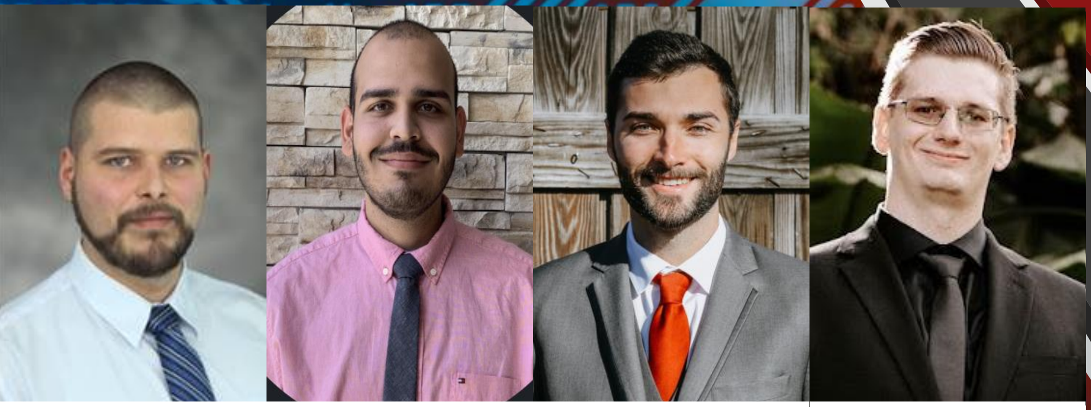
S.T.E.A.L.T.H

Secure Transmission via Electronic And Laser Technology Hardware

CREOL Group 5

Austin Brigham, OSE
Austin Horvath, OSE
Wyatt Chancellor, EE
Moises Cruz, CE, EE

Special thanks to our Supporter, Sponsor, and Mentor,
Dr. Kyle Renshaw, Head of CREOL's Knight Vision Lab



Wyatt Chancellor | Moises Cruz | Austin Horvath | Austin Brigham

Introduction

Our team mission is to engineer a self-contained free space optical communication system that is optimized to be light weight, low power, and compact. Optimization of these parameters enables the inclusion of such a system on aerial platforms to aid in meeting their communication needs.

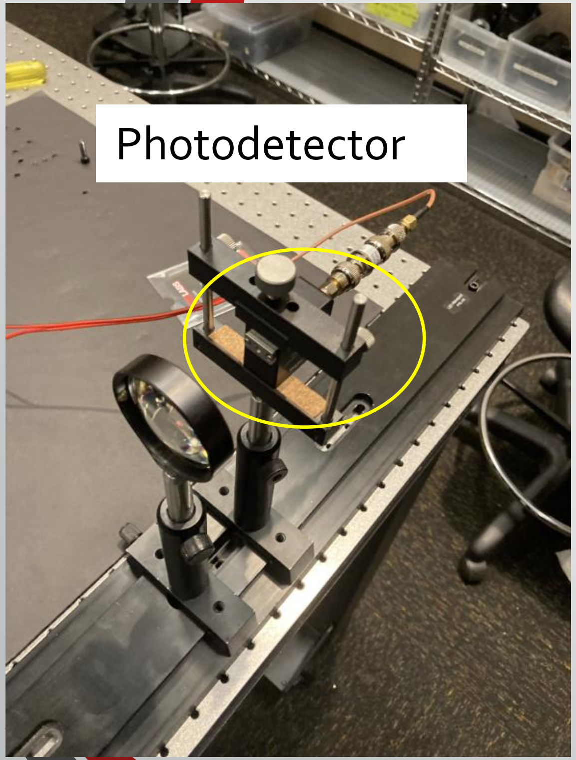
Austin Horvath’s Insights

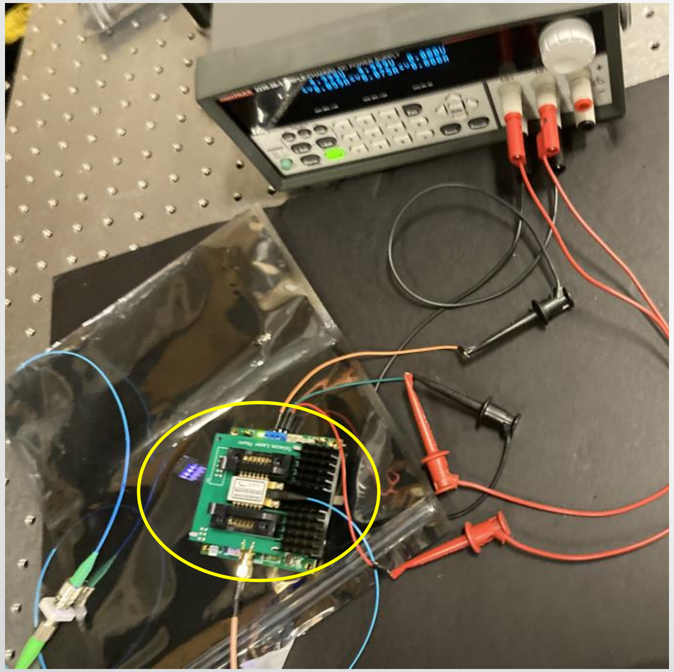
Austin Brigham’s Insights

Moises Cruz's Insights

Wyatt Chancellor's Insights

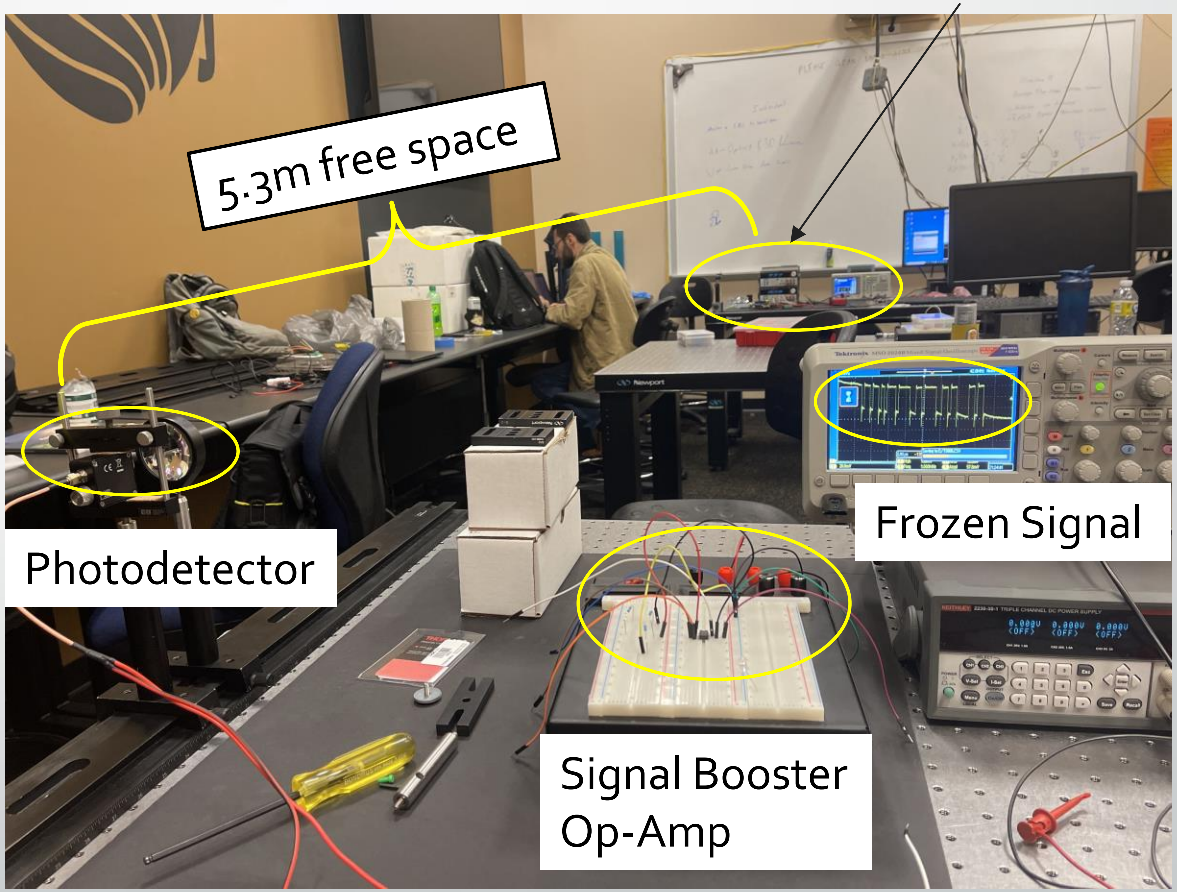
Functional Protype In Action





Laser and Driver

Transmission Side



Objectives and Constraints

- The system should be compact enough to be portable.
- The system needs to be lightweight.
- The system must successfully transmit and receive data at a minimum of 5 m.
- The system should be able to transmit data accurately.
- Operation of the system must be eye safe.
- The receiving end of the system must be sensitive enough to detect a signal from a comparatively small amount of irradiance at range.
- The system must be able to be run off of a mobile power source.
- The system needs to be undetectable.

