DUNE VD/PD Cryogenic Digital Optical Links
DUNE Photodetector Consortium Workshop

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Fermilab

Outline

Brief review of the strategy

Testing results of TOSAs (laser diodes, monitor photodiodes)

Testing of laser driver ICs

- Electrical testing
- Combined electrical/optical testing
- Plans for improving results

LED/Photodiode-based solutions

Sidebar: Optical spectrum of laser diodes at 295 K and 77 K

Discussion

Some Background
Digital Optical Links vs Analog Optical Links

Digital Optical Links are characterized by…

Noise margin advantages (+)

Flexibility in coding (error detection/correction) (+)

Signal to quantization noise is unavoidable (-)

Much industry experience and many components (at room temperature) (+)

Time Division Multiplexing may be employed (+)

Analog Optical Links are characterized by …

Lower cost and complexity in typical installations (+)

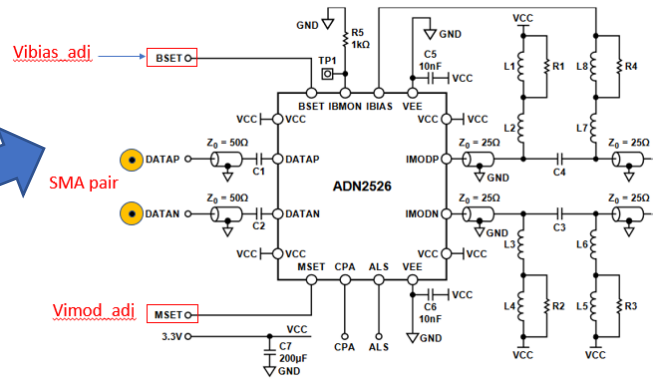
Higher signal to noise requirements typically imply higher power (-)

Transfer function must be well characterized to insure extraction of original signal (calibration) (-)

Strategy: Digital Optical Links Test Program
295 K and 77 K

COTS
SFP+ Transceivers

Laser Driver Selection



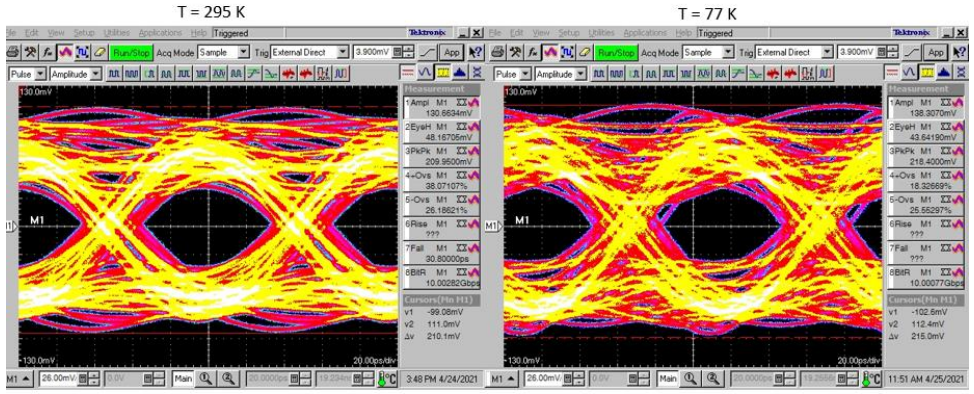
COTS Laser Driver ICs

Laser Diode Selection

COTS Laser Diode (TOSAs)

Driver Testing

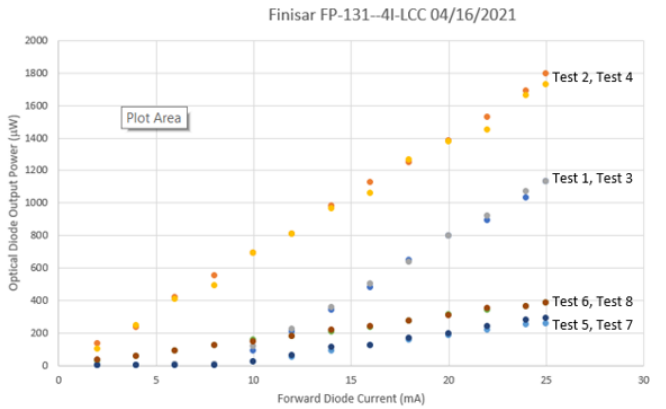
Control of Modulation Current



Peak to Peak = 210 mV (cursors)

Peak to Peak = 215 mV (cursors)

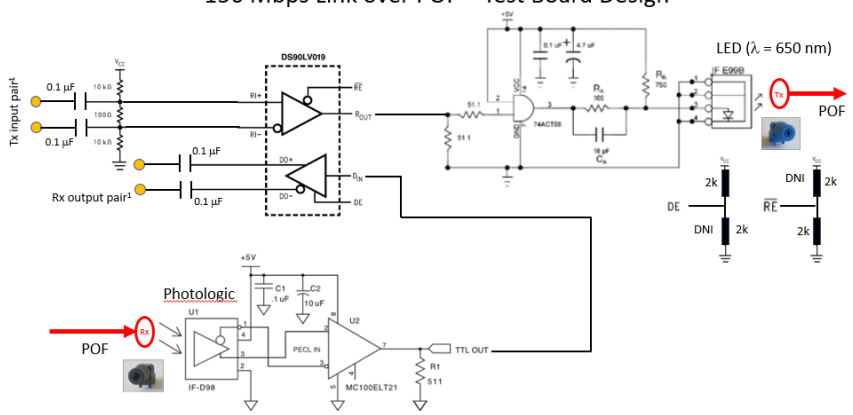
Diode Testing



Slope efficiency estimate
1800 µW/25 mA
~= 72 µW/mA*

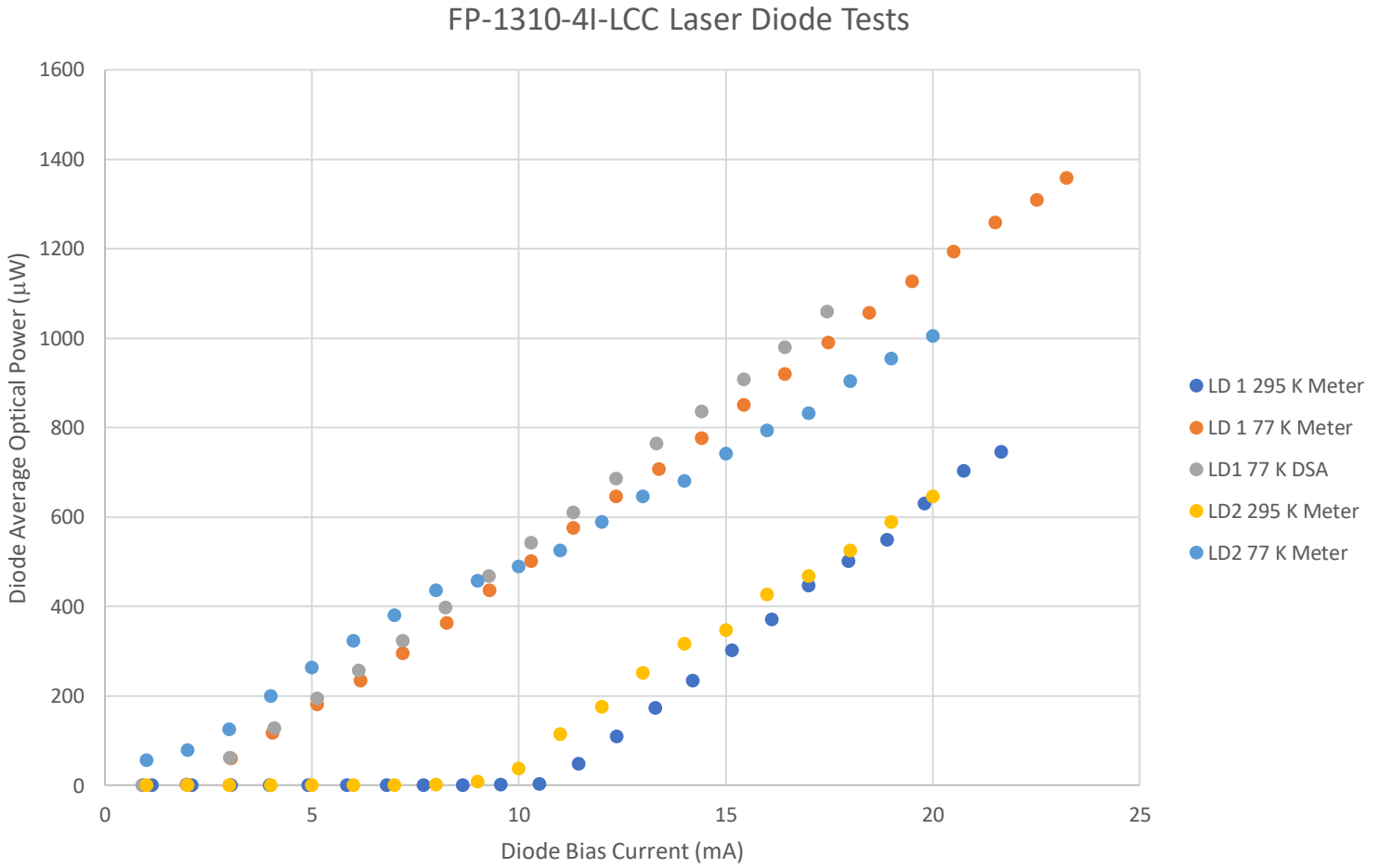
Alternative Approach:
LED/Photologic Pair
Over Plastic Optical Fiber
(~150 Mbps)

156 Mbps Link over POF – Test Board Design



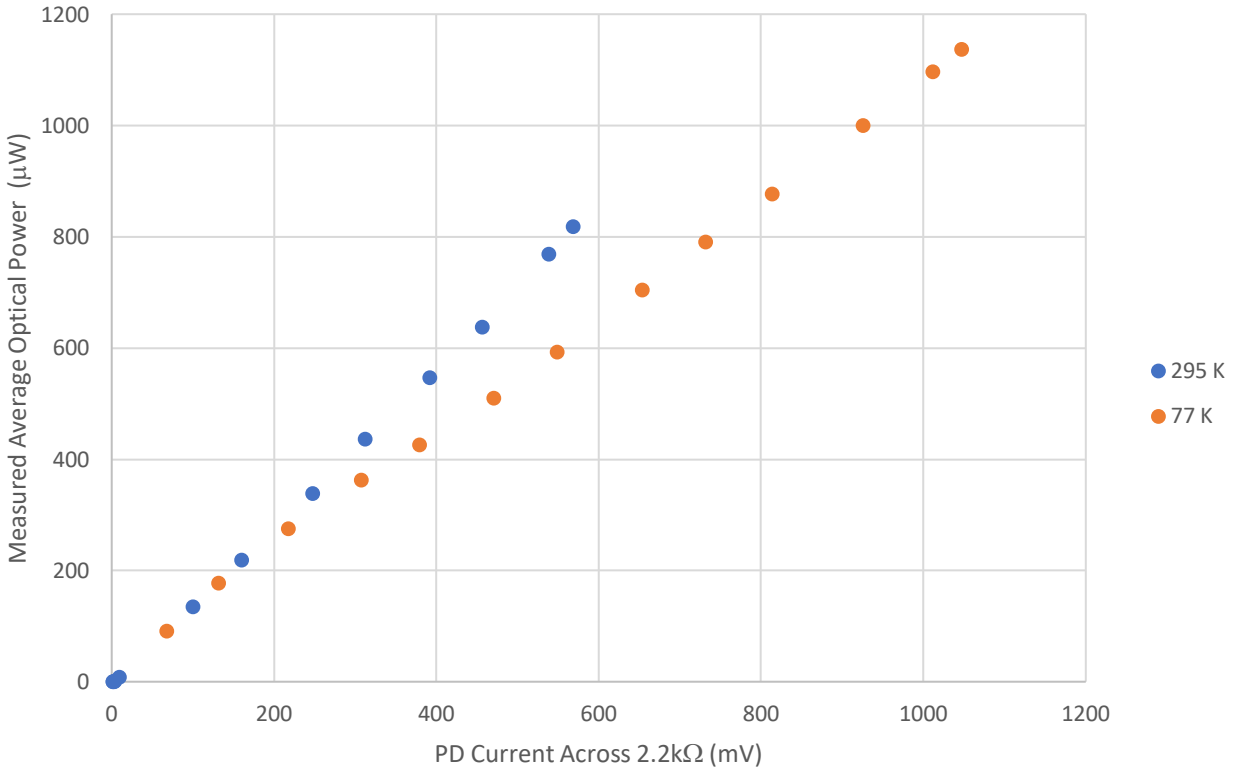
Plan: Bring Together for Custom Gbps Transmitter

