WWDM Transceiver Update and 1310 nm eye-safety

Brian E. Lemoff and Lisa A. Buckman
Hewlett-Packard Laboratories
lemoff@hpl.hp.com

IEEE 802.3 HSSG Meeting

Montreal, Quebec
July 5-9, 1999

HEWLETT PACKARD

Overview

I. Review of HP WWDM Proposal

II. Demultiplexer results

III. Crosstalk results

IV. Multimode link results

V. 1310nm eye-safety

HP Labs / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

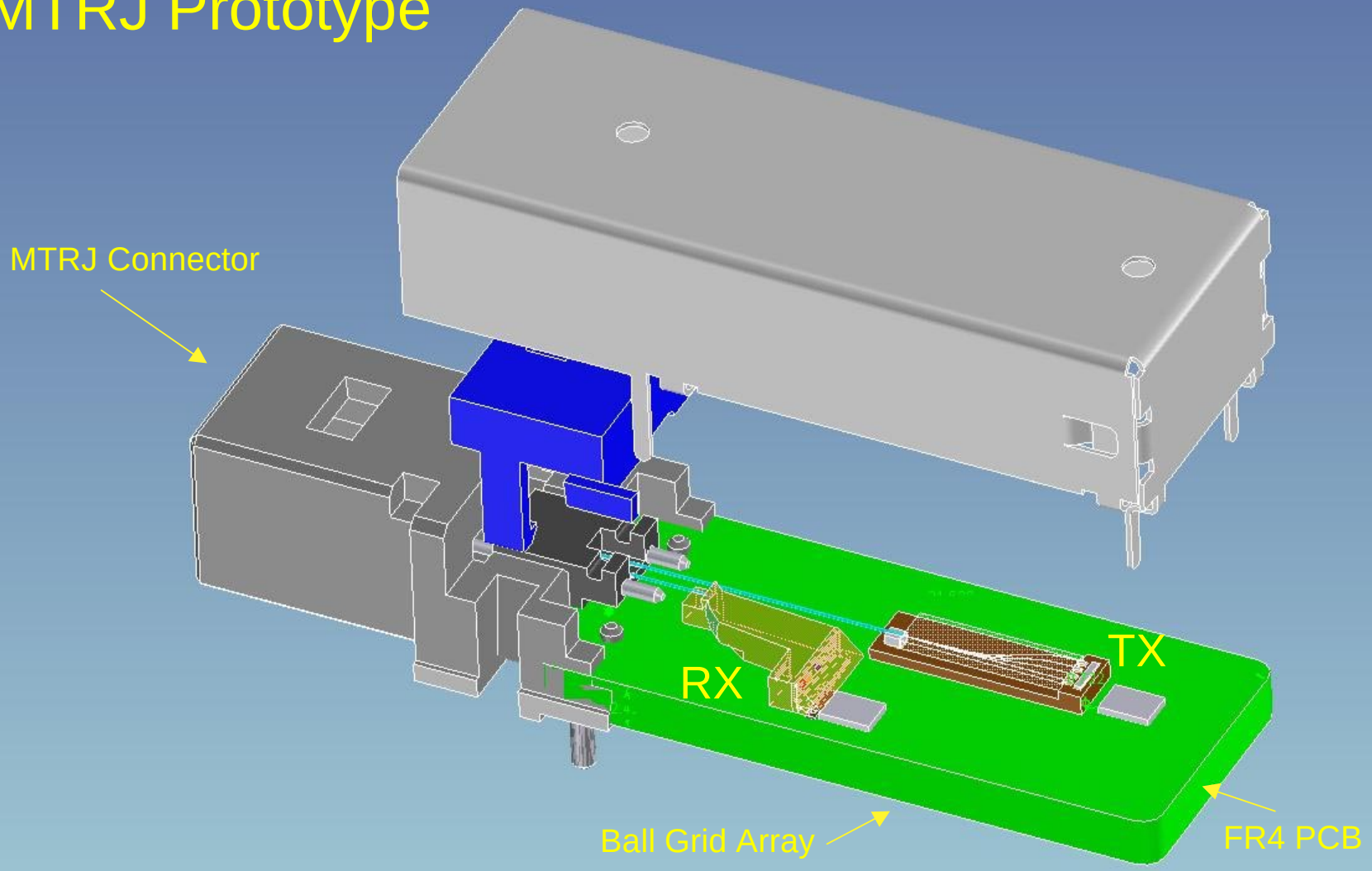
HP WWDM Proposal

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 / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

