DUNE Cryogenic Optical Links
Internal Review Presentation

April 12, 2021

Introduction

Agenda:

Tests of Commercial Off The Shelf (COTS) SFP+ Modules

Test Plans and Activities for Discrete Components of Transmitter Channels (Tx) of SFP+ Modules

Test Methods and Results Obtained Thus Far for Tx Channel Components

Test Plans and Results for Receiver Channel (Rx) Components

Summary: Where we are, where we intend to go, and issues and risks we face

Collaboration and Consultation (includes but not limited to):

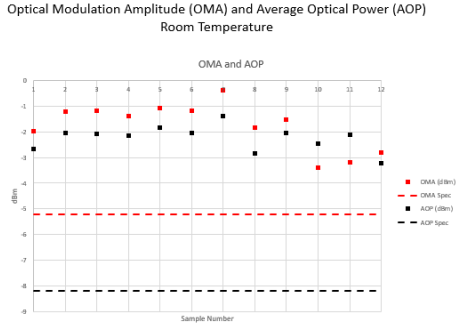
FNAL: D. Christian, G. Deuerling, J. Greskoviak, A. Prosser, R. Rivera
BNL: H. Chen, S. Gao, V. Radeka,
LBNL: M. Turqueti
CERN: J. Troska, F. Vasey
SMU: J. Keyzer, T. Liu, J. Ye, W. Zhang

Testing of COTS SFP+ Modules

Question: Can a COTS module be found that operates at 77K (best hope for quick solution)?

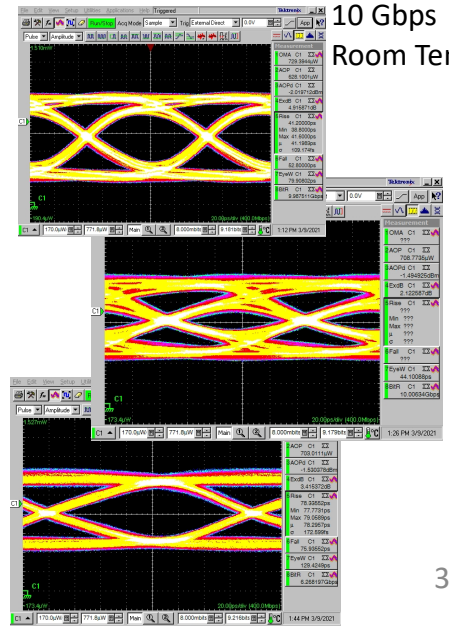
Focus on Small Form factor Pluggable (SFP+) Modules
- Mature technology
- Widely used in telecommunications

We obtained samples of SFP+ modules (1310 nm wavelength, rated for 10 Gbps)
- Fabry-Perot (FP) laser diode equipped
- Distributed FeedBack (DFB) laser diode equipped



Samples were characterized at room temperature for later comparison
Samples were then tested in LN2 at PAB

Summary of results:
- Some DFB equipped samples (Tx) sustained multi-Gbps transmission in BER Tests
- No samples recovered from a power cycle in LN2
- No Rx channel sustained error free communication in LN2



This leads us to believe that a Tx based on some elements inside an SFP+ may be engineered to make a suitable Tx module for LN2 if the right components are selected.

Discrete Approach to Tx Channel Based On SFP+ Modules
Laser Diodes (TOSAs)

Essential Components of Tx:

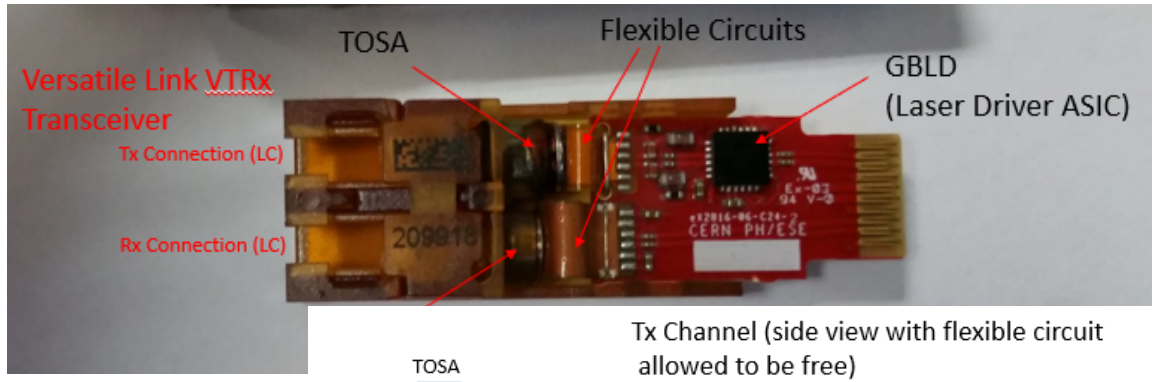
Laser Diode
Optical Interface
} Packaged as Transmitter Optical SubAssembly (TOSA)

