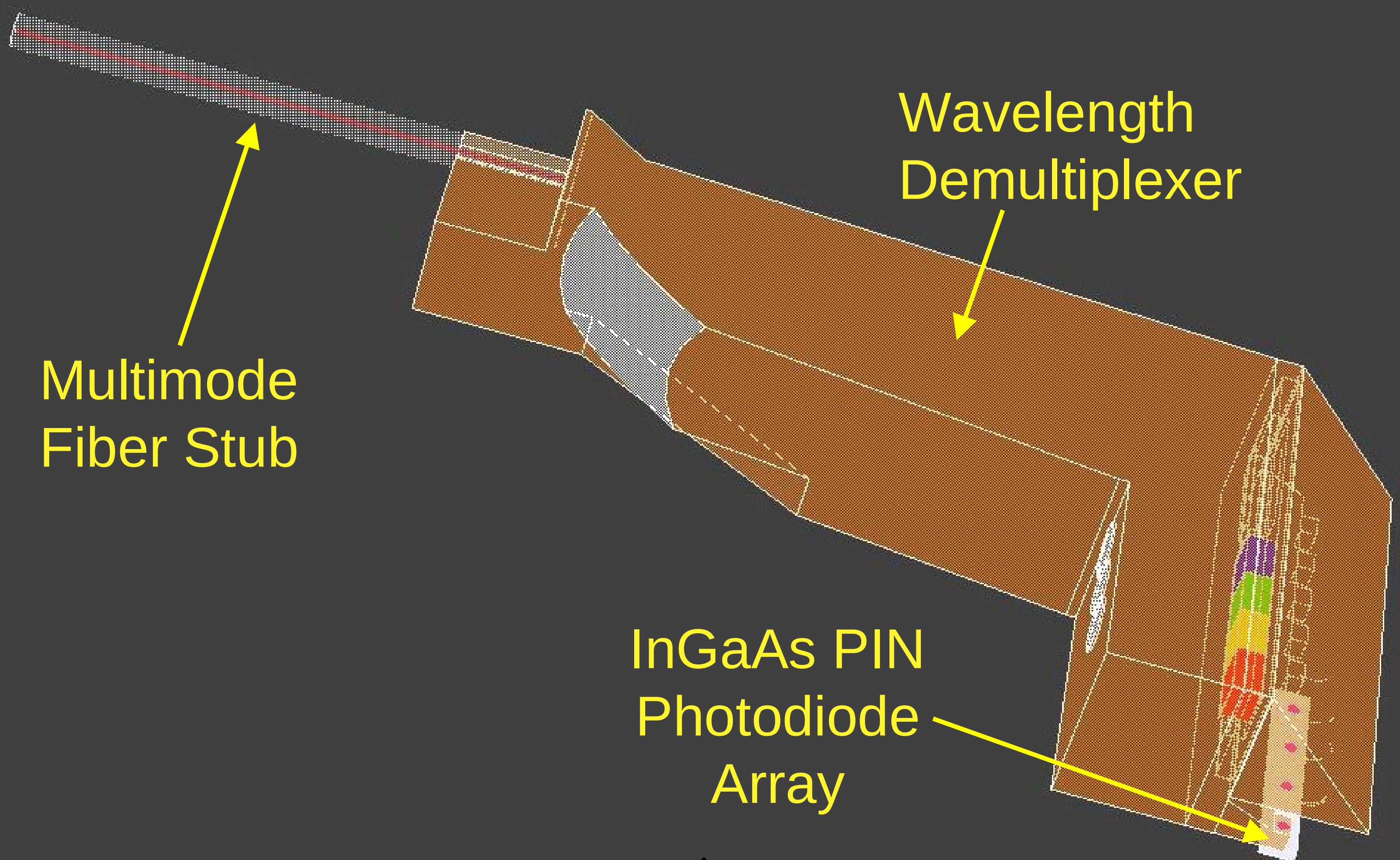
Robotic assembly achieves <1μm alignment in a fast, fully automated process. Similar equipment already used in production for 1000LX transceivers.

Wavelength Multiplexer uses standard silica waveguide process with ~400 devices/wafer. Sawed, not polished, chips are used to lower cost without sacrificing performance.

Transmitter Optical Subassembly

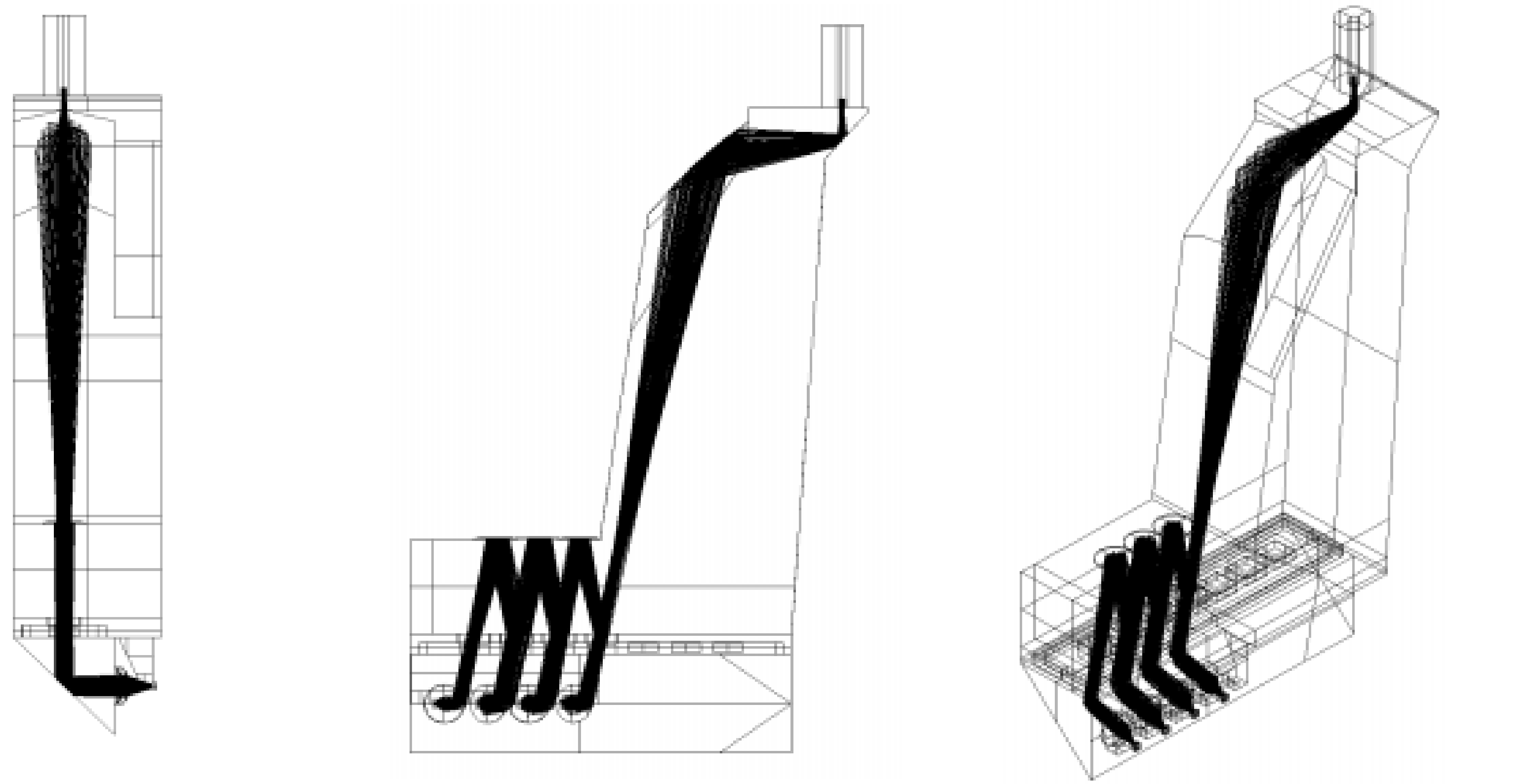


Receiver Subassembly



Wavelength Demultiplexer

Three views of ray tracing in wavelength demultiplexer



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How can Demux be low cost?