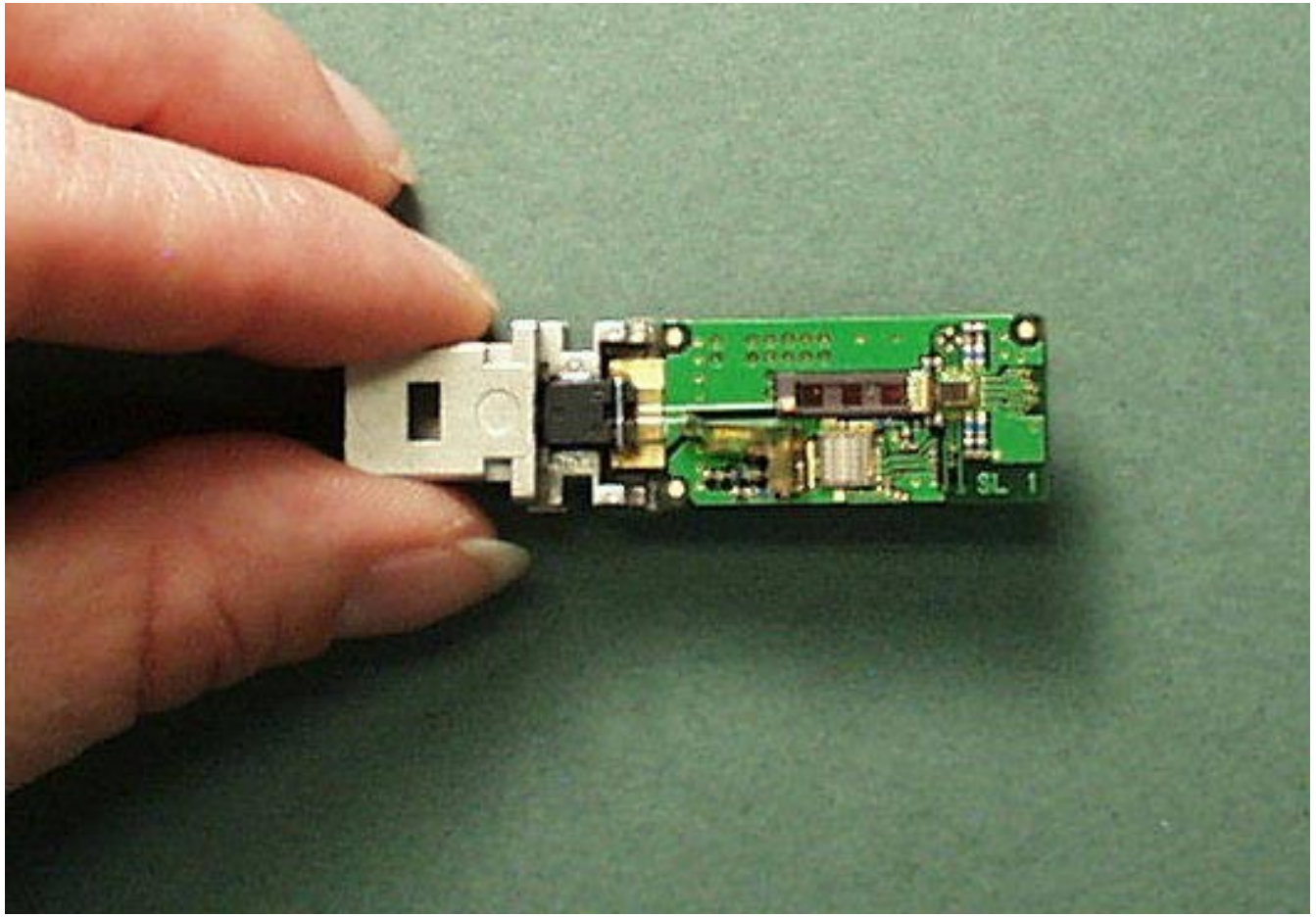
HP Labs WWDM MTRJ Prototype



HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab
Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

Assembled WWDM MTRJ Module

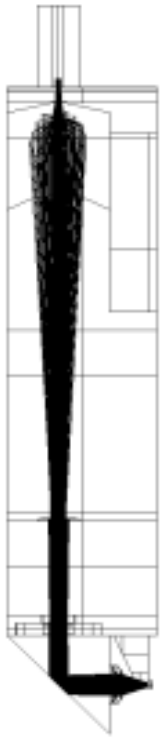


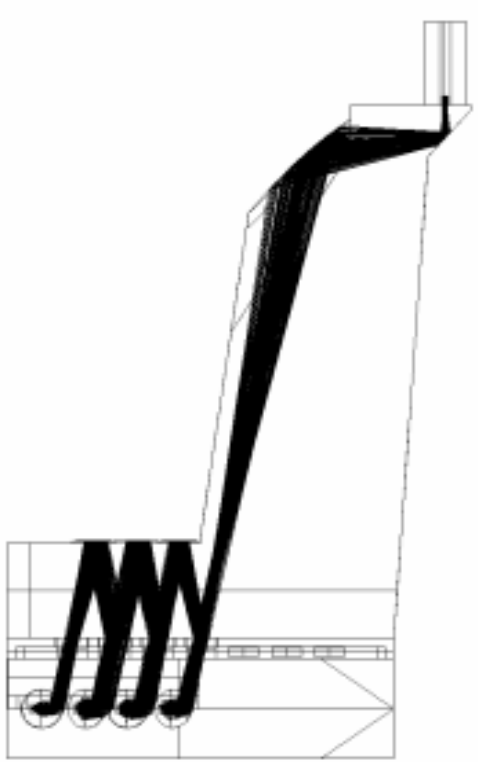
HP Labs / Communications and Optics Research Lab

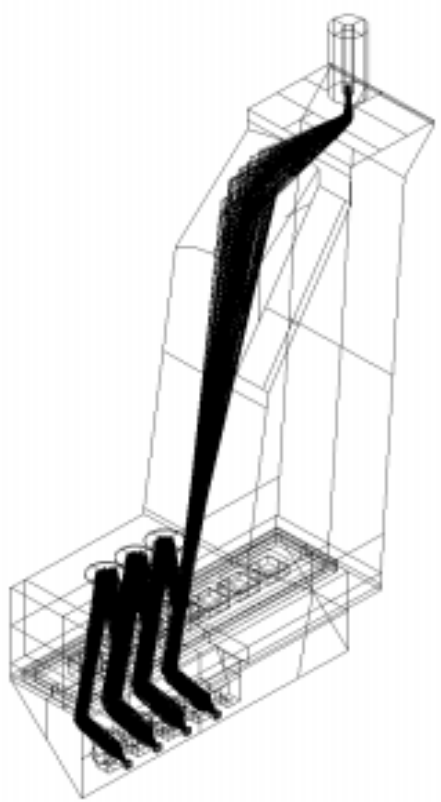
Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