Laser Diode Driver (LDD) (integrated circuit)

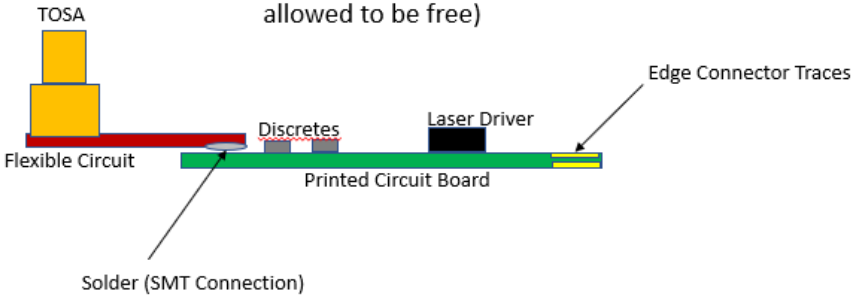
We are ordering and testing COTS TOSAs and LDDs at room temperature (295 K) and LN2 (77 K)

Testing of Laser Diodes initially uses devices with manufacturer provided fiber pigtail (simplifies optical coupling)

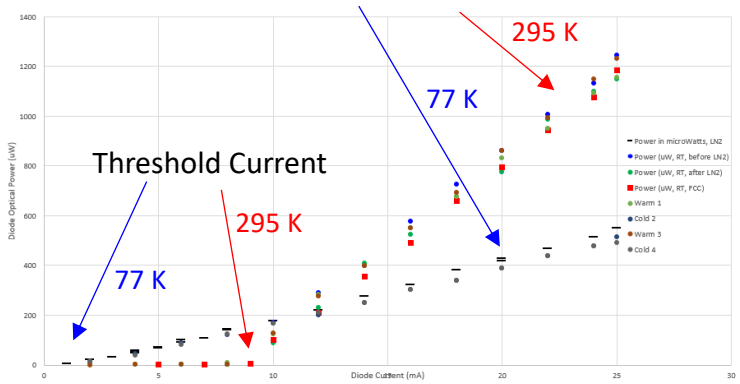
Anatomy of an SFP+ Device



Tx Channel (side view with flexible circuit allowed to be free)



Slope Efficiencies (uW/mA)



Limited testing carried out so far shows…

1. One FP TOSA continues to operate in LN2 with reduced threshold current and reduced slope efficiency
2. Another FP TOSA stopped lasing in LN2

Discrete Approach to Tx Channel Based On SFP+ Modules
Laser Drivers Diode (LDDs)

Essential Components of Tx:

- Laser Diode
- Optical Interface

Packaged as Transmitter Optical SubAssen

- Laser Diode Driver (LDD) (integrated circuit)

We are ordering COTS LDDs and designing custom evaluation boards for 295 K and 77 K test cycles

Testing will include:

1. Electrical tests of bias current and modulation signal
2. Optical modulation and BER testing with suitable (pigtailed) TOSA

Design and fabrication of boards includes careful consideration of discrete components best known to survive 77 K temperatures.

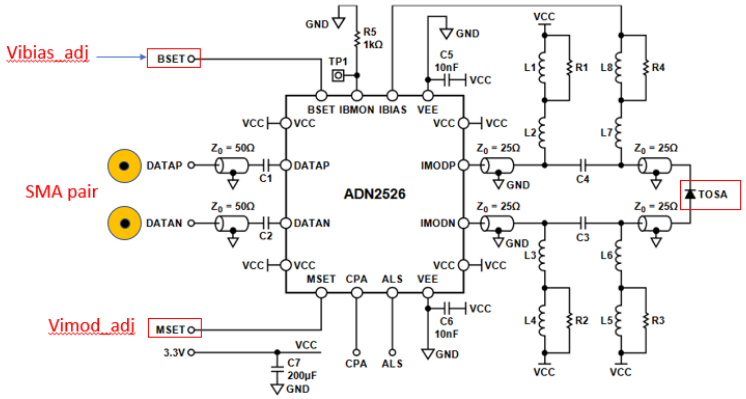
Components from:

- Analog Devices
- Maxim
- Texas Instruments

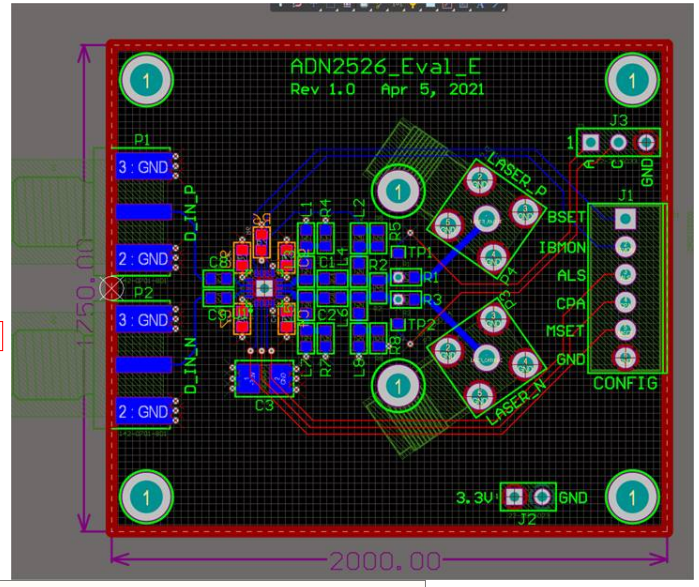
have been ordered for these tests.

All test circuit designs are based on best reference design guidance from IC manufacturers

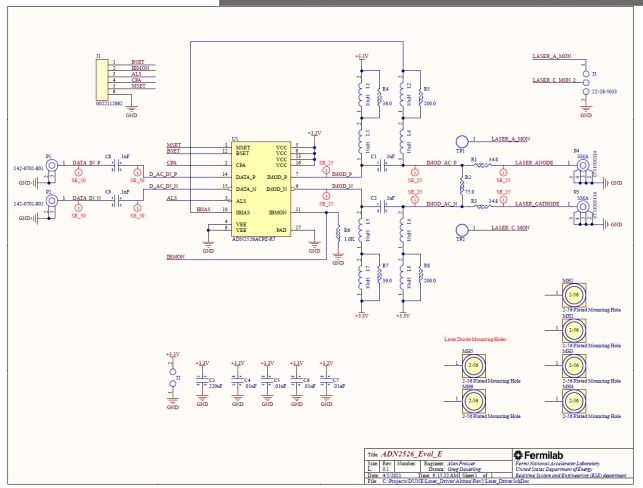
Simple Evaluation Board for Analog Devices ADN2526 Optical Tests



LDD Eval Board Layout*



LDD Eval Board Schematic*



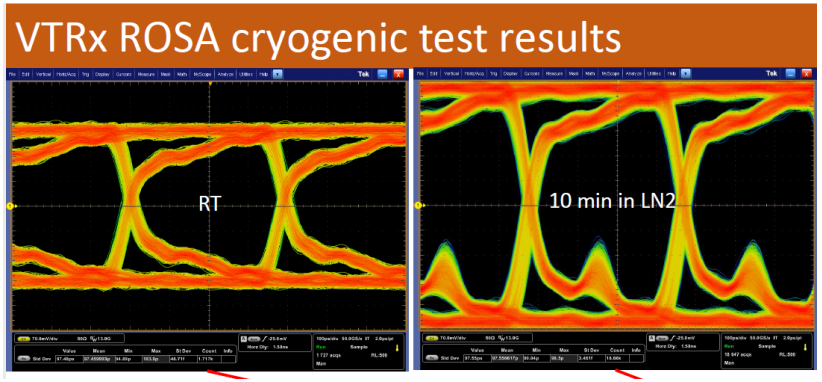
* G. Deuerling

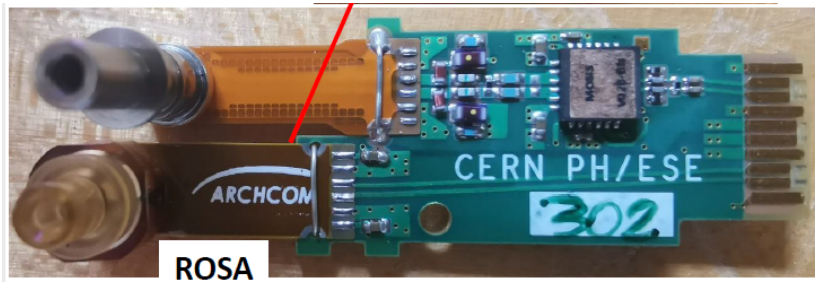
Discrete Approach to Rx Channel Design

Essential Components of SFP+ Rx:
- Photodiode
- Optical Interface
- TransImpedance Amplifier (integrated circuit)