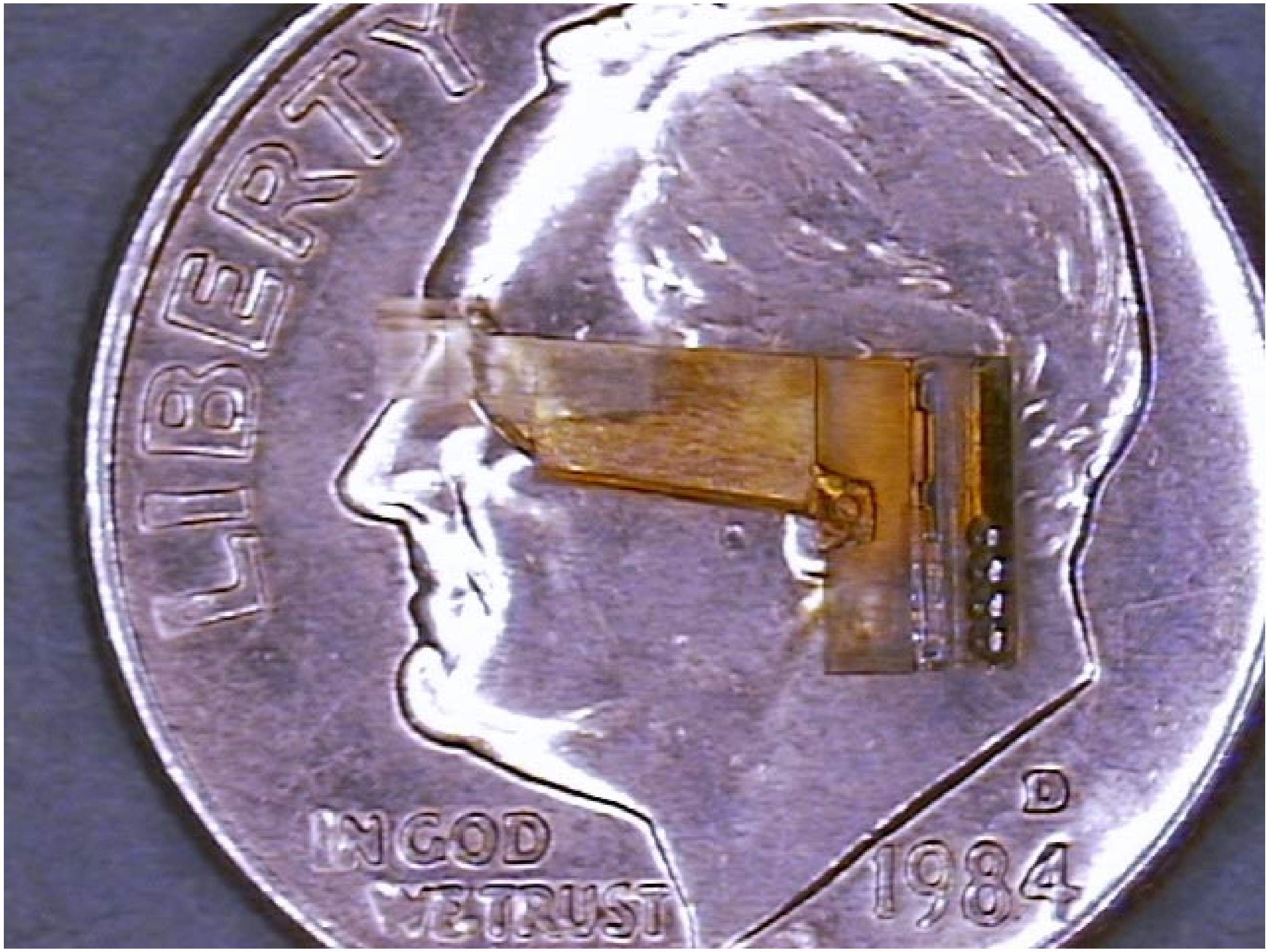
- **<u>Injection-molded plastic optics</u> -** *Once a mold is built, a complex and precise optical system can be replicated at minimal incremental cost.*

- **<u>Alignment free assembly</u> -** *Molded mechanical features allow parts to fit together without requiring alignment.*

- **<u>Tiny dielectric interference filters</u>** *- Small area per chip means one growth can yield HUGE part count.*

- **<u>Ease of fiber attachment</u>** *- Molded V-groove, integrated into demux passively aligns fiber stub.*

Wavelength Demultiplexer

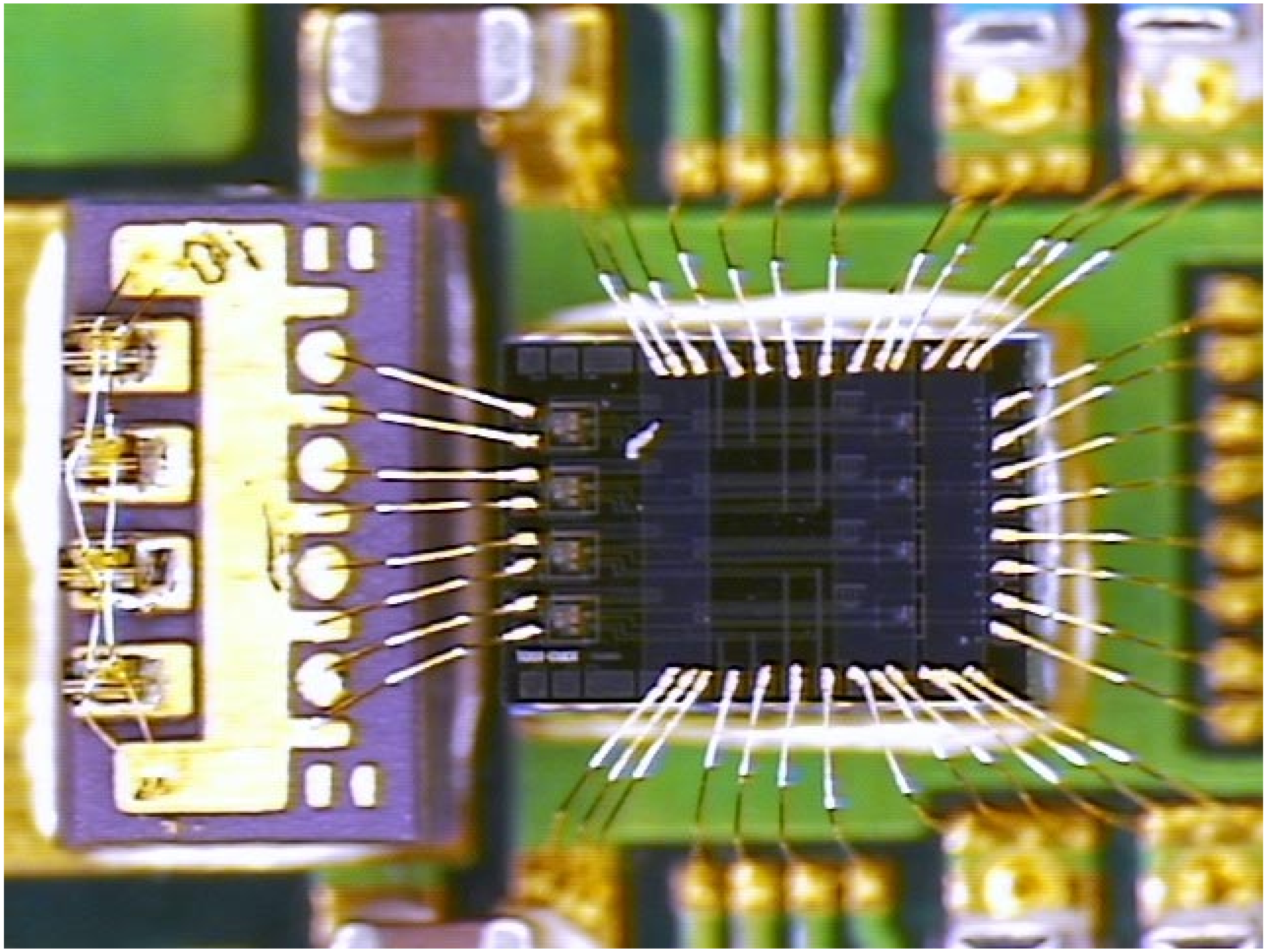


Integrated Circuits

Leveraging Parallel Optics technology, fully integrated multichannel TX and RX ICs are available up to 2.5-Gbd in Silicon. 3.125-Gbd ICs will soon be available.

Newer SiGe technologies will make these ICs extremely simple and robust.