Cumulative TOSA Laser Diode Testing Summary
FP-1310-4I-LCC (4 Gbps rated)

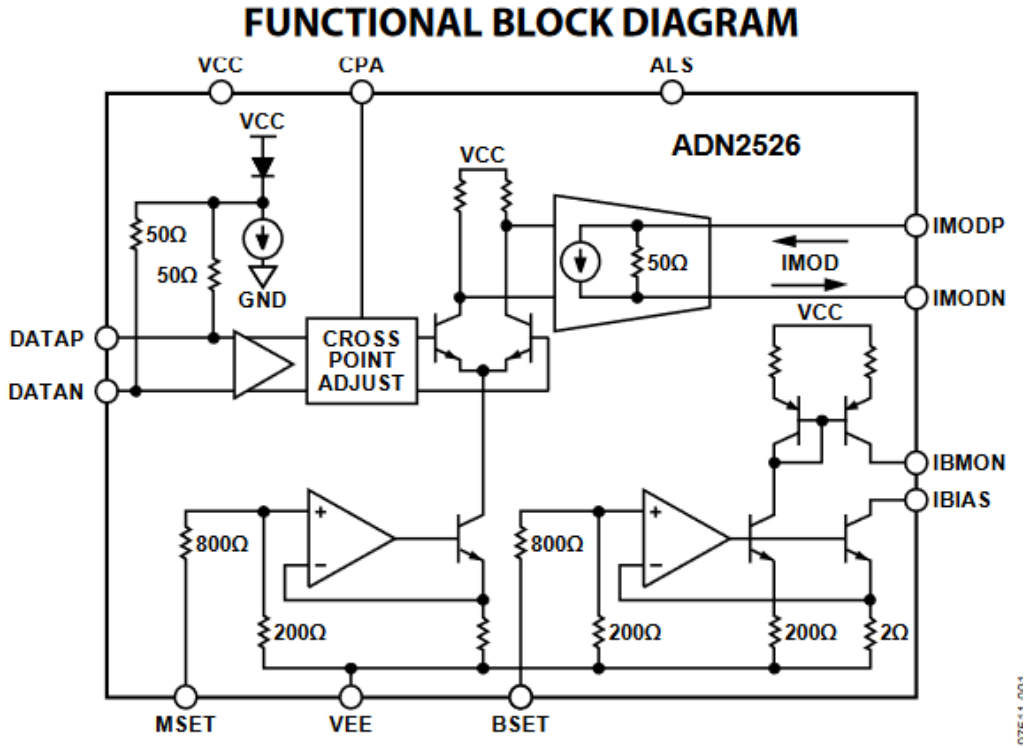


Results obtained with 50 µm core Multimode Fiber and Matrix LC Latch
LD1 results obtained with laser mounted on ADN2526 Test Board (controlled by laser driver BSET circuit)
LD2 results obtained with laser directly connected to trim pot circuit

TOSA Monitor Photodiode Testing Summary
FP-1310-4I-LCC (4 Gbps rated)



ADN2526 Laser Driver



Results obtained with 50 µm core Multimode Fiber
and
Matrix LC Latch

Testing with ADN2526 Laser Driver Custom LN2 Board – Version 1

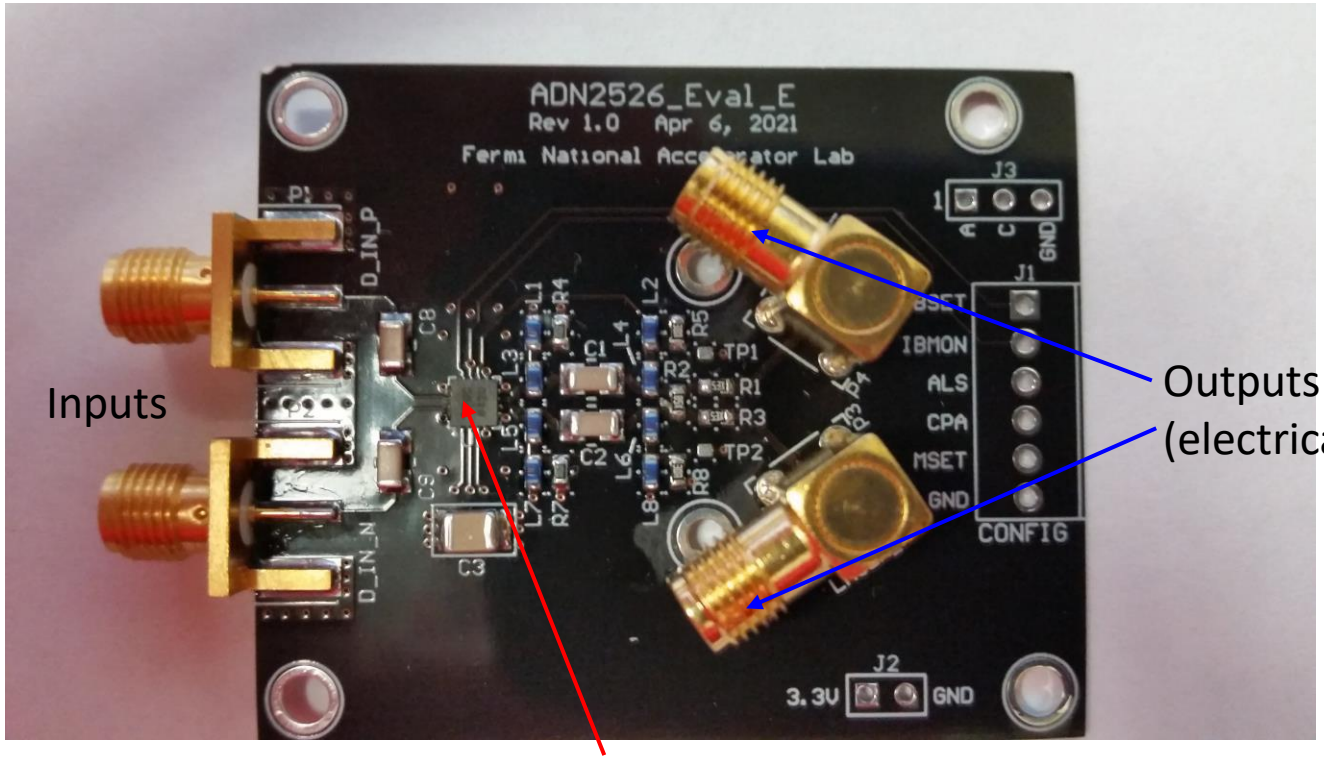
Room temperature testing first, followed by testing in LN2
- Electrical Testing
- Optical Testing (with Finisar FP-1310-4I-LCC and MMF)

ADN2526

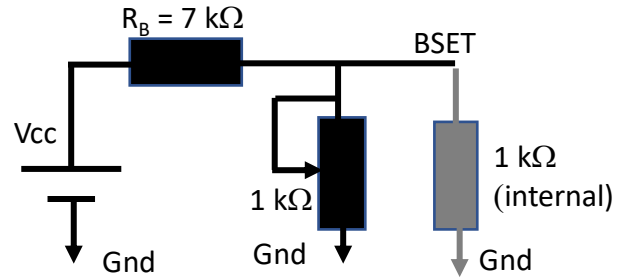
BIAS CONTROL INPUT (BSET)				
BSET Voltage to IBIAS Gain		90		mA/V
BSET Input Resistance		1000		Ω
MODULATION CONTROL INPUT (MSET)				
MSET Voltage to IMOD Gain	50	78	100	mA/V
MSET Input Resistance		1000		Ω

FP-1310-4I-LCC

Operating Current	T_c = 25°C	I_{OP}		32		mA

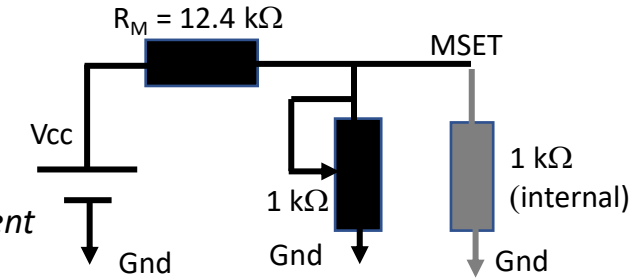


To establish Bias Current



For BSET = 0.22V (Ibias = 20 mA)