Packaged as Receiver Optical SubAssembly (ROSA)

SMU (W. Zhang) has carried out limited tests on early VTRx from CERN that seemed to show promise for Rx channel



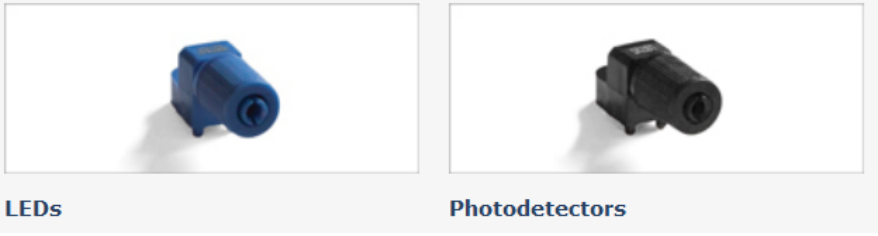


VTRx

We are investigating the use of “lower speed” technology to simplify the design and relax requirements.

LBNL (M. Turqueti) has tested a COTS LED/Photodetector pair that may operate over Plastic Optical Fiber (POF) in LN2.

We will procure and test this arrangement for rates up to 156 Mbps over ~10 meters of POF.



Summary
Next Steps, Issues and Concerns

Next Steps:

1. Continue to obtain and test TOSAs, LDDs, and Rx components such as are available
2. Better understand the implications of LN2 challenges (optical coupling, component selection, band gap dependence on T)
3. Attempt to find industrial partners to secure supplies of reliable components

Some Issues and Concerns:

1. The telecom world has evolved to advanced technologies (EML TOSAs) that goes beyond the single channel devices we are attempting to construct. This makes supply of the single channel components less certain. We are having difficulty obtaining a range of components to test (e.g. TOSAs)
2. For optimum performance, we may need to “mix and match” components from different spectral regimes due to band gap dependence on T. We may not be equipped to analyze this from our test stand (under investigation)
3. The issues of optical coupling and mechanical packaging need to be fully addressed. There may be additional sensitivity to this due to:
    1. CTE related mis-alignment
    2. Numerical aperture effects in LAr.
4. Long term reliability

ADCs

- Divya Sirikonda and Andres Quintero Parra (engineers working with Gustavo Cancelo) have tested two 14-bit 125 Msps ADCs in LN2 at PAB.
  - Analog Devices LTC2145-14
  - TI ADC3244
- Both were mounted on (commercial) daughter boards coupled to (commercial) evaluation boards.
- Both initially Failed in LN2 (LDOs mounted next to ADCs didn’t work in LN2)
- Both worked in LN2 when the LDOs were removed & power was provided by a bench supply
  - No performance evaluation was possible in this configuration because power supply noise limited performance to ~8 bits ENOB (warm and cold)
  - Even this might be good enough

ADCs (continued)

- Scott Holm (PPD/EED) has adapted the test fixture for the DUNE COLDADC to test QIE-11
- QIE-11 was designed for CMS using the AMS 350nm SiGe BiCMOS process
- QIE-11 is one of many Q (Charge) I (Integrator) E (and Encoder) ASICs designed by Tom Zimmerman at FNAL.
- Current splitting design provides large dynamic range (~17 bit equivalent) with ~1% resolution over the full dynamic range (pseudo floating point output format)
- Cryogenic tests on WH14 will start this week.
- If QIE-11 performs well, reliability would be straightforward to assess, since the design was done at FNAL.

FPGAs

- A number of FPGAs are knows to work well at LAr temperature (an Altera Cyclone IV was used on the ProtoDUNE-SP TPC FEMBs)
- Ryan Rivera is maintaining a spreadsheet of FPGAs know to operate at LN2 temperature
- ADC testing at PAB will proceed using a “Cryo CAPTAN” and custom daughter boards containing ADCs & LDOs known to work well in LN2 (same type as used on the ProtoDUNE-SP TPC FEMBs).
  - CAPTAN is a family of FPGA-based stackable DAQ boards developed at FNAL by CD/EED
  - Cyro CPATAN is a similar board developed at LBL for use at cyrogenic temperature.
  - Tests of the TI and Analog Devices ADCs will start at PAB in about two weeks.