Wavelength Demultiplexer

Three views of ray tracing in wavelength demultiplexer





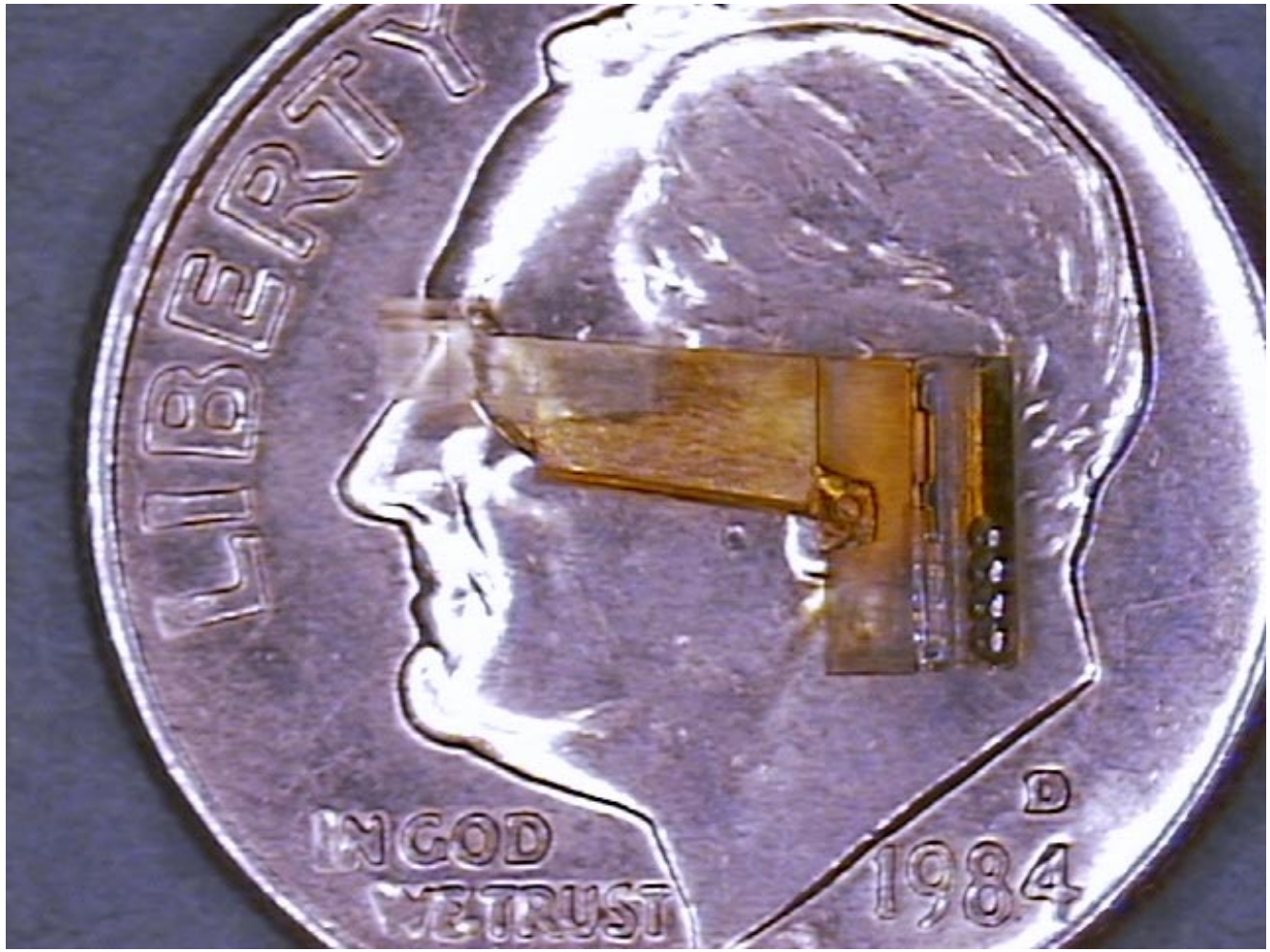


HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

Wavelength Demultiplexer



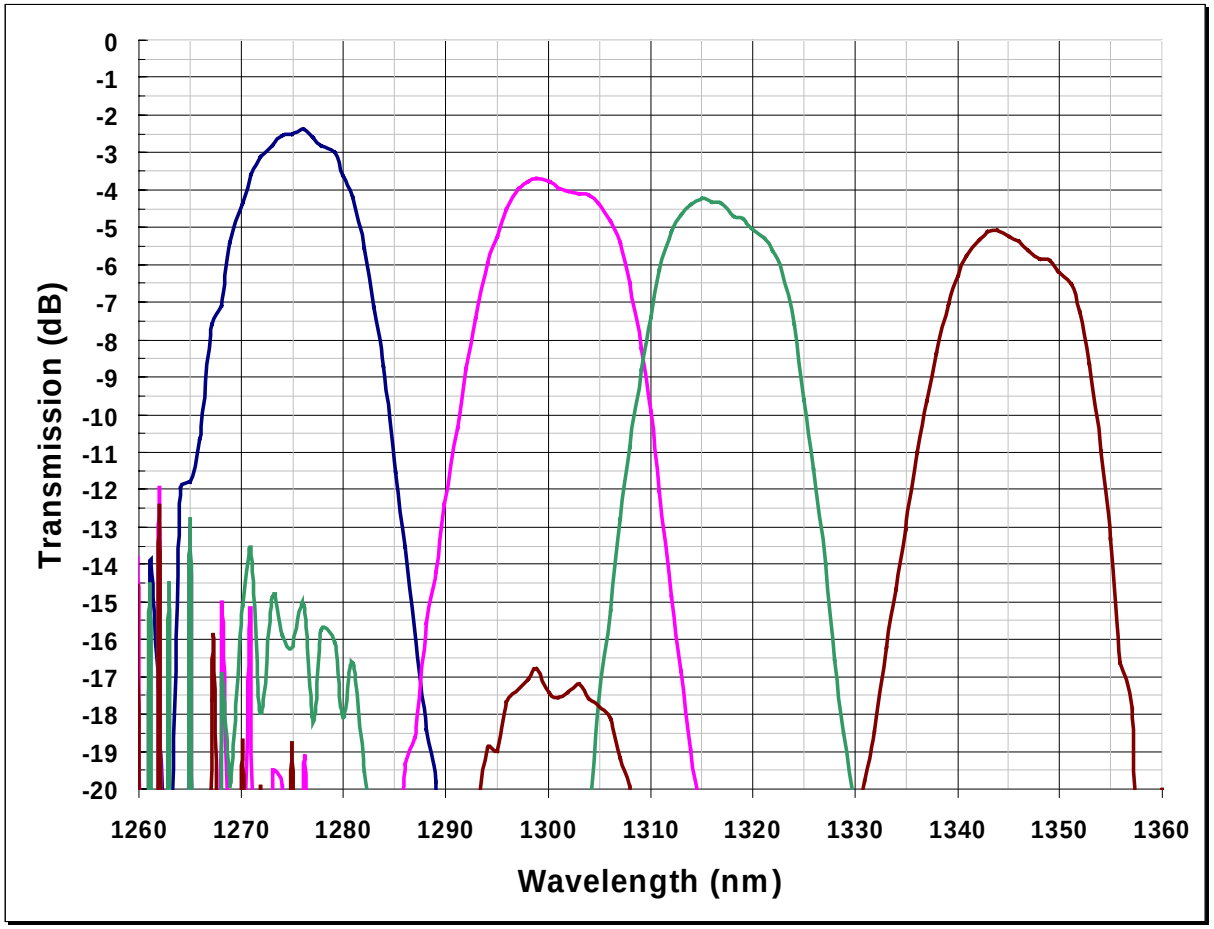
HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