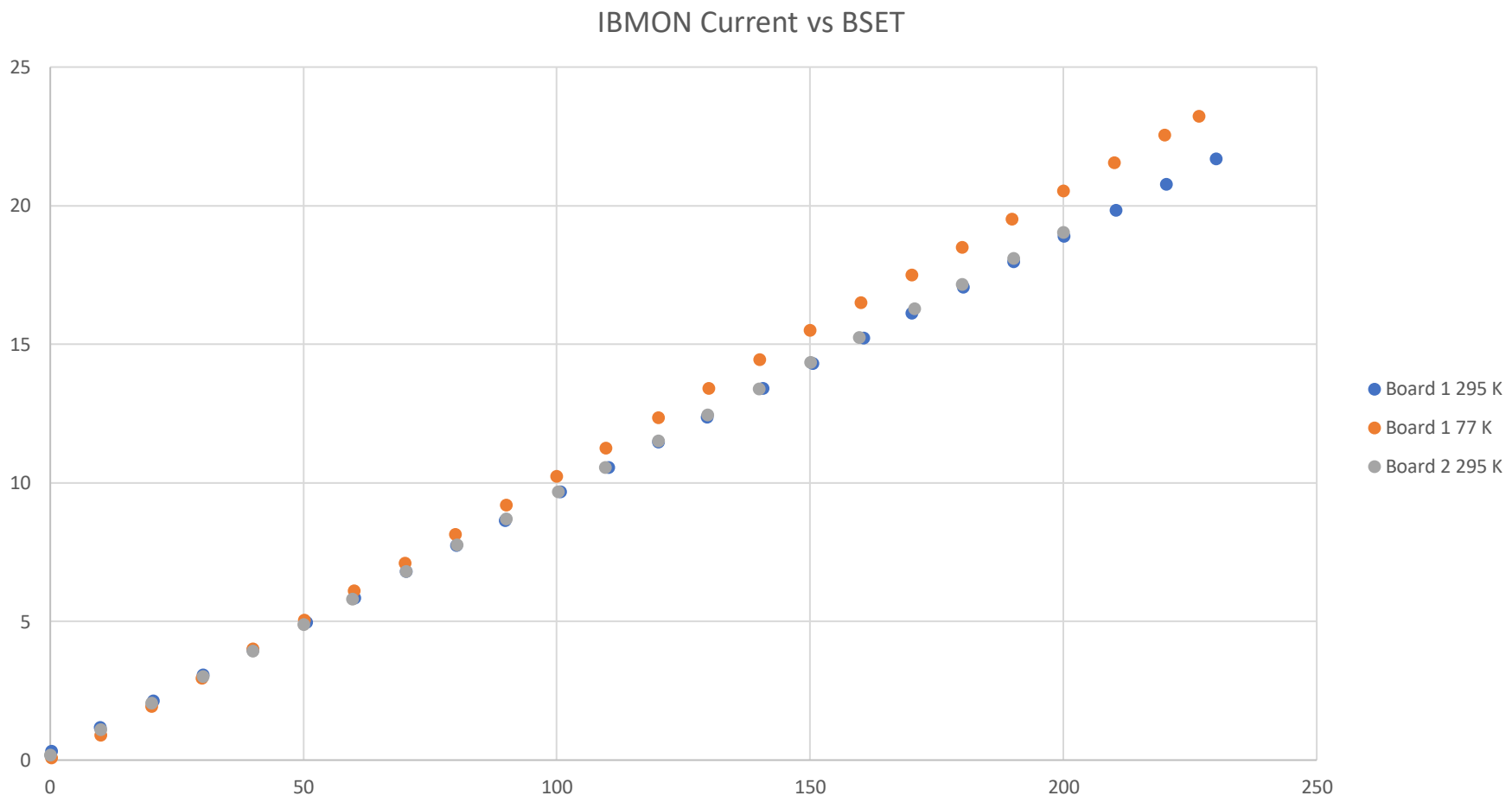
To establish Modulation Current



For MSET = 0.13 (Imod = 10 mA)*

**Based on FP-1310-4I-FCC Measured Slope Efficiency with MMF. Calculations in Extra Slides*

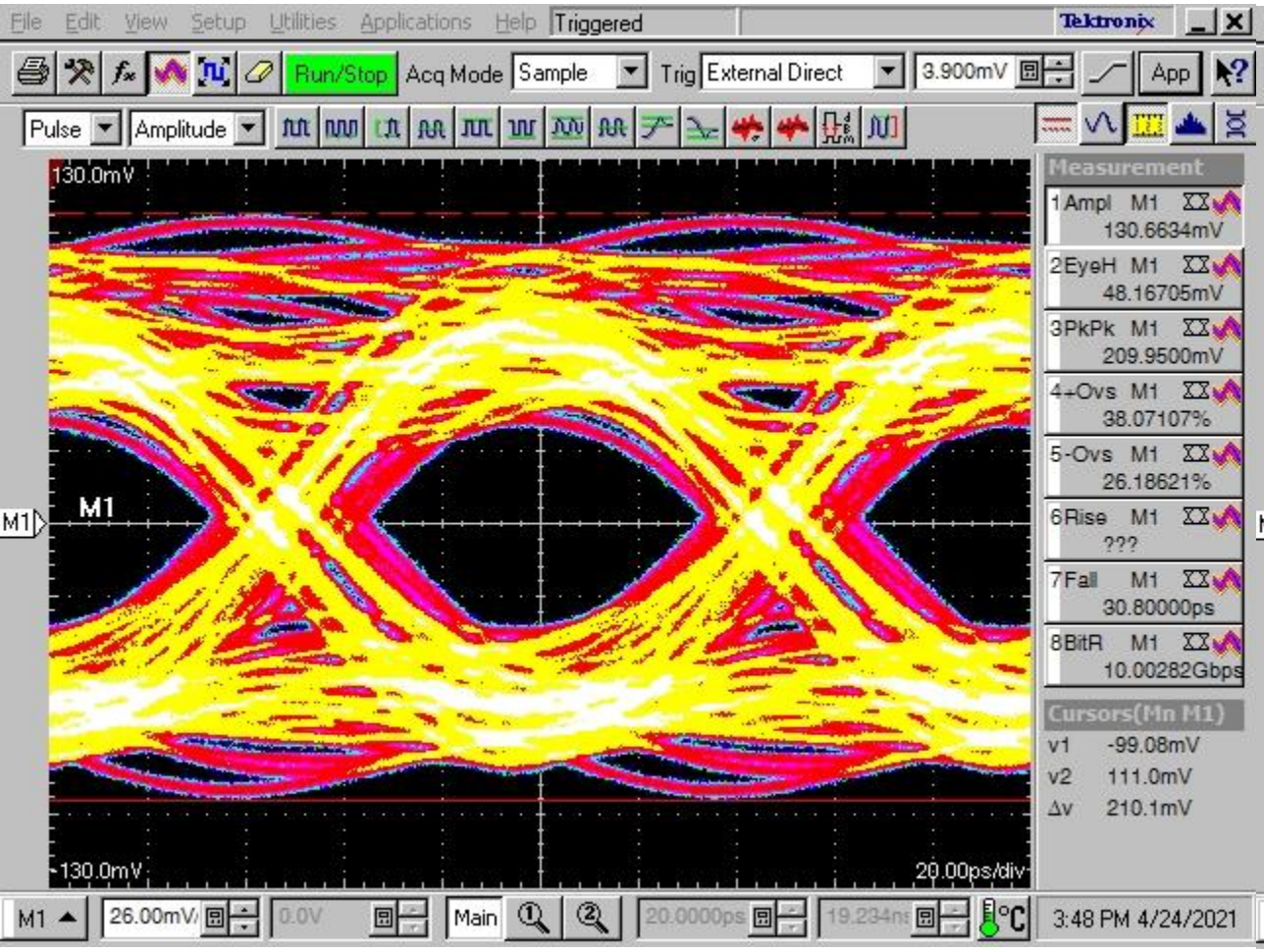
ADN2526 Laser Driver Electrical Testing
Bias Setting Performance (BSET)



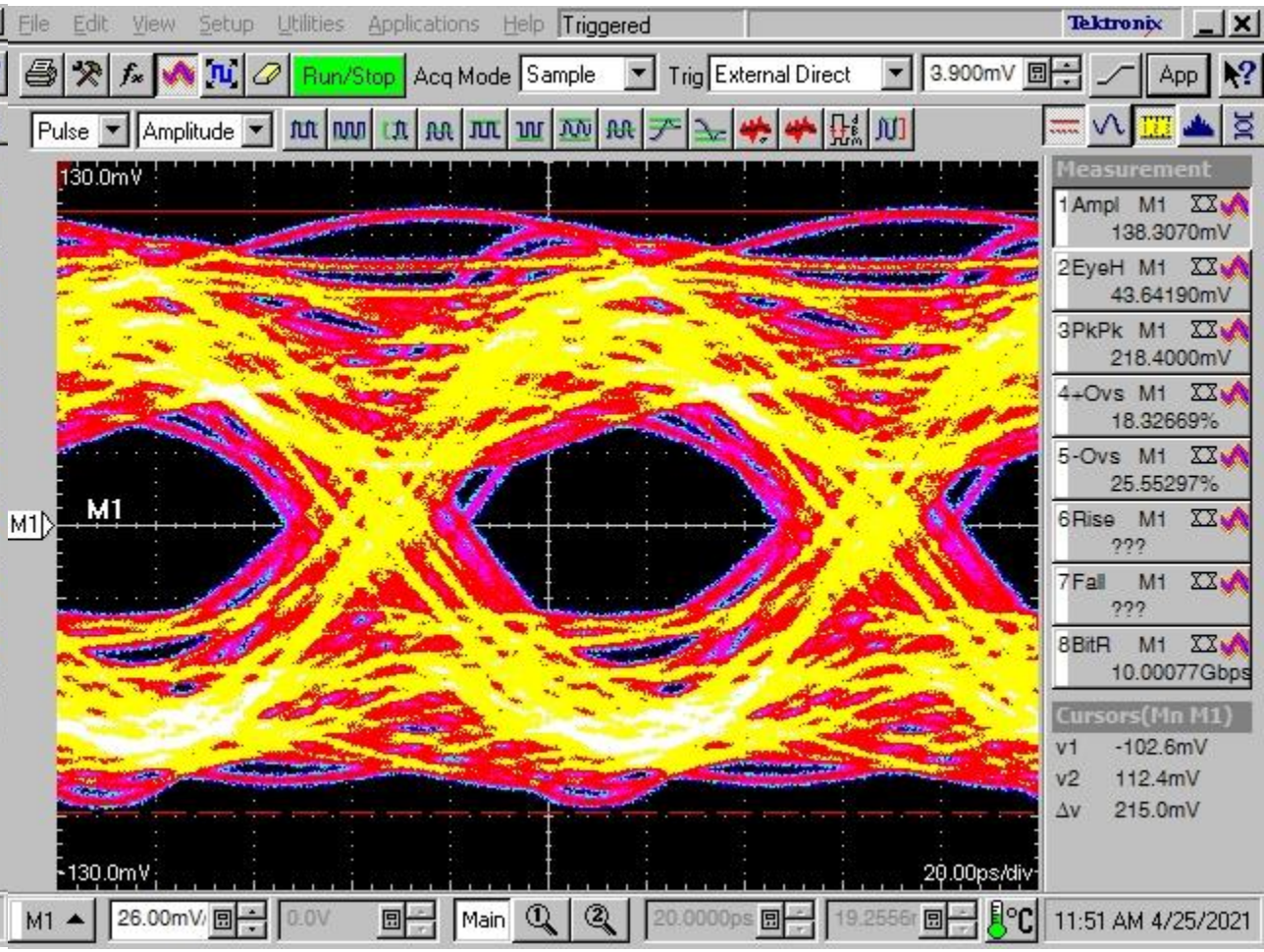
Results agree nicely from one device to the next
Results for one device tested show little variation when immersed in LN2

ADN2526 Laser Driver Electrical Testing – Board 1
Modulation Setting Performance (MSET) and Temperature

295 K



77 K



Peak to Peak Amplitude = 210 mV

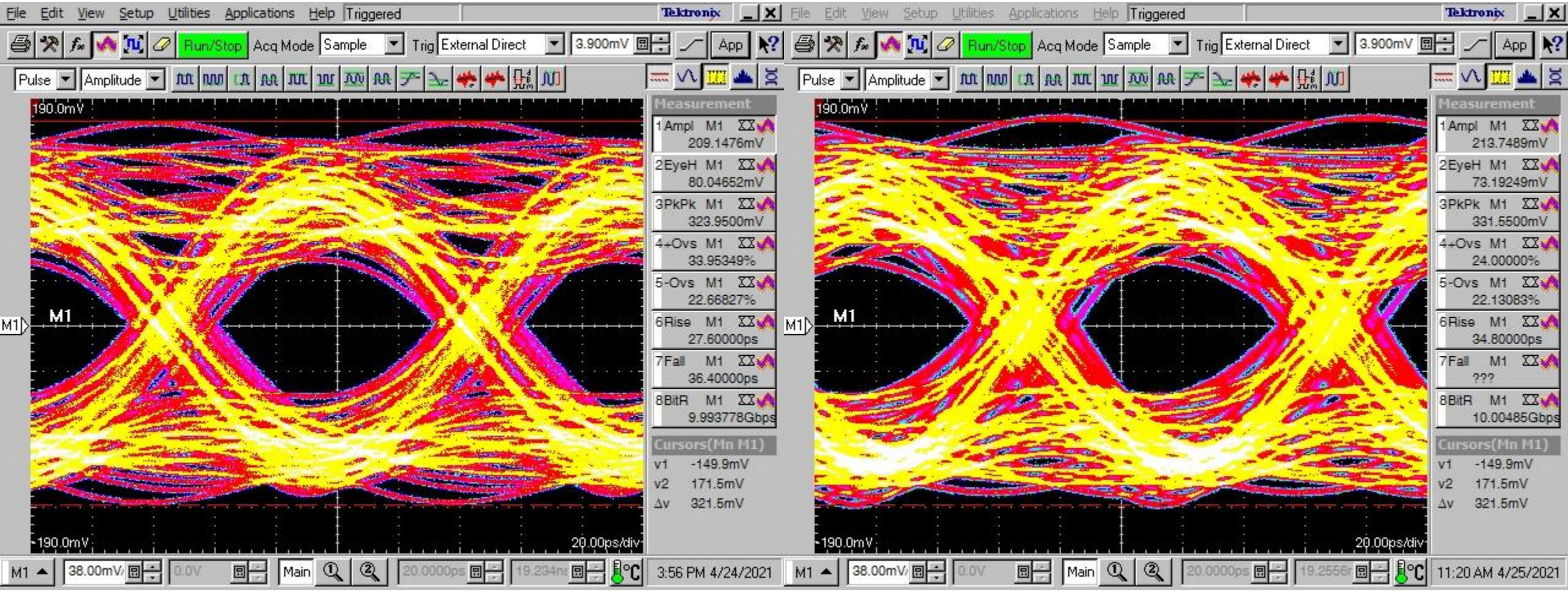
10 Gbps
PRBS7 Electrical Input Pattern
MSET = 75 mV ; Ibias = 19 mA