Requirement Specifications

Requirement	Description
Weight*	System shall weigh no more than 1 kg
Power Consumption*	System shall consume no more than 2000 mW
Volumetric Footprint*	System must fit within 500 mm^3
Propagation Range	System shall successfully send and receive data over a distance exceeding 3 m
Laser Wavelength	System shall use a operate in the eyesafe telecom band centered at 1550 nm.
Transmission Speeds	System shall be able to transmit data at a speed between 800 Mbps to 1.5 Gbps
Daylight Operation	System must be able to overcome ambient solar flux with an OSNR of 10/1 or better.
Battery	Design system to run off a drone battery that operates at 24VDC at full charge, 16VDC at low charge.

Related Electrical/Computer Standards

- Low-Voltage Differential Signaling (LVDS)
  - Allows data to be transmitted at much higher speeds than other transmission standards
  - Transmits information as the difference between two voltages on a pair of wires
  - For S.T.E.A.L.T.H., LVDS is used at the output of the serializer to achieve transmission speeds of 1 Gbps
- Low-Voltage Complementary Metal Oxide Semiconductor (LVCMOS)
  - More common way of transmitting data
  - Logic levels are determined by the voltage at the pins
  - For S.T.E.A.L.T.H., the Cyclone IV will transmit and receive 16 bits of data to the DS92LV16 pins using LVCMOS

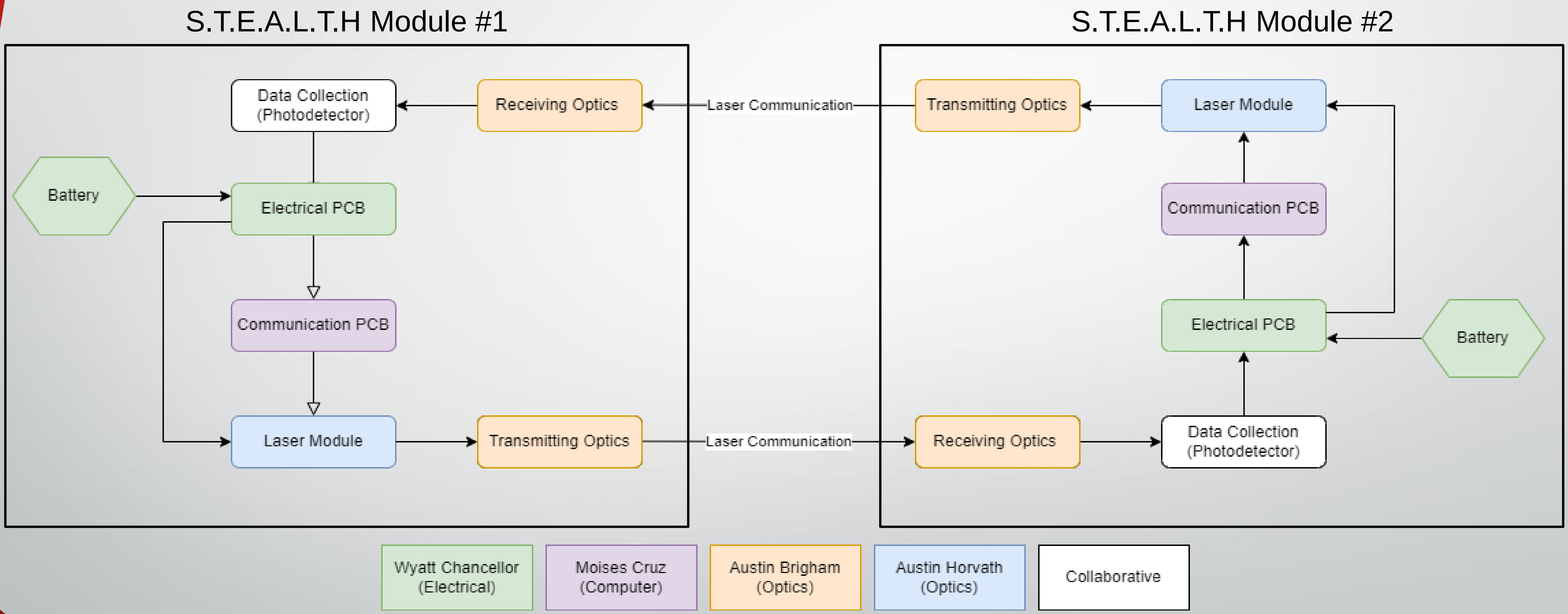
Related Laser Standards

- 4 laser classes
- According to documentation, our laser is required to be classified as Class 3B (EHS) because of its output power of 20 mW.
  - However, lasers with the same wavelength are known to be eye safe.

Related Laser Standards

Class FDA	Class IEC	Laser Product Hazard	Product Examples
I	1, 1M	Considered non-hazardous. Hazard increases if viewed with optical aids, including magnifiers, binoculars, or telescopes. <0.39 mW	laser printers, CD players, and DVD players
IIa, II	2, 2M	Hazard increases when viewed directly for long periods of time. Hazard increases if viewed with optical aids. <1 mW	bar code scanners
IIIa	3R	Depending on power and beam area, can be momentarily hazardous when directly viewed or when staring directly at the beam with an unaided eye. Risk of injury increases when viewed with optical aids. Between 1 mW and 4.99 mW	laser pointers
IIIb	3B	Immediate skin hazard from direct beam and immediate eye hazard when viewed directly. Between 5 mW and 499.9 mW	laser light show projectors, industrial lasers, and research lasers
I4	4	Immediate skin hazard and eye hazard from exposure to either the direct or reflected beam; may also present a fire hazard. >500 mW	laser light show projectors, industrial lasers, research lasers, and medical device lasers for eye surgery or skin treatments

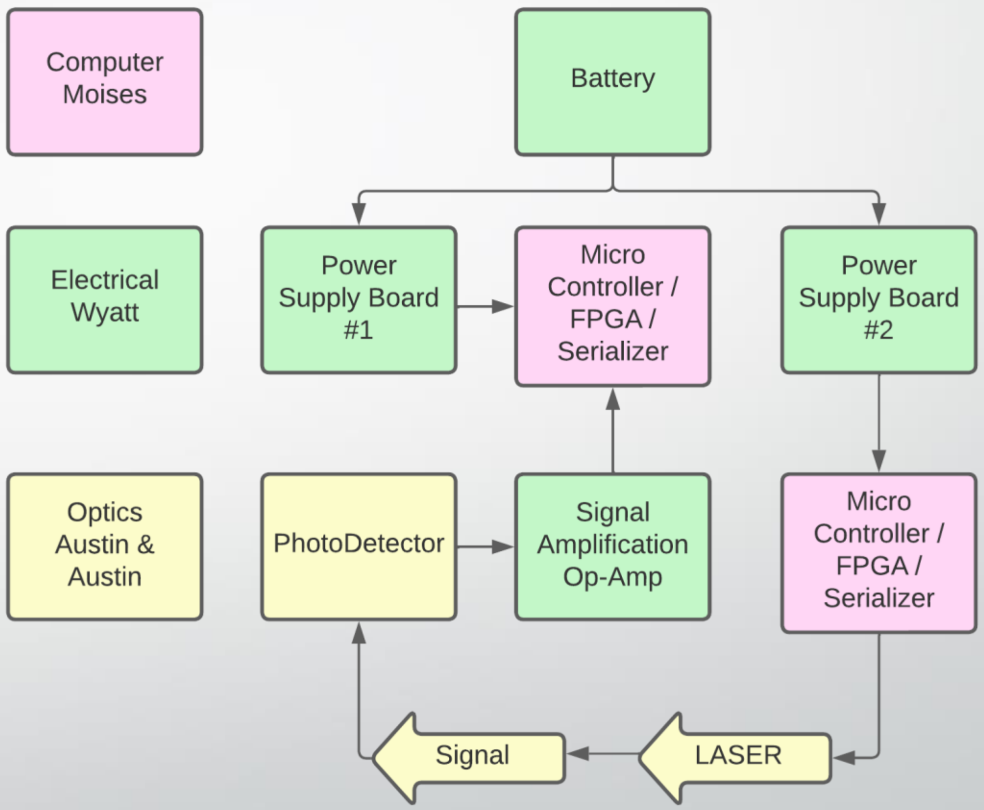
Overall Bi-Directional System Block Diagram



Due to part availabilities for the fiber collimator, our working prototypes in the following slides were constrained to be one-directional instead of the originally proposed bidirectionality.

