DUNE VD/PD Cryogenic Digital Optical Links
DUNE Collaboration Meeting

May 20, 2021

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

Testing of LED/Photologic solution

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 (+)

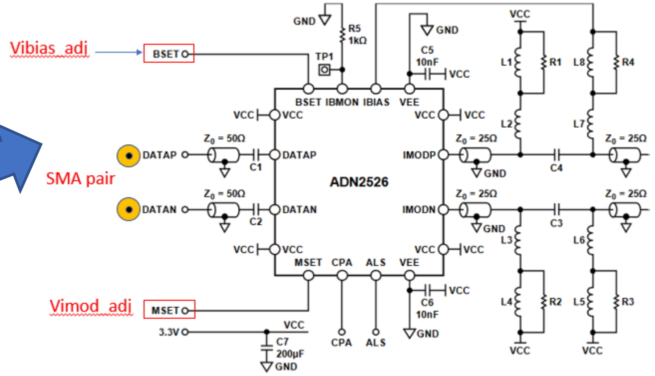
Analog Optical Links are characterized by …

- 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



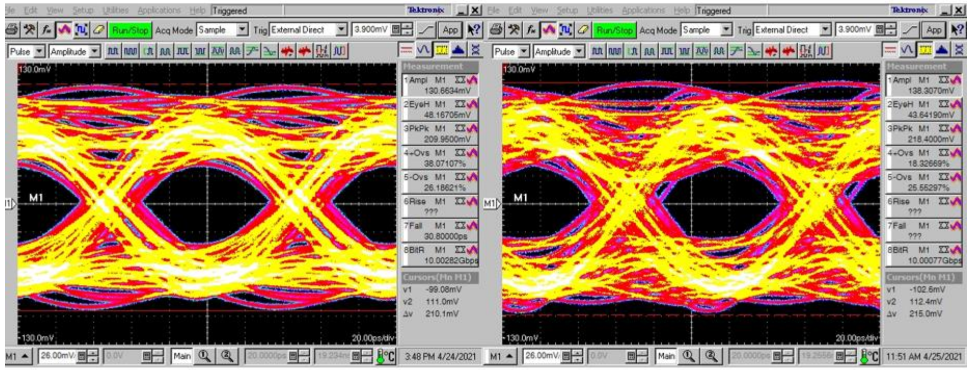
COTS Laser Driver ICs

Driver Testing

Control of Modulation Current

T = 295 K

T = 77 K



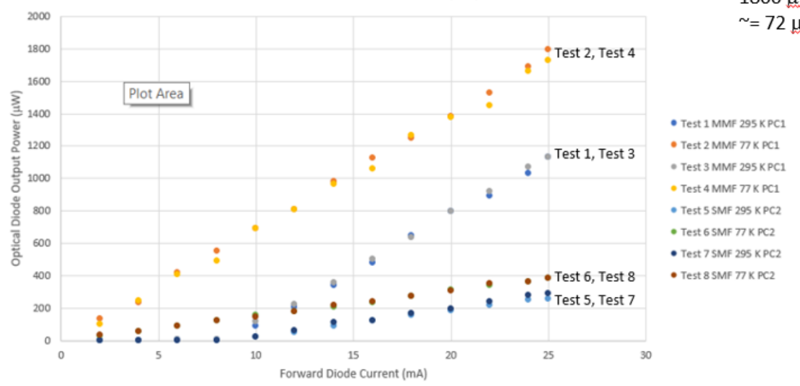
Peak to Peak = 210 mV (cursors)

Peak to Peak = 215 mV (cursors)

Laser Diode Selection

COTS Laser Diode (TOSAs)

Diode Testing

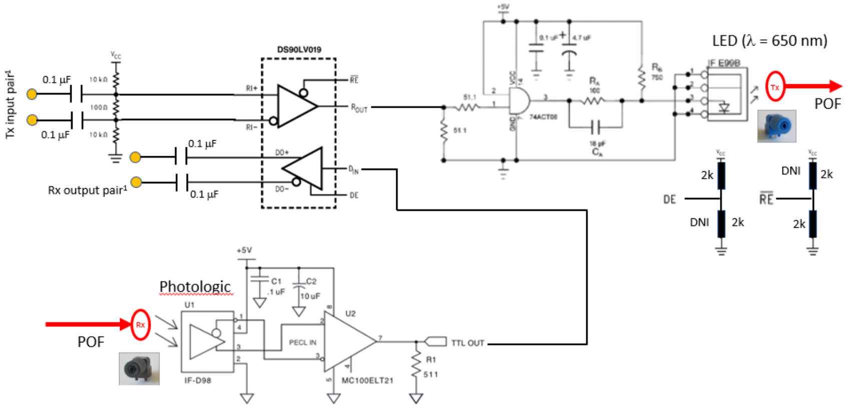


Slope efficiency estimate
1800 µW/25 mA
~= 72 µW/mA*

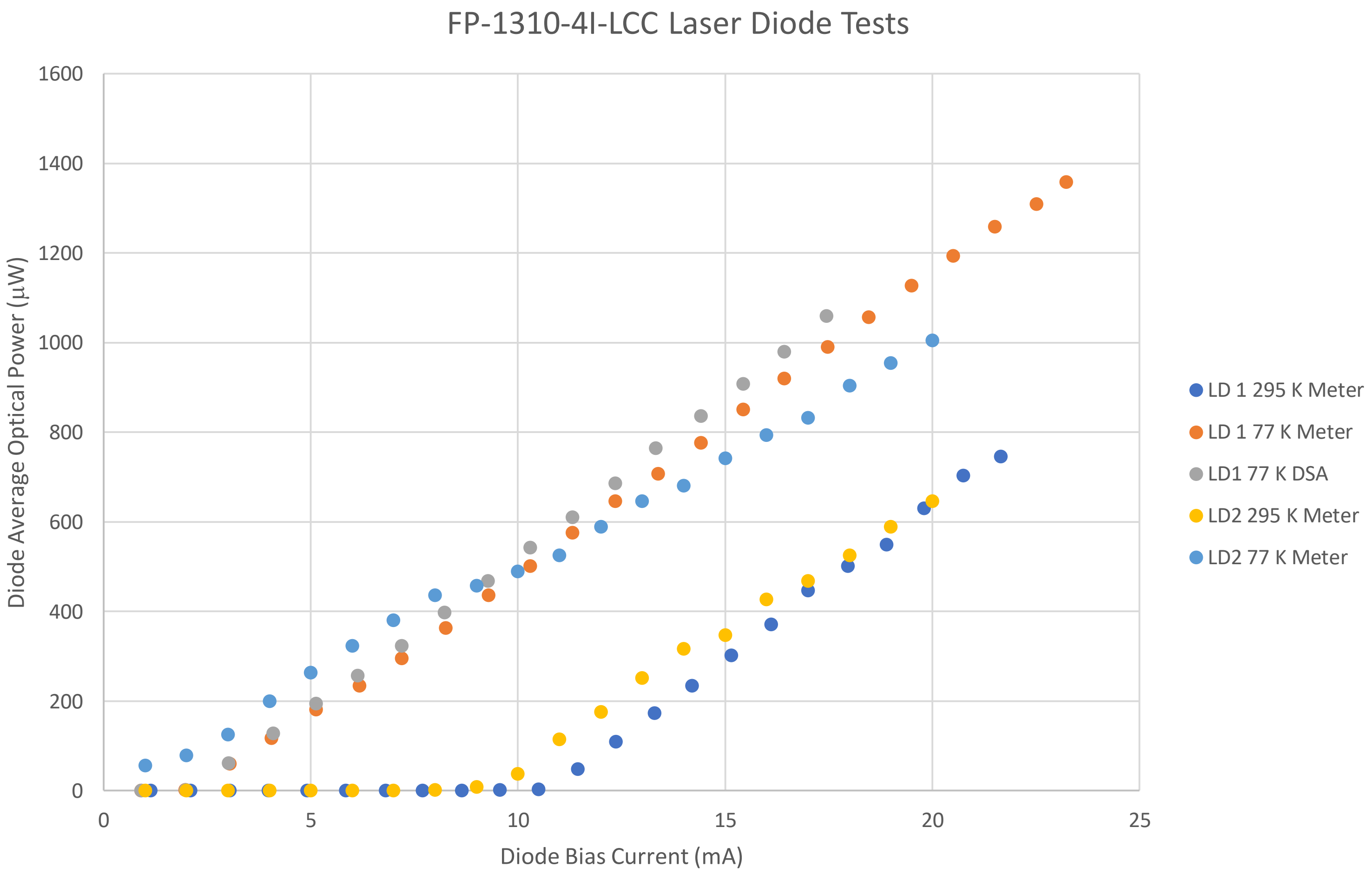
Plan: Bring Together for Custom Gbps Transmitter

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

156 Mbps Link over POF – Test Board Design

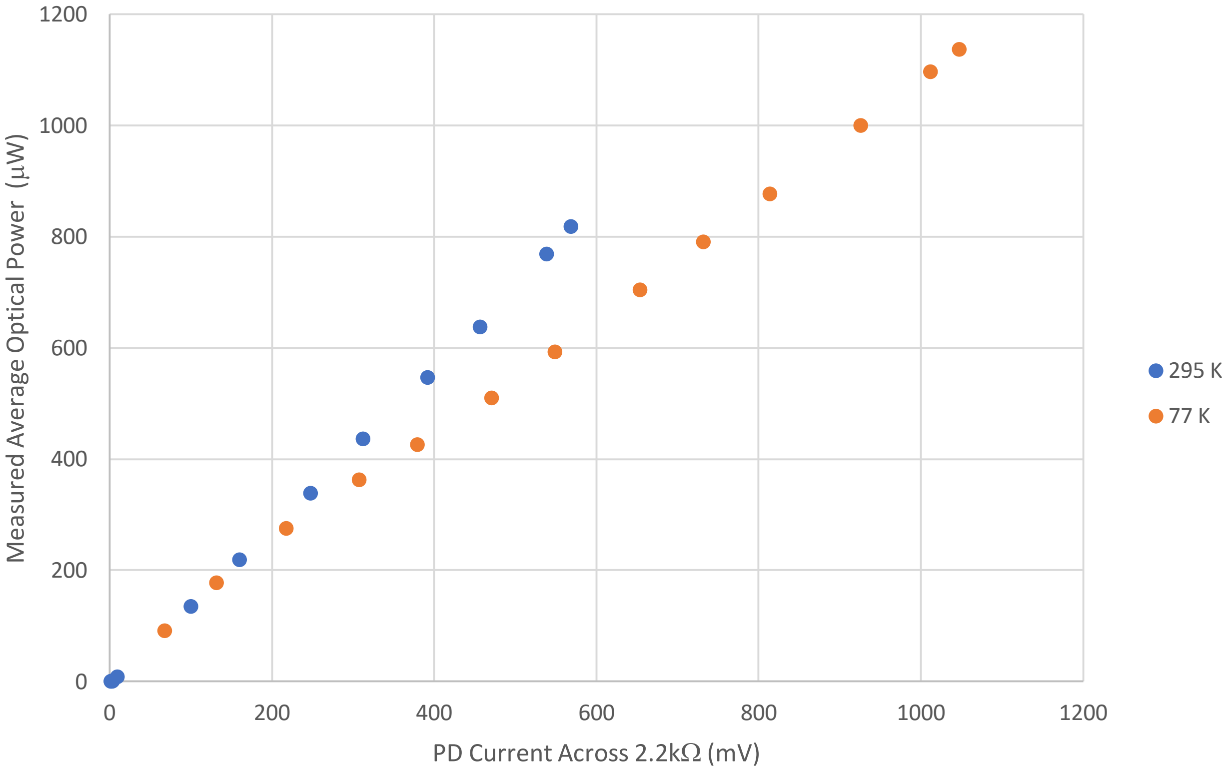


Cumulative TOSA Laser Diode Testing Summary
FP-1310-4I-LCC (4 Gbps rated)

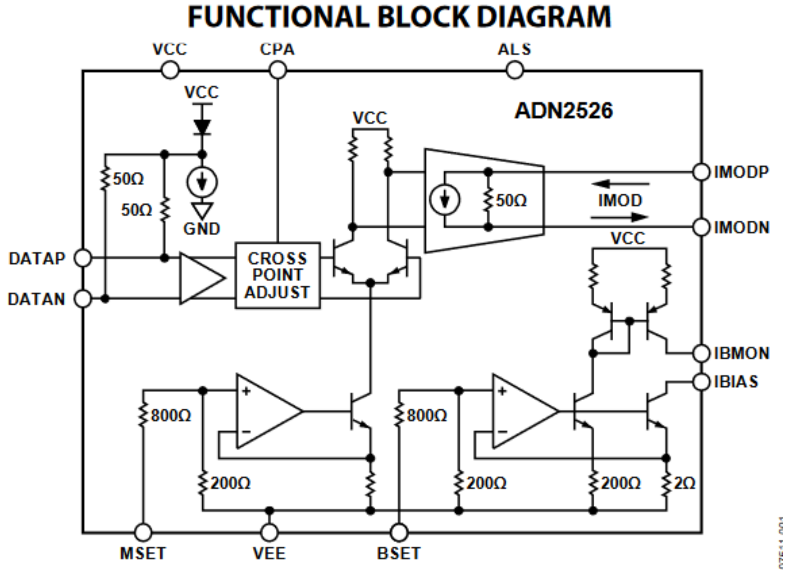


Results obtained with 50 μm core Multimode Fiber and Matrix LC Latch
LD1 results obtained with laser mounted on ADN2526 Test Board (controlled by laser driver BSET circuit)
LD2 results obtained with laser directly connected to trim pot circuit

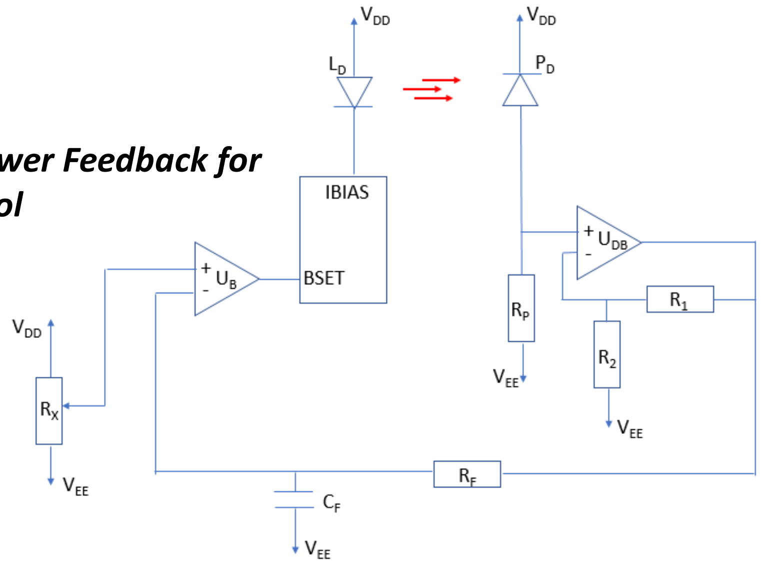
TOSA Monitor Photodiode Testing Summary
FP-1310-4I-LCC (4 Gbps rated)



ADN2526 Laser Driver



Optical Power Feedback for Bias Control



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

Testing with ADN2526 Laser Driver Custom LN2 Board

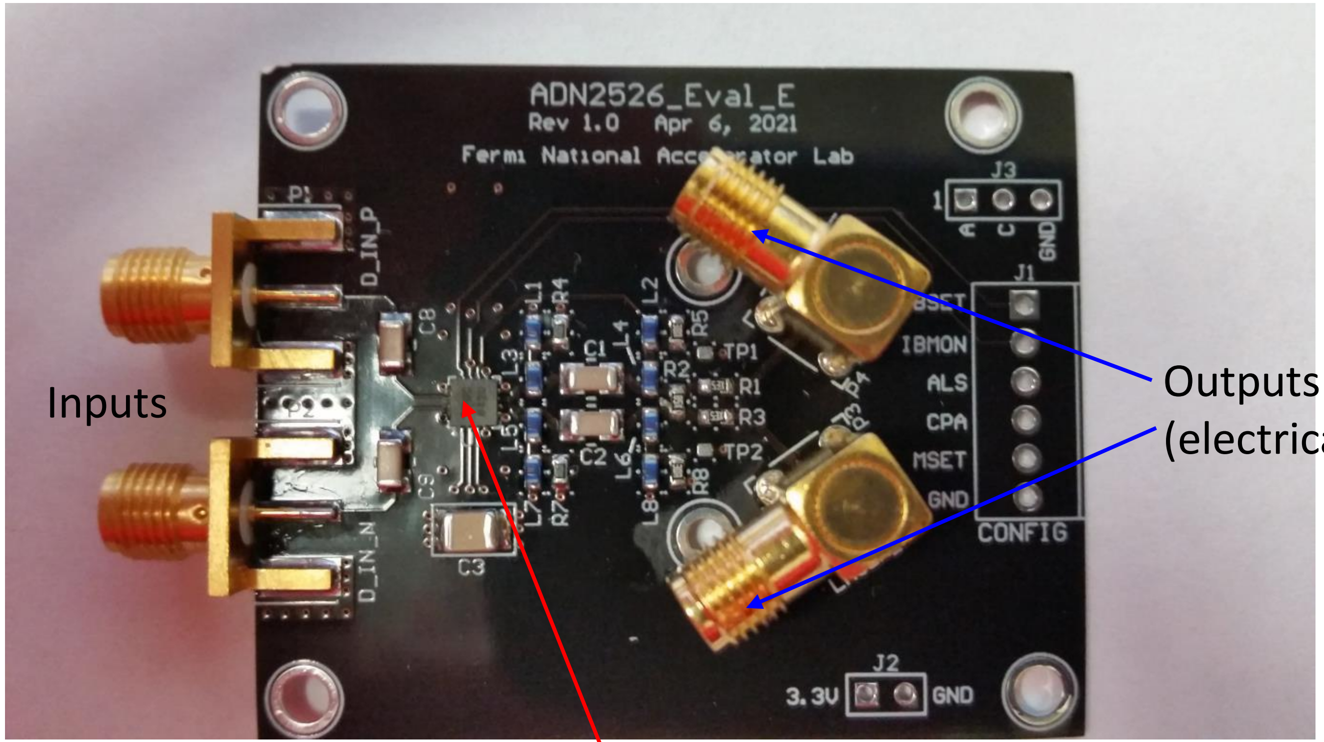
Room temperature testing first, followed by testing in LN2
- Electrical Testing
- Optical Testing (with Finisar FP-1310-4I-LCC and MMF)