Peak to Peak Amplitude = 215 mV

ADN2526 Laser Driver Electrical Testing – Board 1
Modulation Setting Performance (MSET) and Temperature

295 K

77 K

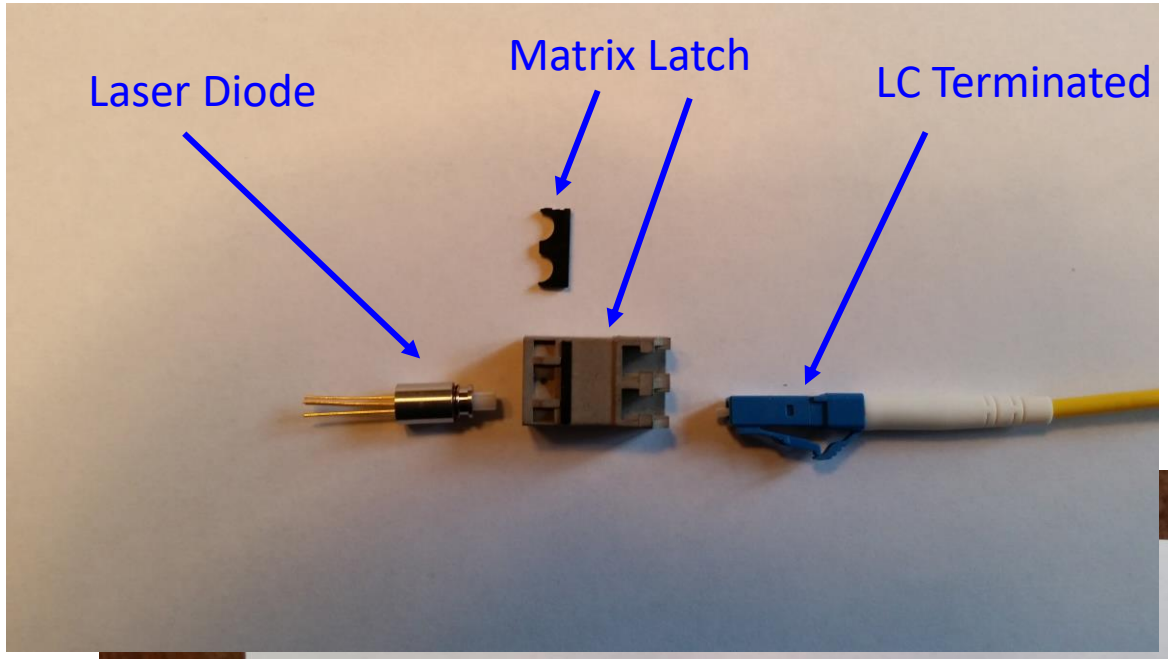


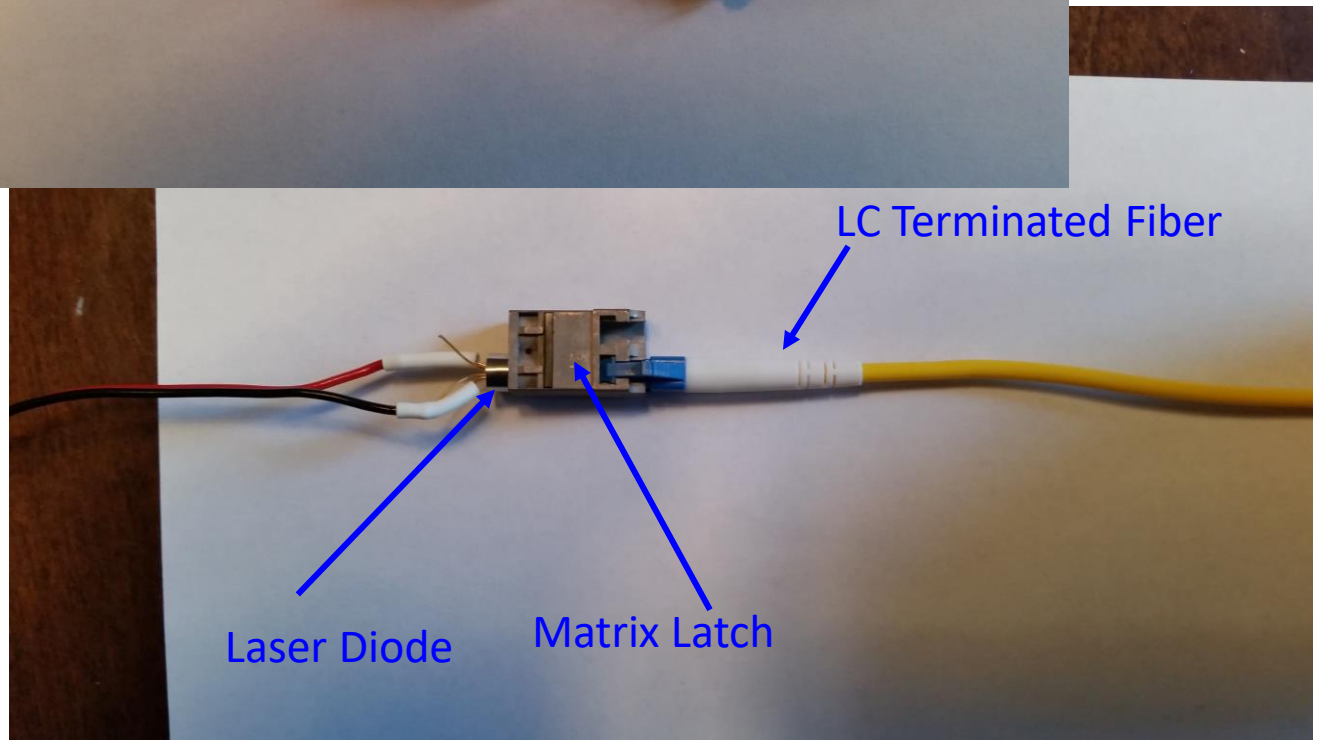
Peak to Peak Amplitude = 321 mV

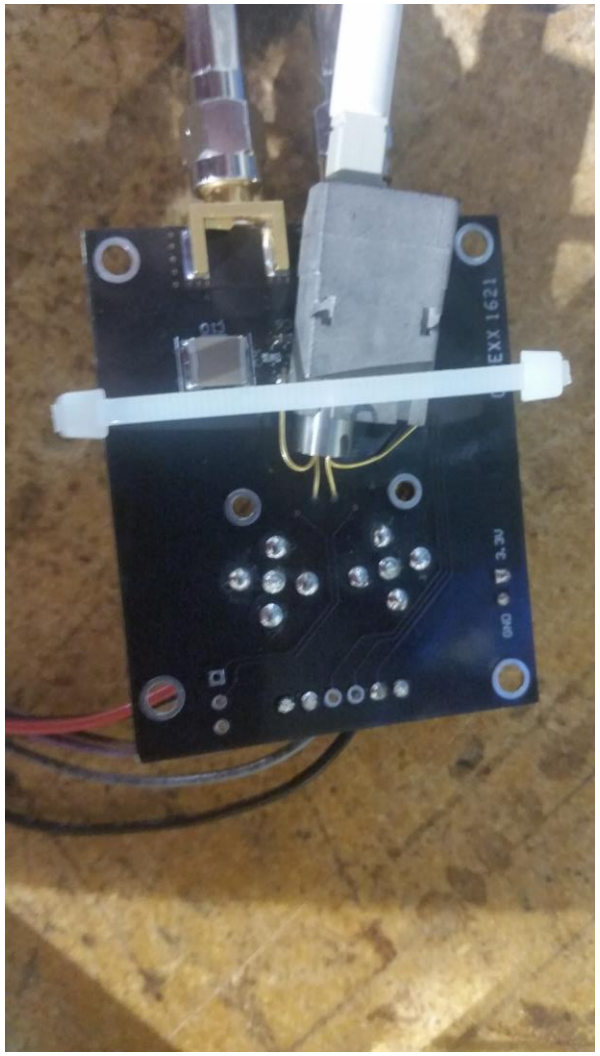
10 Gbps
PRBS7 Electrical Input Pattern
MSET = 125 mV ; Ibias = 19 mA

Peak to Peak Amplitude = 321 mV

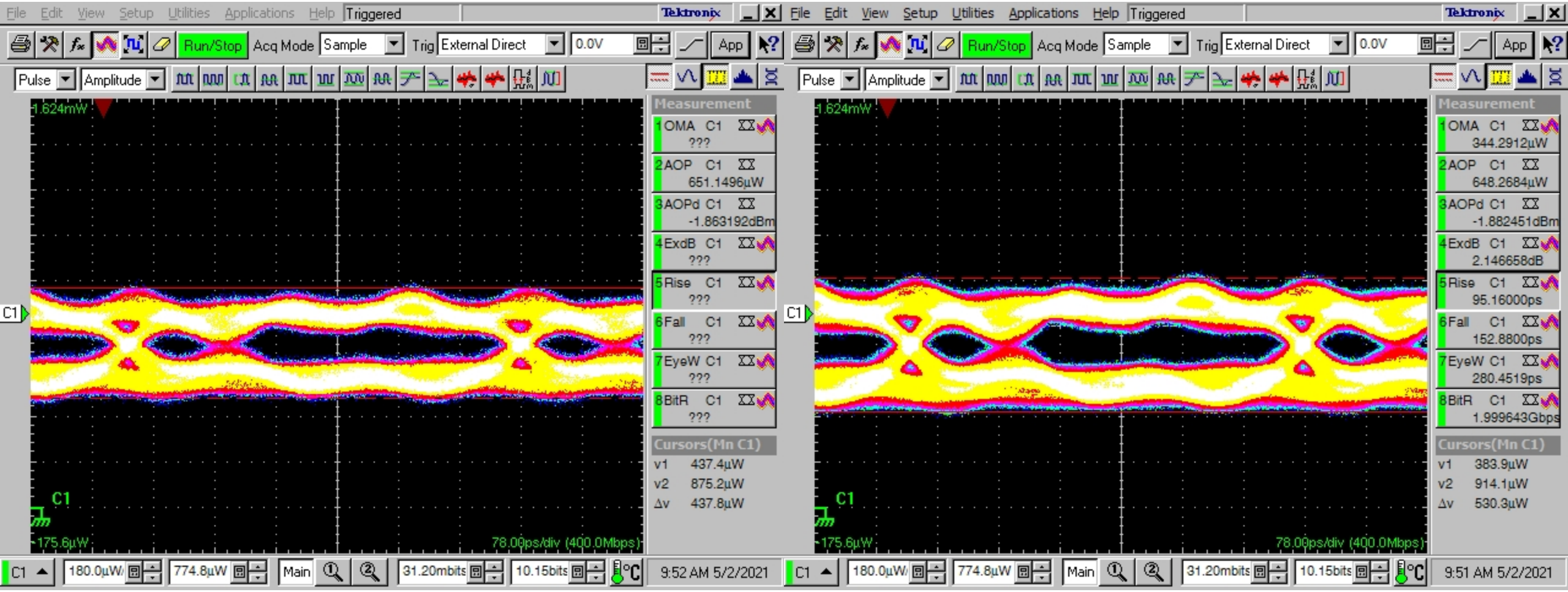
ADN2526/FP-1310-4I-LCC Combined Testing
Making the Optical Connection