Electrical Power Design Approach

- Key Factors:
  - Equipment Availability
  - Size of Components
  - Reasonable BOM Cost
- Implementation Factors:
  - Light Weight
  - Efficient
  - Reliable
  - Low Power Consumption
  - Functionality at all battery voltage levels



Electrical Systems Block Diagram

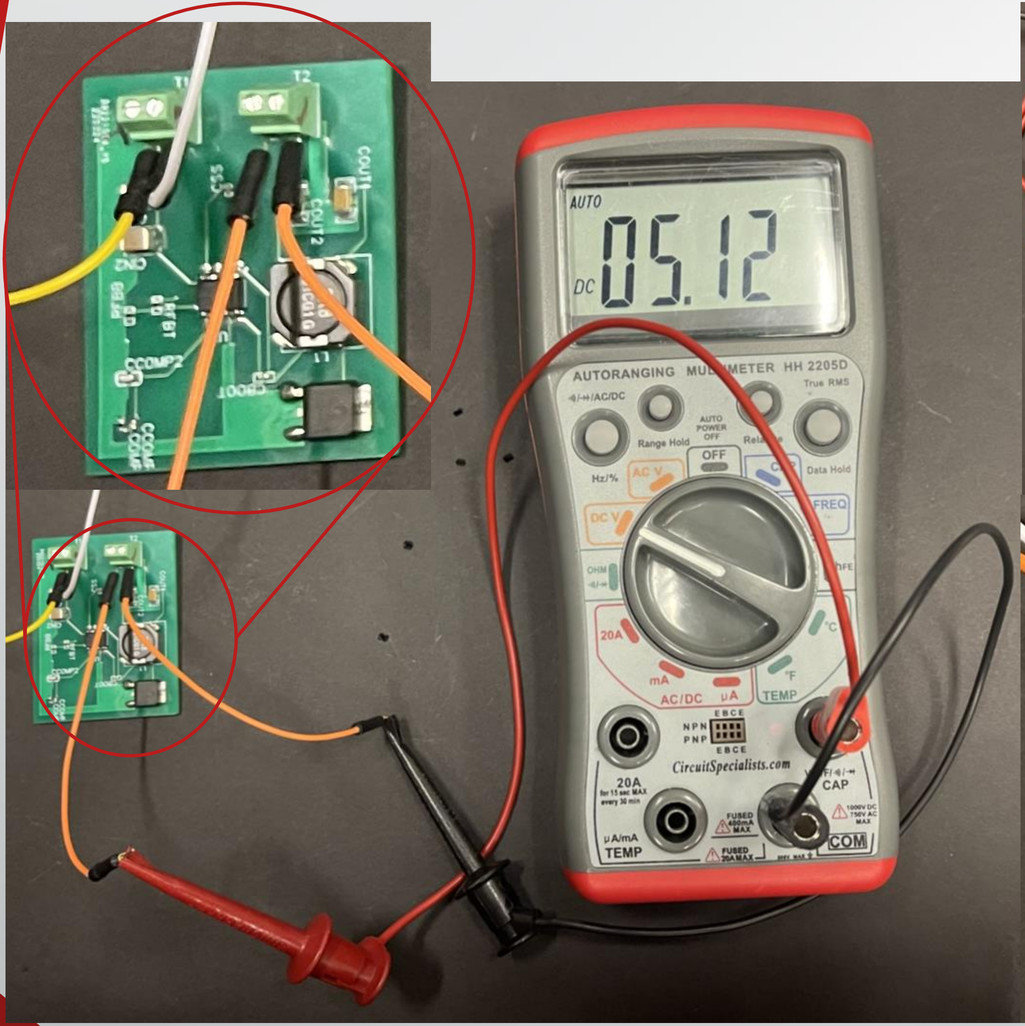
Electrical Load Table - Initial

	Microcontroller	**Laser**	**TEC**
Part Manufacturer	Intel	OptiLab	OptiLab
Part Number	Cyclone IV FPGA	DFB-1550-DM-4	Integrated to laser
DC/DC Buck Converter Part Manufacturer	Texas Instruments	Texas Instruments	Texas Instruments
DC/DC Buck Converter Part Number	tps54332	lm43600	tps54332
Buck Converter Voltage Input	Vin MAX = 24.5V Vin MIN = 16.0V	Vin MAX = 24.5V Vin MIN = 16.0V	Vin MAX = 24.5V Vin MIN = 16.0V
Buck Converter Output	Vout = 5V Iout = 3.5A	Vout = 1.5V Iout = 0.2A	Vout = 2.5V Iout = 1.4A
Load (Watts)	Pout = 17.5W	Pout = 0.3W	Pout = 3.5W

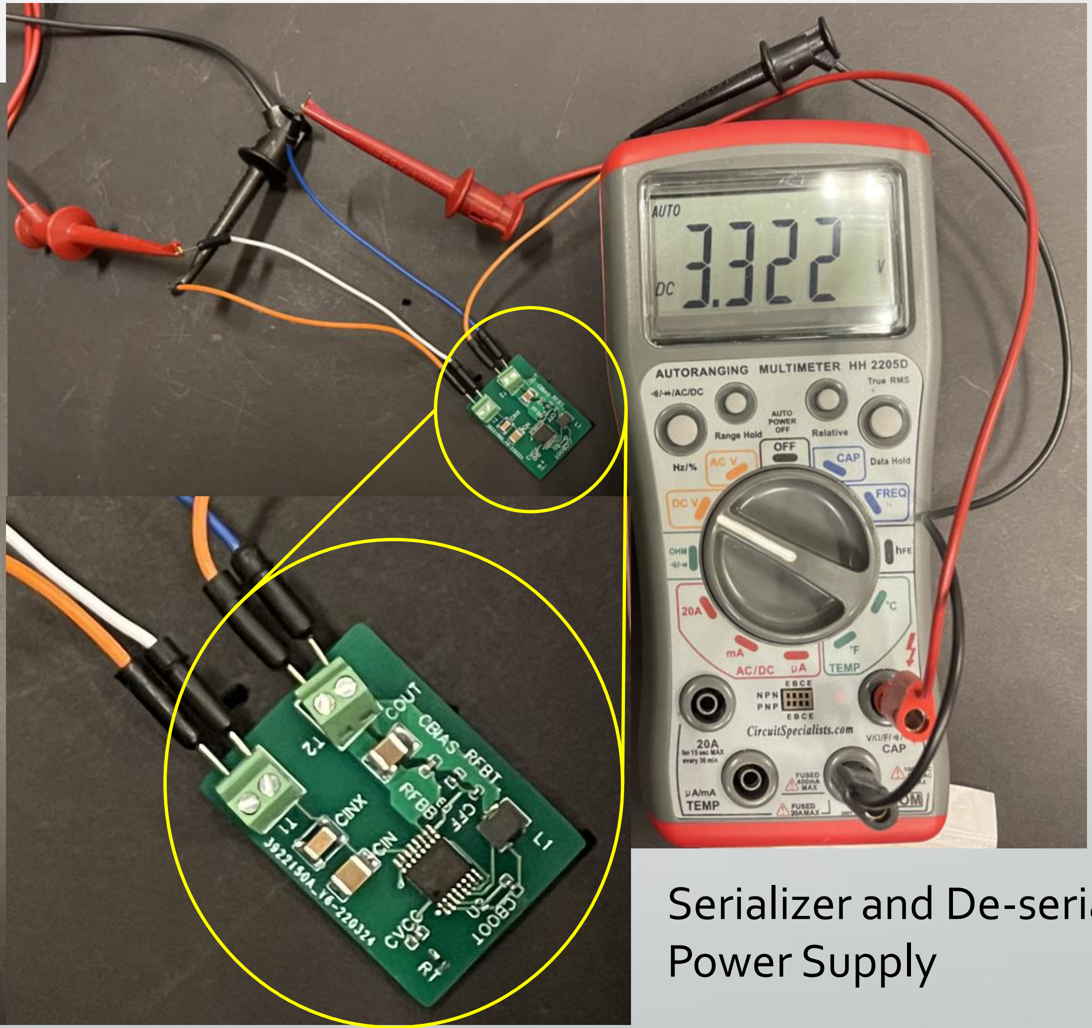
Electrical Load Table - Final

	Microcontrollers	Laser Driver &TEC	Signal Op-Amp
Part Manufacturer	Intel	MOT – Modular One Technologies	Texas Instruments
Part Number	Cyclone IV FPGA	MOT6722GA_2525	LM741
Power Supply Part Manufacturer	Texas Instruments	YWBL-WH	YWBL-WH
Part Number	tps54332	YWBL-WH14dhe9wf7p-01	YWBL-WH14dhe9wf7p-01
Converter Voltage Input	Vin MAX = 24.5V Vin MIN = 16.0V	Vin MAX = 24.5V Vin MIN = 16.0V	Vin MAX = 24.5V Vin MIN = 16.0V
Converter Output	Vout = 5V Iout = 3.5A	Vout = ±5 Vdc Iout = 1.5A	Vout = ±15 Vdc Iout = Nominal
Load (Watts)	Pout = 17.5W	Pout = 1-8W	Pout = Nominal