4-channel Transmitter IC



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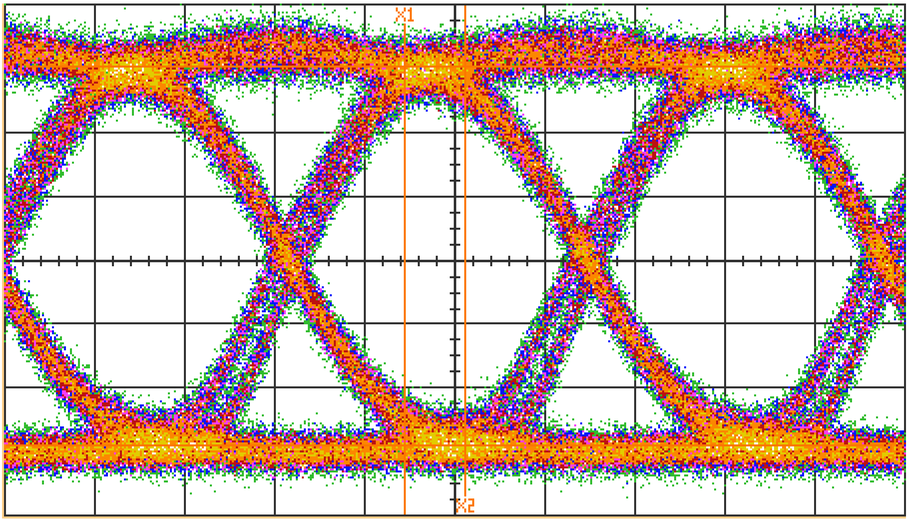
Single-channel TX eye-diagram

- 4-ch Si-Bipolar TX IC
- directly modulated DFB
- 2.5 Gb/s
- 9.5 dB extinction ratio
- Ibias = 8 mA
- Imod = 25 mA
- P (SMF) = -5.8 dBm
- 4 lasers on simultaneously
- butt-coupled into SMF
- uncooled
- unisolated



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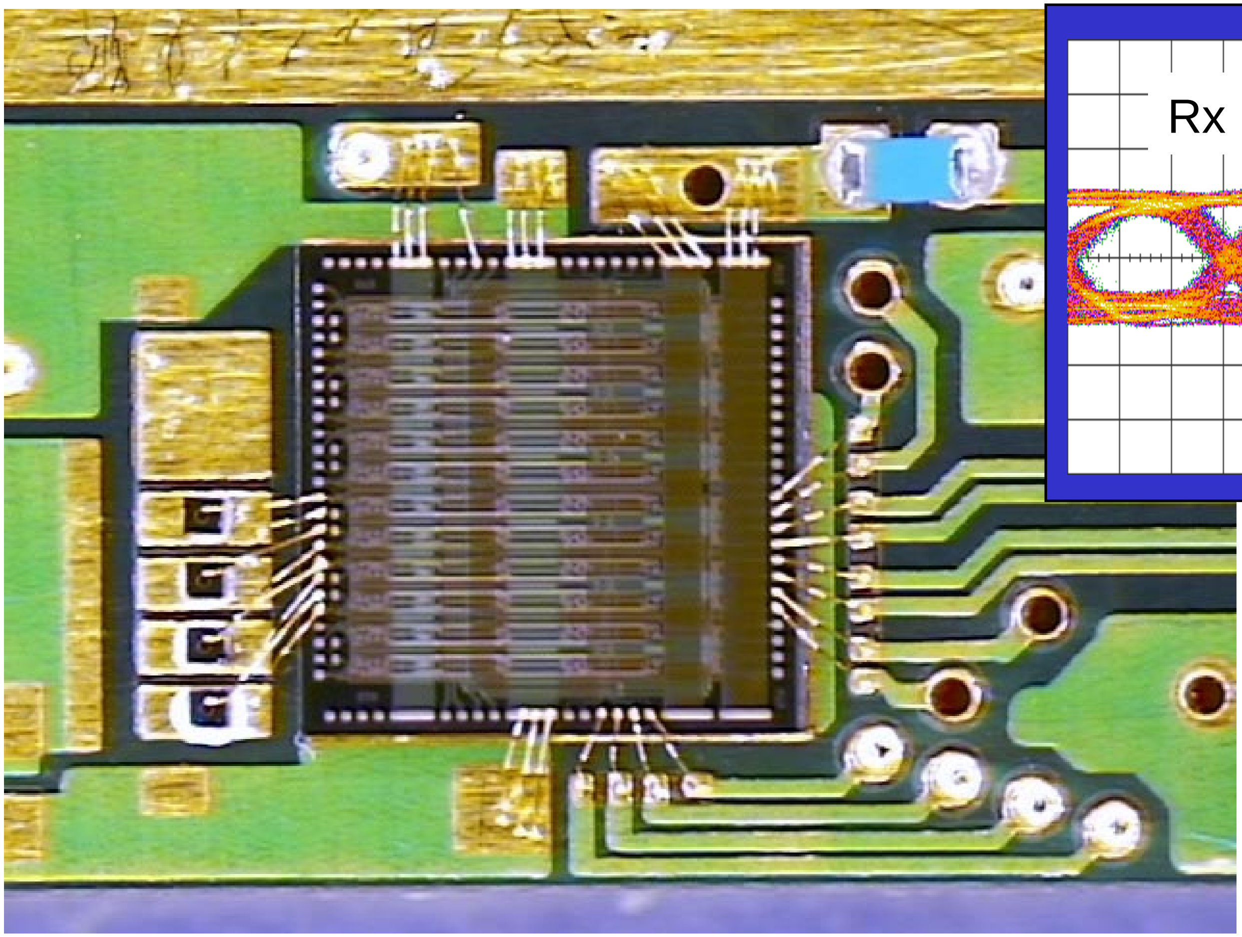
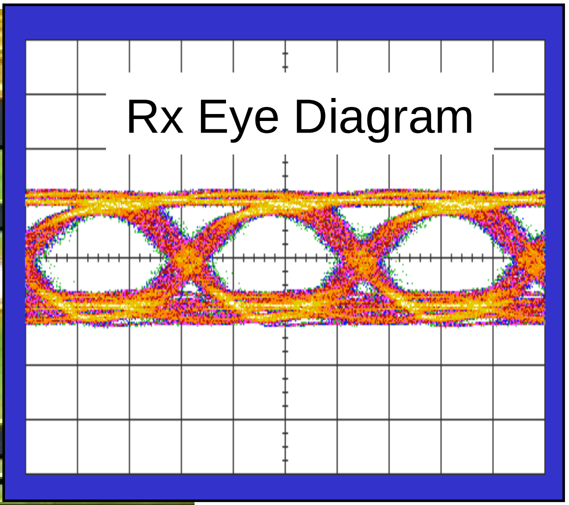
12-Channel RX IC - Using 4 channels