ADN2526

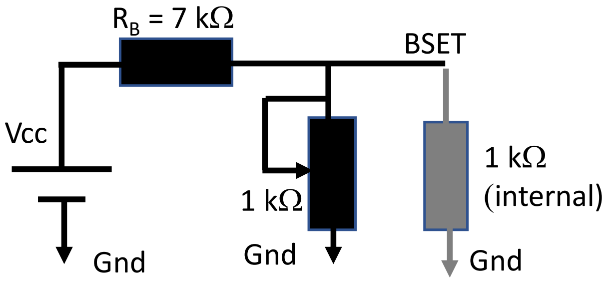
BIAS CONTROL INPUT (BSET)				
BSET Voltage to IBIAS Gain		90		mA/V
BSET Input Resistance		1000		Ω
MODULATION CONTROL INPUT (MSET)				
MSET Voltage to IMOD Gain	50	78	100	mA/V
MSET Input Resistance		1000		Ω

FP-1310-4I-LCC

Operating Current	$T_c = 25^oC$	I_{OP}		32		mA

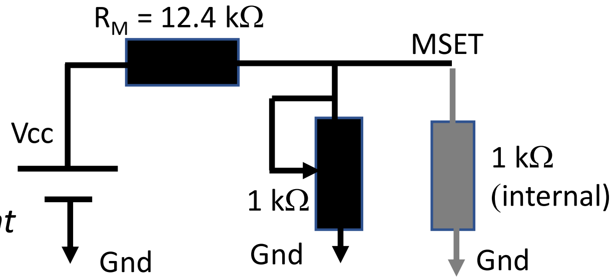


To establish Bias Current



For BSET = 0.22V (Ibias = 20 mA)

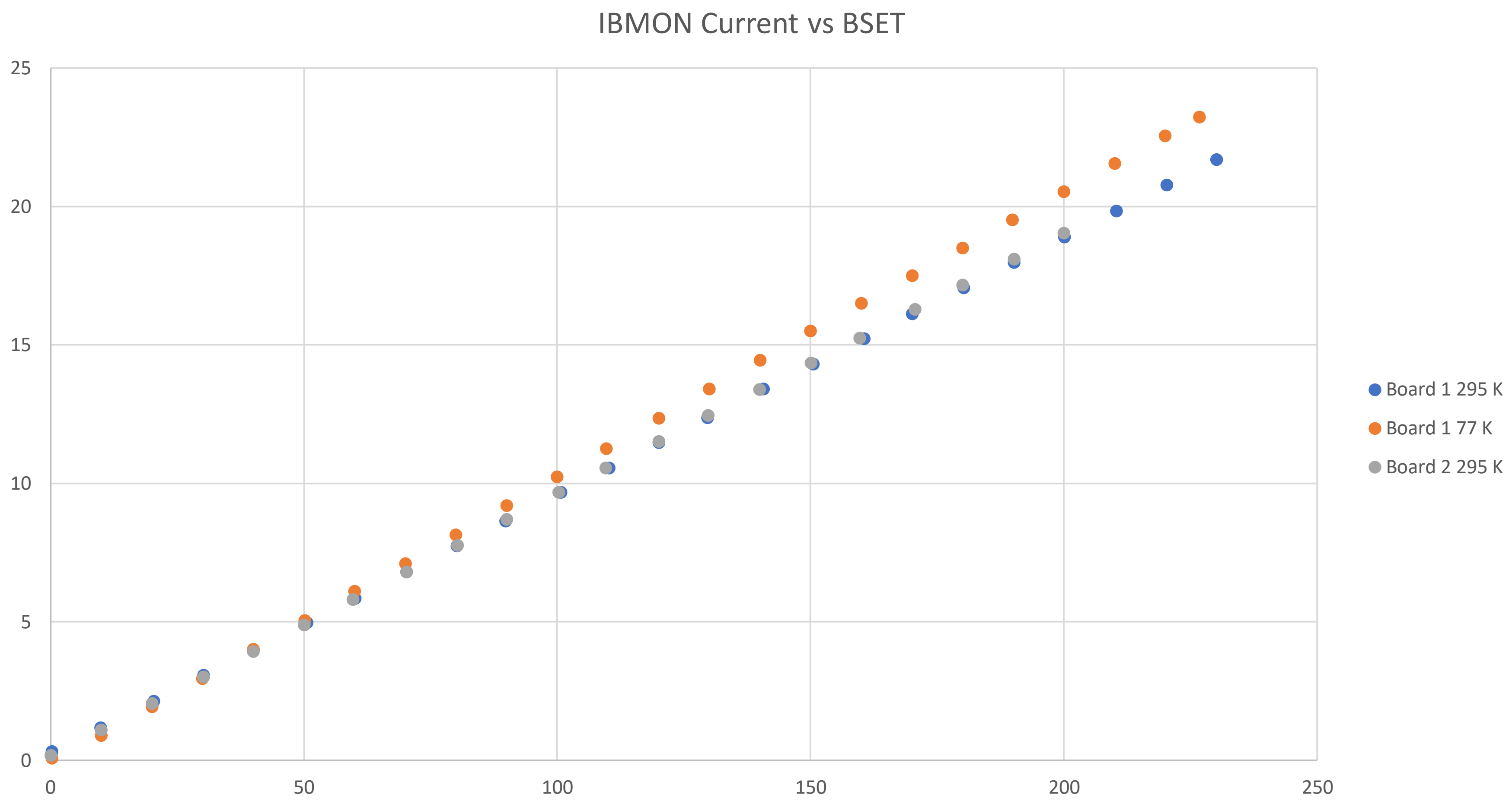
To establish Modulation Current



For MSET = 0.13 (Imod = 10 mA)*

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

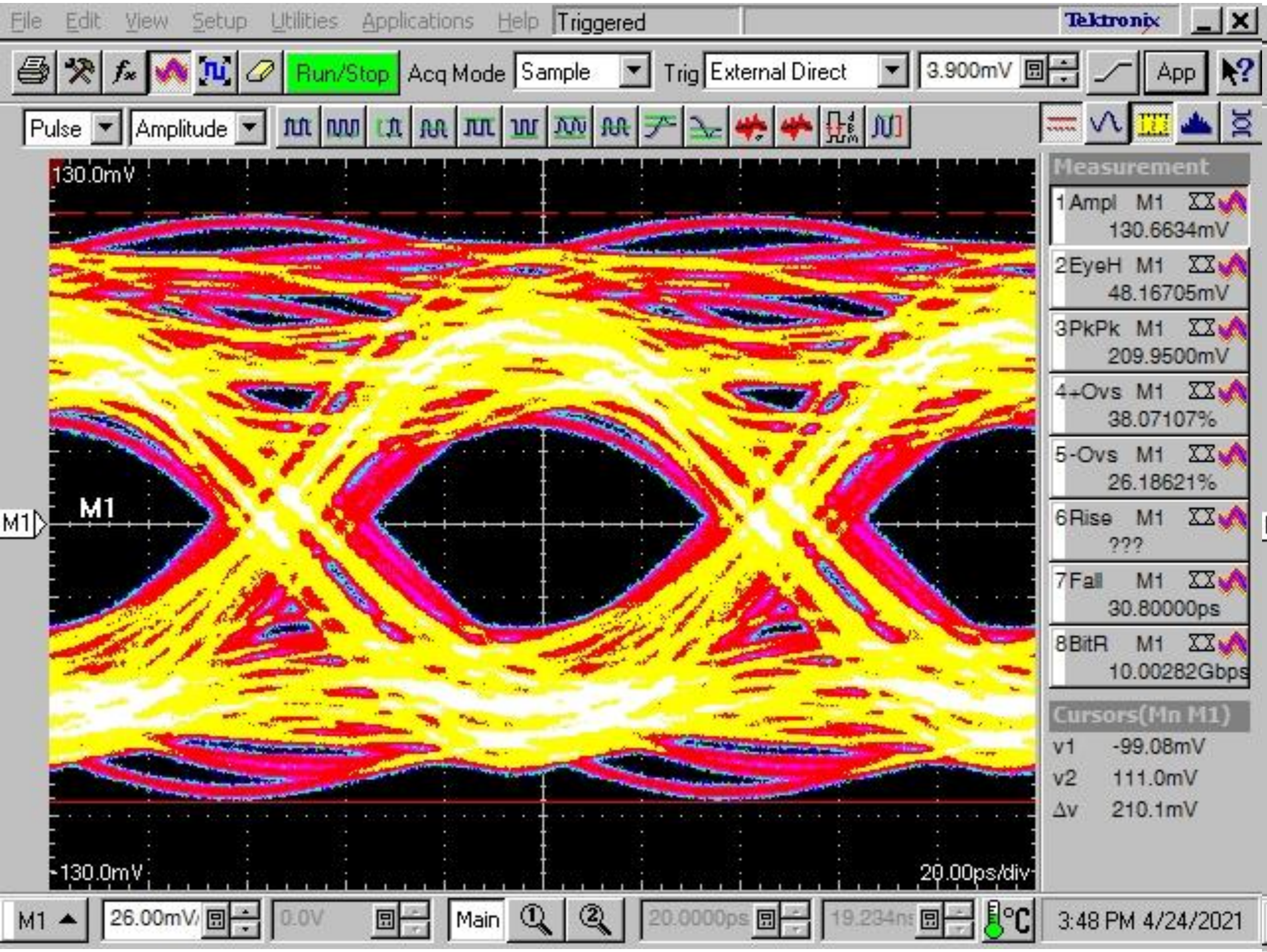
ADN2526 Laser Driver Electrical Testing
Bias Setting Performance (BSET)



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

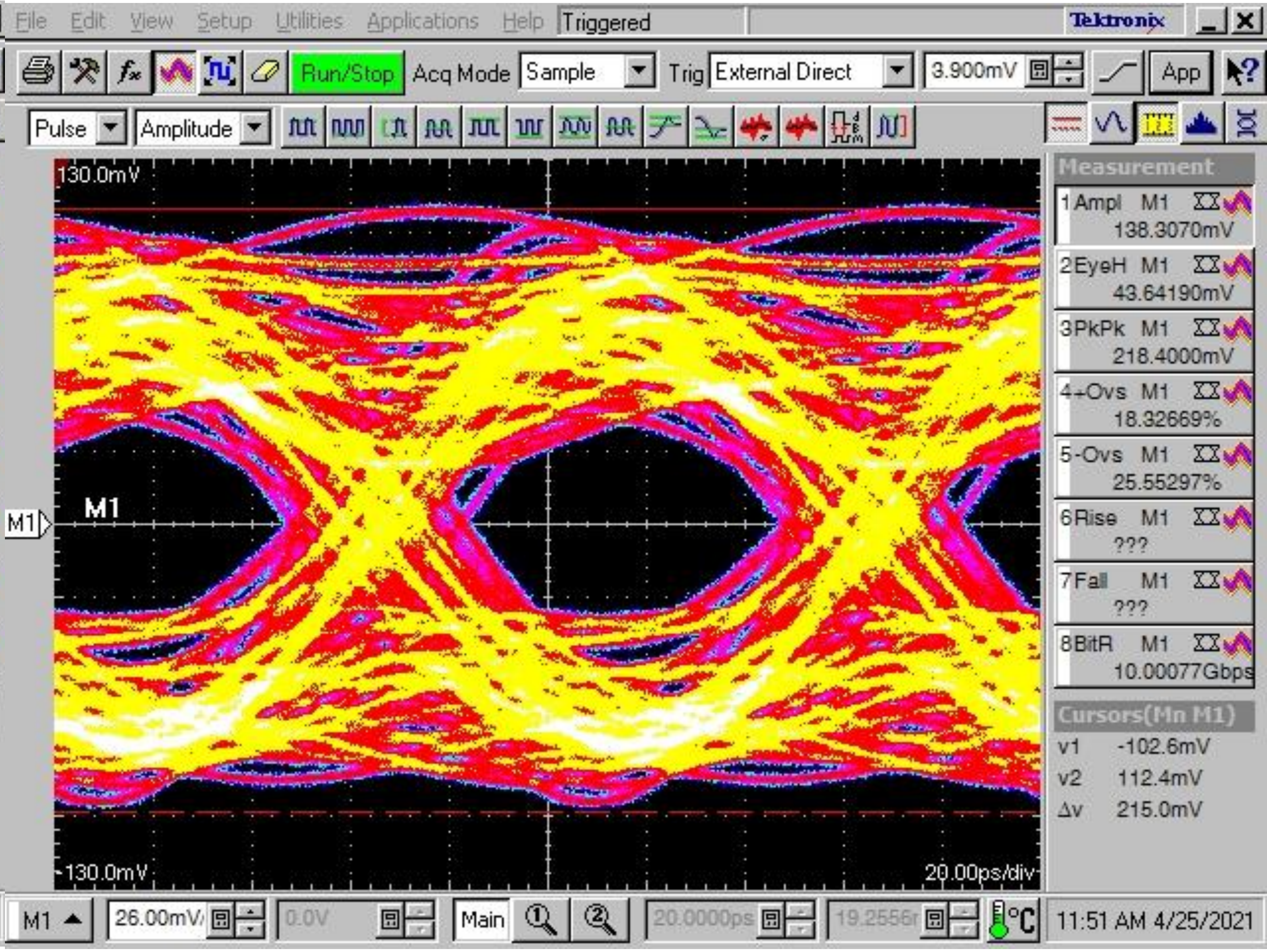
ADN2526 Laser Driver Electrical Testing – Board 1
Modulation Setting Performance (MSET) and Temperature