Electrical Functional Prototype PCBs - Designed

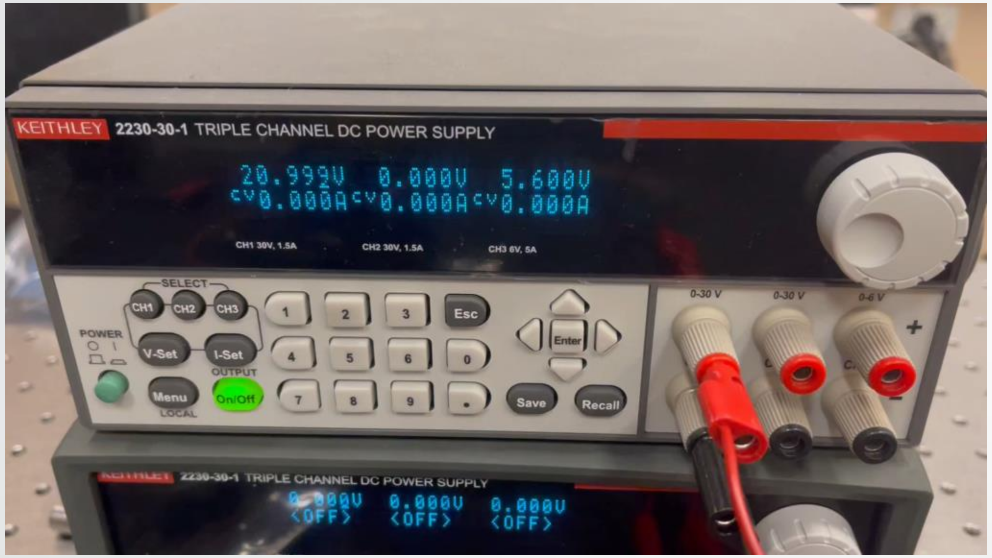


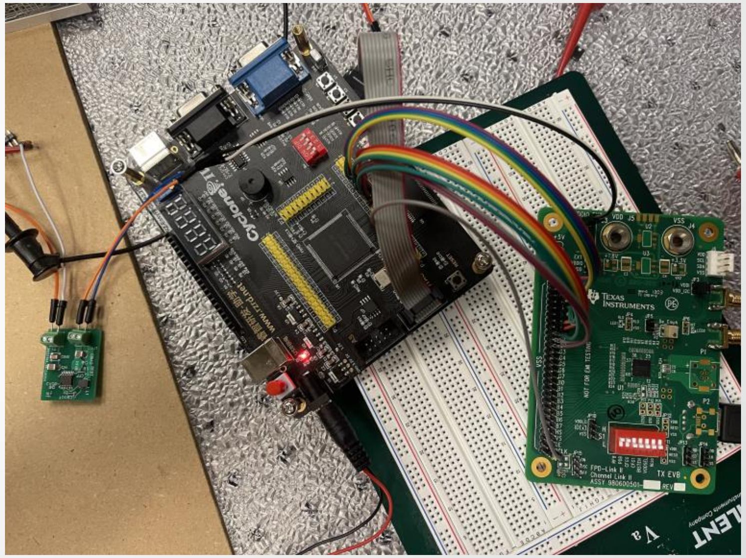
Laser Modulation /
Microcontroller Power Supply

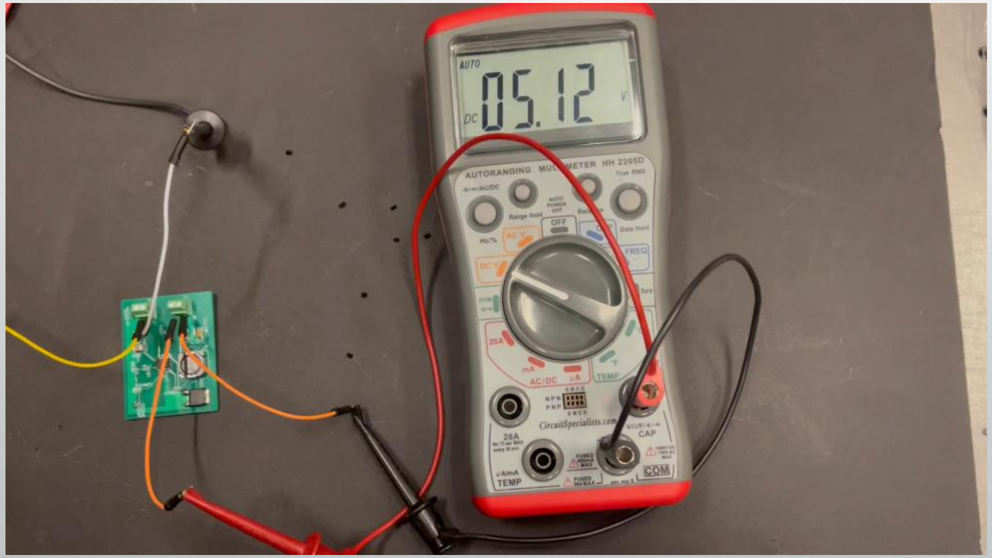


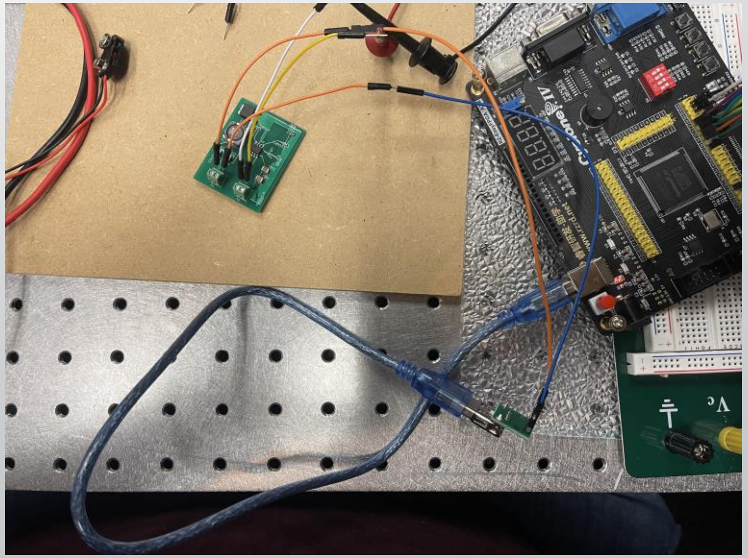
Serializer and De-serializer
Power Supply