Demultiplexer Transmission Spectrum

First results using home-grown interference filters

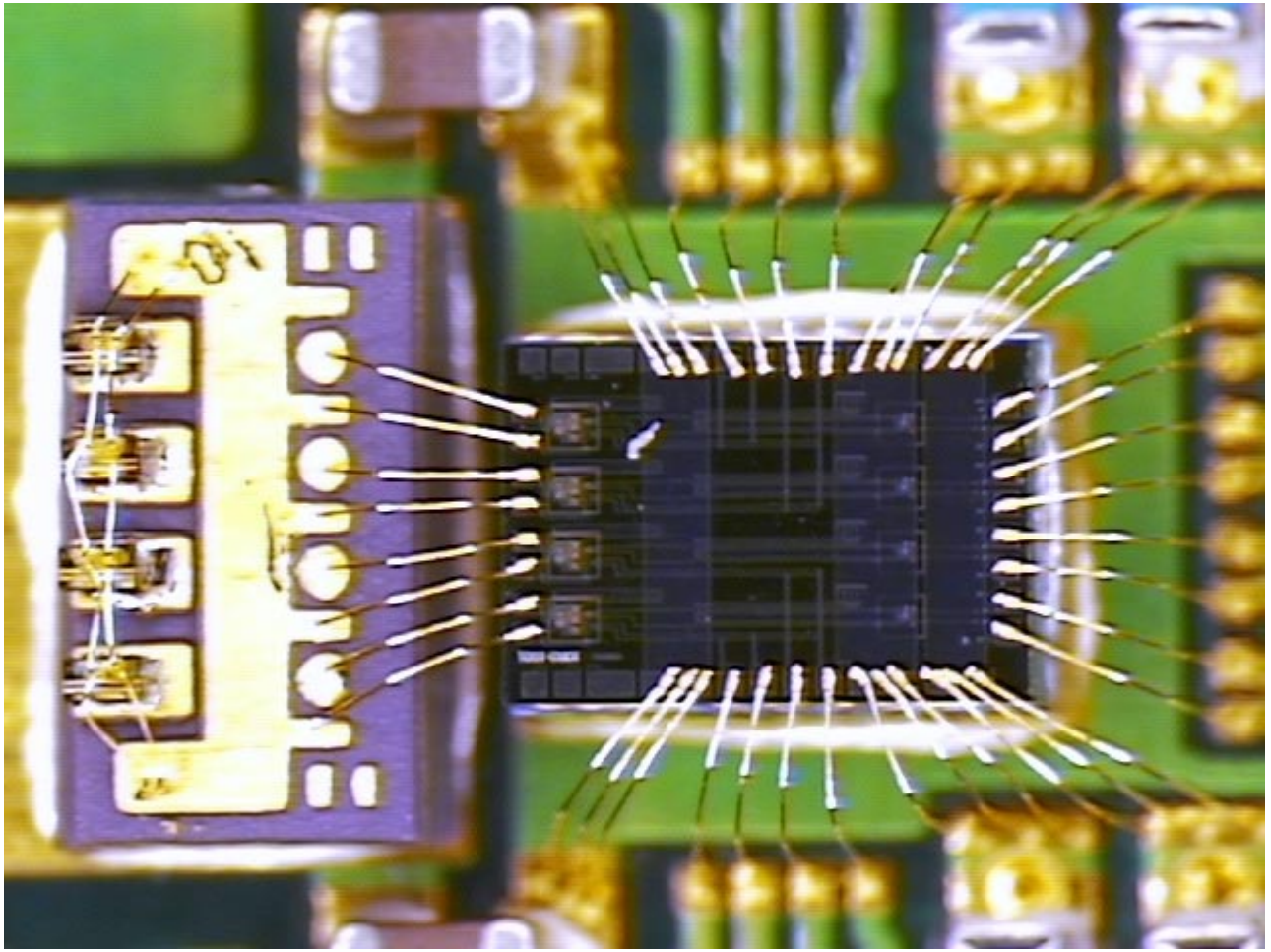


HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

4-channel Transmitter IC

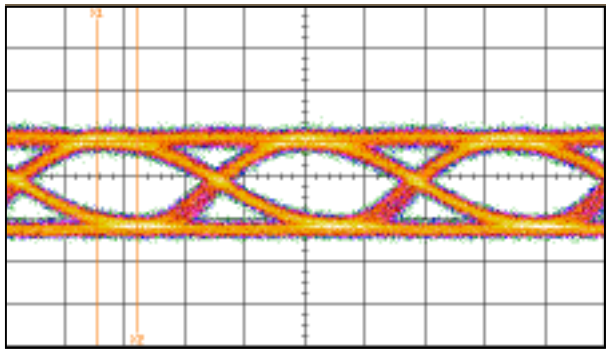


Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

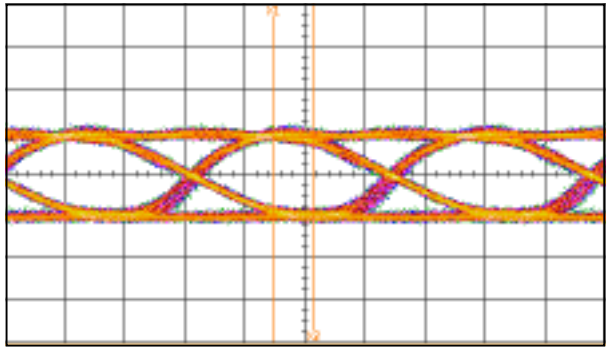
TX Interchannel Crosstalk Performance