295 K



Peak to Peak Amplitude = 210 mV

77 K

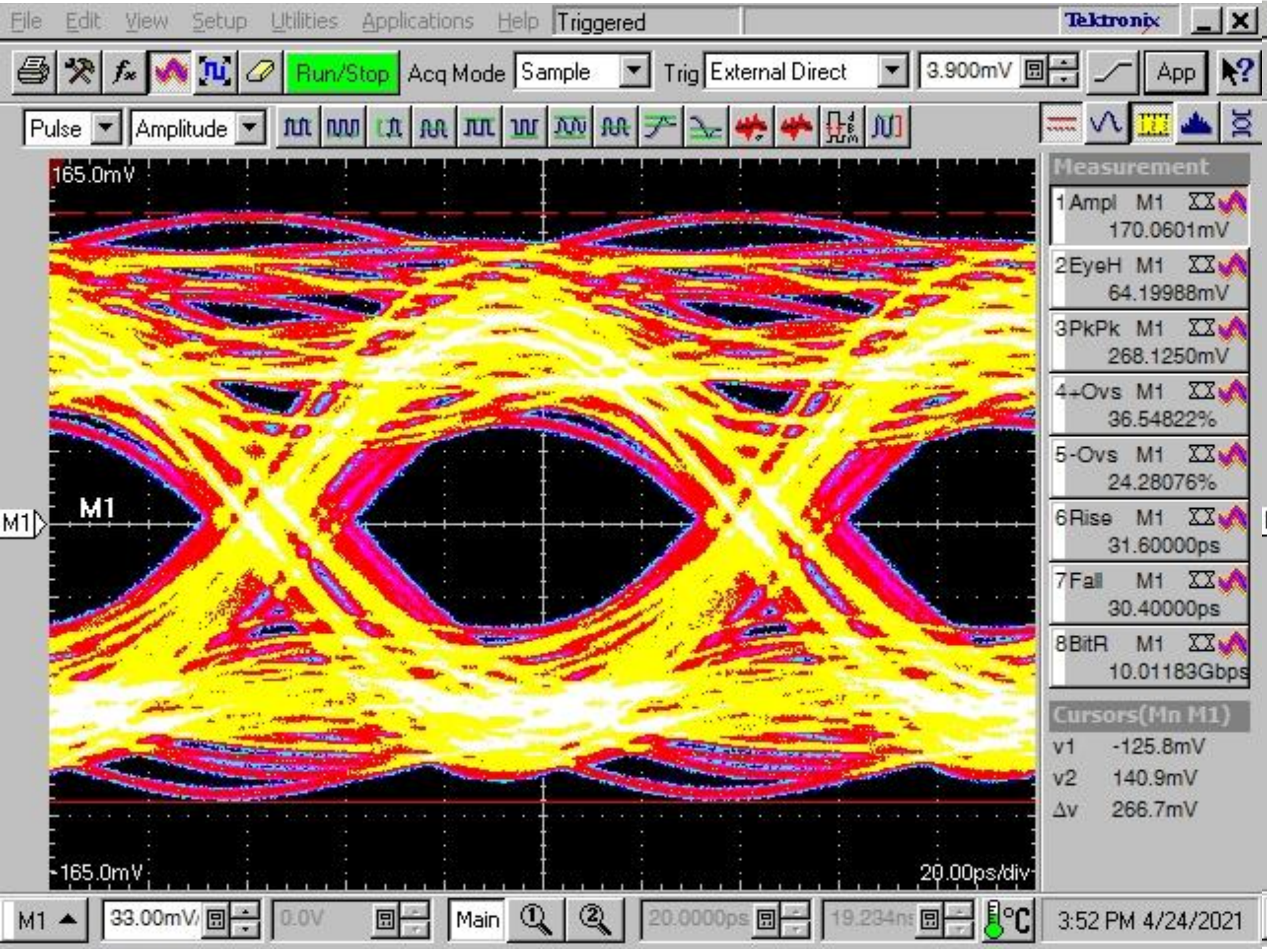


Peak to Peak Amplitude = 215 mV

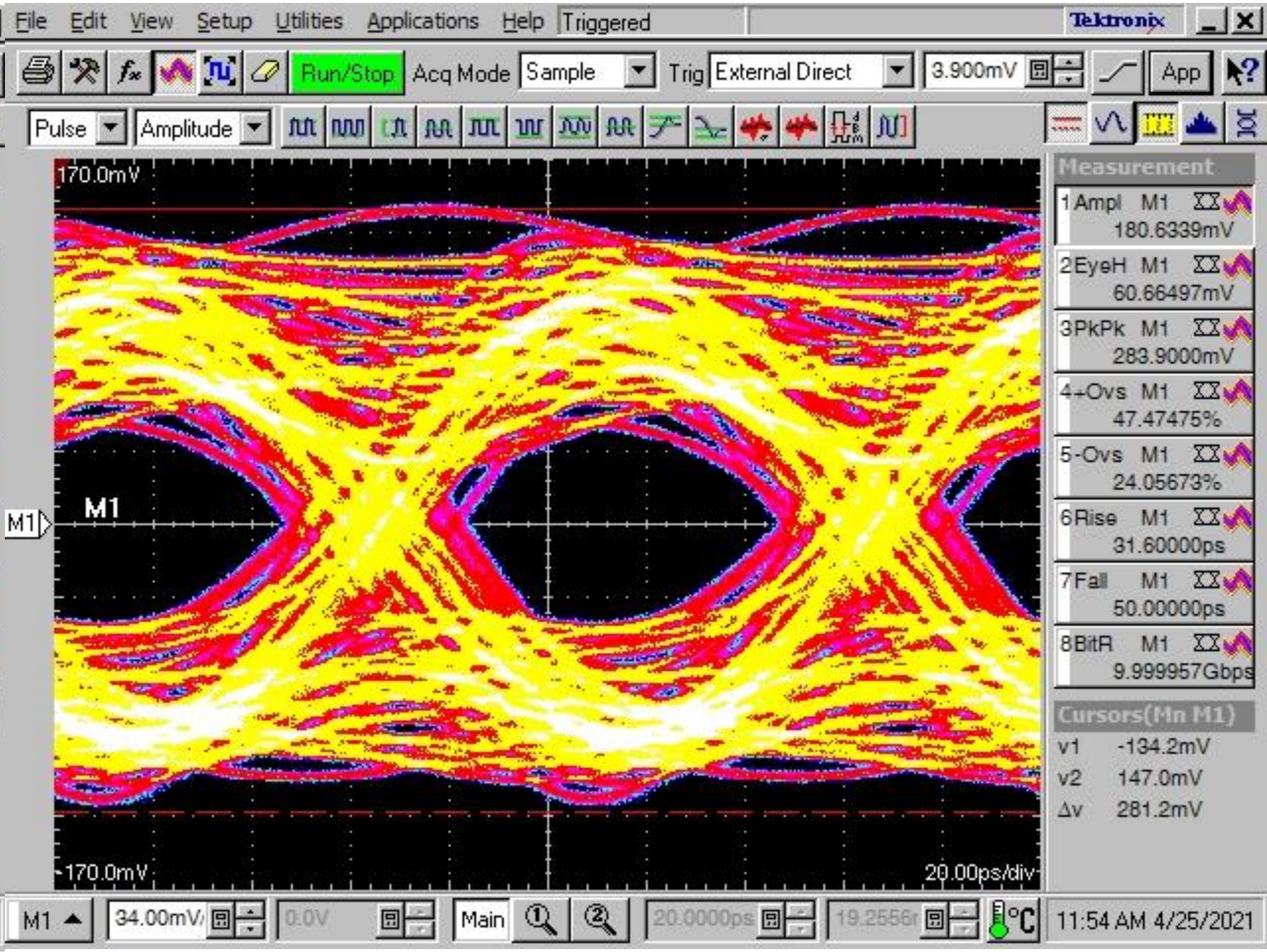
10 Gbps
PRBS7 Electrical Input Pattern
MSET = 75 mV ; Ibias = 19 mA

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

295 K



77 K



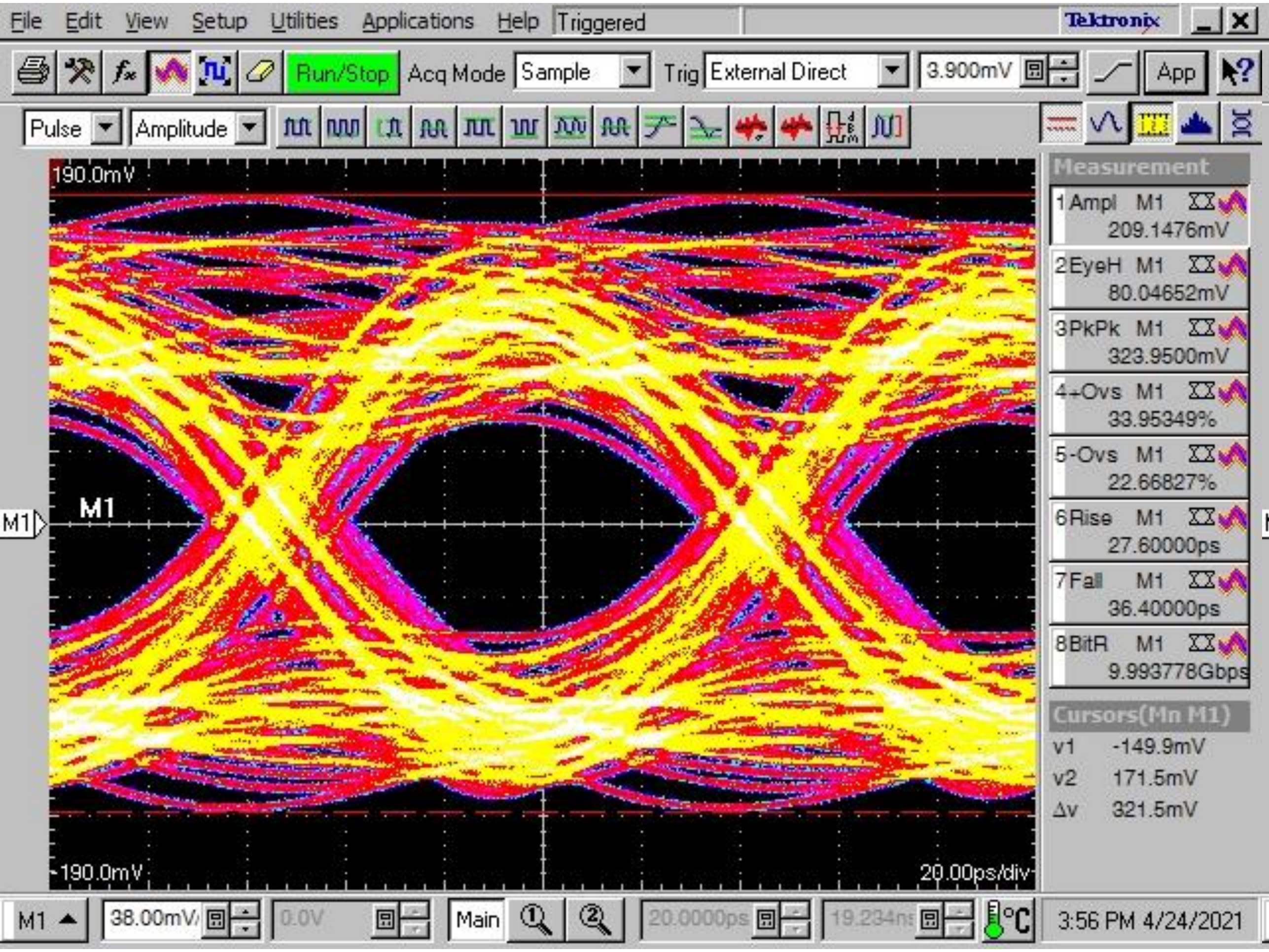
Peak to Peak Amplitude = 267 mV

Peak to Peak Amplitude = 281 mV

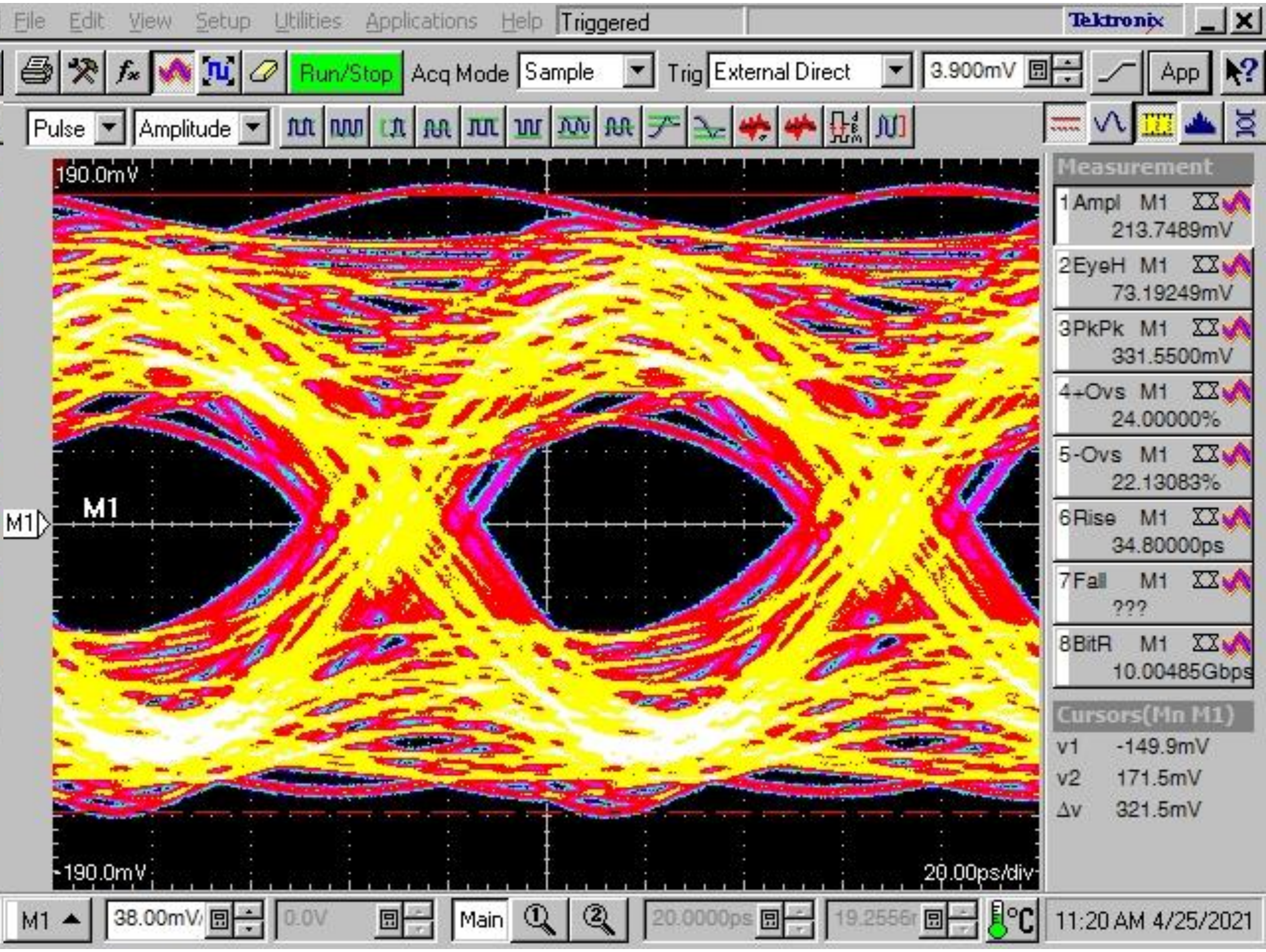
10 Gbps
PRBS7 Electrical Input Pattern
MSET = 100 mV ; Ibias = 19 mA