Soon-to-be available 4-channel IC will greatly reduce RX footprint





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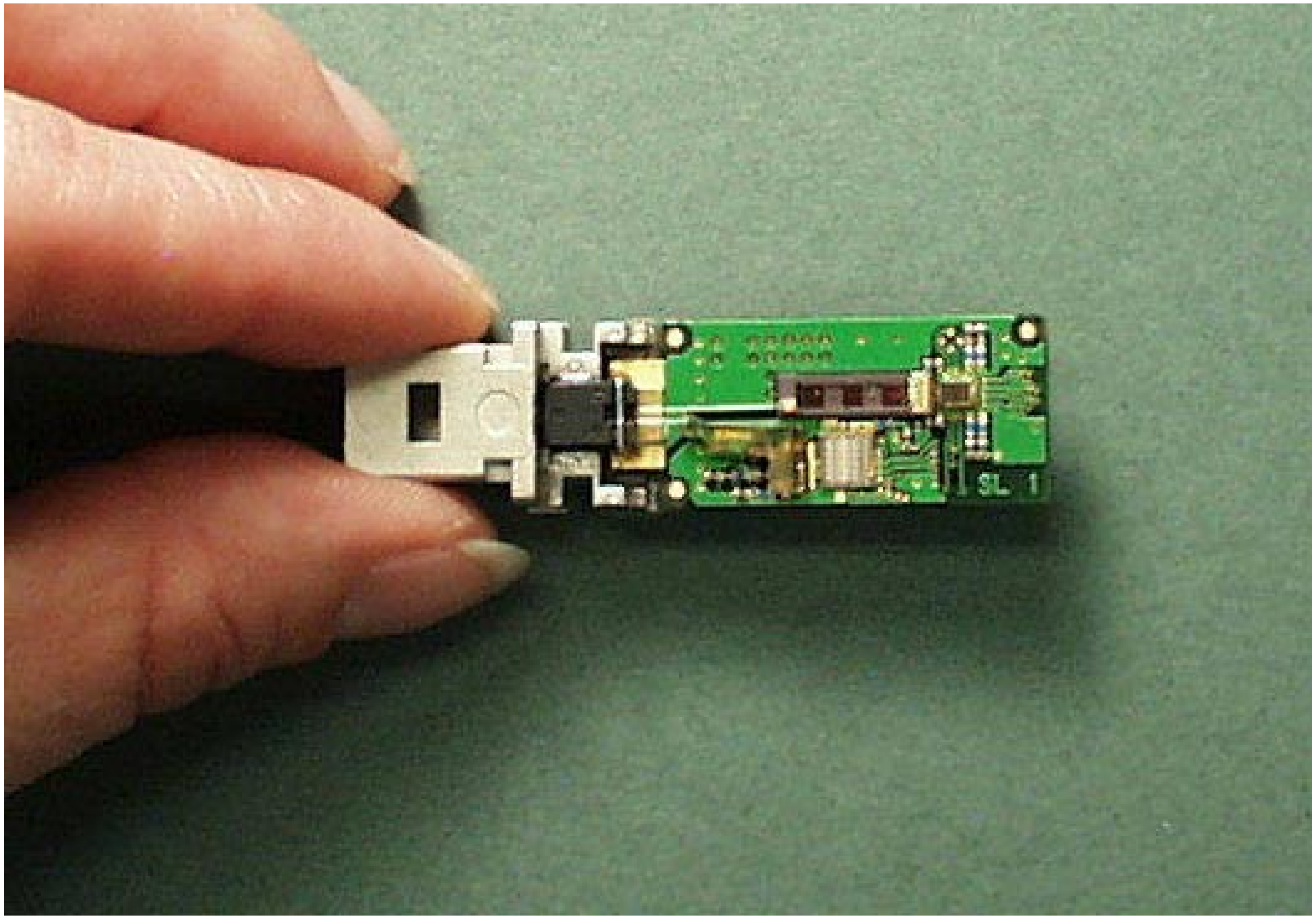
Assembled WWDM MTRJ Module



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Class 1 Eye Safety

Power Budget should allow 4-channel eye-safe operation

Eye-safe limit at 1300 nm:	+8 dBm
Limit per channel:	+2 dBm
Demultiplexer loss:	<3 dB (expected)
Link Budget:	<7 dB (expected)

∴ Received Power Limit due to eye safety = -8 dBm

Parallel Rx IC's are available with better than -20 dBm sensitivity. Thus, other considerations (e.g. power dissipation, EMI) may play a bigger role in limiting received power than eye safety.

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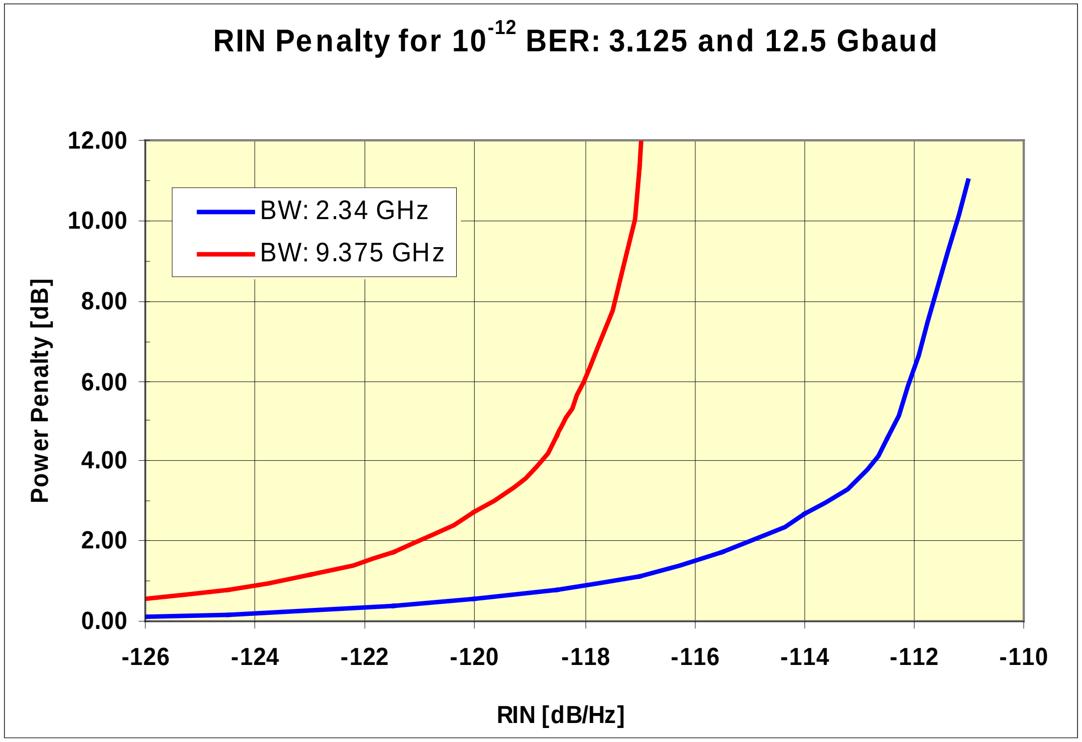
WWDM DFB Source Study - GOALS

Experimentally verify that DFBs with low SMSR and no isolator have:

- RIN < -117 dB/Hz
- BER < 10^{-12}
- Small mode-partition noise power penalty

Examine RIN and corresponding BER at high ambient temperature

Power Penalty due to RIN - Model



- Power budget determines how much RIN can be allowed
- GbE specifies -117 dB/Hz
- 12.5 GBd applications require ~ 6 dB less RIN for 1 dB penalty

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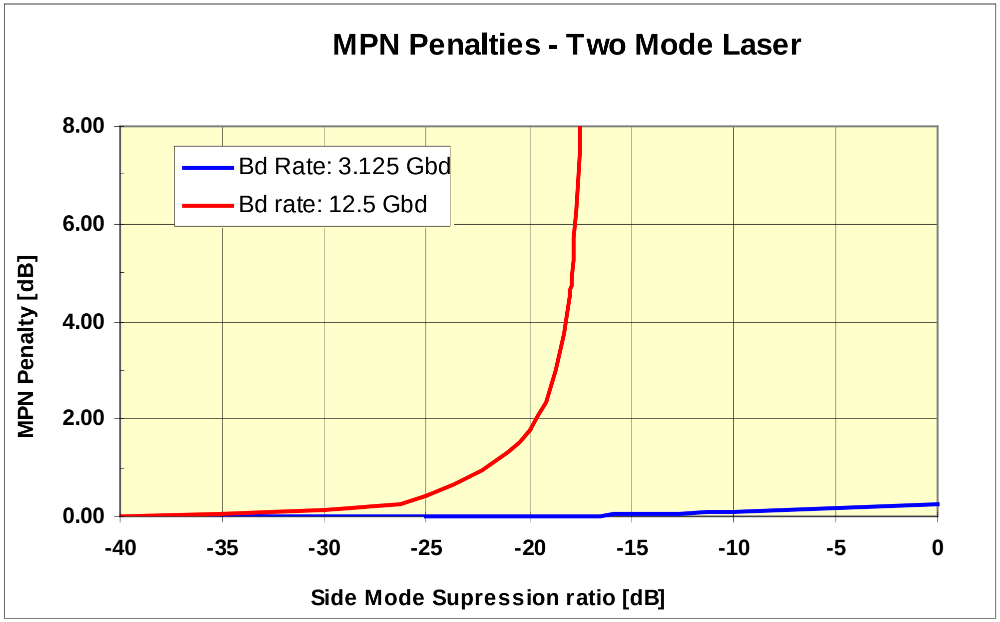
Power Penalty due to Mode-Partition Noise - Model



Parameters:

λ_{min} = 1270 nm

λ_o = 1322 nm

$\Delta\lambda$ = 1.6 nm

S_o (ps/nm^2*km) = 0.092

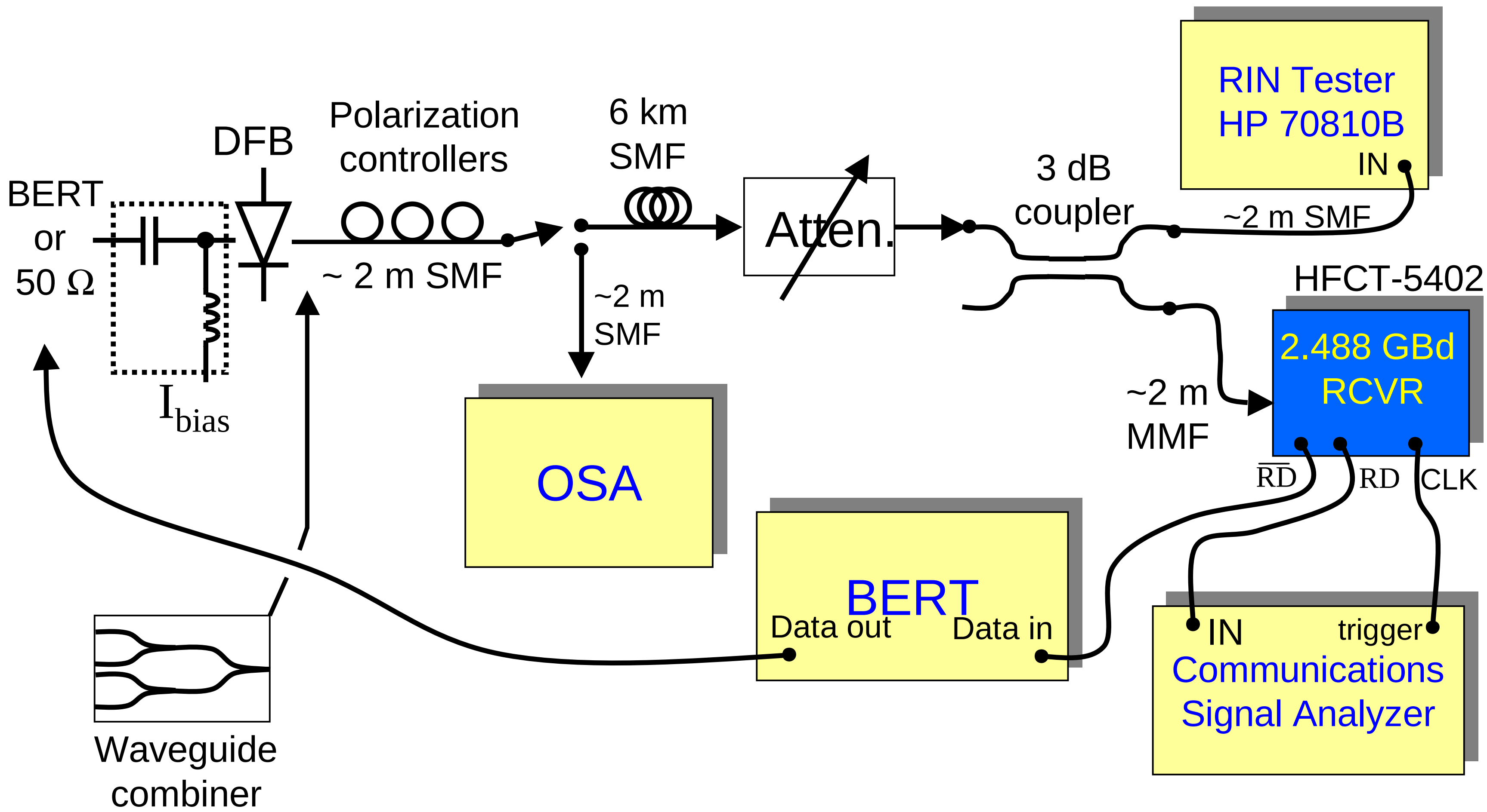
D_1 (ps/(nm-km)) = -5.086

k factor = 0.8

Link length = 6 km

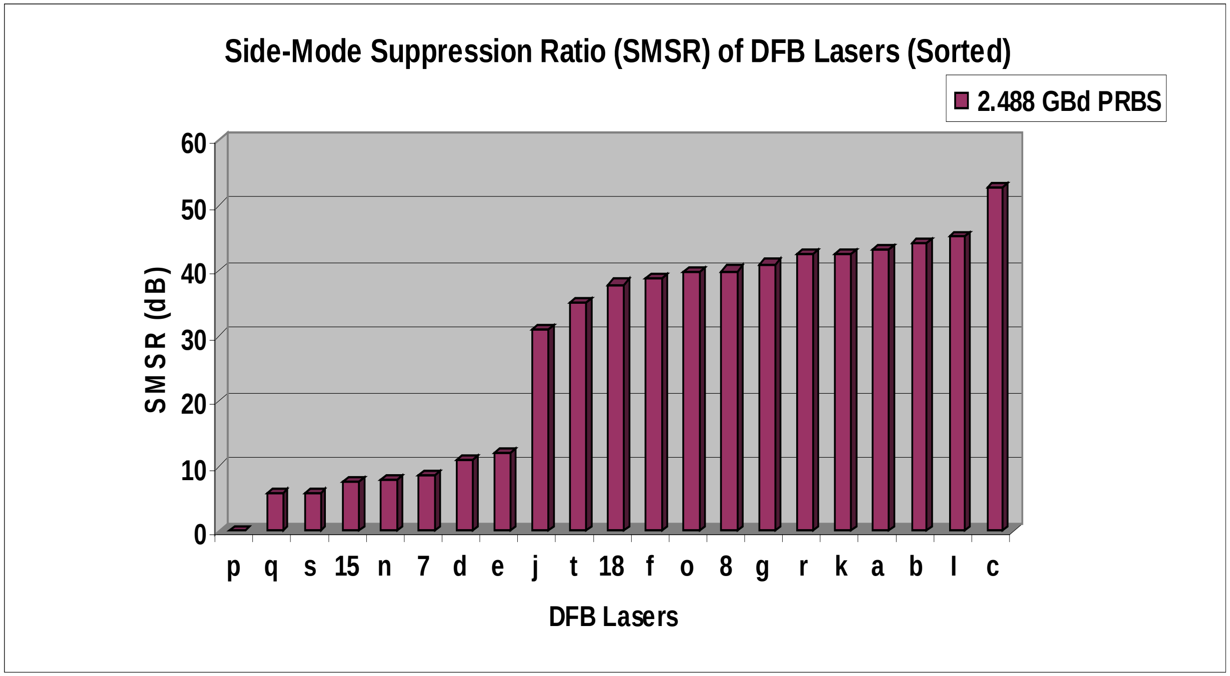
BER = 10^{-12}

Experimental Setup



Side-Mode Suppression Ratio of DFBs

Reject lasers chosen for poor SMSR



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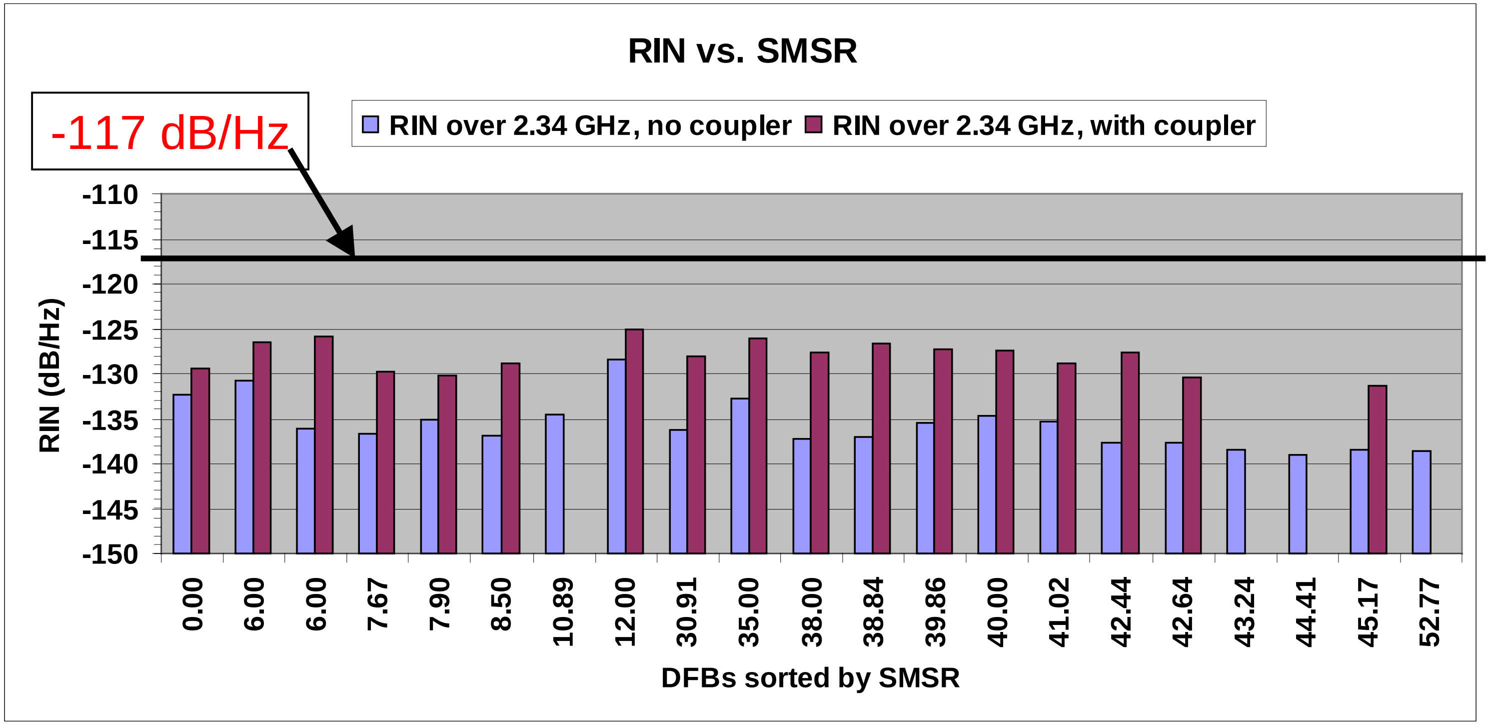
Results: RIN vs. SMSR