Electrical Functional Prototype PCBs – Designed & Implemented



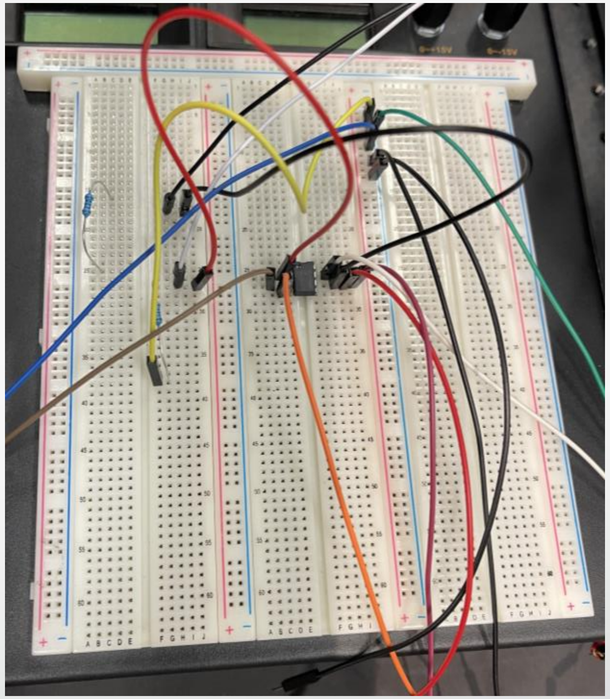




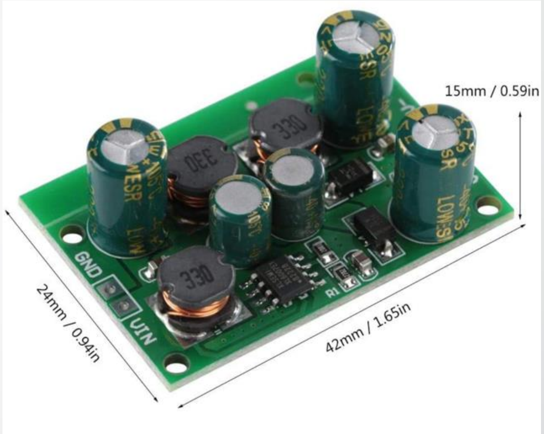


Electrical Adaptations

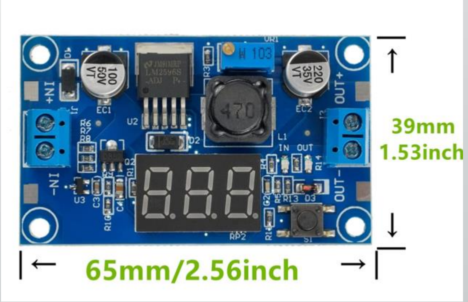
- Challenges:
  - Design Changes as project progressed
  - Part Availability
- Adapting and Overcoming:
  - Could not power all equipment from PCBs designed.
  - Wanted to achieve a system purely operated on battery power
  - Procured small, light weight, cost effective PCBs.
  - Small breadboard circuit for signal detection Op-Amp
  - Small breadboard for transmitted signal gain Op-Amp



Functioning prototype Signal Boosting Op-Amp

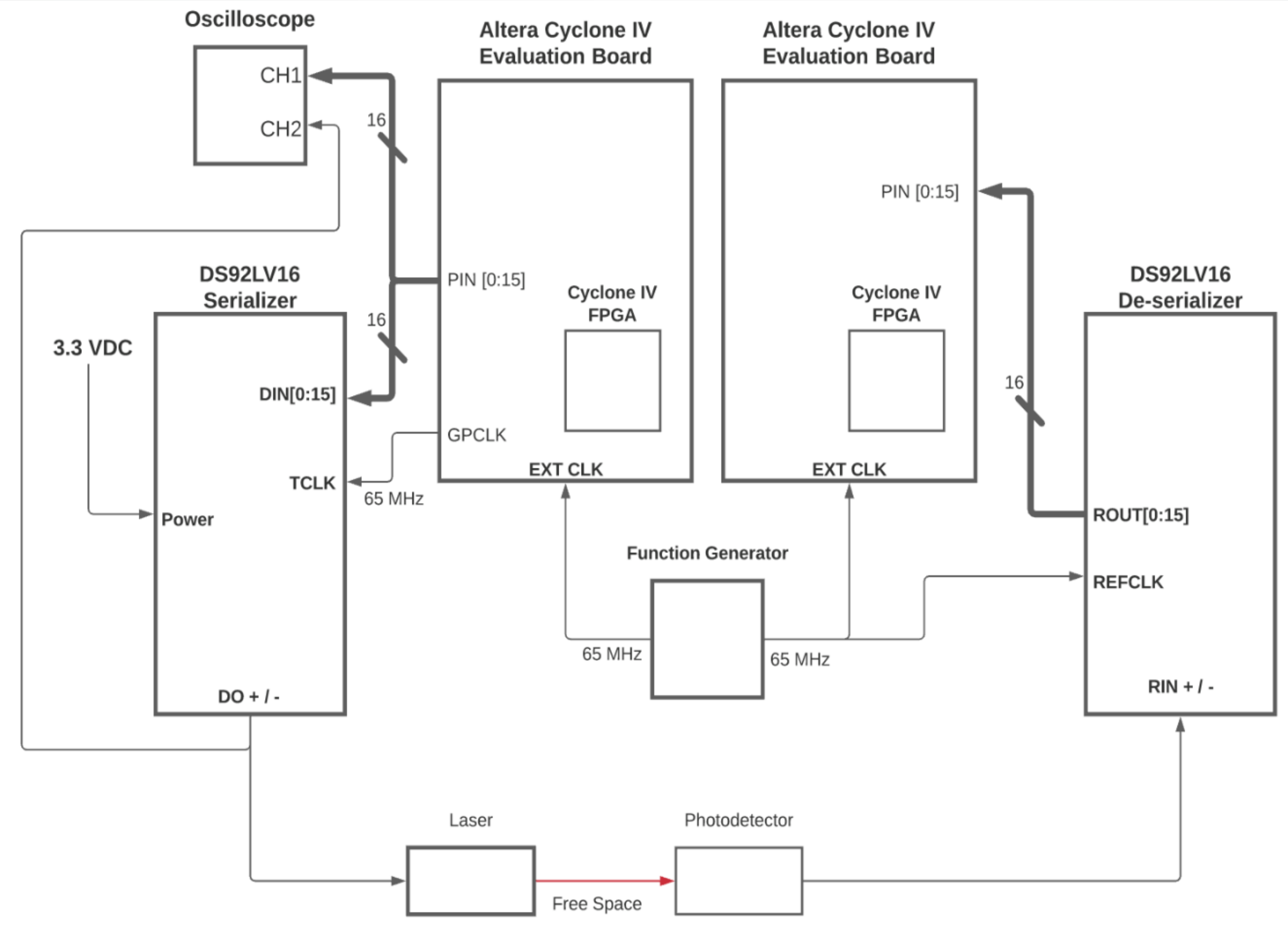


Power Supply for Laser Driver



Power Supply for FPGA

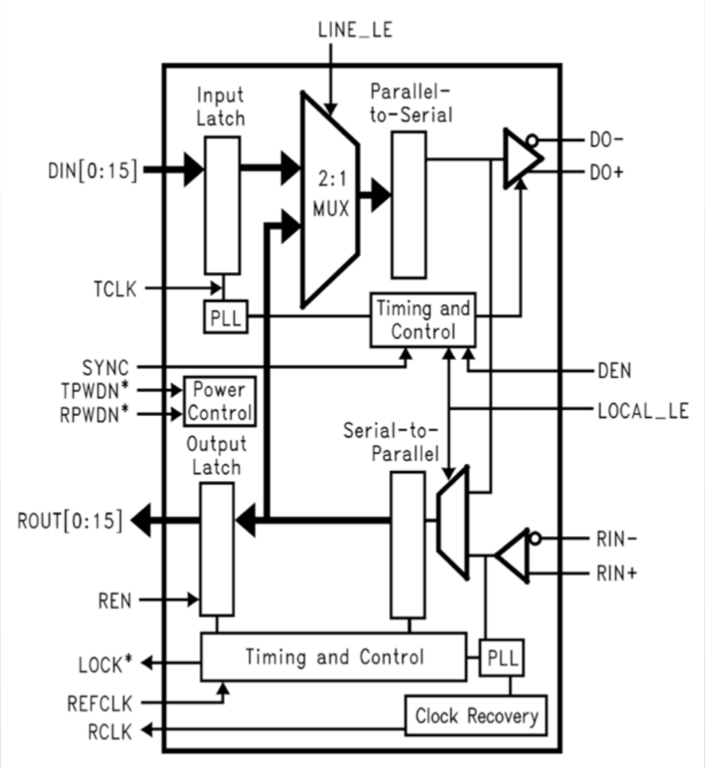
Computing Subsystem Block Diagram



Block Diagram of the computing subsystem

Computing Subsystem Components

- TI DS92LV242X Serializer & De-Serializer
  - Translates up to 24-bit parallel bus into a serial stream
  - Takes 24 bits of data at the serializer block (DIN[23:0]) and outputs these bits into a serial differential signal (DO +/-), and an input frequency (TCLK) between 10 – 75 MHz
  - Capable of transmitting data at a serial payload rate of up to 1.28 Gbps