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

295 K



77 K

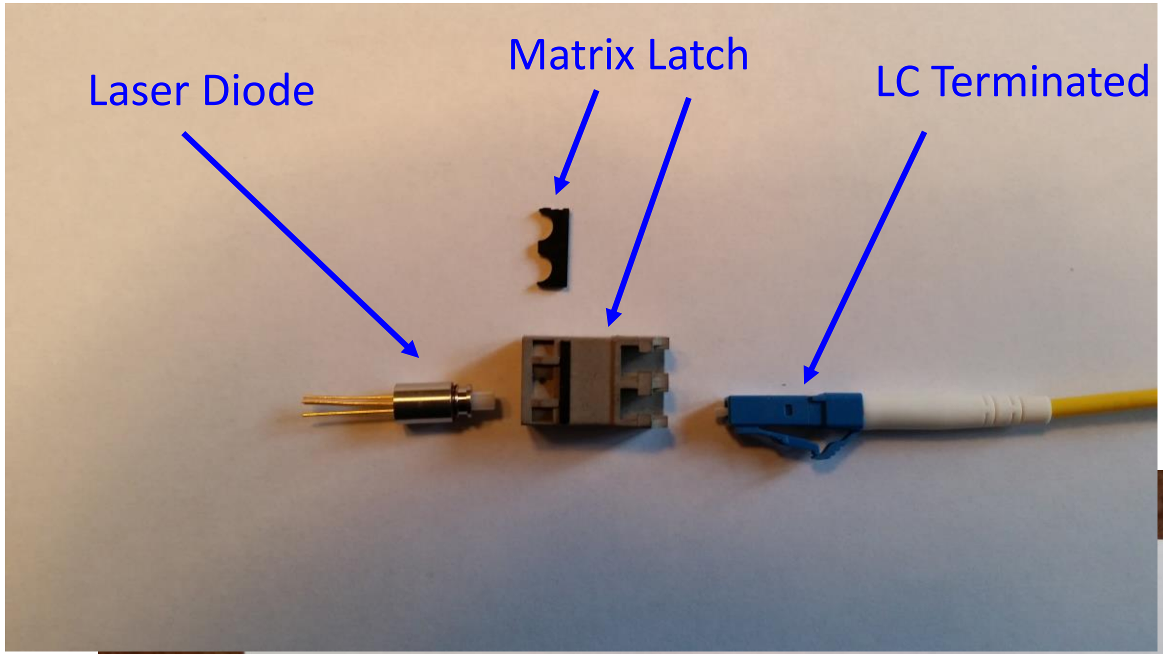


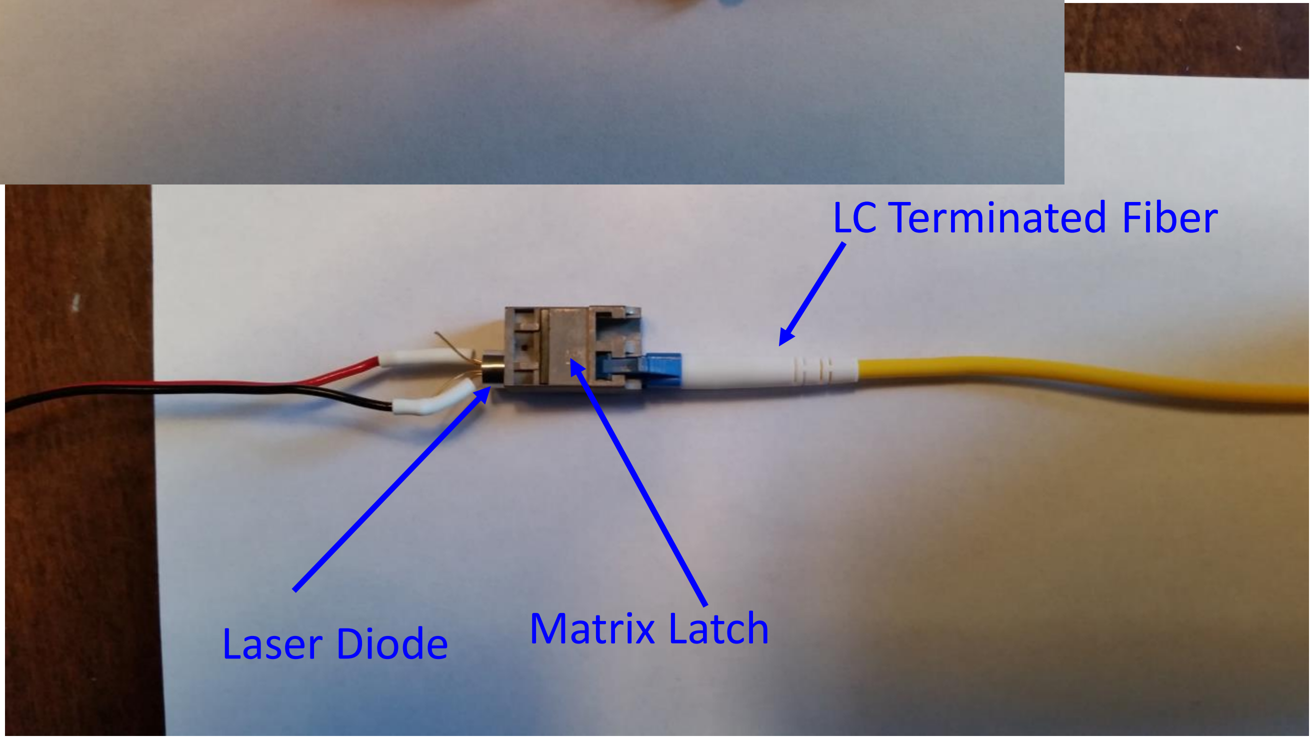
Peak to Peak Amplitude = 321 mV

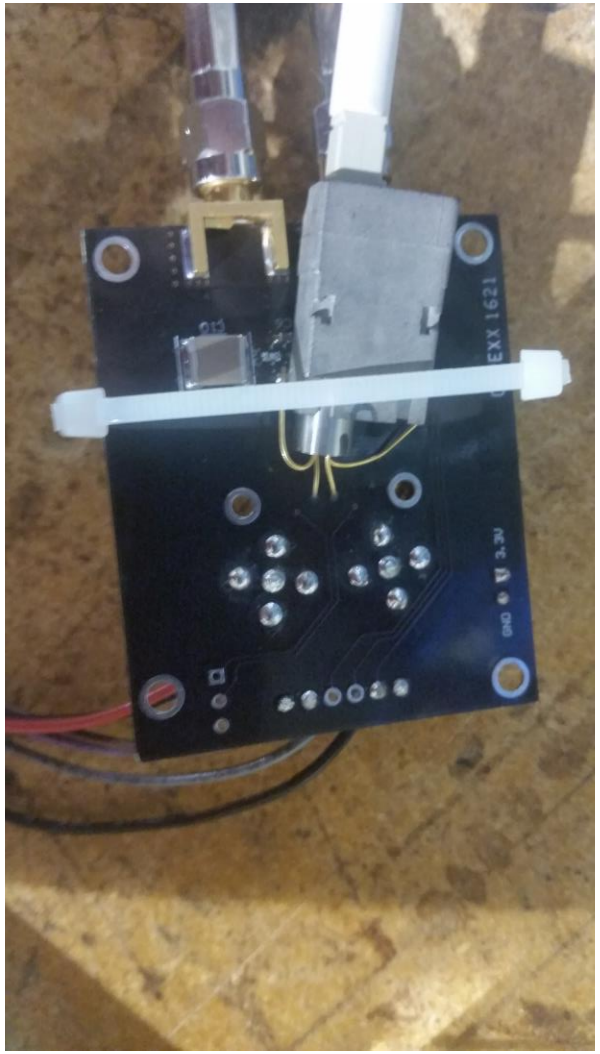
Peak to Peak Amplitude = 321 mV

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

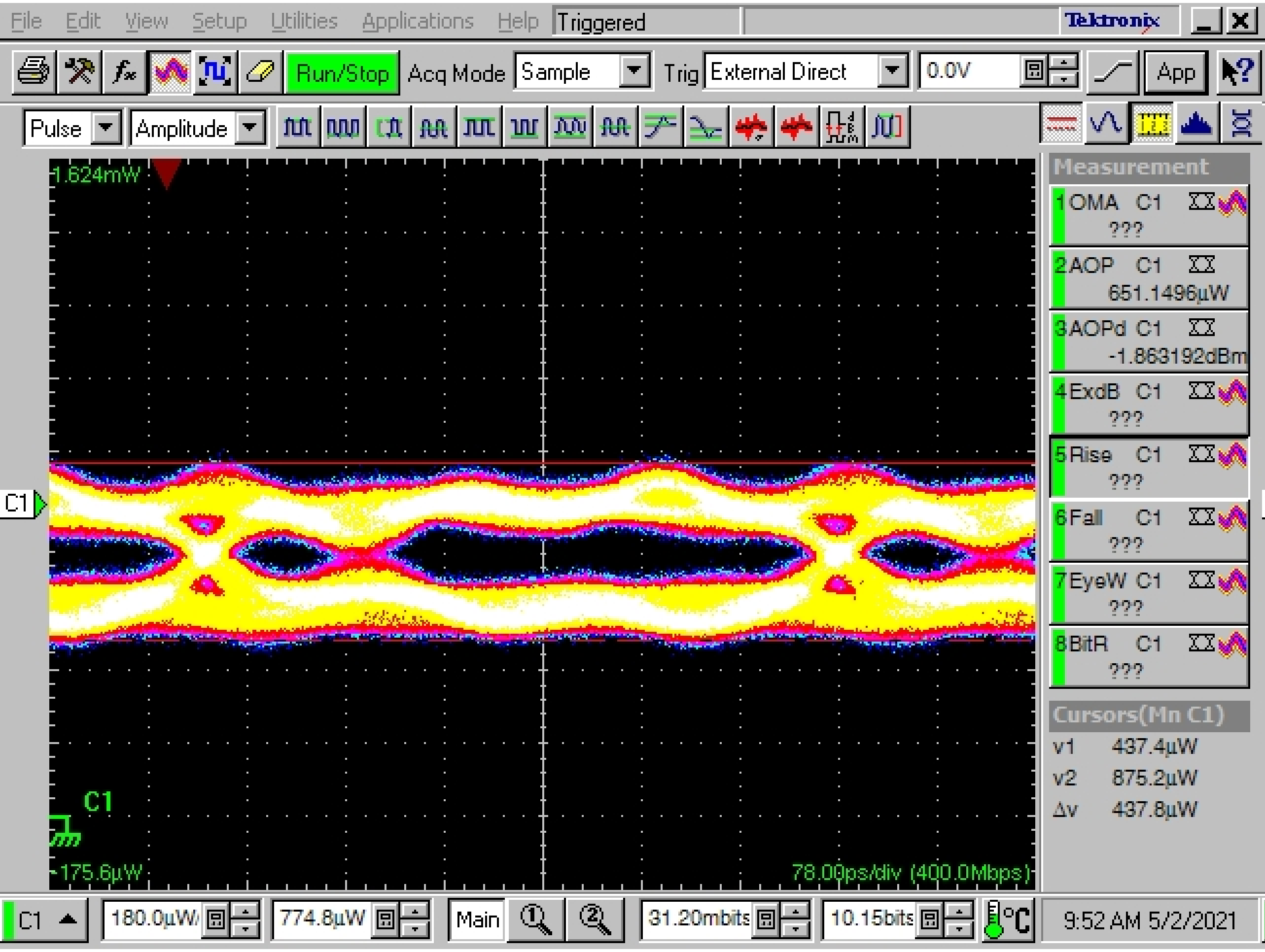
ADN2526/FP-1310-4I-LCC Combined Testing
Making the Optical Connection

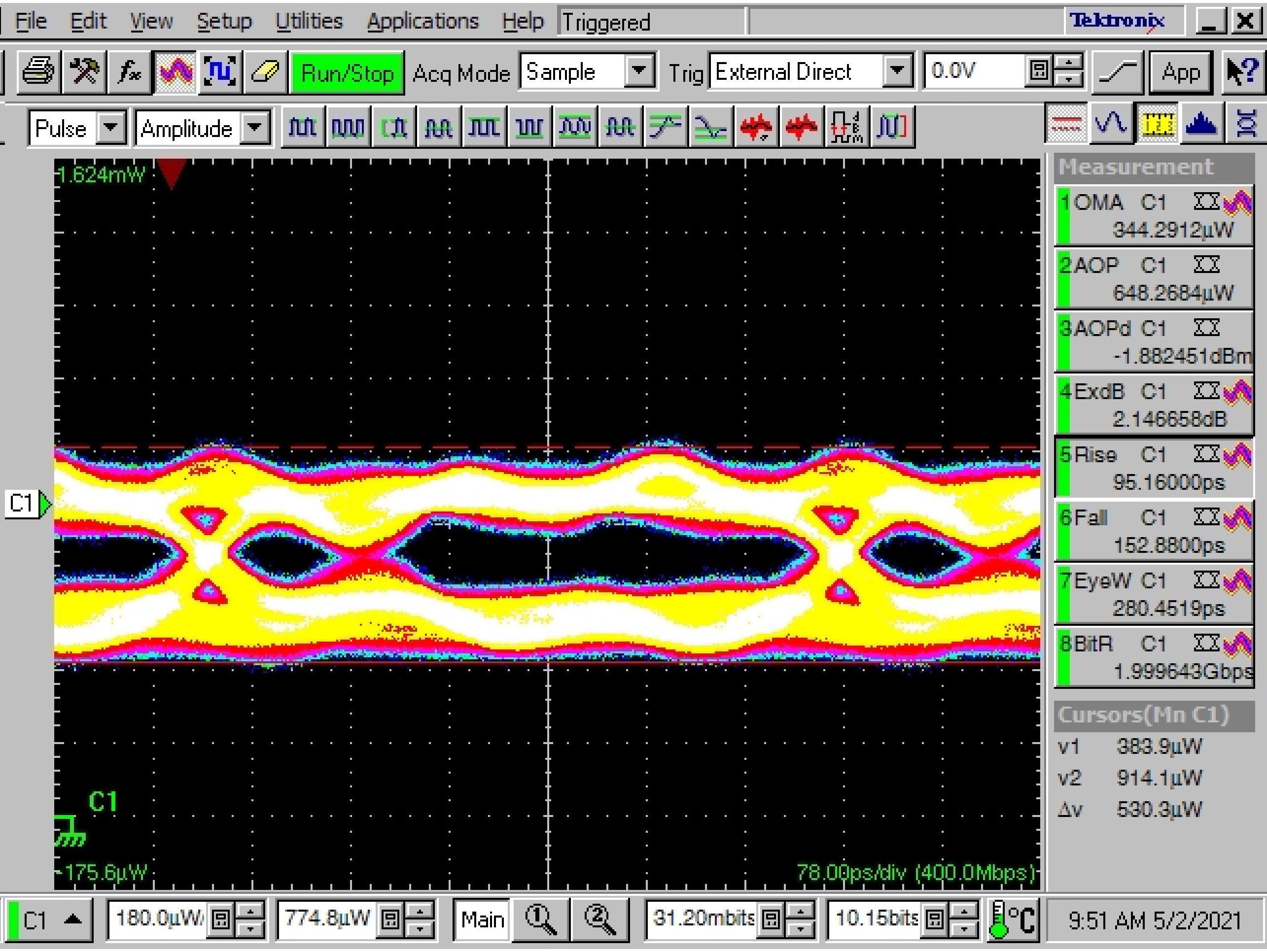






ADN2526/FP-1310-4I-LCC Combined Testing – Board 1
Optical Eye Performance at 295 K (PRBS7, 2 Gbps)