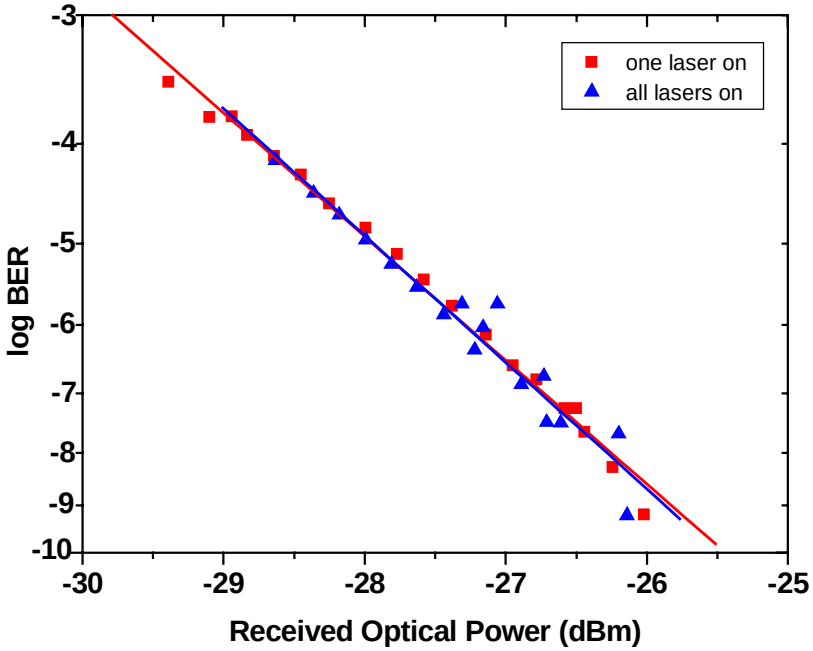
Measured with external RX; 2.488 Gb/s 2^7-1 PRBS

Single TX channel on, others off



All 4 channels on





BER curves show no power penalty for single channel vs. four channels on TX.

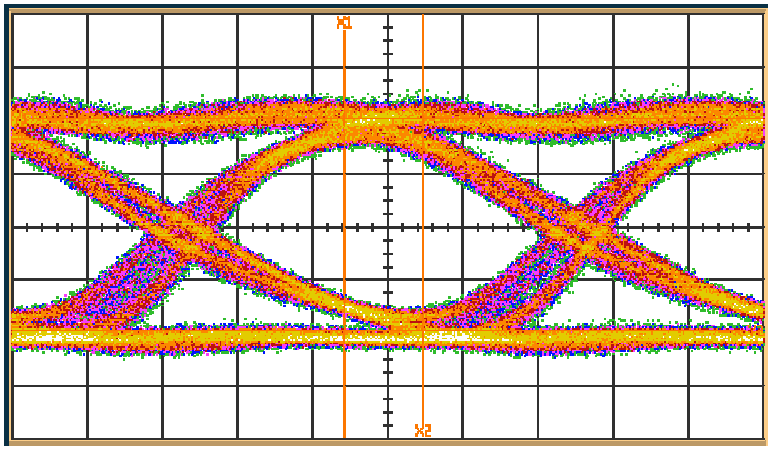
HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab

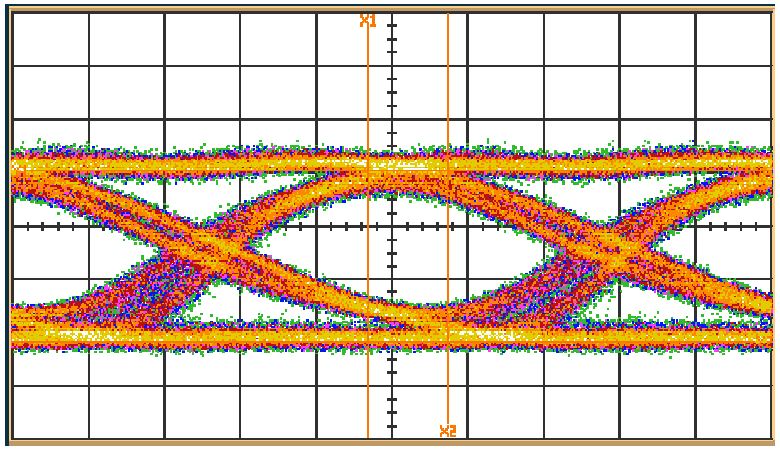
Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