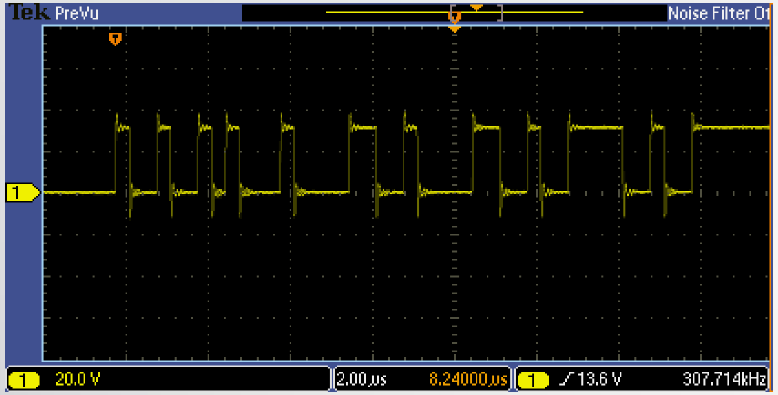
Block Diagram of DS92LV16

Computing Subsystem Components

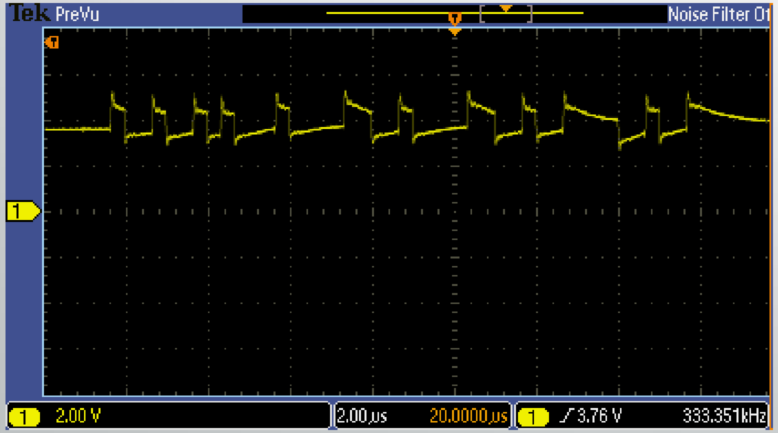
- Altera Cyclone IV FPGA
  - Identified in TI documentation for the DS92LV16
  - Can be programmed using VHDL or Verilog using Altera's Quartus II Software Suite
  - GPIO switching speeds are adequate to meet the requirements of the DS92LV16
  - Low cost and low power

Functional Prototypes

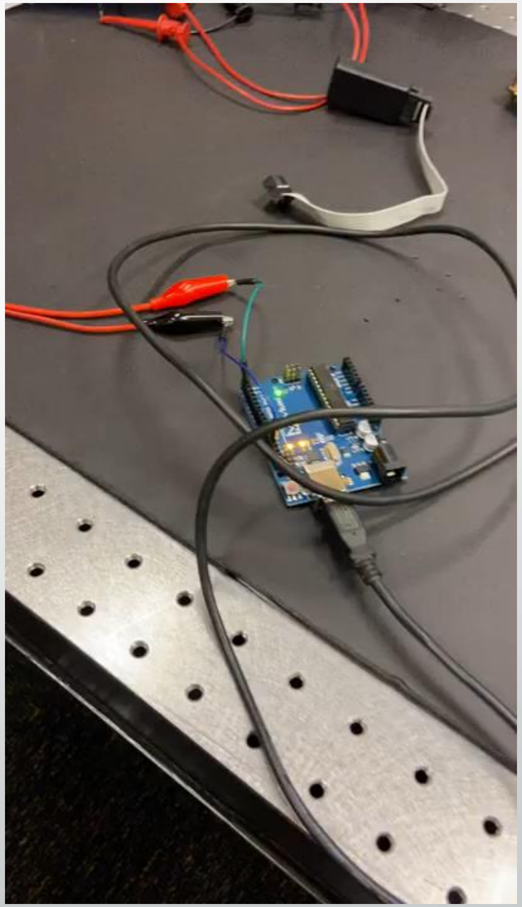
Tested sending a string from the FPGA, as well as a transmission between two Arduino UNO Boards



FPGA transmitted string (“HELLO”)



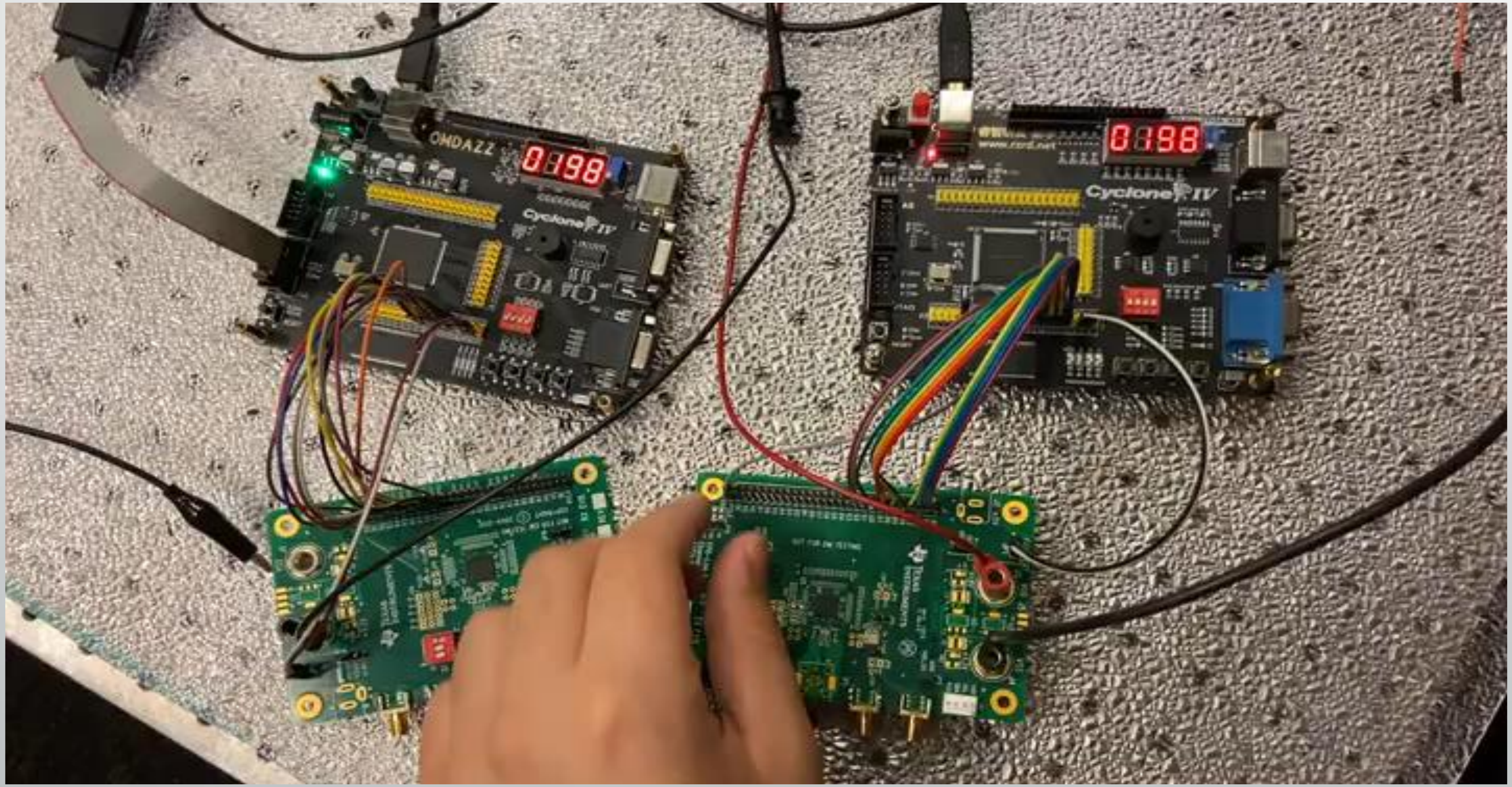
Recovered waveform on an oscilloscope



Transmitting a message optically and recovery example with Arduino boards

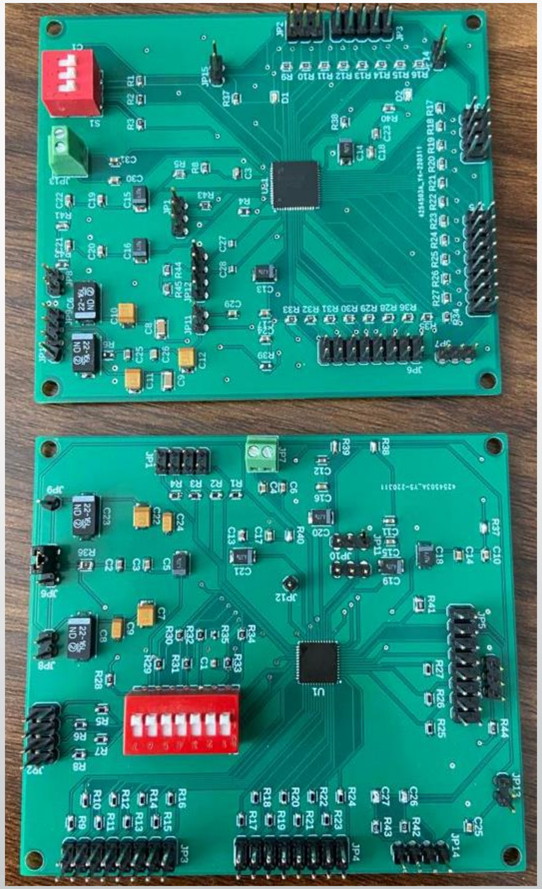
Working Prototypes

Prototype showing communication between the two FPGAs through the serializer and de-serializer