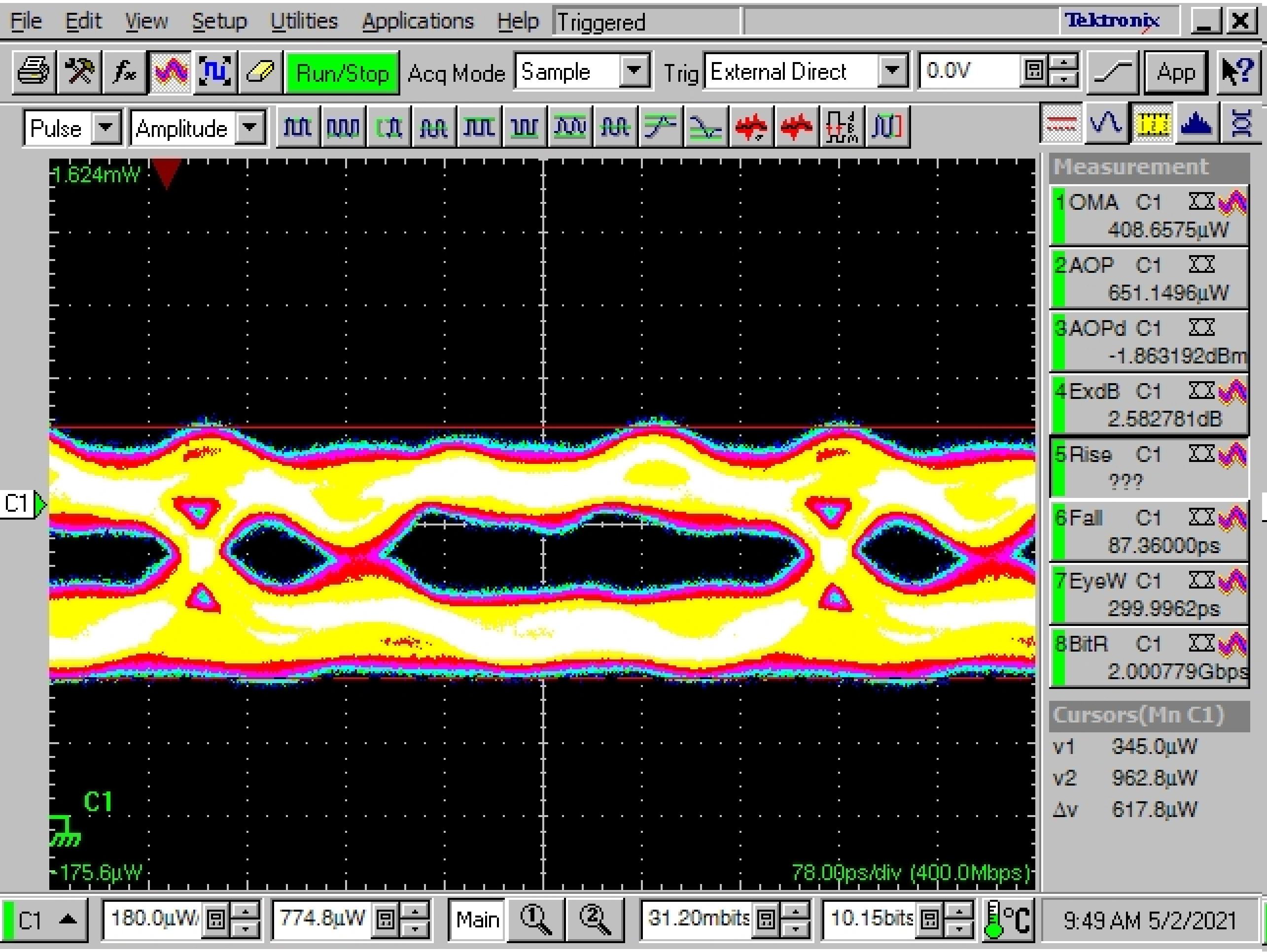




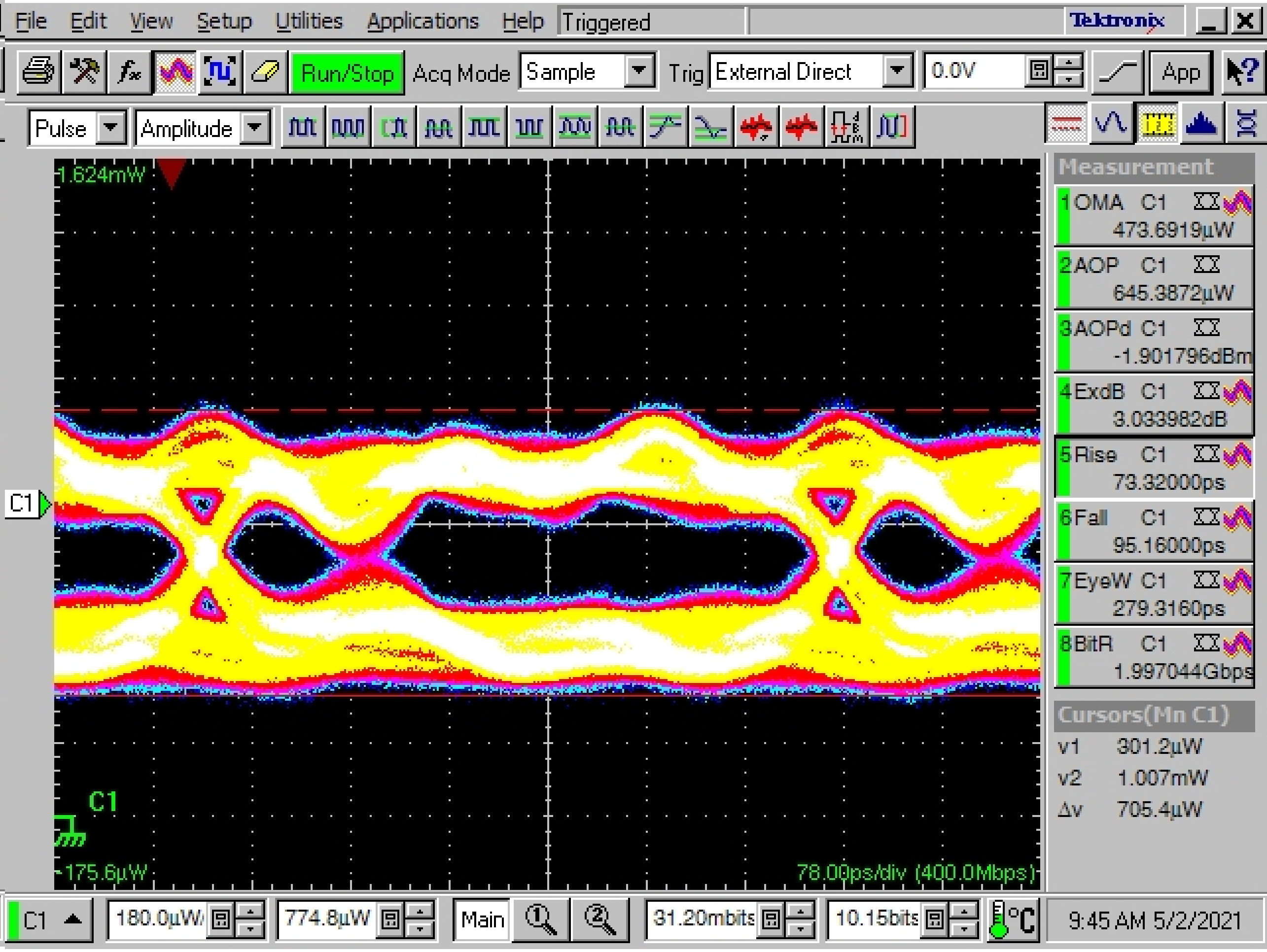
MSET = 30 mV
Peak to Peak Amplitude = 438 µW

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)

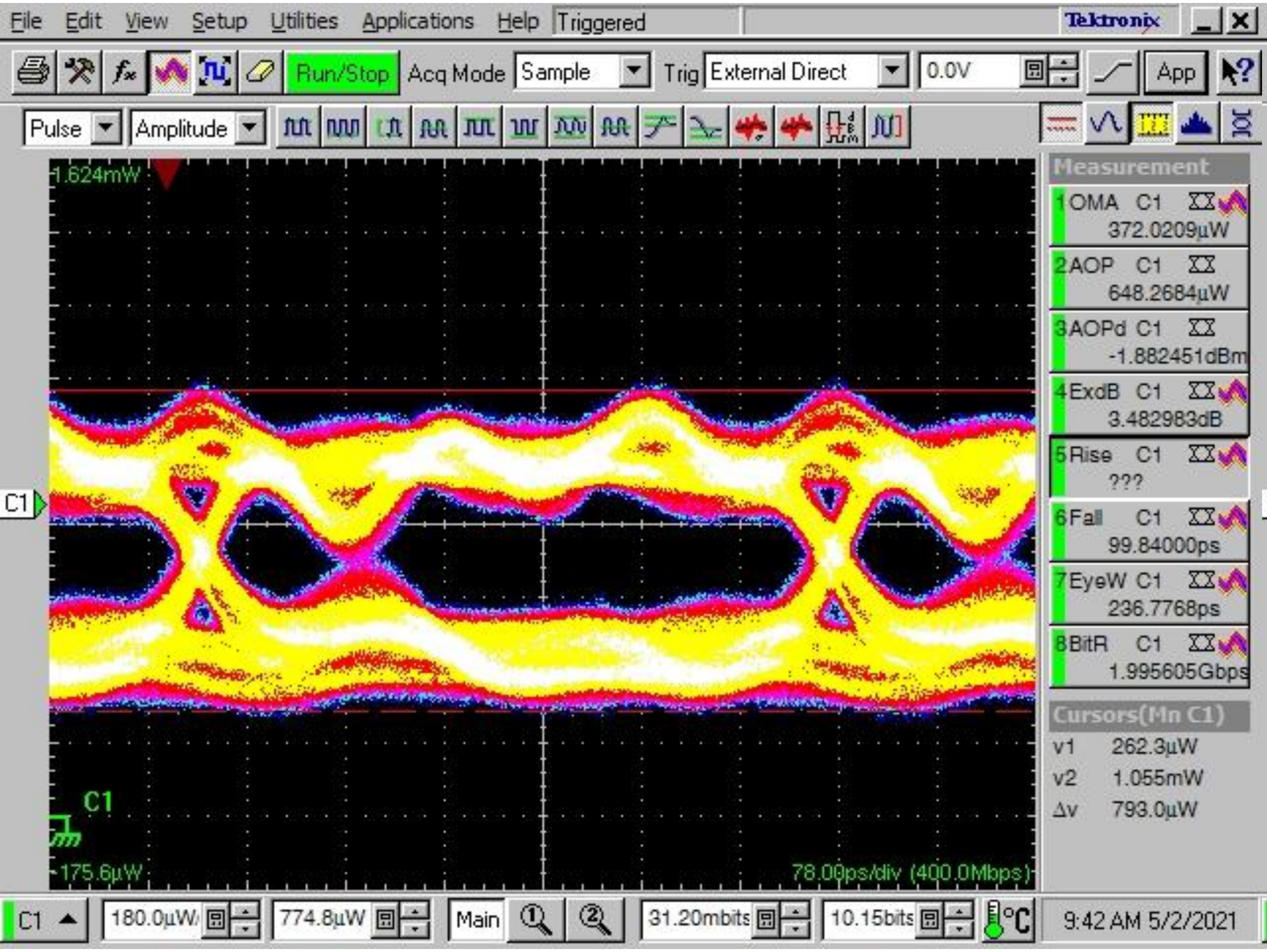


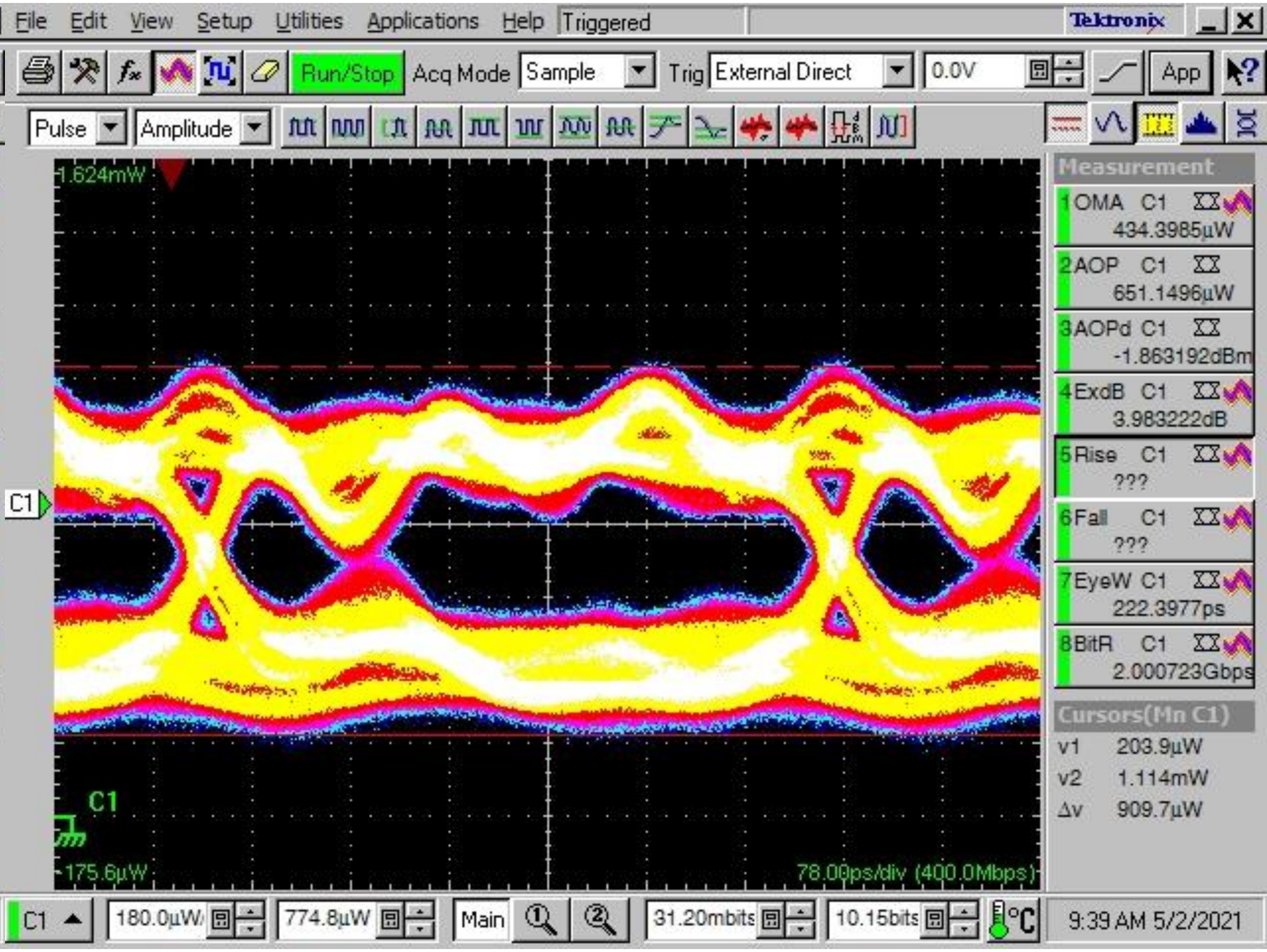
MSET = 50 mV
Peak to Peak Amplitude = 617 µW