TX Interchannel Crosstalk at 3.125 Gbaud

One channel on, three off
3.125 Gb/s PRBS
extinction 8.4 dB



All four channels on
3.125 Gb/s PRBS
extinction 9.0 dB

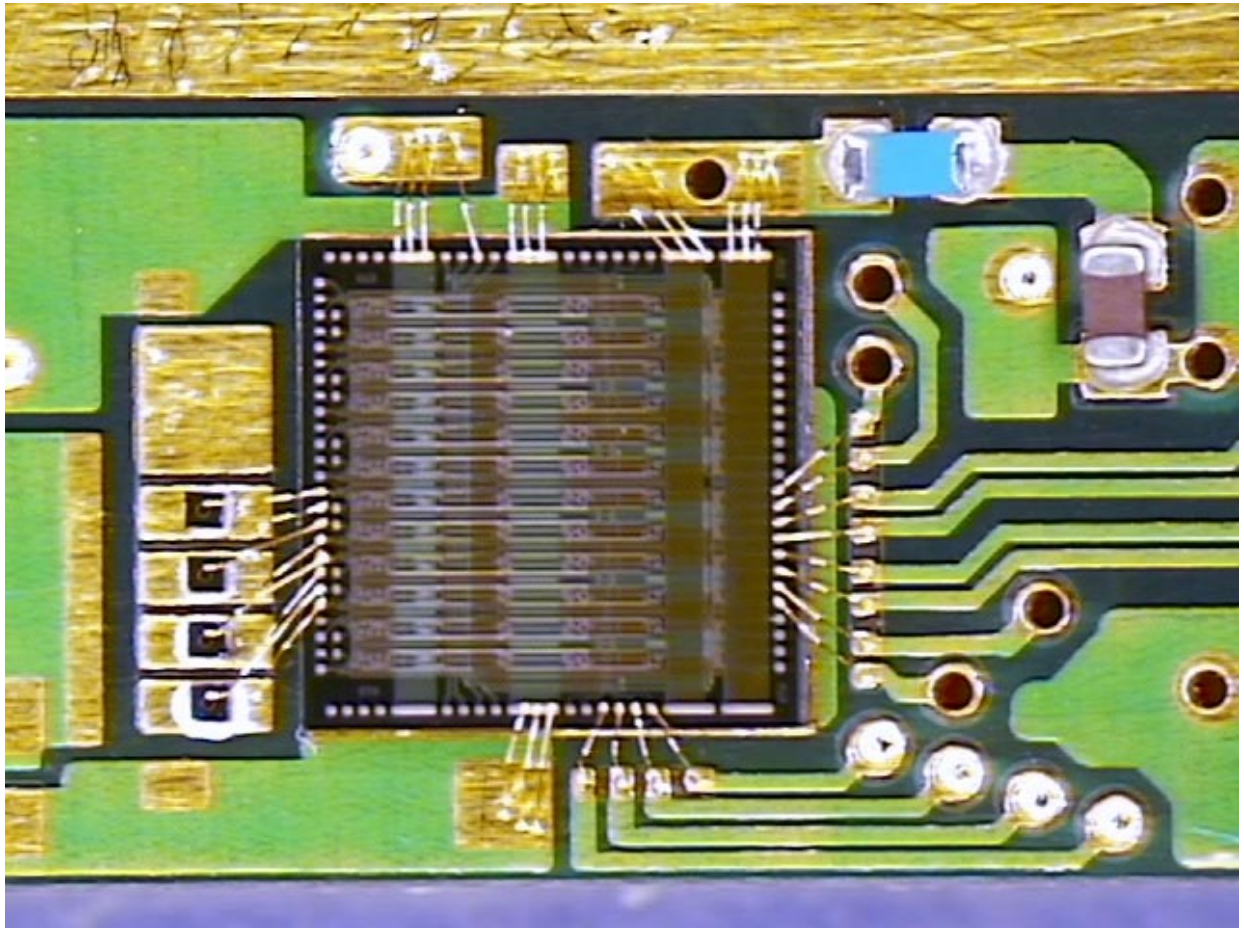


HEWLETT PACKARD

HP Labs / Communications and Optics Research Lab
Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