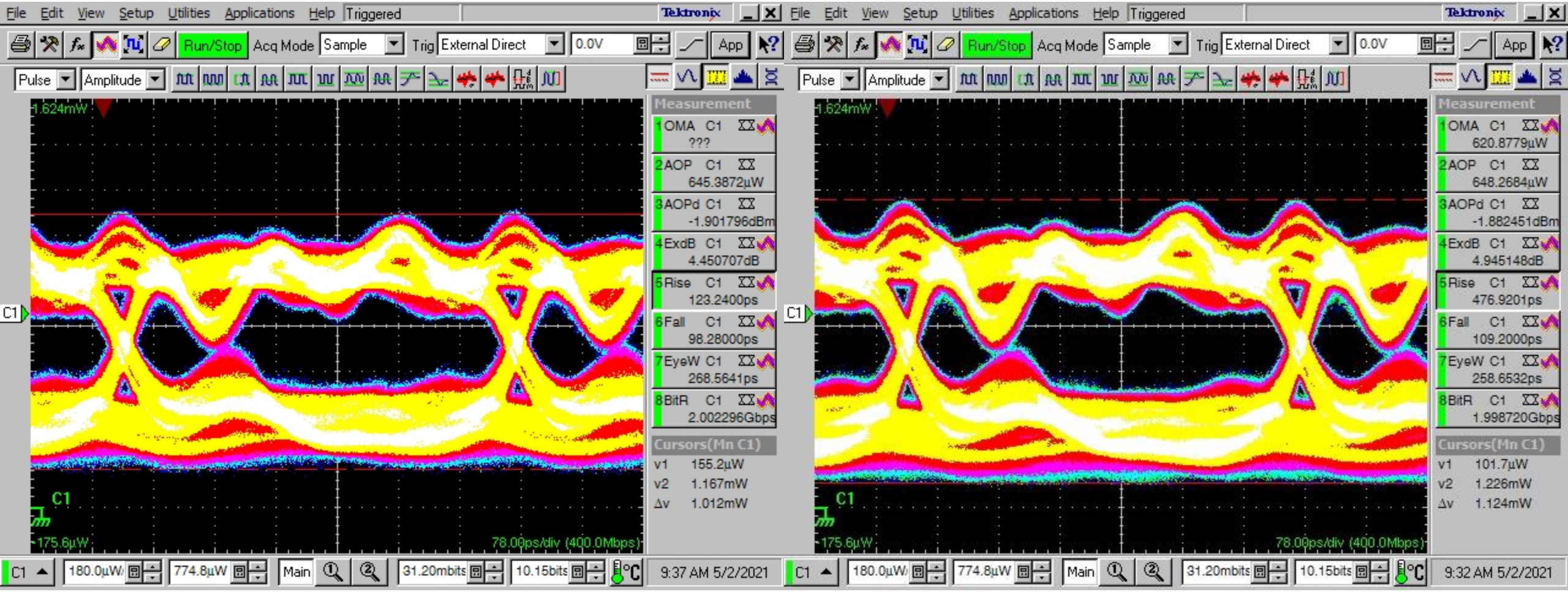
ADN2526/FP-1310-4I-LCC Combined Testing – Board 1
Optical Eye Performance at 295 K (PRBS7, 2 Gbps)



MSET = 30 mV
Peak to Peak Amplitude = 438 µW

MSET = 40 mV
Peak to Peak Amplitude = 530 µW

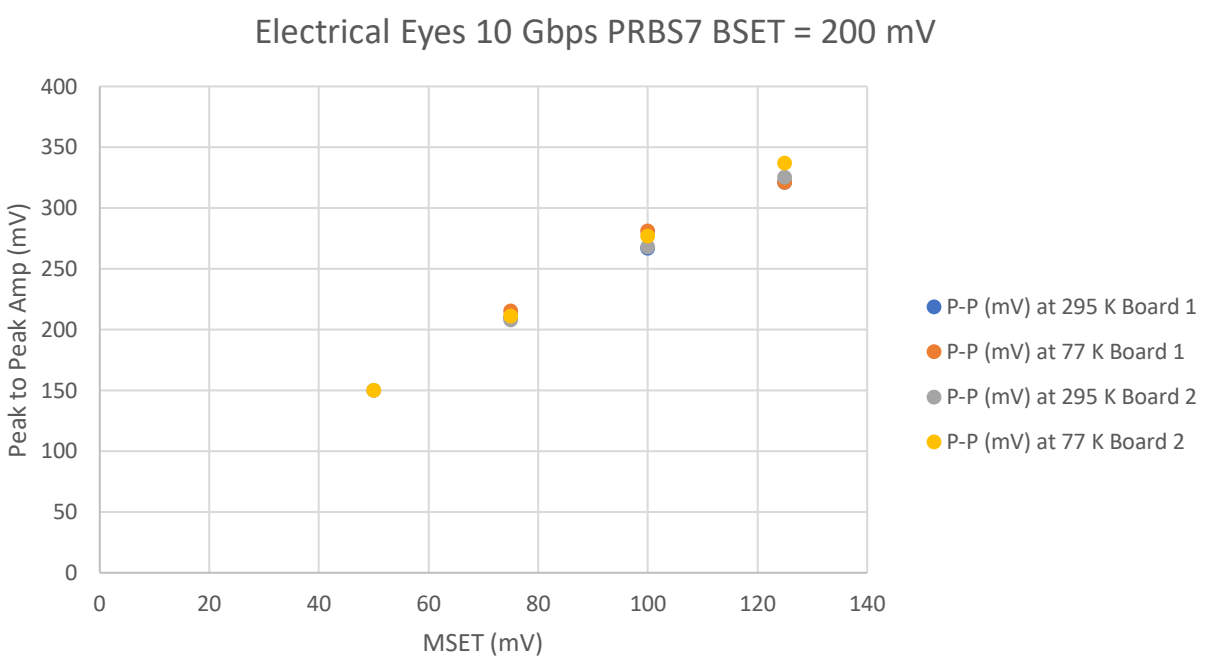
ADN2526/FP-1310-4I-LCC Combined Testing – Board 1
Optical Eye Performance at 295 K (PRBS7, 2 Gbps)

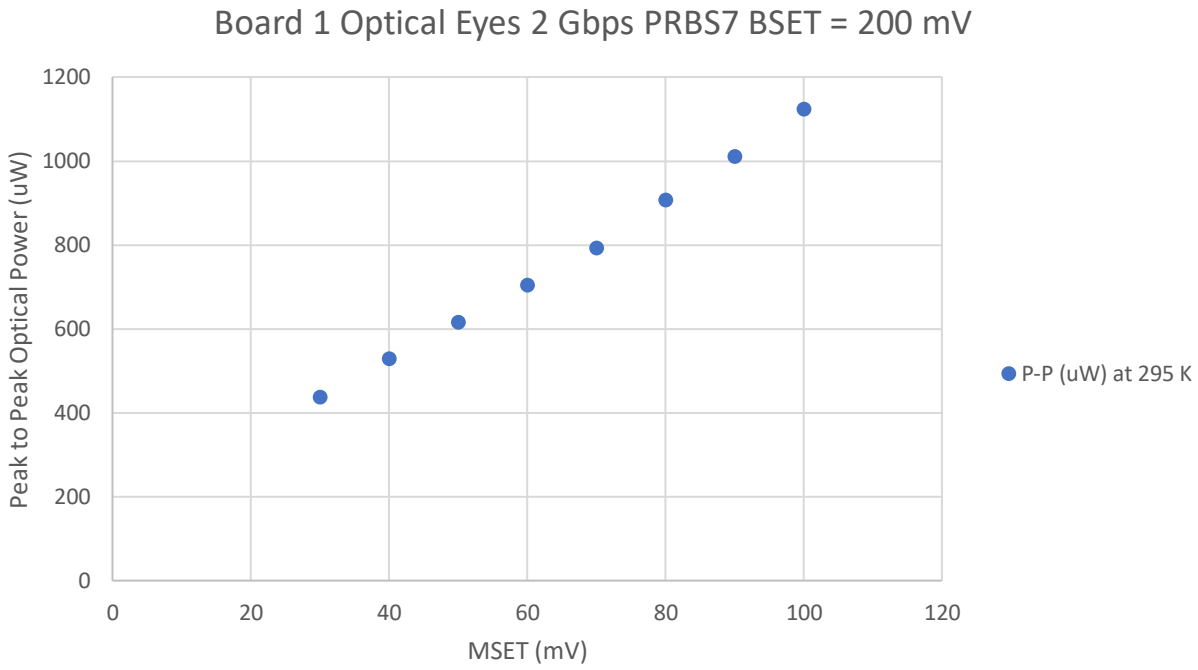


MSET = 90 mV
Peak to Peak Amplitude = 1012 µW

MSET = 100 mV
Peak to Peak Amplitude = 1124 µW

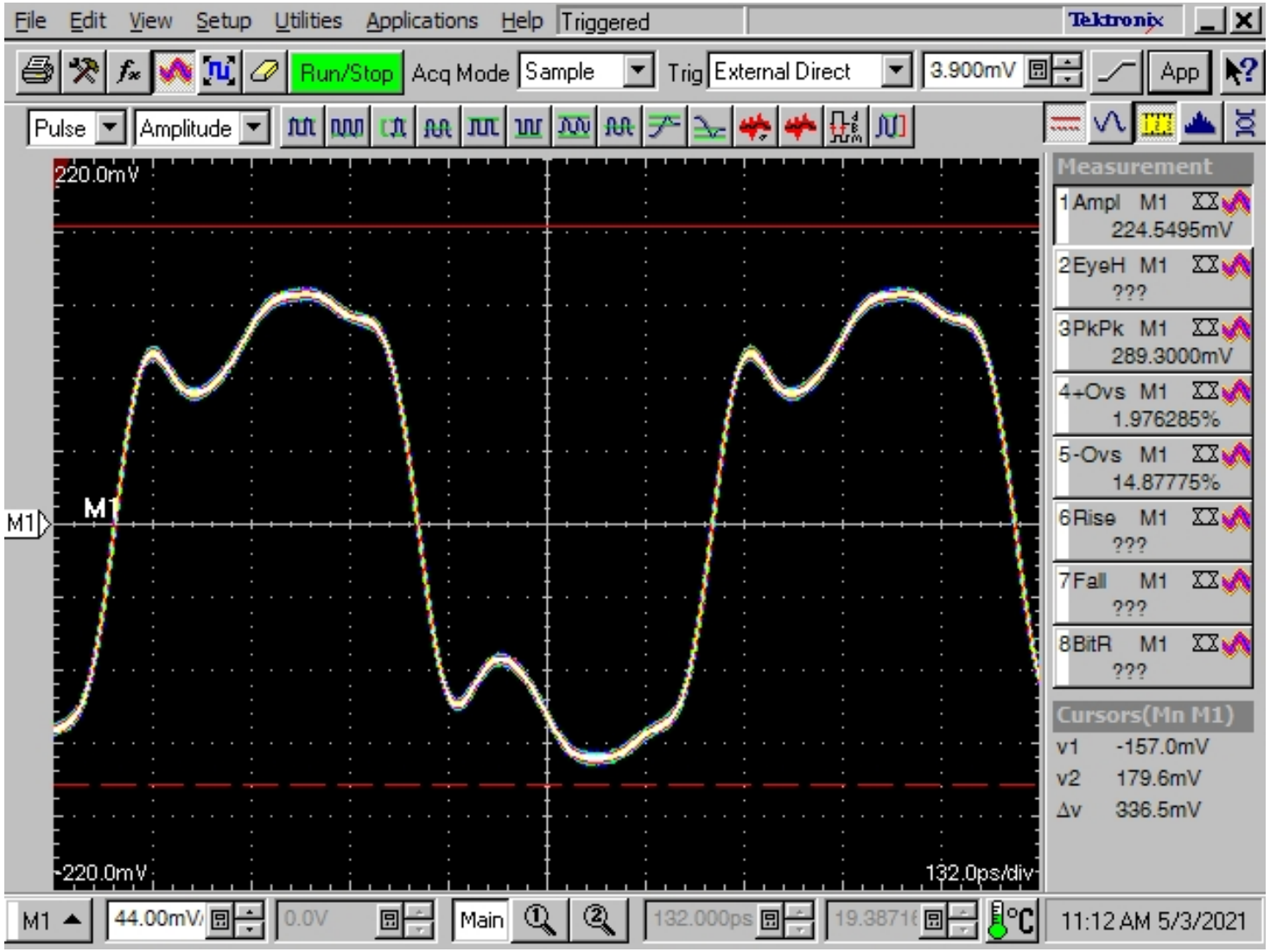
ADN2526 Board 1
Dynamic Performance Summary vs Modulation Setting