MSET = 60 mV
Peak to Peak Amplitude = 705 µW

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

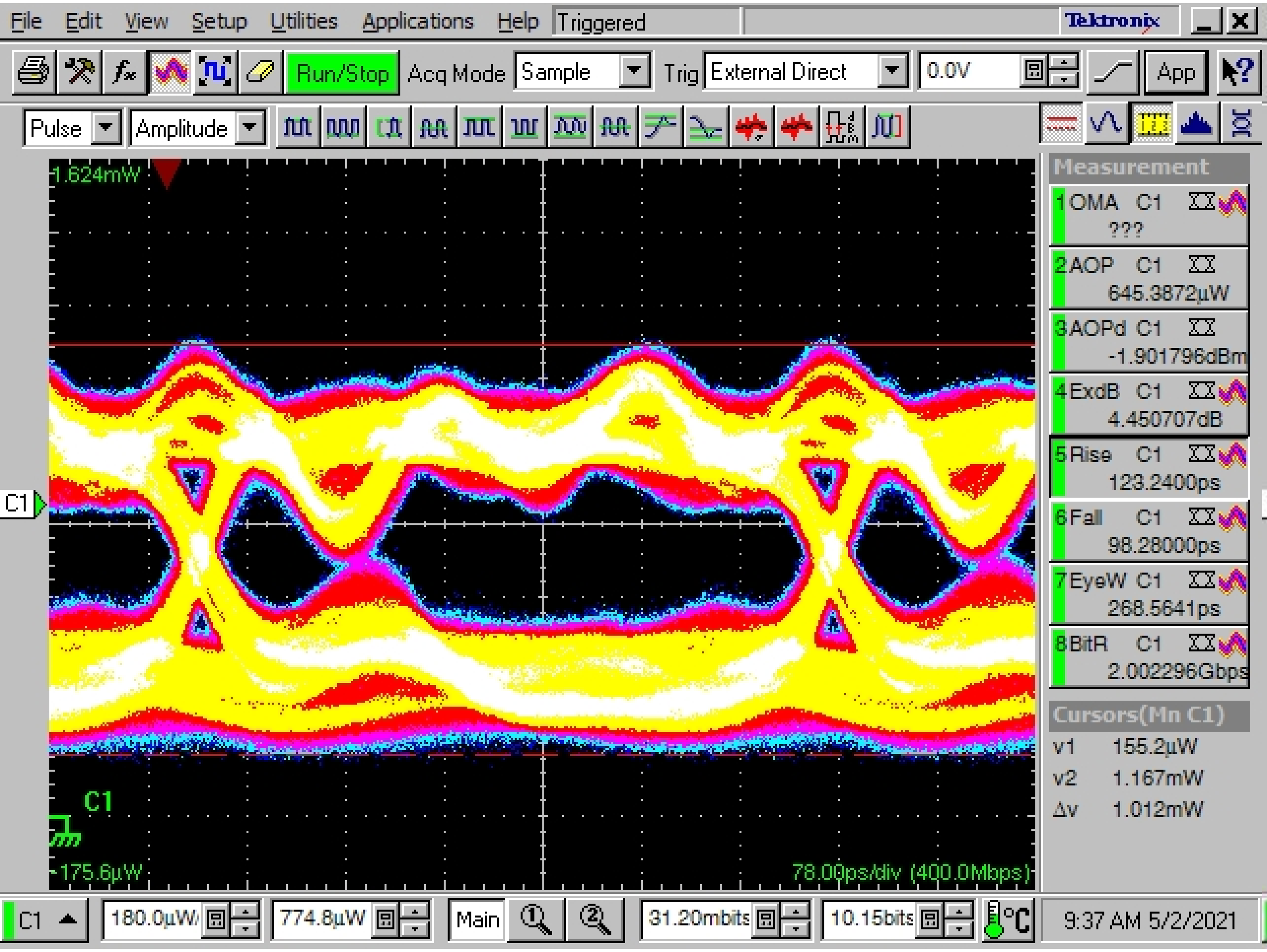


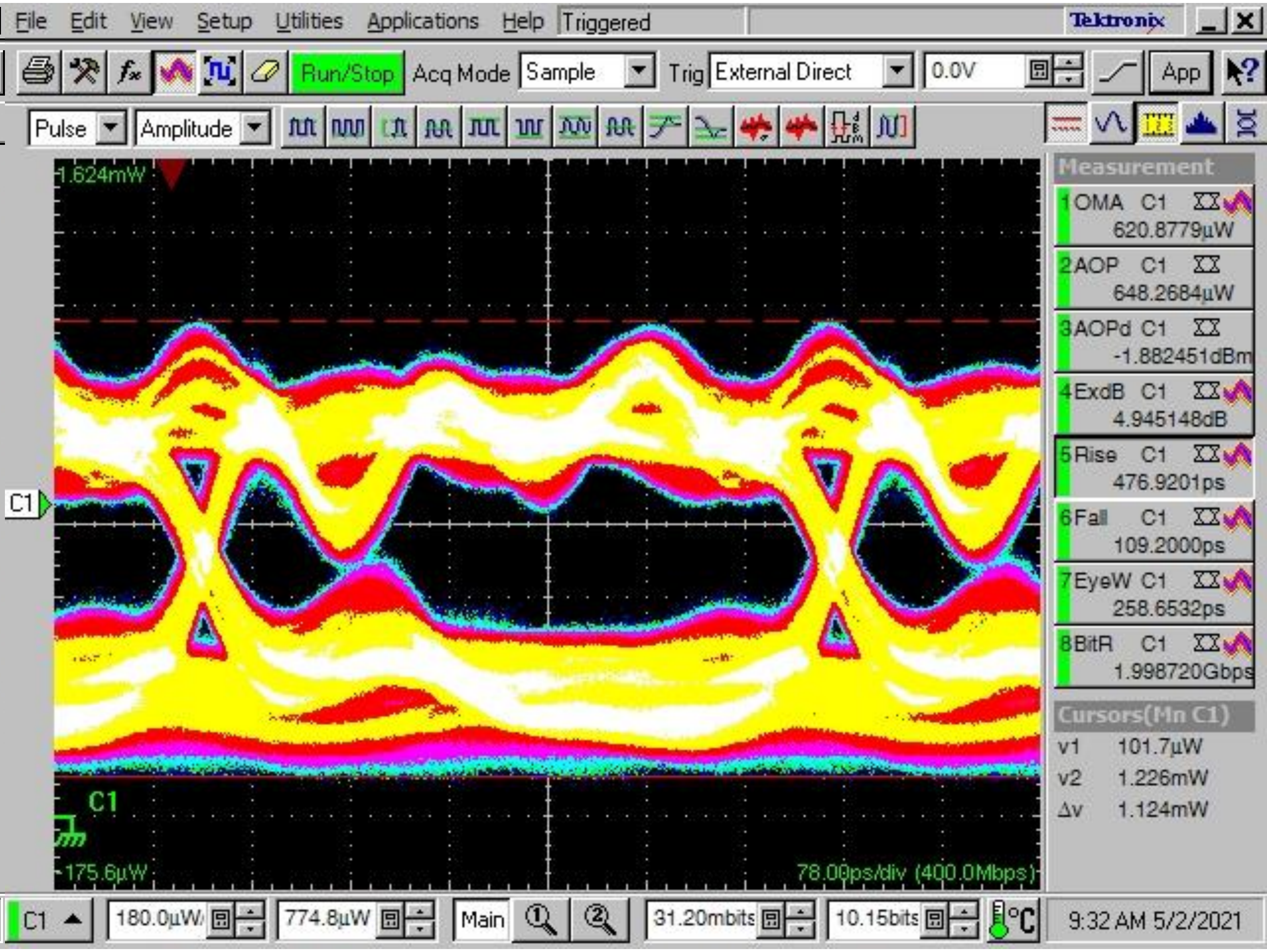


MSET = 70 mV
Peak to Peak Amplitude = 793 µW

MSET = 80 mV
Peak to Peak Amplitude = 908 µW

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

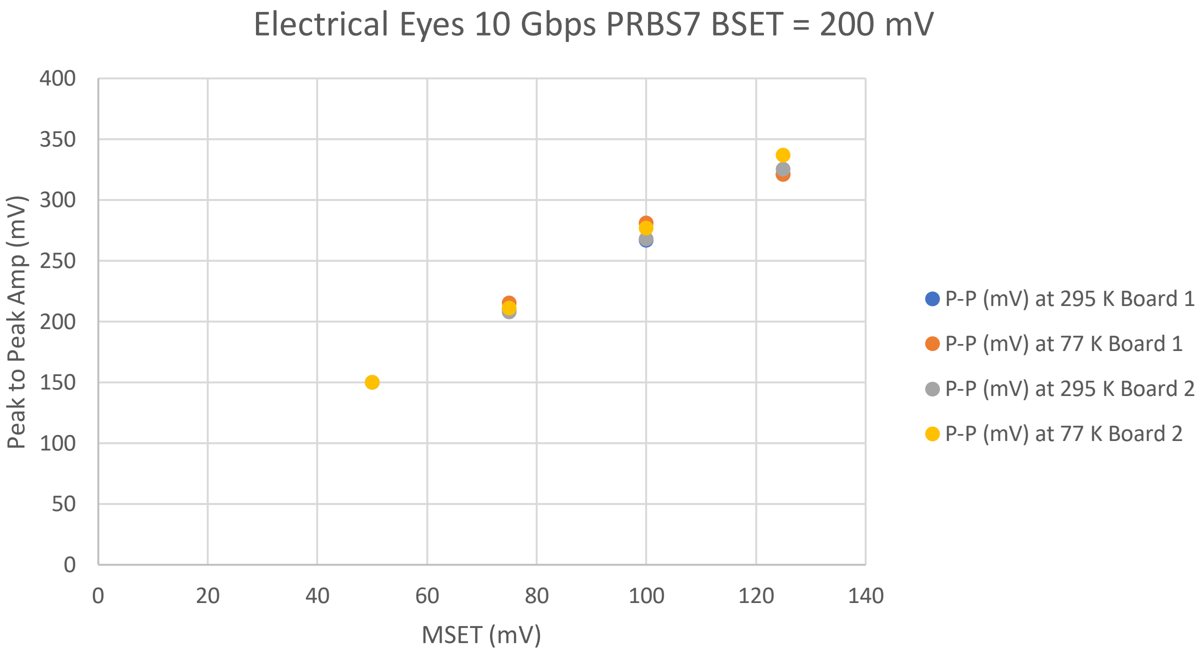


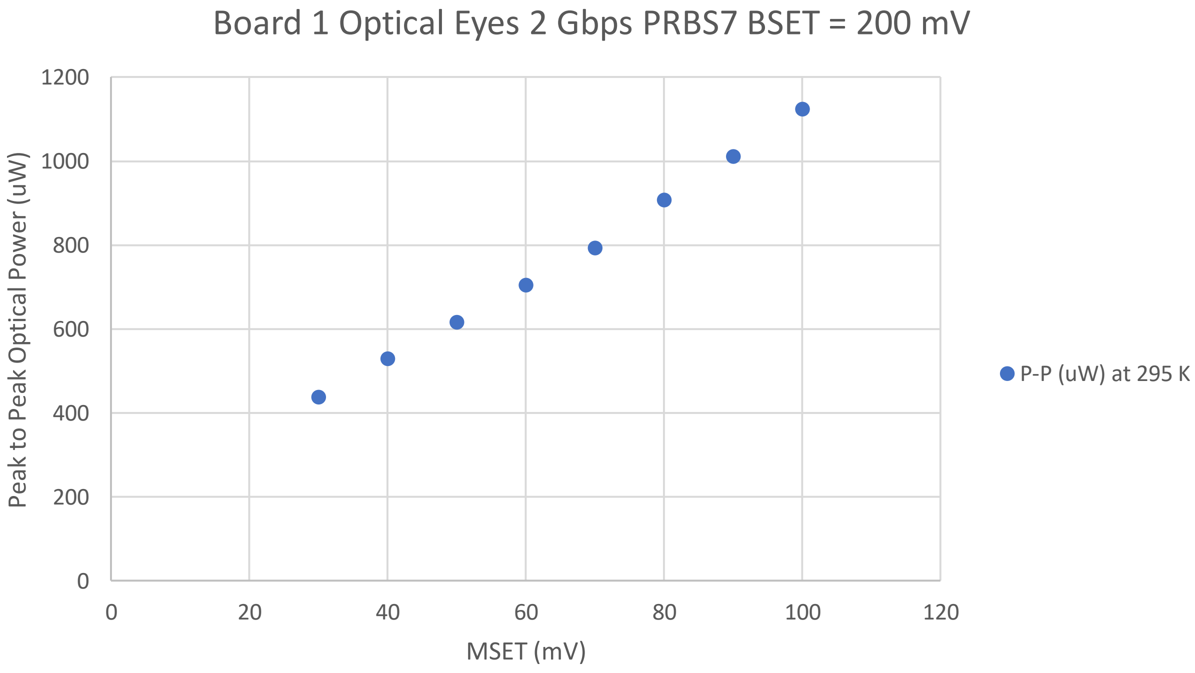


MSET = 90 mV
Peak to Peak Amplitude = 1012 µW

MSET = 100 mV
Peak to Peak Amplitude = 1124 µW

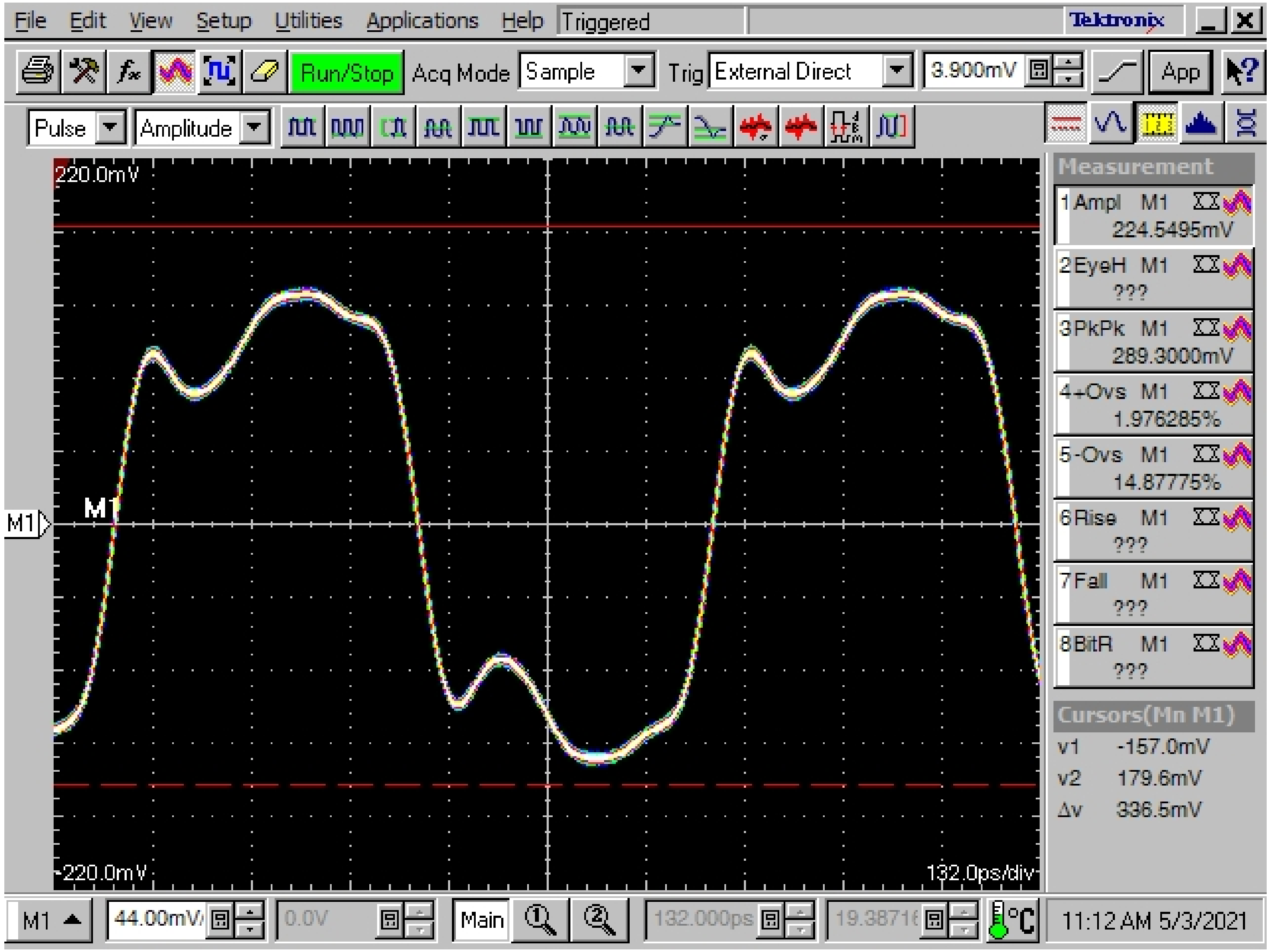
ADN2526 Board 1
Dynamic Performance Summary vs Modulation Setting

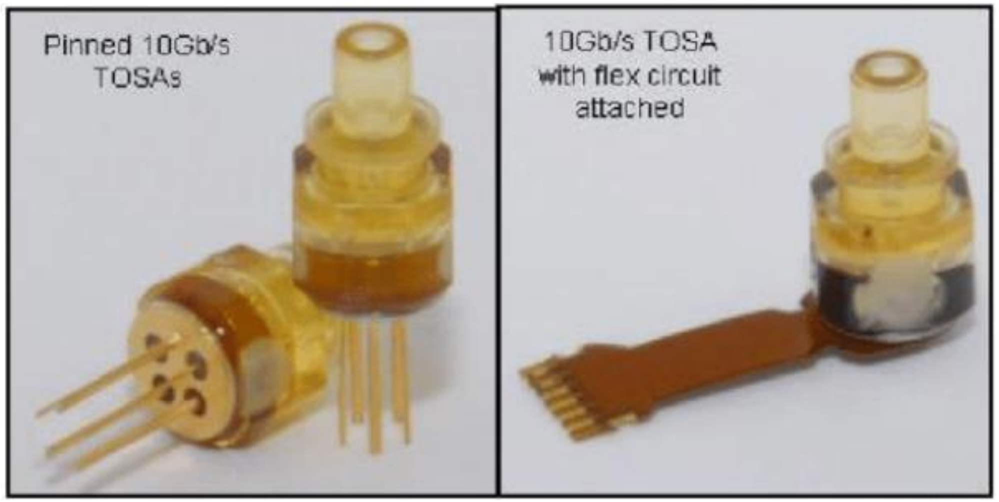




Lack of corresponding optical data was due to issues securing the laser diode to the board

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

ADN2526/FP-1310-4I-LCC Combined Testing
Next Steps – Laser Diode Approach

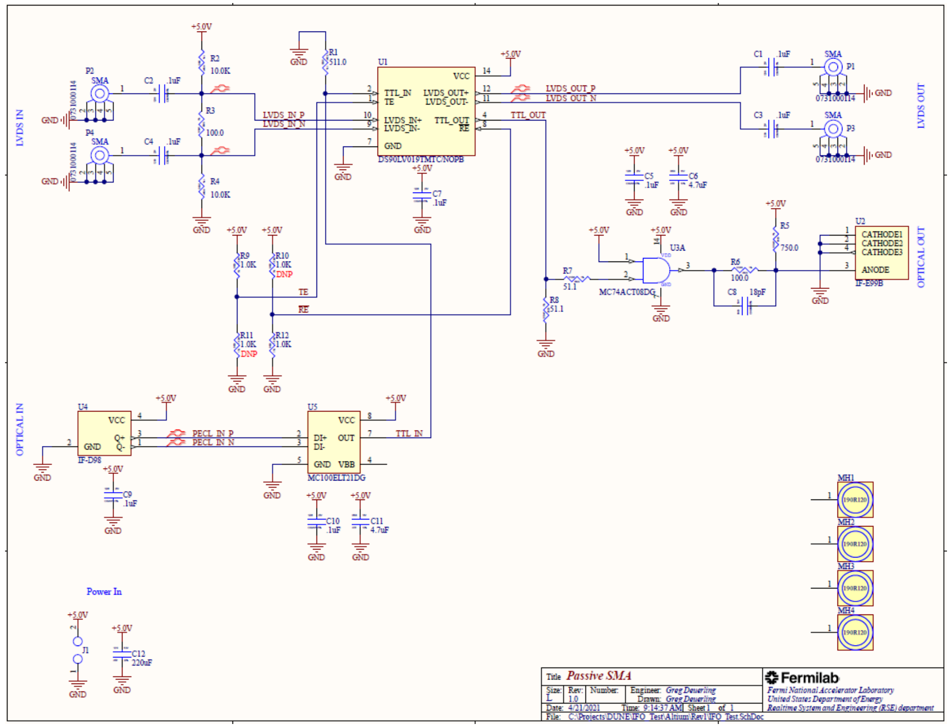
1. Improved Test Board Design: signal integrity
   a. No electrical test load and output SMAs will be used. The design will only support laser diodes for output results.
   b. We will put a cryogenically suitable 3.3 low dropout voltage regulator on the board for noise reduction.
   c. We will “hard wire” fixed resistors (no pots with long leads) for setting MSET and BSET (with a dual footprint option if we need it).
   d. I have some references on SFP+ module layout guidelines that we should review as this is not unlike those designs.
   e. Incorporate feedback from optical signal (TOSA monitor photodiode)