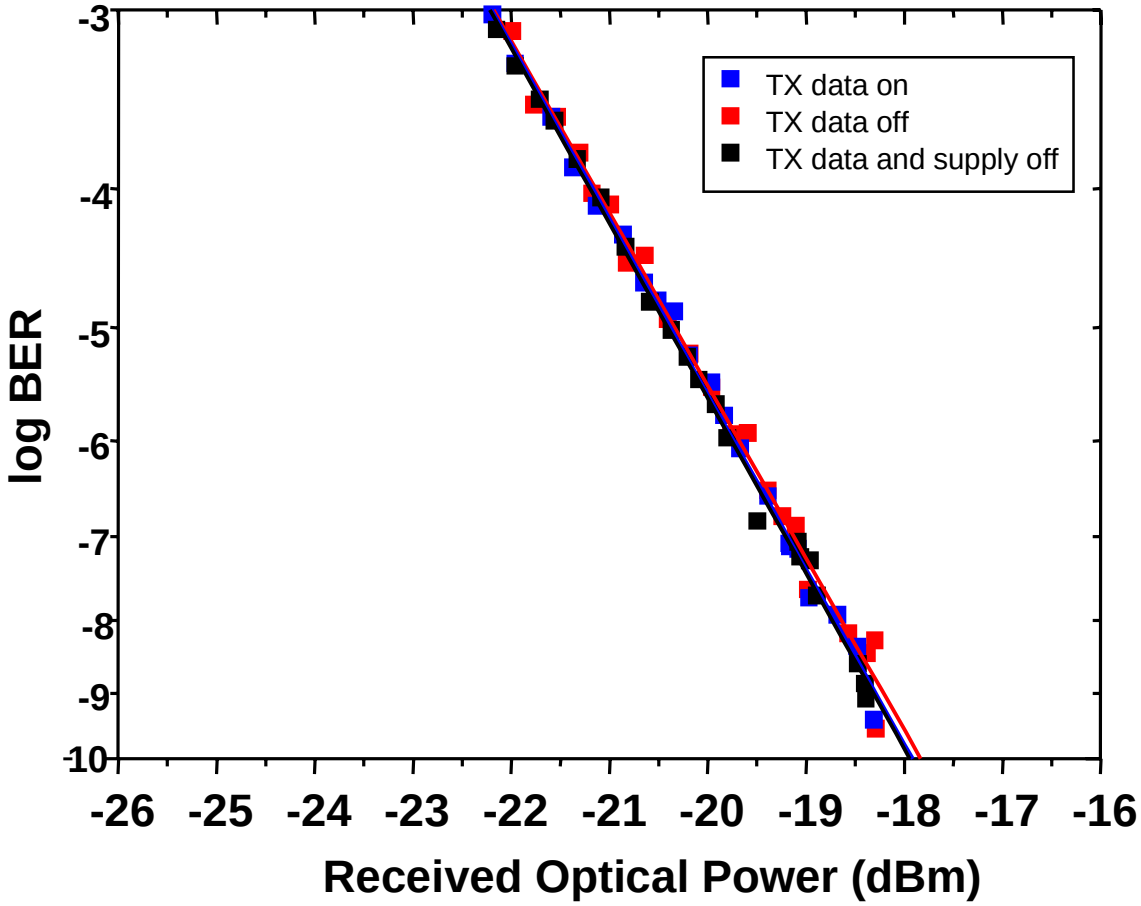
12-Channel RX IC - Using 4 channels

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



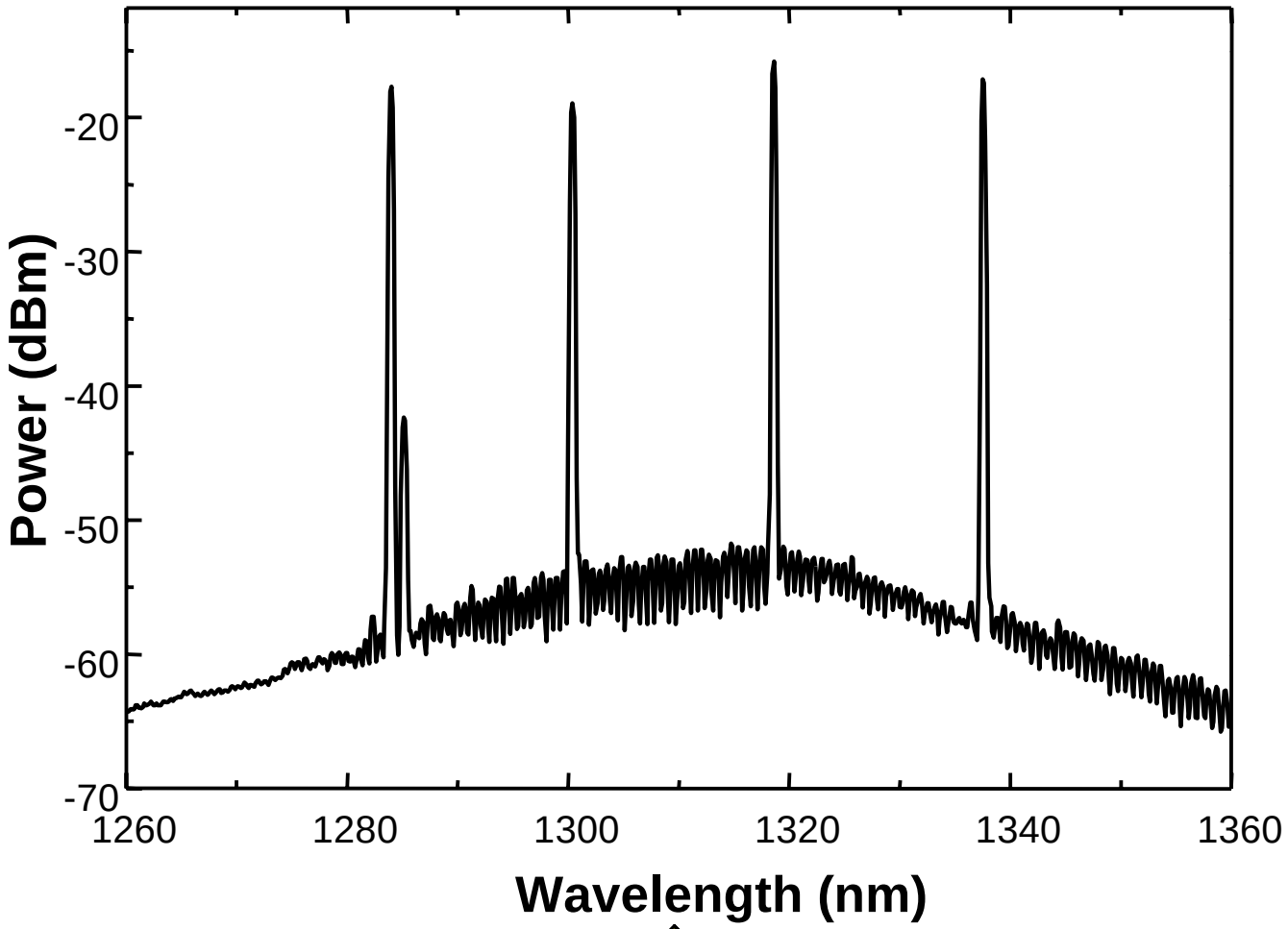
TX-to-RX Crosstalk at 2.488 Gb/s

No power penalty is observed in RX due to 4-channel TX data



Multiplexed Spectrum

Using multimode polymer waveguide combiner



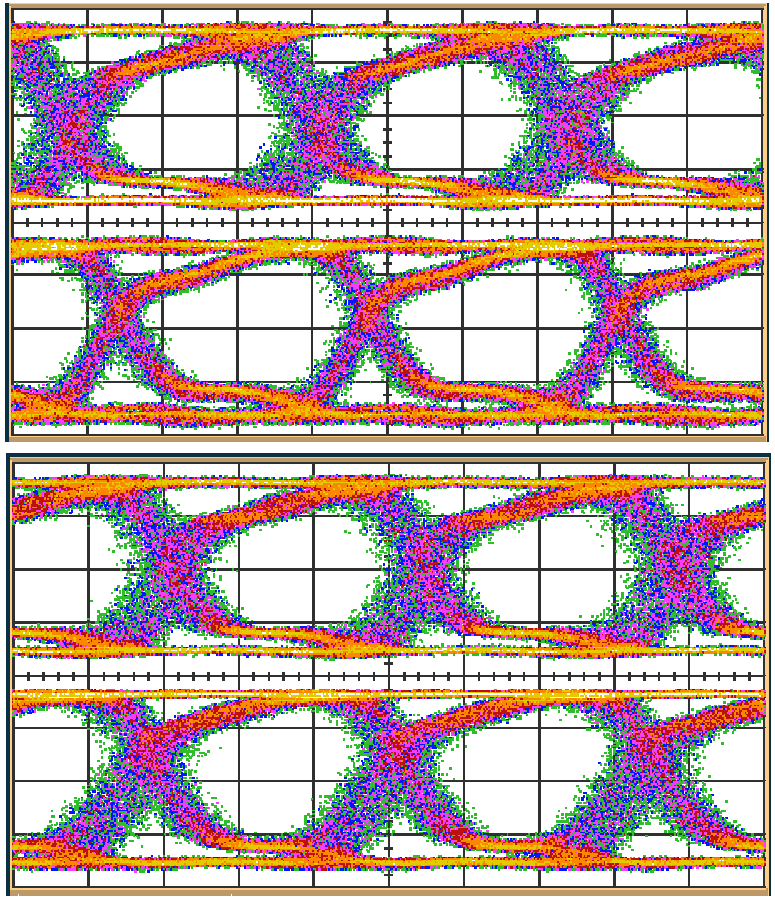
SpectraLAN-LX Link Results: 300 m MMF

1340 nm

1320 nm

1300 nm

1280 nm



2.488 Gbaud/channel

2^7-1 PRBS

Multimode Polymer Mux

Injection-molded demux

Total launch power: -2 dBm

HP Labs / Communications and Optics Research Lab

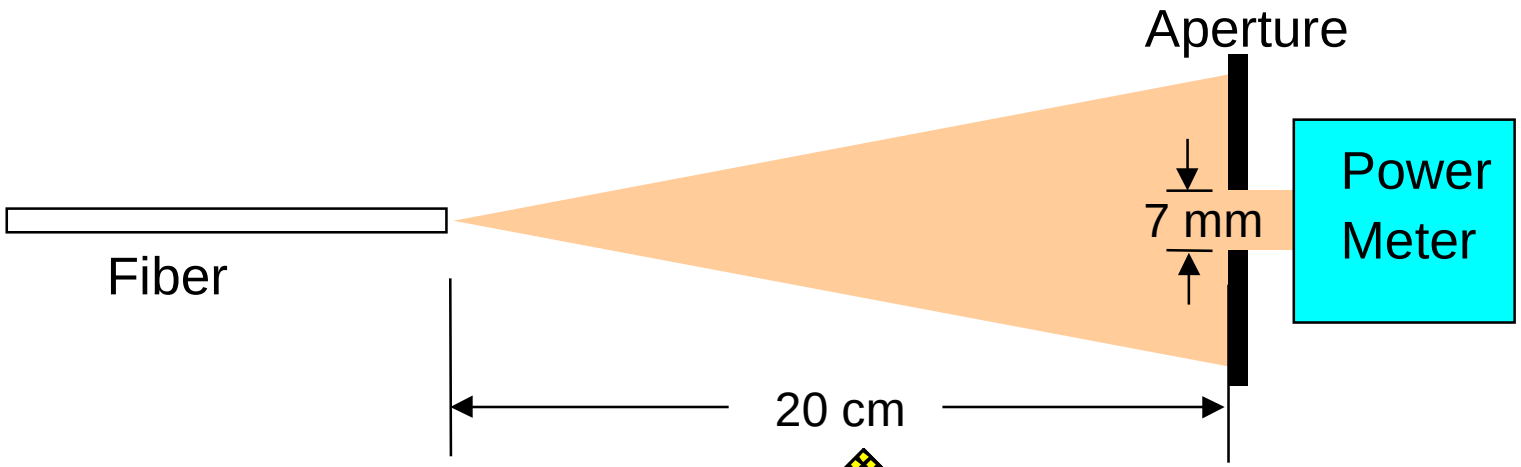
Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.

Class 1 Eye Safety

At 1310nm, in SMF, FDA/CDRH is more restrictive than IEC

FDA Center for Devices and Radiological Health
21 CFR Ch1 (4-1-98 Edition), sec. 1040.10 guidelines specify that for Class 1:

No more than 0.195 mW of average power may pass through an aperture 7 mm in diameter at a distance of 20 cm from the end of the fiber.



Class 1 Eye Safety - (cont'd)

According to Corning spec., SMF mode field diameter is between 8.8 μm and 9.8 μm. Thus use 9.8 μm as worst case (i.e. lowest NA). Assume gaussian beam.

Waist (1/e^2 intensity radius) = 4.9 μm at fiber tip.

At 20 cm, we have:

$$w(z) = \frac{\lambda z}{\pi w_0} = \frac{(1310\,\text{nm})\,(20\,\text{cm})}{(3.1416)\,(4.9\,\mu\text{m})} = 17\,\text{mm}$$

$$I(r) = \frac{2P}{\pi w^2}\exp\left(\frac{-2r^2}{w^2}\right) \propto \exp\left(-0.0069\,r^2\right)$$