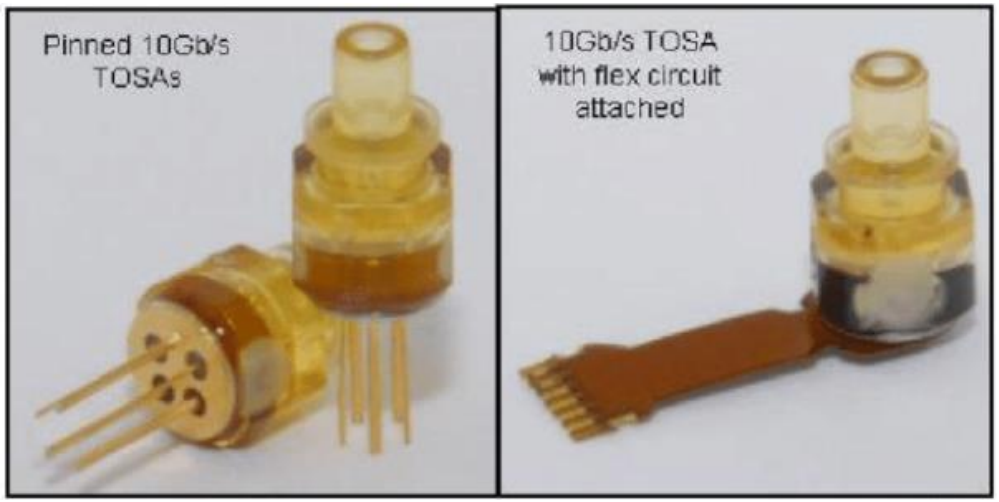




Lack of corresponding optical data was due to issues securing the laser diode to the board

ADN2526 Board 2
OMA Pattern (clock-like) at 10 Gbps





LC TOSA with pins

LC TOSA with flexible circuit (impedance controlled)

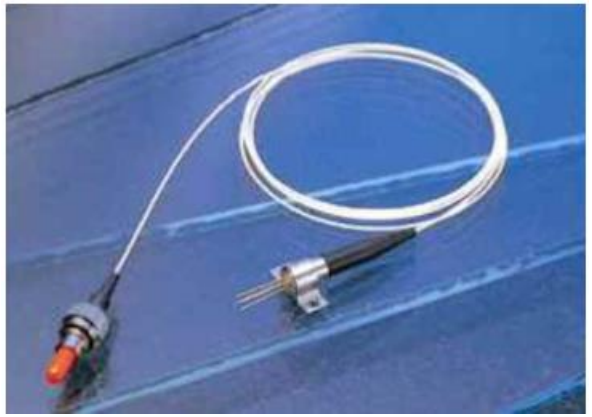
Clearly some signal integrity improvements will be desirable

Optical Coupling Improvements

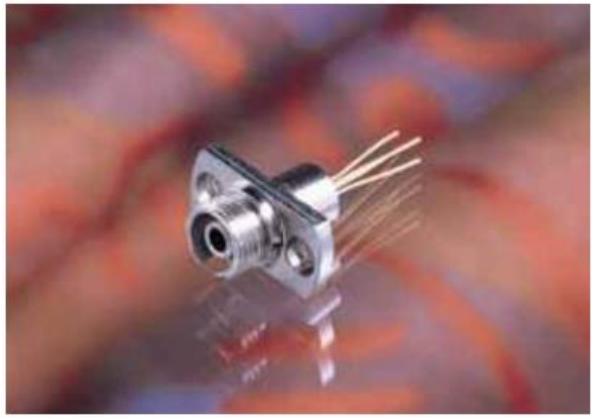
1. Pigtailed TOSAs with SMF (vertical mount for secure attachment to board; FC terminated fiber)

2. FC receptacle vertical mount TOSA (no pigtail – permits flexibility in selecting optical fiber (SMF vs MMF))

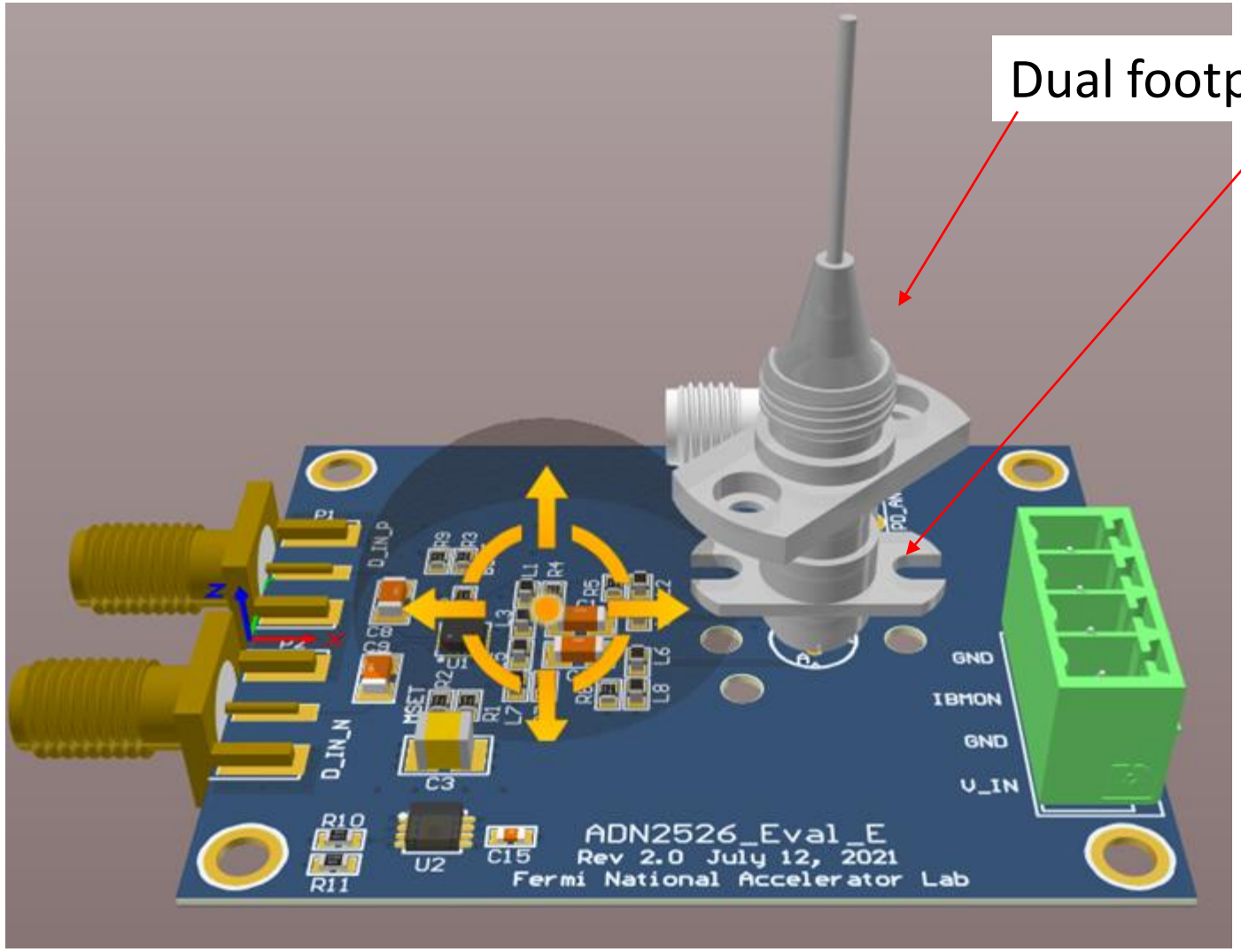
Pigtailed with horizontal mount shown
(Vitex, Lasermate)



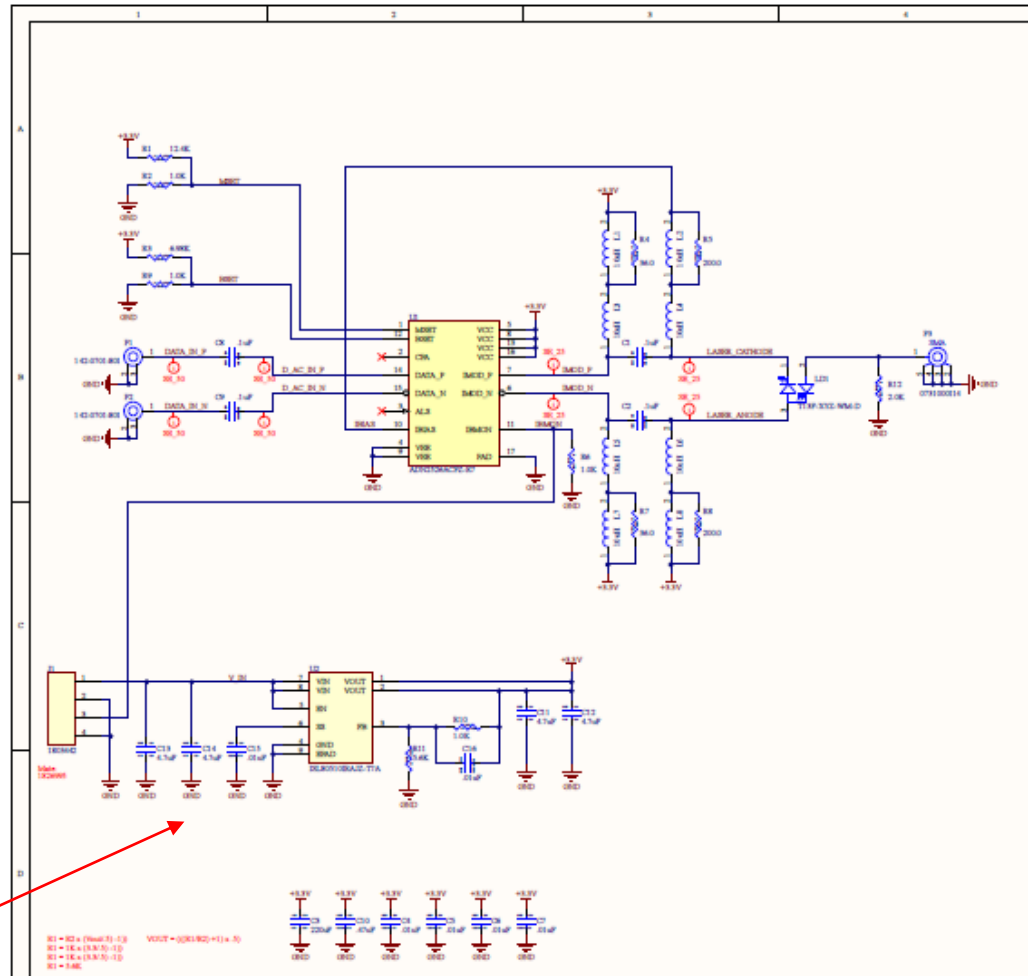
FC Receptacle shown
(LaserMate)