Note: 2.34 GHz = 0.75 x 3.125 GBd

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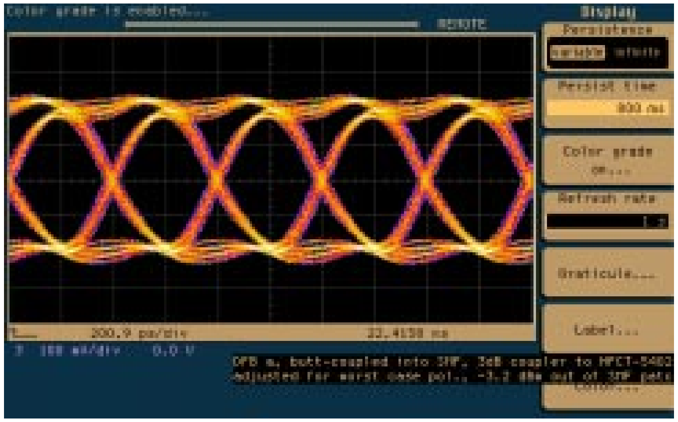
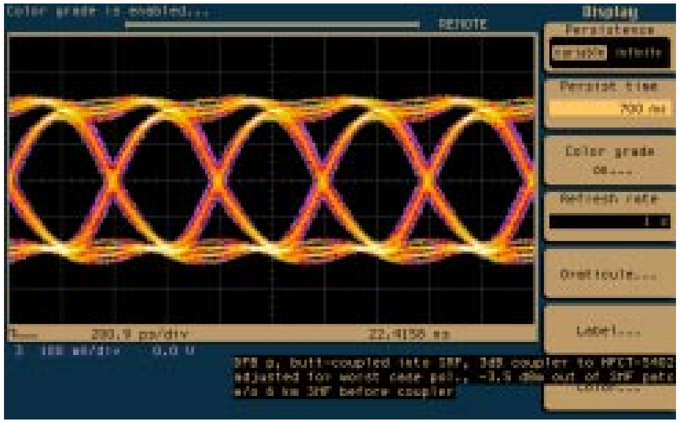
Typical Received Eye Diagrams at 2.488 GBd

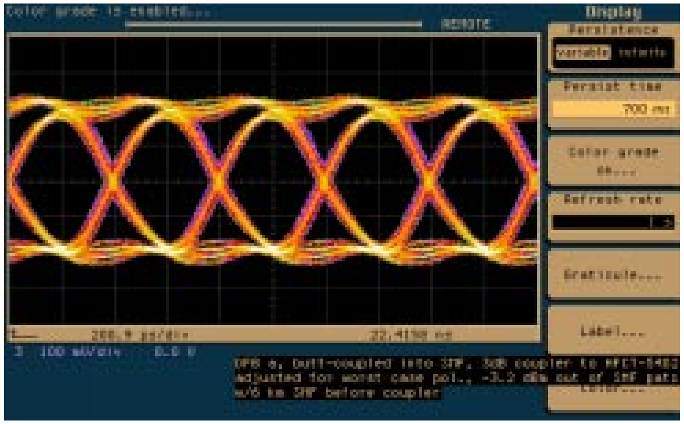
DFB a (SMSR = 43.24 dB) | DFB p (SMSR = 0 dB)

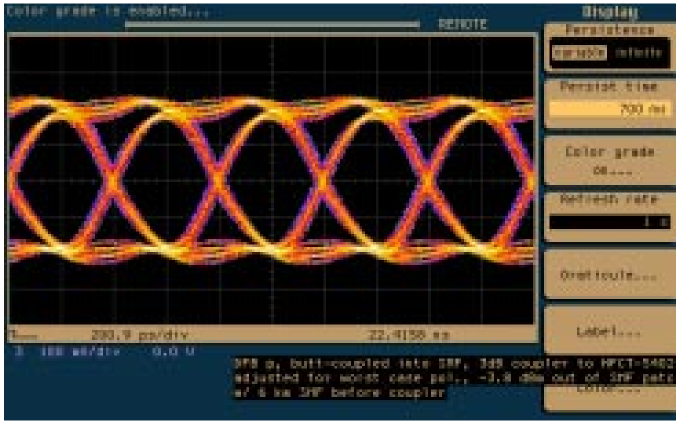
Back-to-back





6 km SMF





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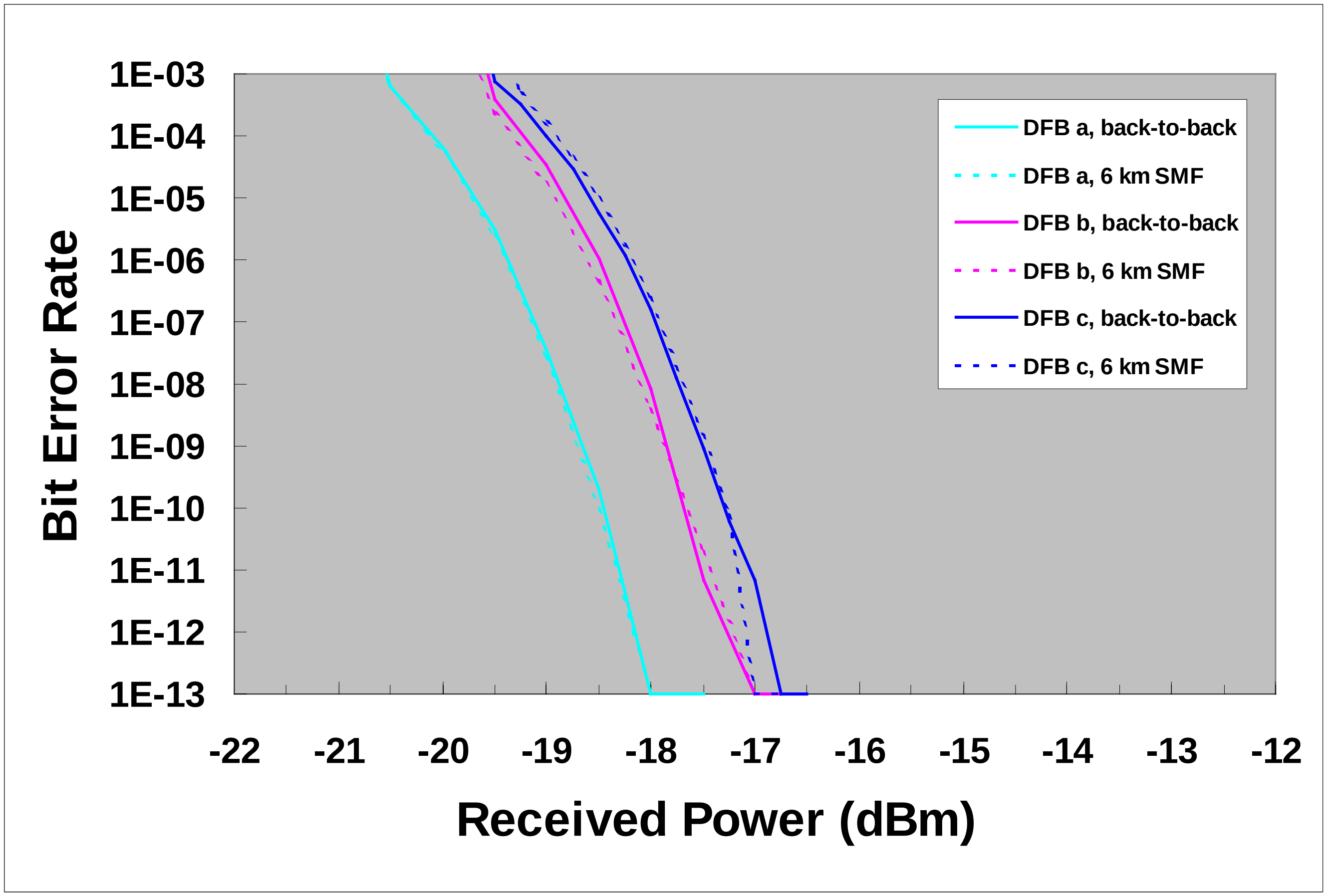
Typical BER for DFBs with High SMSR