Class 1 Eye Safety - (cont'd)

The fraction of power passing through a 7mm aperture is:

$$\eta = \frac{2}{\pi w^2}\int_0^a 2\pi r \exp\left(\frac{-2r^2}{w^2}\right)dr = 1-\exp\left(\frac{-2a^2}{w^2}\right)$$

$$\eta = 1-\exp\left(\frac{-2(3.5\,\text{mm})^2}{(17\,\text{mm})^2}\right) = 0.081$$

Thus, allowed Class 1 fiber power, is

$$P = \frac{0.195\,\text{mW}}{0.081} = 2.41\,\text{mW} = +3.8\,\text{dBm}$$

(Note: For 8.8 μm mode field diameter, $P = +4.7\,\text{dBm}$.)

Why is there confusion?

A limit of +2dBm is often cited

Lucent Technical Note: “Laser Safety and Optical Fiber Communications Systems”, March 1999 computes a +2dBm Class 1 eye-safety limit.

The authors followed the identical calculation, but took “Mode Field Diameter” to mean 1/e intensity, rather than $1/e^2$ intensity, as it is normally defined. They also assumed 8.8μm as MFD.

Question: What is largest MFD allowed and how accurate is the gaussian model in predicting eye-safety?

Thanks to Richard Booman and Scott Lowrey of Network Elements for bringing this Lucent Technical Note to my attention.

Eye Safety and WWDM

Power Budget should allow 4-channel eye-safe operation

Eye-safe limit at 1300 nm:	+3.8 dBm
Limit per channel:	-2.2 dBm
Demultiplexer loss:	<6 dB (worst case)
Link Budget:	<8 dB (expected)

∴ Required receiver sensitivity <-16.2 dBm

Several dB of margin remains with existing Si IC technology.

Next generation IC's will have even more margin.

HP Labs / Communications and Optics Research Lab

Brian Lemoff and Lisa Buckman/ Optical Comm. & Meas. Dept.