ADN2526 EVAL_E_V2 - Improved Design

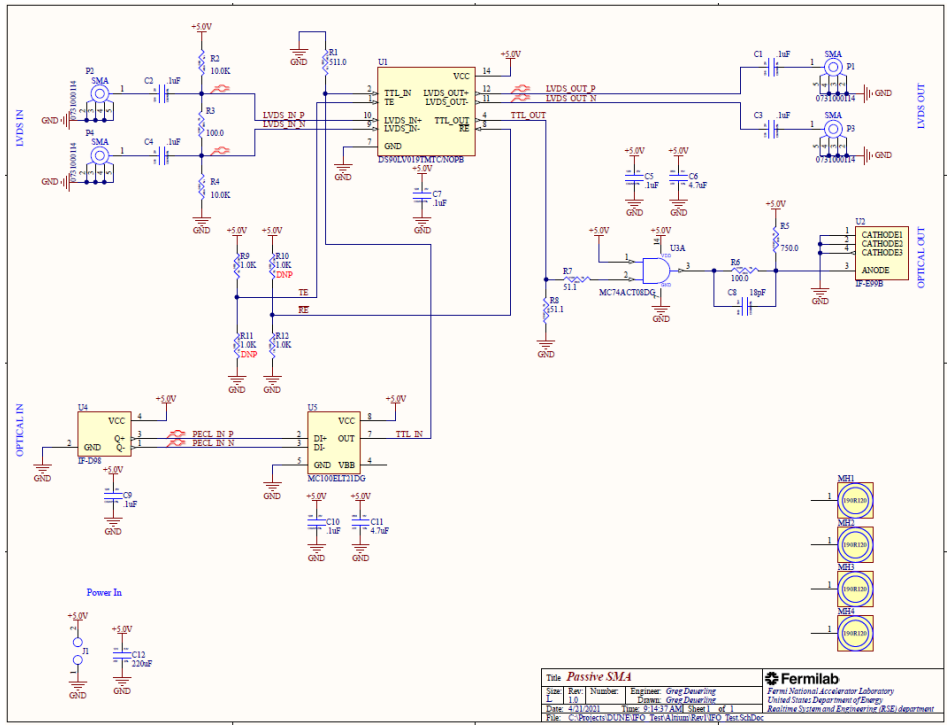


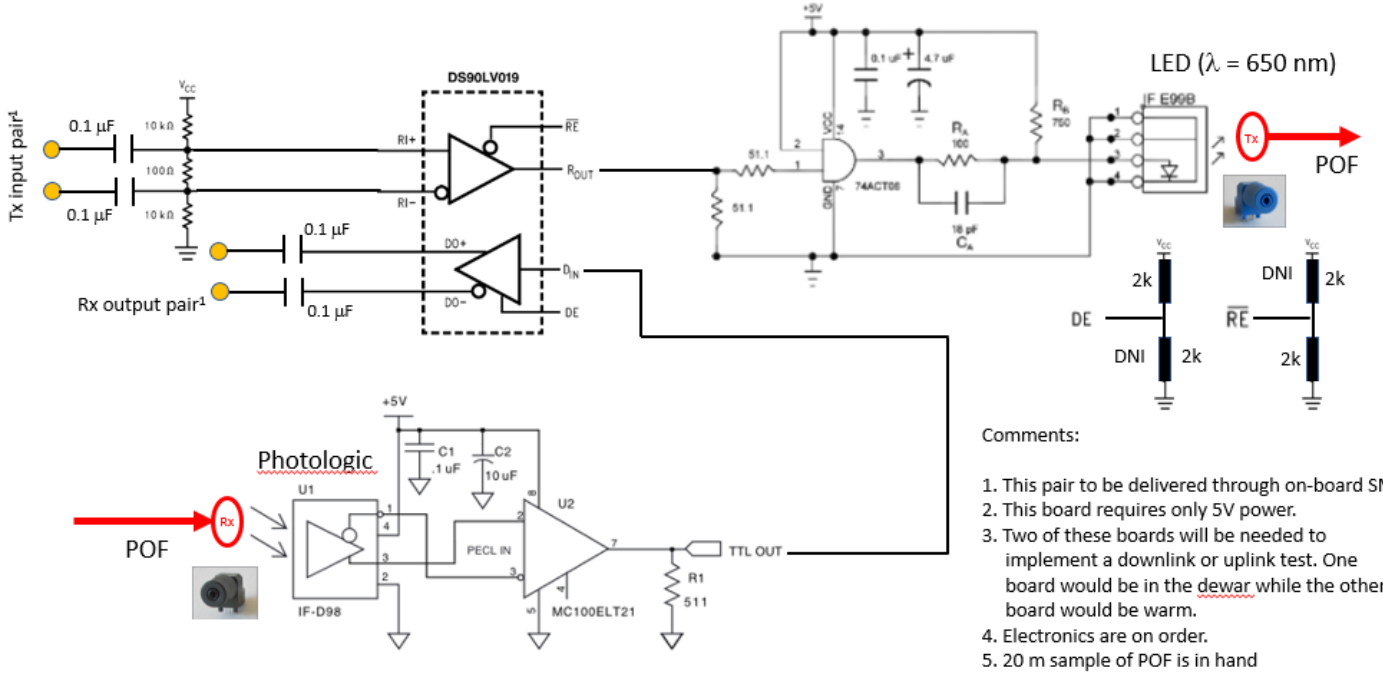
Dual footprint for two optical coupling options



On-board LN2 suitable voltage regulation

Alternative Approach: 156 Mbps Link over POF – Test Board





Low and Medium Speed Optical Communication

- Industrial Fiberoptics 650nm high speed LED communications
- 155Mbps @ 75 meter w/1000µm core plastic fiber
- Evaluating 4-156Mbps medium speed (IF-D98) and DC-50Mbps low-speed receiver (IF-D97)
- To be evaluated for:
  - Optical JTAG extender
  - System clock
  - Etc.
- SMU Physics has joined the effort and is evaluating devices (results will be available soon)

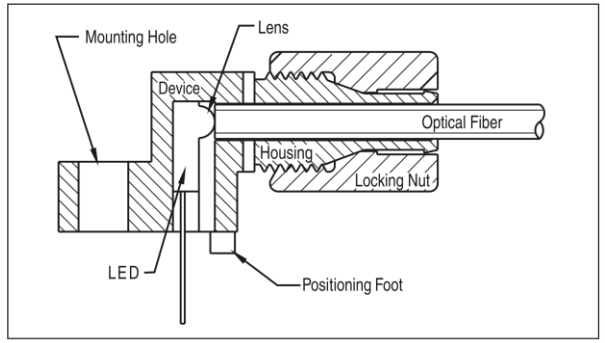
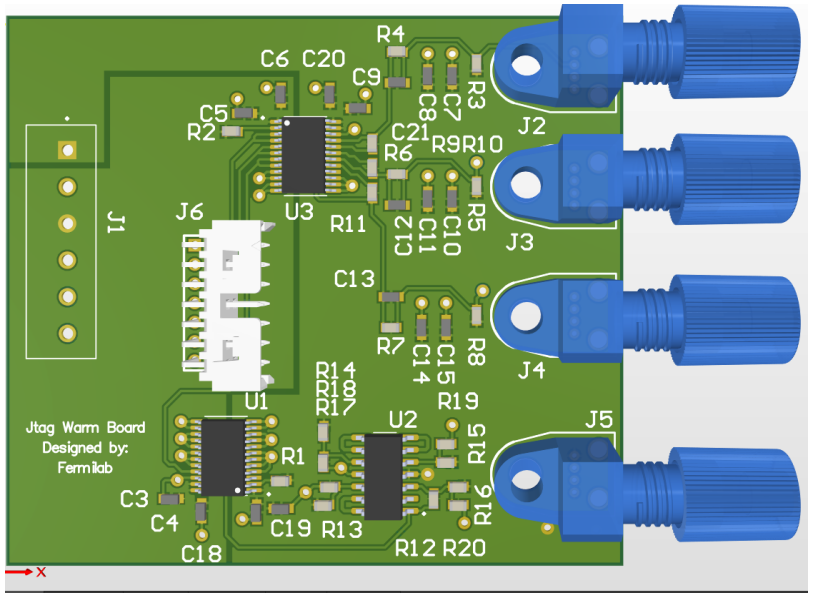


FIGURE 5. Cross-section of fiber optic device.

Test application:
Optical JTAG extender

- Development at Fermilab
- Uses exclusively supporting components pre-qualified by BNL, LBL and JPL
- Limited to ~1Mbps @ 30M by light propagation time.



Rx Option for Gbps

Completing a COTS ROSA-based design

Analog Devices ADN2891 Limiting Amplifier

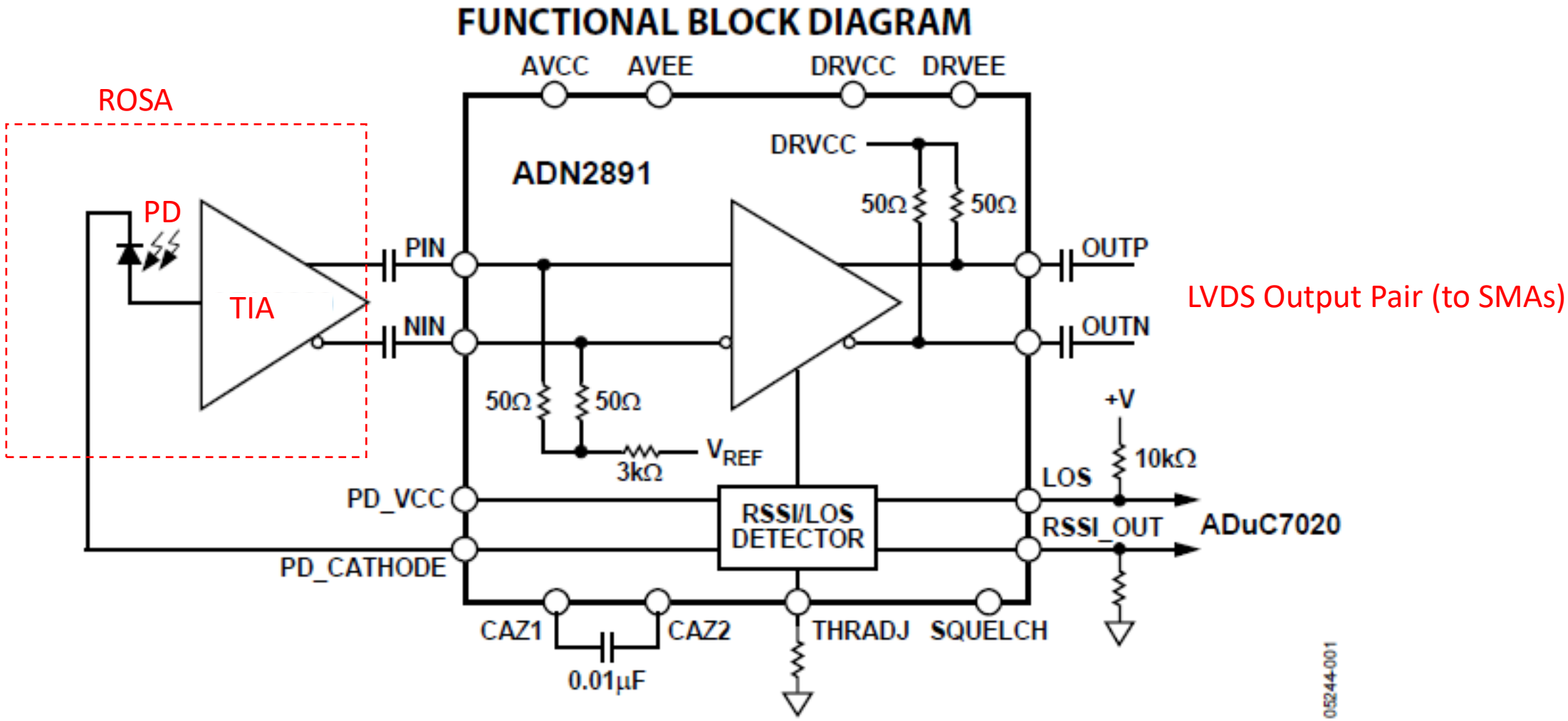


Figure 1.