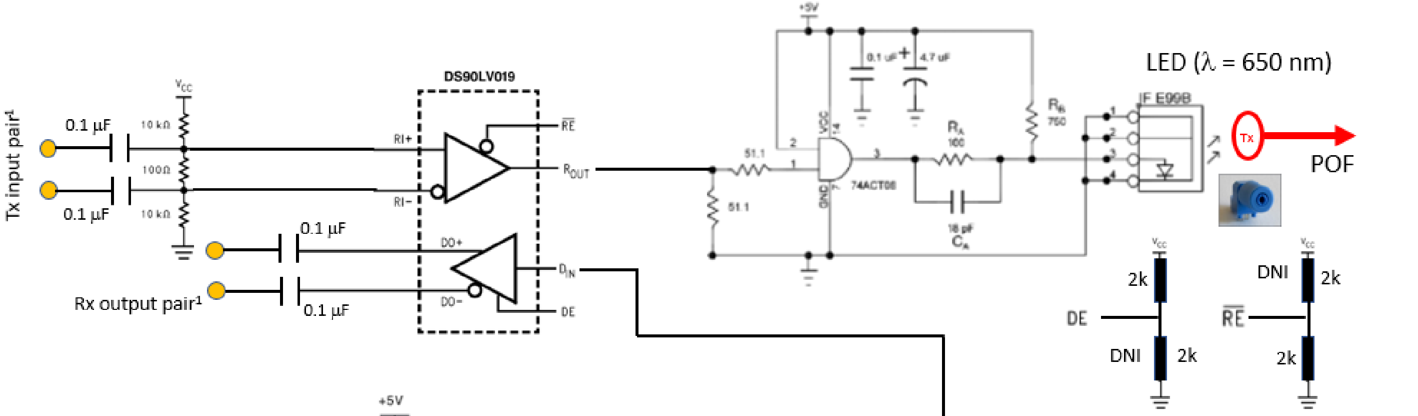
2. Improved Test Board Design: mounting of laser diodes
   a. Option 1 based on laser diodes with leads. This could be used with pigtailed lasers that we have ordered as well as with the current version and the LC latch.
   b. Option 2 based on laser diodes with flexible circuits and controlled impedance traces. I will be placing an order for devices of this type from TrueLight if I can’t find the same laser diode we have been testing with in this format (so far, no luck)

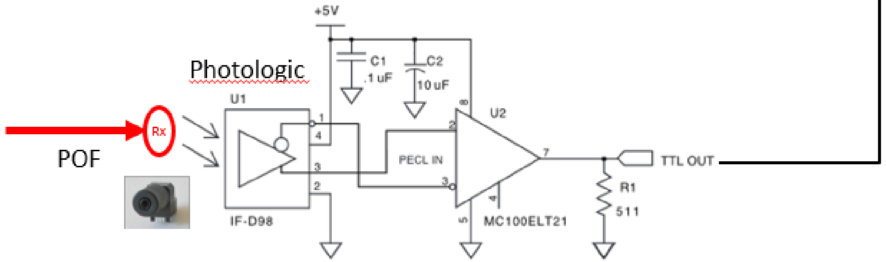
3. We plan on testing the effects of the use of (larger core) multimode fiber on bit error rate performance over representative lengths (warm and cold) (calculated RMS pulse broadening ~ 1.4 ps over 20 meters of MMF)

4. We must pursue other solutions to the optical connection problem (Matrix latches no longer available)

Alternative Approach: 156 Mbps Link over POF – Test Board





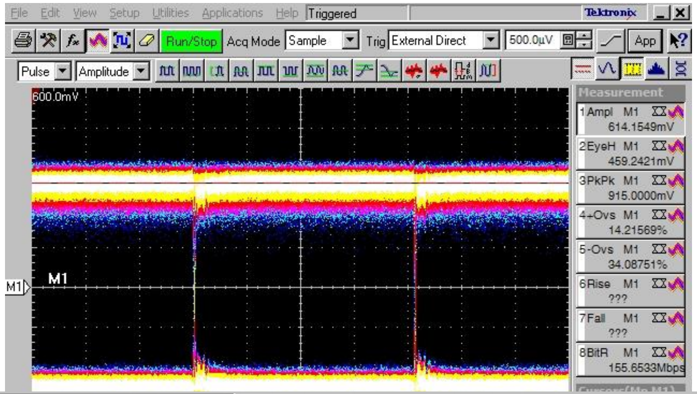


Comments:

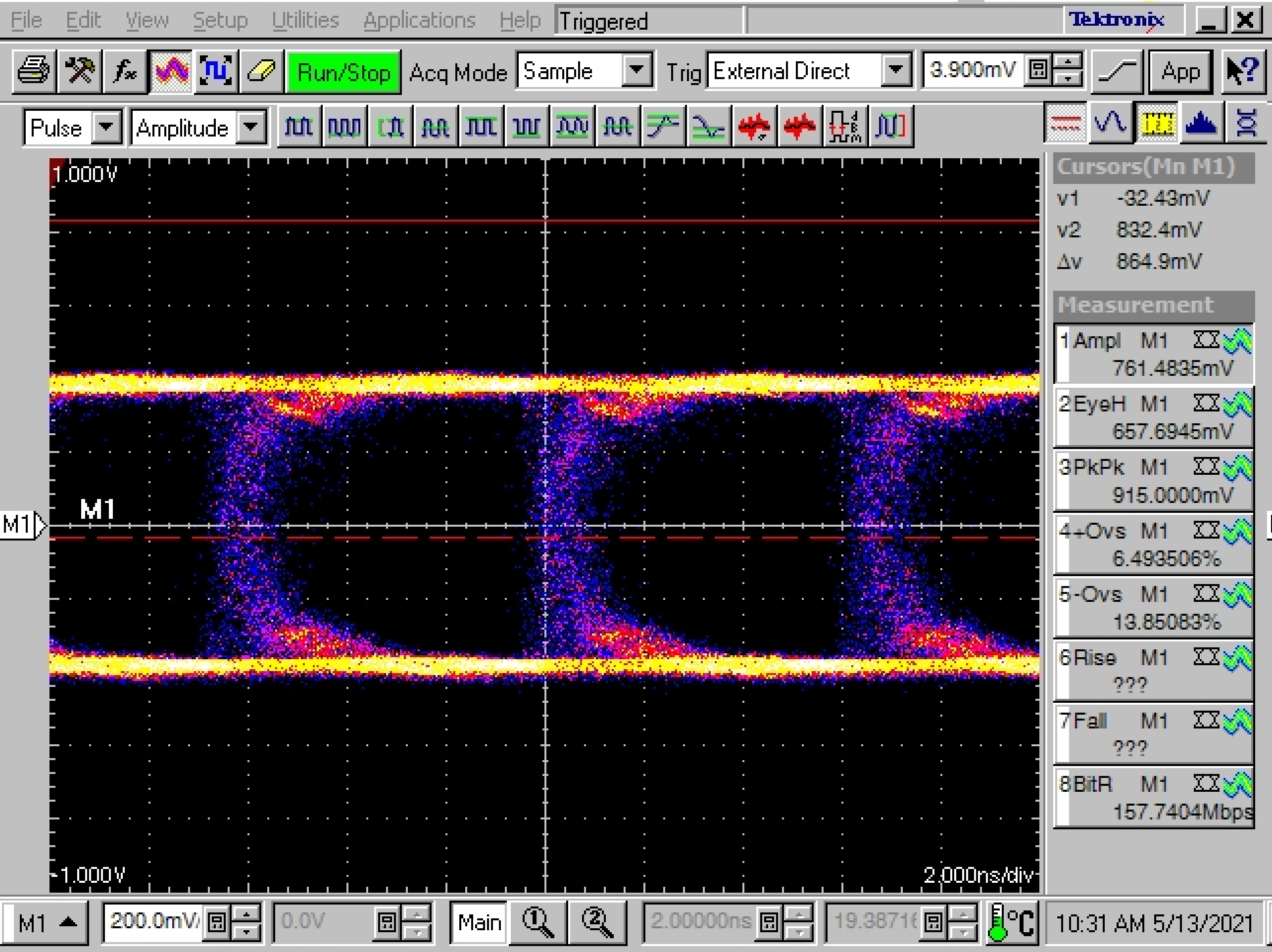
1. This pair to be delivered through on-board SMAs
2. This board requires only 5V power.
3. Two of these boards will be needed to implement a downlink or uplink test. One board would be in the dewar while the other board would be warm.
4. Electronics are on order.
5. 20 m sample of POF is in hand

156 Mbps Link over POF – Cold Tx to Warm Rx

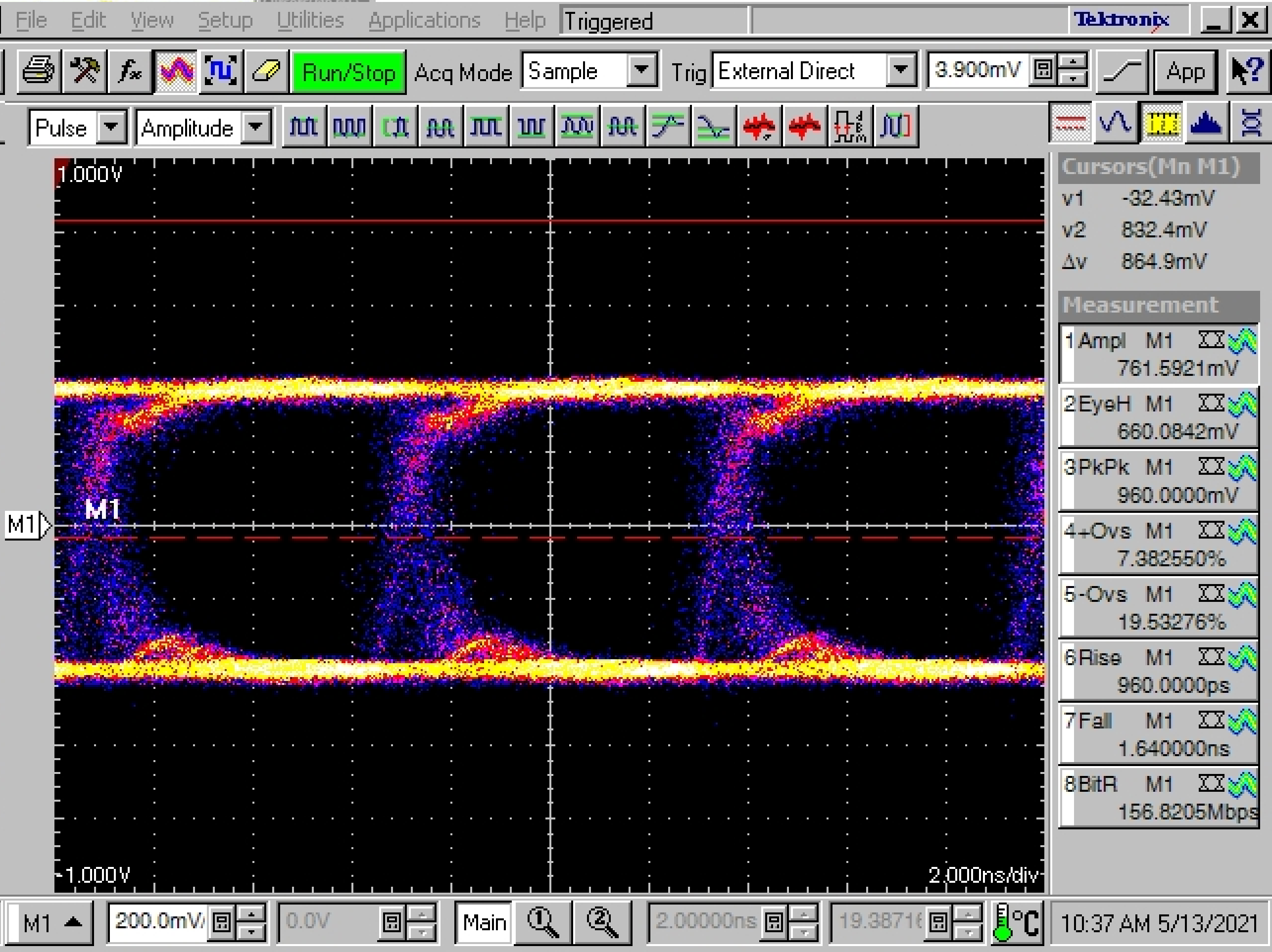
Electrical Input to LED



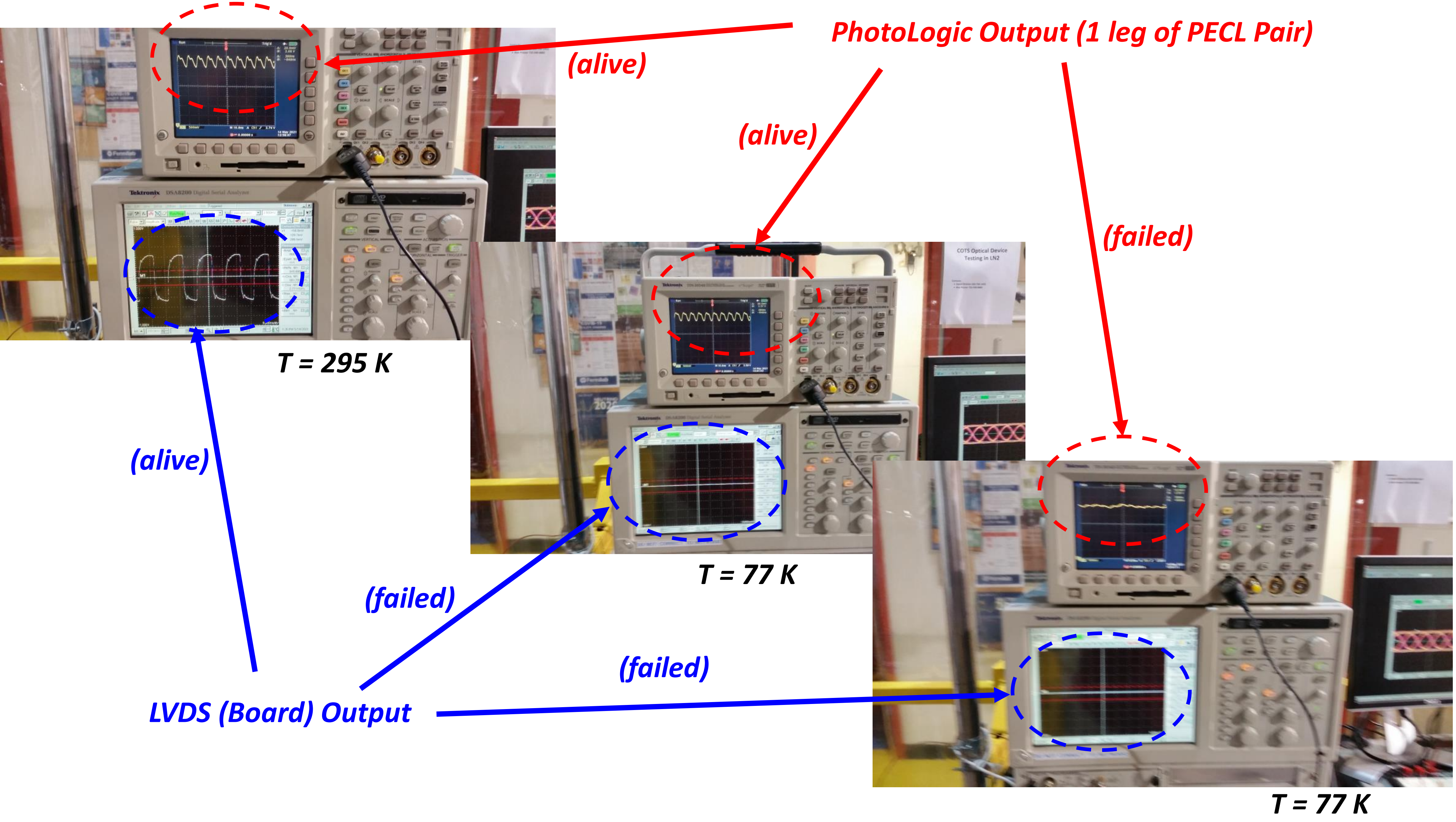
Electrical Output From PhotoLogic Rx @ 295 K