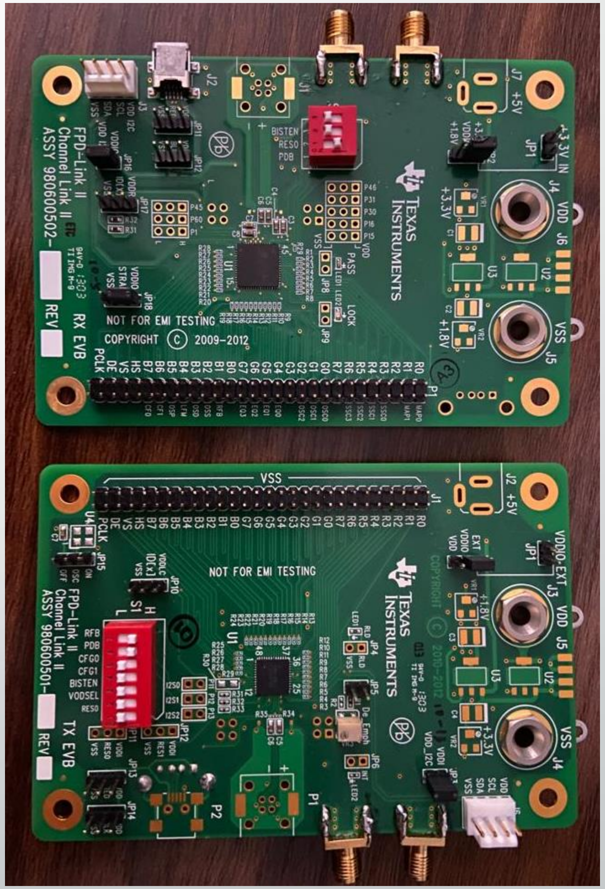


Computing Subsystem Challenges

- Serializer & De-Serializer
  - Designed PCB not working
  - Used a development board I procured to test functionality for prototypes
- FPGA
  - One FPGA was not interfacing with my PC to load the program
  - Re-tested on Tuesday and it works now (a USB port on my PC was faulty)



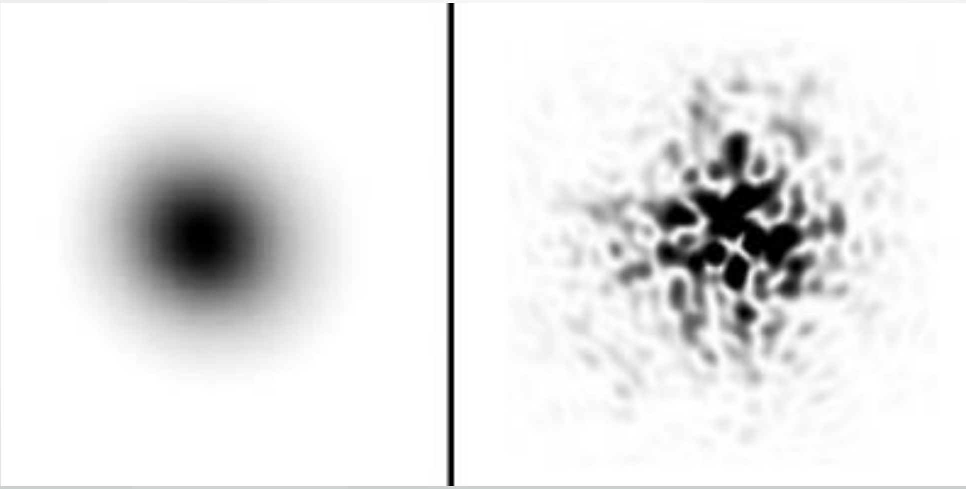
Designed SERDES PCB
(Not functional)



Procured SERDES Board

Atmospheric Turbulence

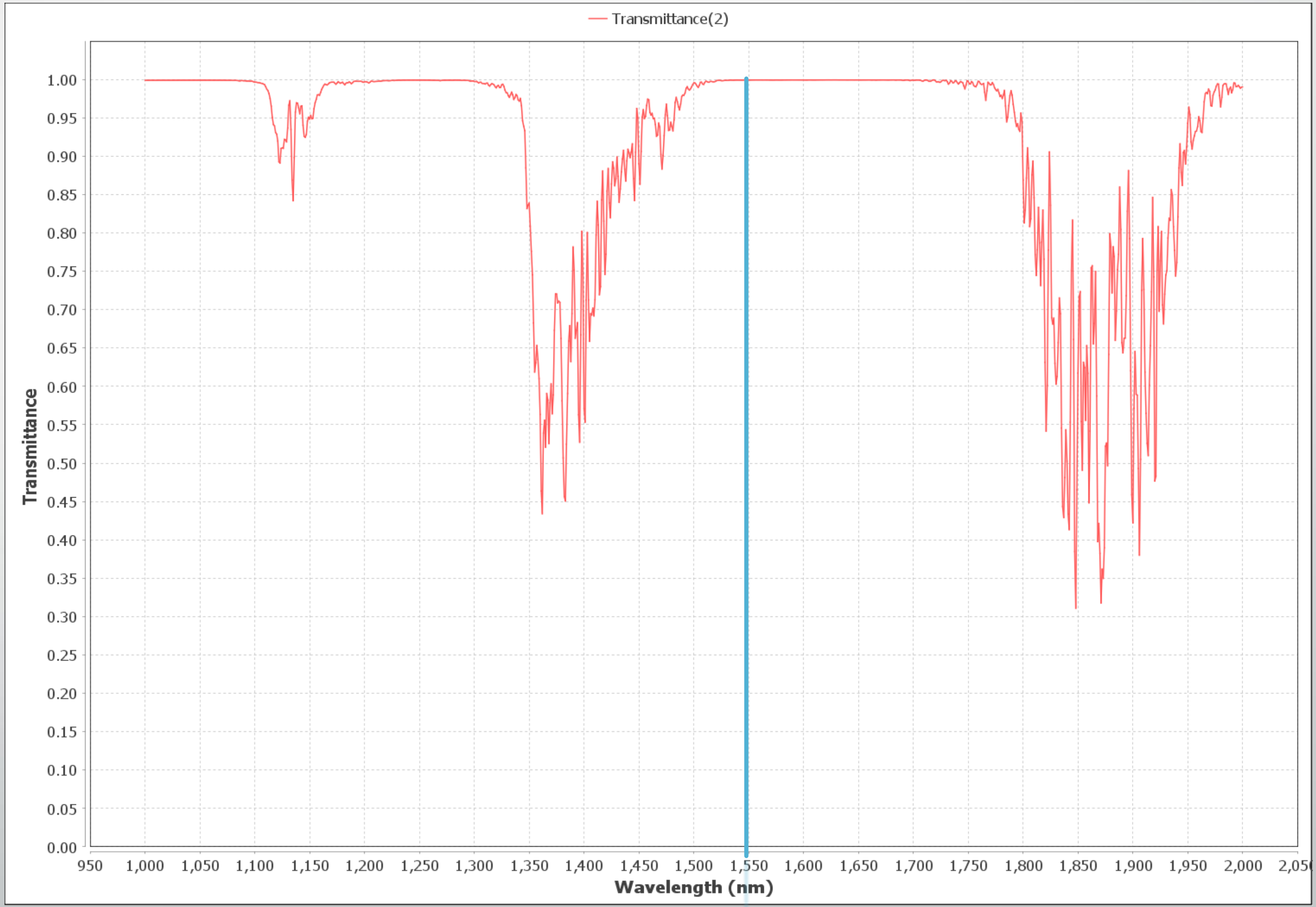
- Changes in effective refractive index of the air as described by refractive index structure parameter C_n^2.
- Cumulative phase changes result in altered beam cross-section at range.