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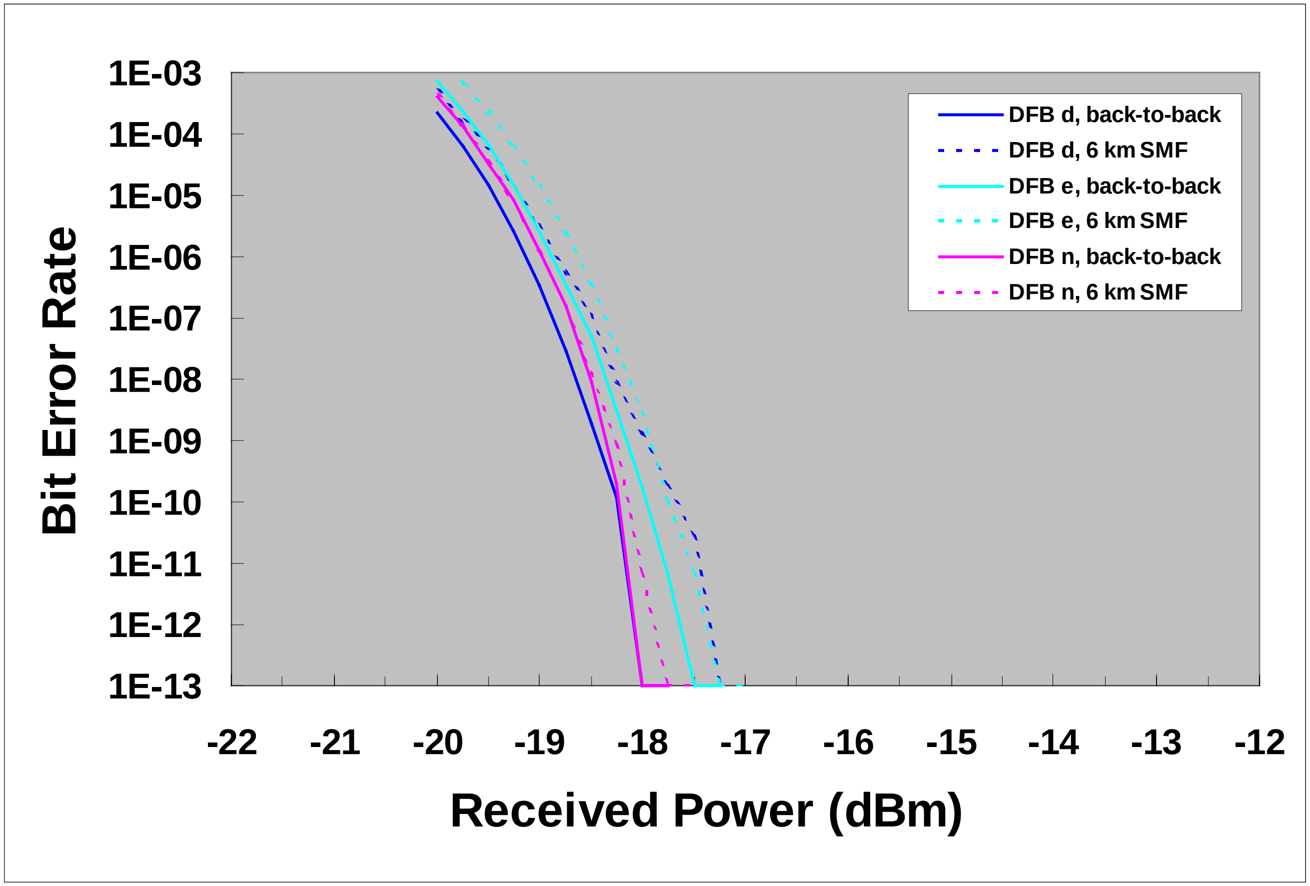
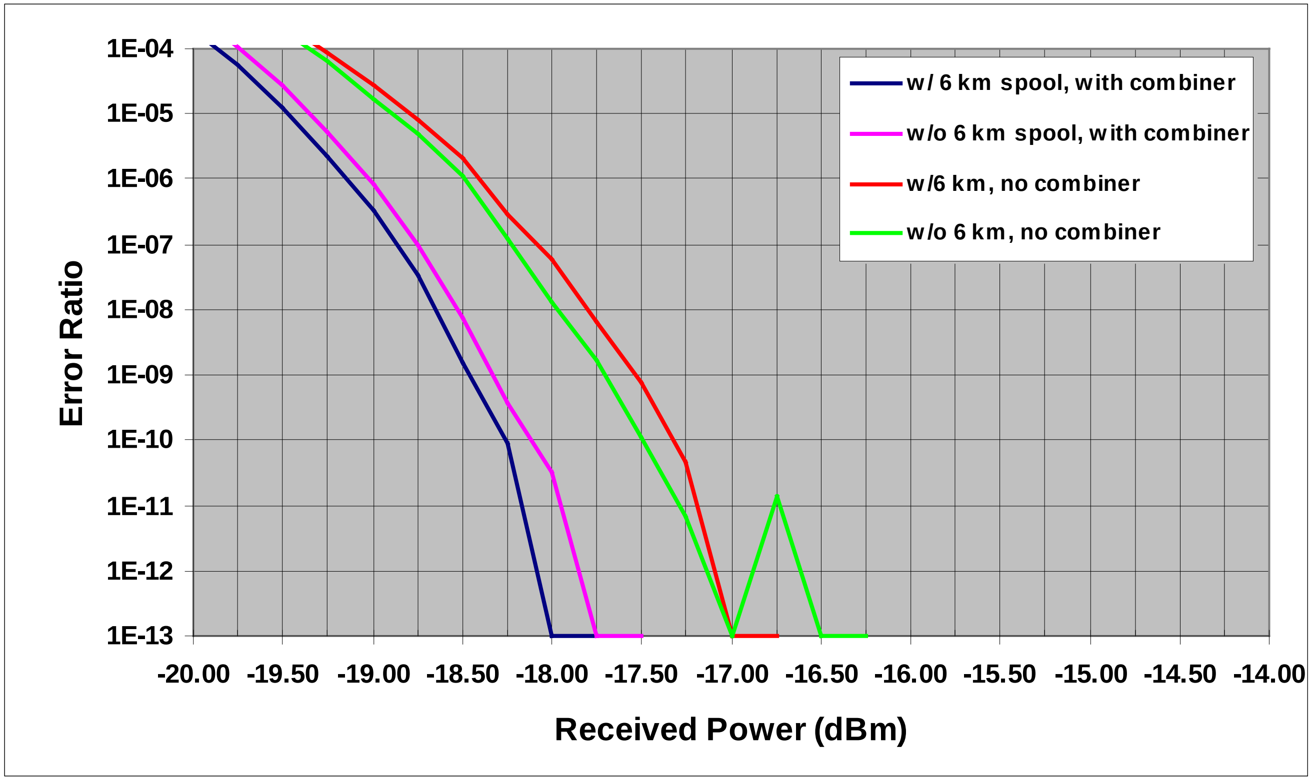
Typical BER for DFBs with Low SMSR