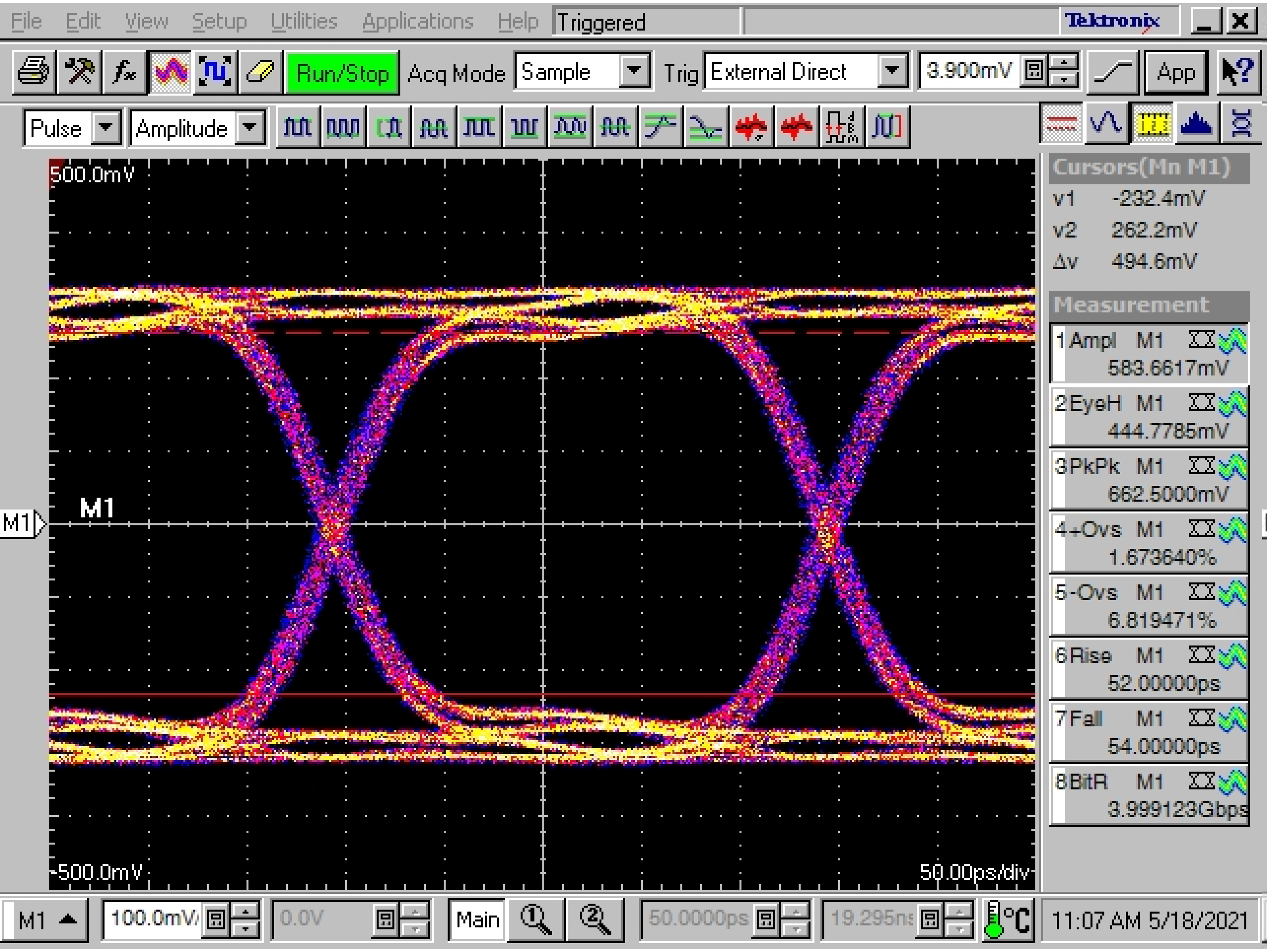
Electrical Output From PhotoLogic Rx @ 77 K



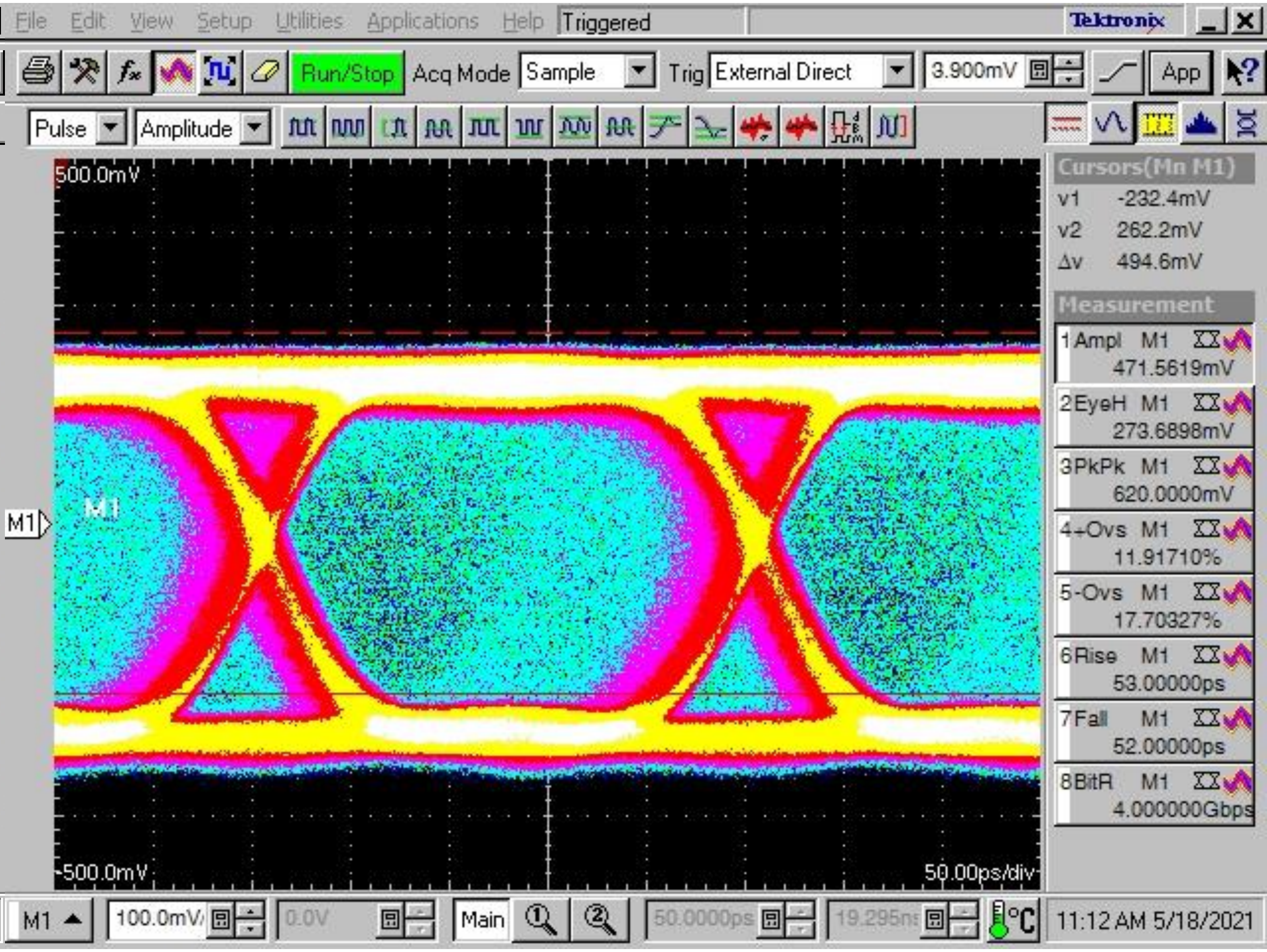
156 Mbps Link over POF – Warm Tx to Cold Rx



SFP+ Rx Channel – Warm Tx to Cold Rx
PRBS7, 4 Gbps



T = 295 K



T = 77 K

Samples which are in the eye opening prevent the BER test from synchronizing

InGaAsP Spectral Shift Estimate (1310 nm Laser Diodes)

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

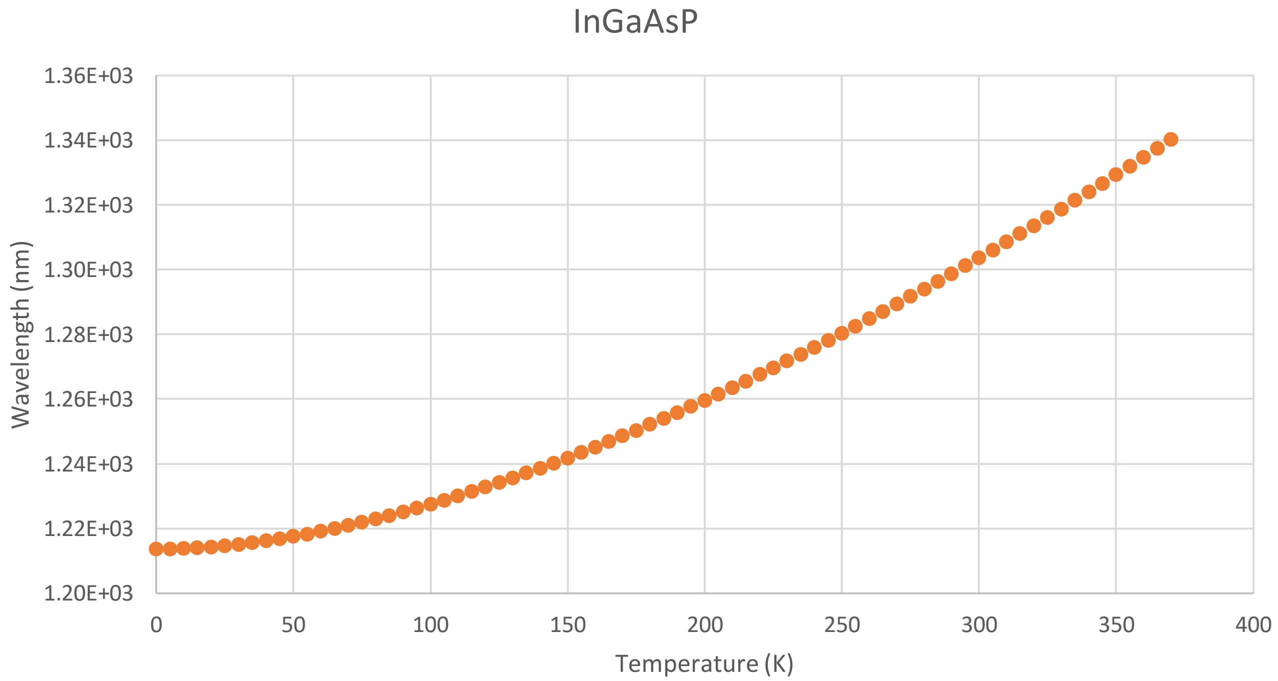
Compute the 0 K band gap:
Using E_g(300 K) = 0.949 eV, solve for E_g(0 K) using Varshni's equation:
E_g(0 K) = 1.019 eV

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

For InGaAsP*:
$\alpha = 4.9 \times 10^{-4}$ eV/K^2
$\beta = 327$ K

Plot photoluminescence wavelength using:

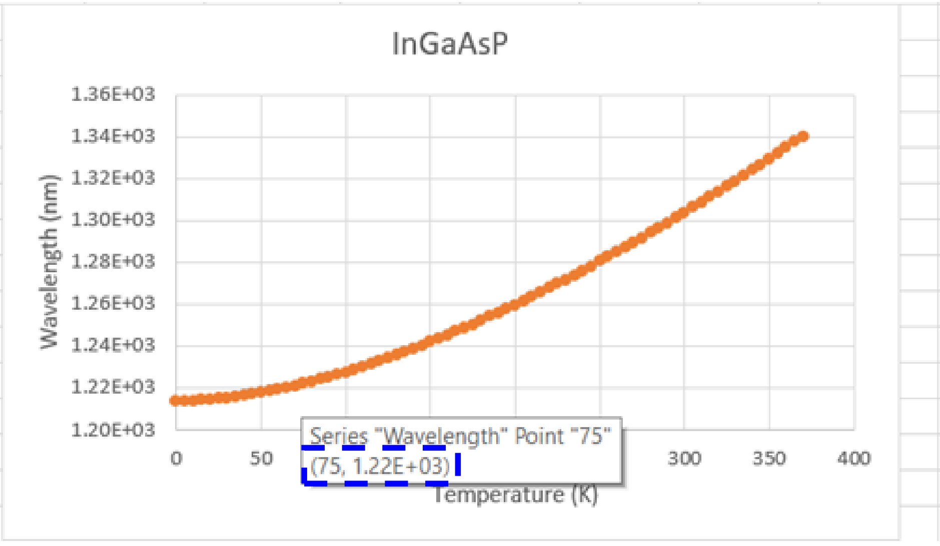
$$\lambda = \frac{hc}{E_g(0) - \frac{\alpha T^2}{T + \beta}}$$

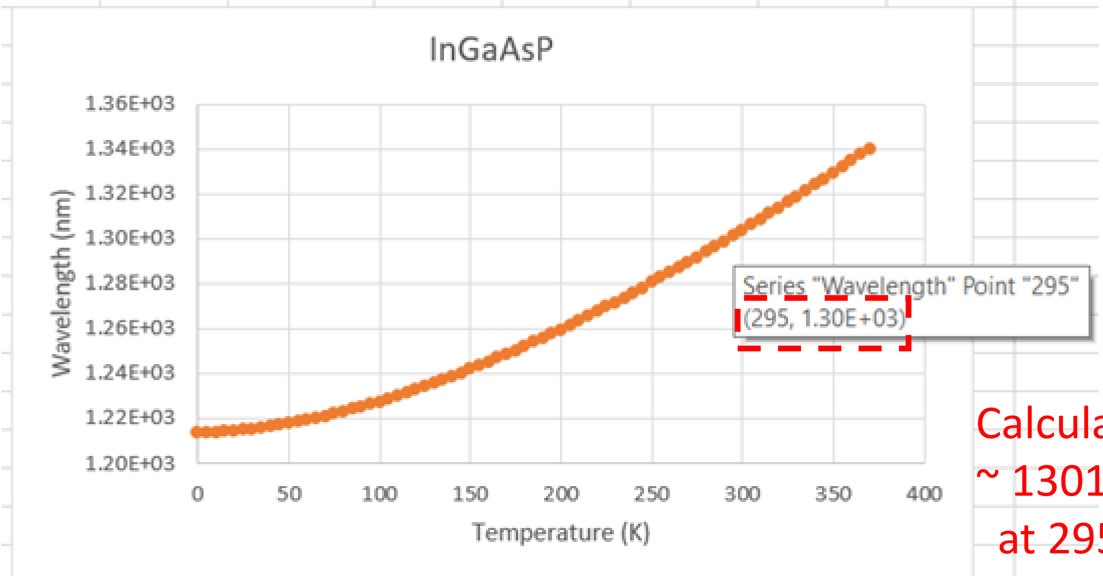


Ref 1: "Temperature Dependence of Photoluminescense of n-InGaAsP"
H. Temkin, et. al., Journal of Applied Physics 52 (1981)

InGaAsP Spectral Shift Estimate (1310 nm Laser Diodes)

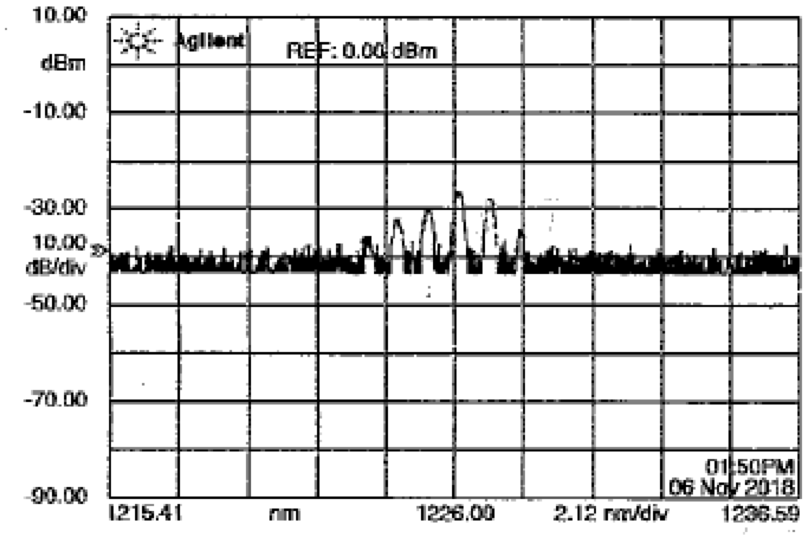
Calculated:
~ 1222 nm
at 75 K

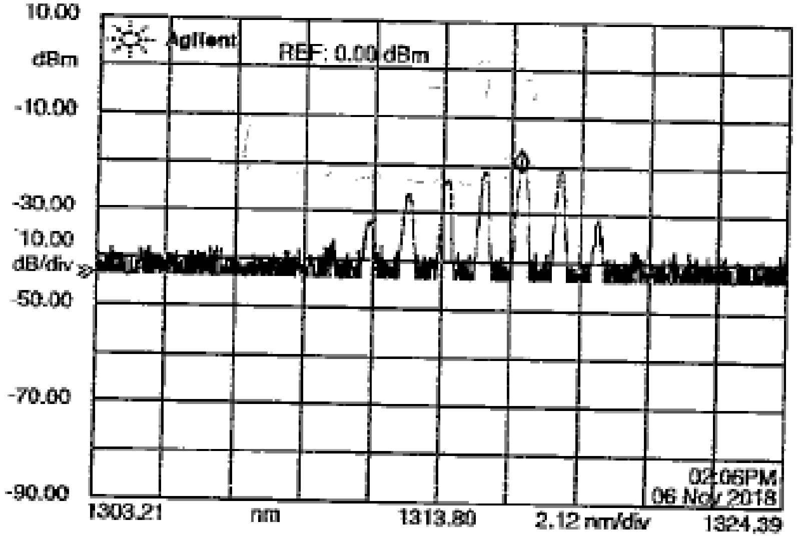




Calculated:
~ 1301 nm
at 295 K

Measured:
Max Peak
~ 1226 nm
in LN2





Measured:
Max Peak
~ 1316 nm
at room
temperature

Discussion