InGaAsP Spectral Shift Estimate (1310 nm Laser Diodes)

Parameters for Varshni's equation have been found for InGaAsP*

Compute the 0 K band gap:
Using E_g(300 K) = 0.949 eV, solve for E_g(0 K) using Varshni's equation:

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta}$$

E_g(0 K) = 1.019 eV

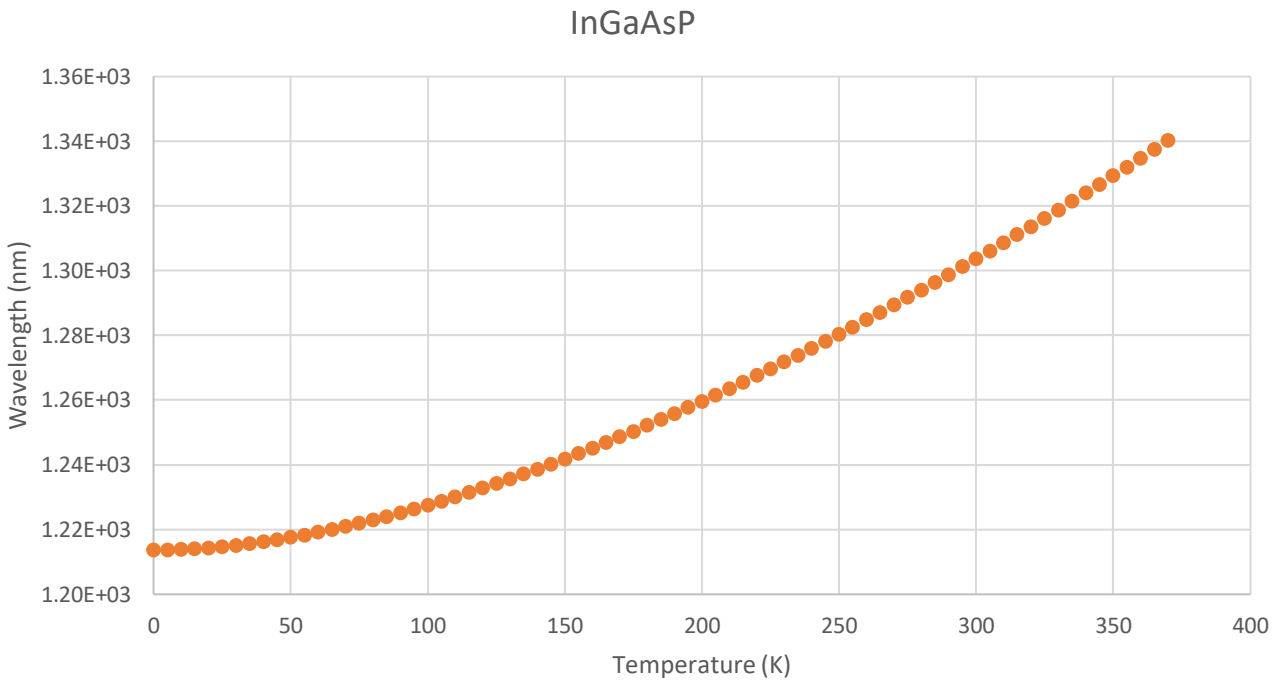
For InGaAsP*:

$\alpha = 4.9 \times 10^{-4}$ eV/K^2

$\beta = 327$ K

Plot photoluminescence wavelength using:

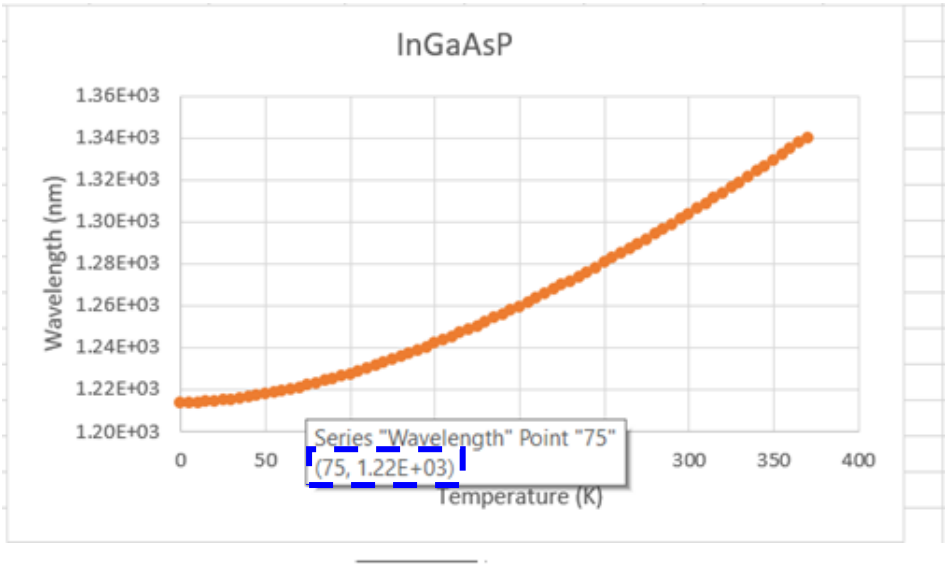
$$\lambda = \frac{hc}{E_g(0) - \frac{\alpha T^2}{T + \beta}}$$

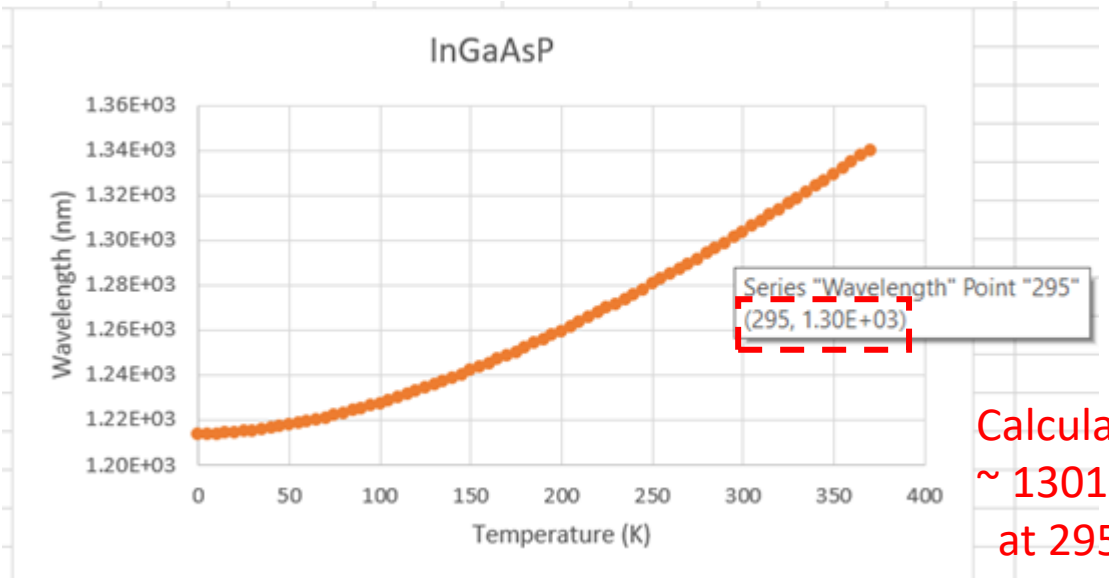


*Ref 1: "Temperature Dependence of Photoluminescense of n-InGaAsP"
H. Temkin, et. al., Journal of Applied Physics 52 (1981)

InGaAsP Spectral Shift Estimate (1310 nm Laser Diodes)

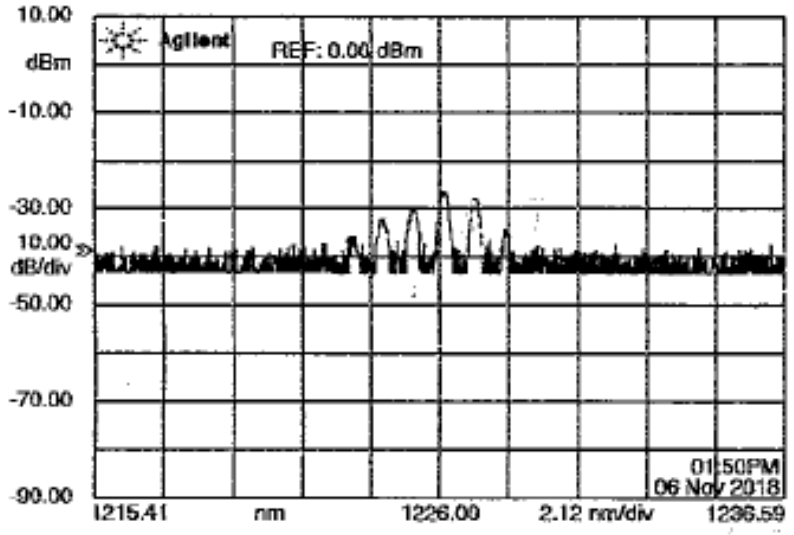
Calculated:
~ 1222 nm
at 75 K

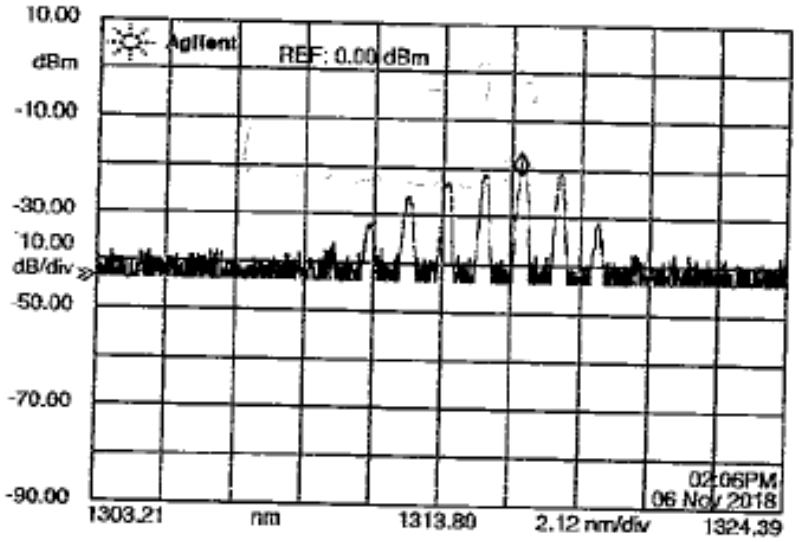




Calculated:
~ 1301 nm
at 295 K

Measured:
Max Peak
~ 1226 nm
in LN2





Measured:
Max Peak
~ 1316 nm
at room
temperature

Discussion