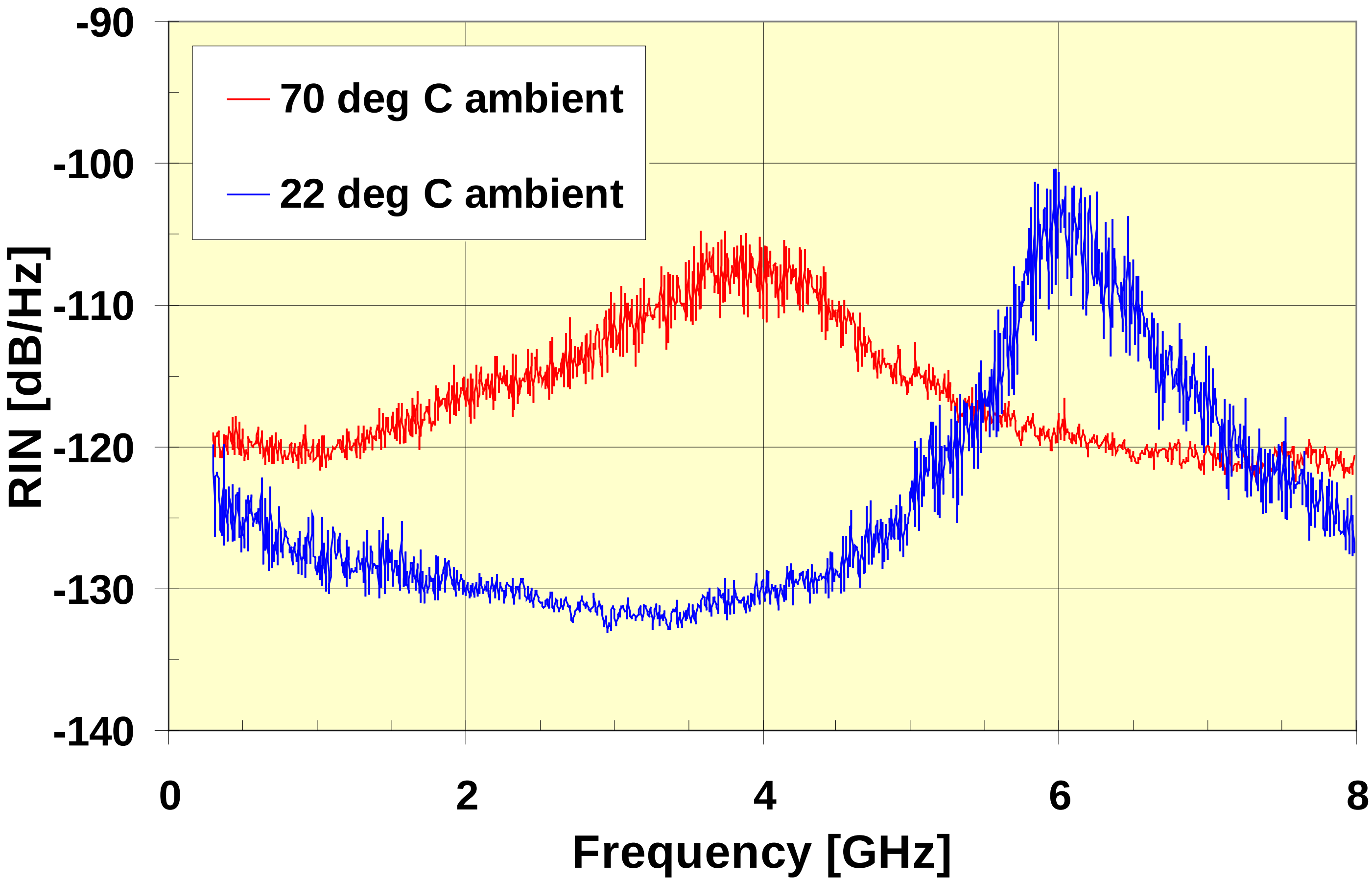
BER with and without the Waveguide Combiner



2.488 GBd
2^7 - 1 PRBS
e.r.~10.4 dB

RIN Temperature Comparison

Laser n (SMSR = 5 dB)

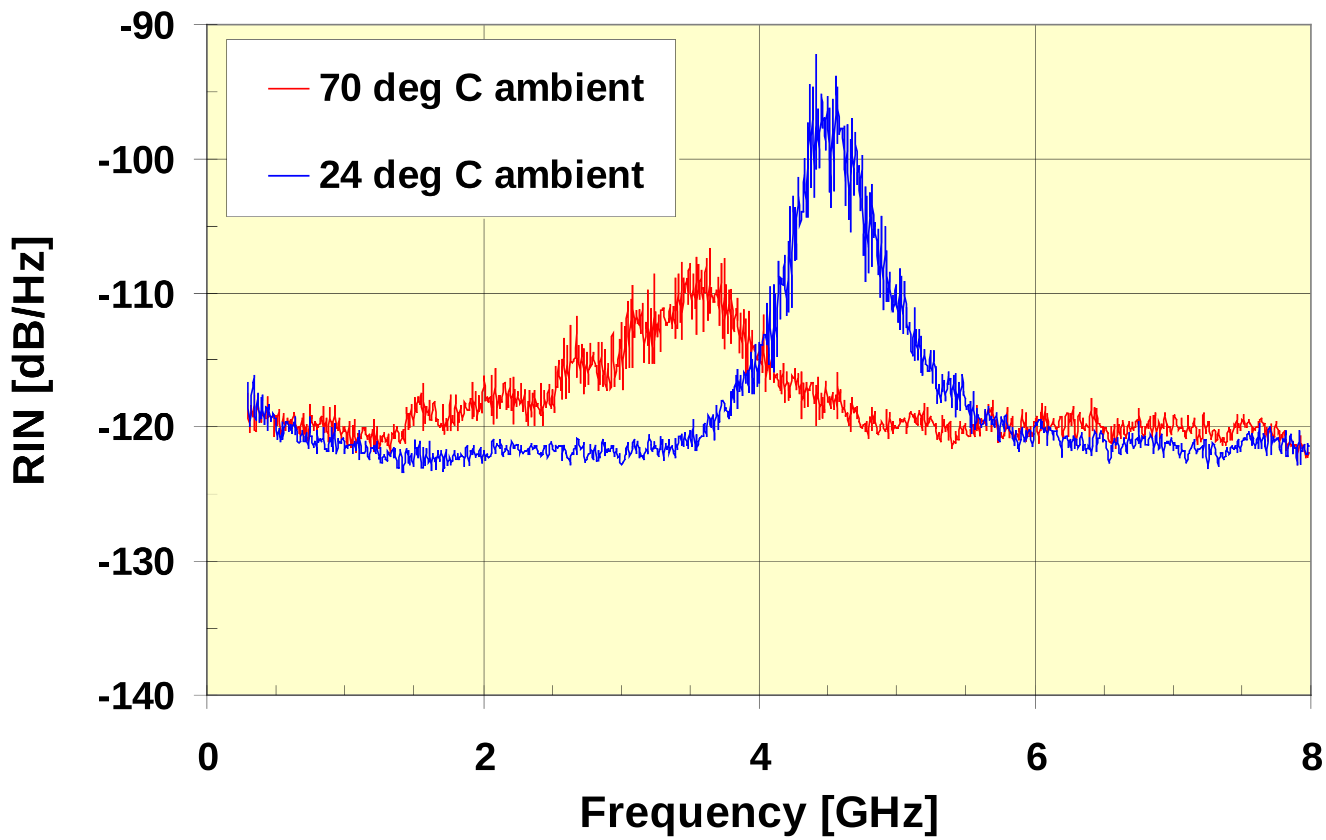


I_{ave} = 35 mA
2.5 Gb/s Rcvr
P_{out} = -7 dBm
RIN_{av} = -119 dB/Hz

I_{ave} = 21.5 mA
2.5 Gb/s Rcvr
P_{out} = -3 dBm
RIN_{av} =-127 dB/Hz

RIN Temperature Comparison

Laser s (SMSR = 40 dB)



I_{ave} = 32.5 mA
2.5 Gb/s Rcvr
P_{out} = -9 dBm
RIN_{av} = -120 dB/Hz

I_{ave} = 14.5 mA
2.5 Gb/s Rcvr
P_{out} = -9 dBm
RIN_{av} =-121 dB/Hz

WWDM DFB Source Study - Conclusions

- 1300-nm DFBs with no specification on SMSR and no isolator are suitable for our application.
- Measured RIN < -117 dB/Hz over all SMSR
- Measured PP < 1 dB due to MPN over 6 km SMF
- Measured BER < 10^{-12} over 6 km SMF
- Current DFBs with I_{bias} ~ 15 mA have sufficient output power and f_r
- BER results improved with waveguide combiner
- Total PP < 2 dB over 6 km SMF

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