A Gaussian beam intensity profile before and after atmospheric propagation

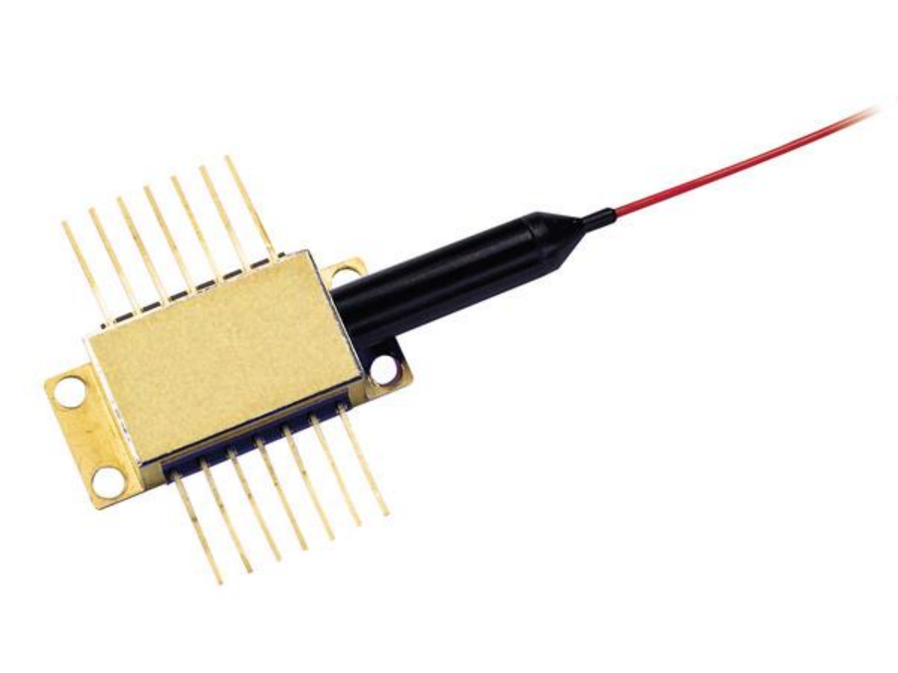
Atmospheric Transmission

- Using the MODTRAN (MODerate resolution atmospheric TRANsmission) software, it was verified that 1550 nm light should have at least 99.9% transmittance over a 1km distance on a clear day in Florida’s climate.



Laser

- Optilab Distibuted Feedback (DFB)-1550-DM-4
  - 14-pin layout
- 1550 nm wavelength
- Rise / fall time of 100 ps / 100 ps
- 4 GHz analog or 5 Gb/s digital optical transmission link
- 20 mW output optical power

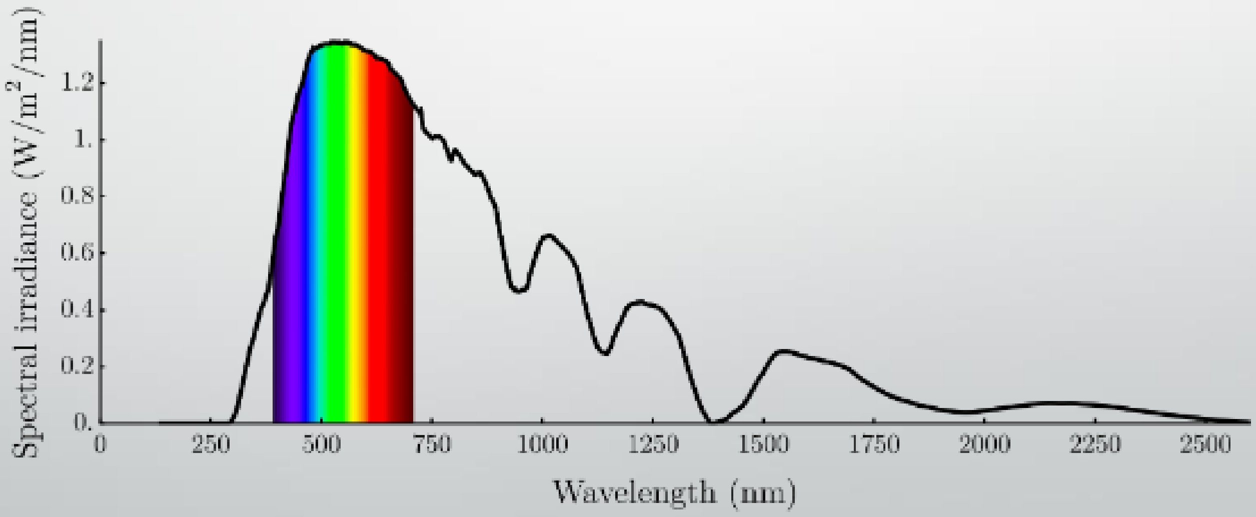


Photodetector

- Thorlabs DET08C/M - 5 GHz InGaAs Free-Space Photodetector
- Rise / fall time is 70 ps / 110 ps respectively
  - Rise / fall time must be less than 1 ns
- Responsivity of 0.90 A/W
  - Photodiode has highest responsivity at 1550 nm.

Direct Sunlight

- Solar irradiance is weaker in the 1550 nm spectral region.
  - Direct sunlight still competes too strongly with optical signal strength.
  - Lower solar irradiance in operating band still benefits indirect sunlight scenarios.



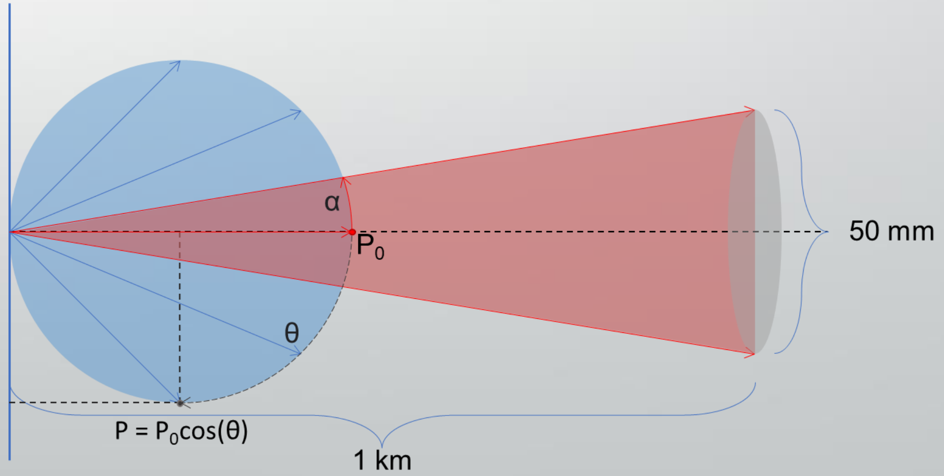
Full spectrum irradiance profile of direct sunlight

Ambient Skylight

- Ambient skylight into the receiving module's aperture is much easier for the optical signal to overcome.
- The total solar flux due to ambient skylight can be modeled as coming from a diffuse Lambertian reflection, and reduces to:

$$\eta_{opt} = P_0 \sin^2(\alpha)$$

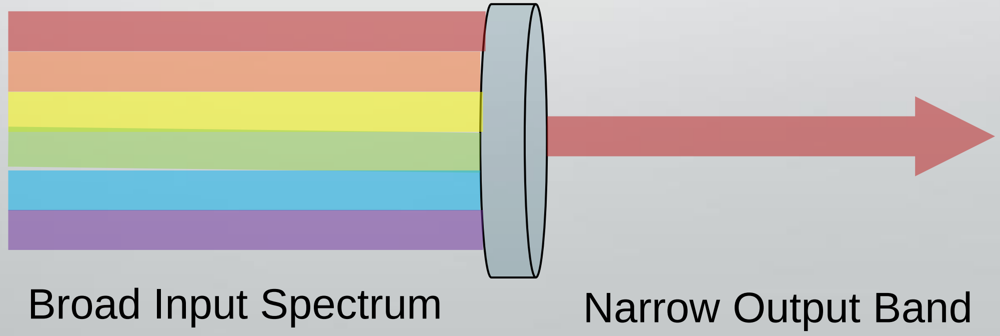
- Estimated ambient solar flux: 3.667 pW
  - Easily overcome with good OSNR when compared to 12 µW signal.



Diffuse Lambertian Reflected Ambient Solar Flux Model

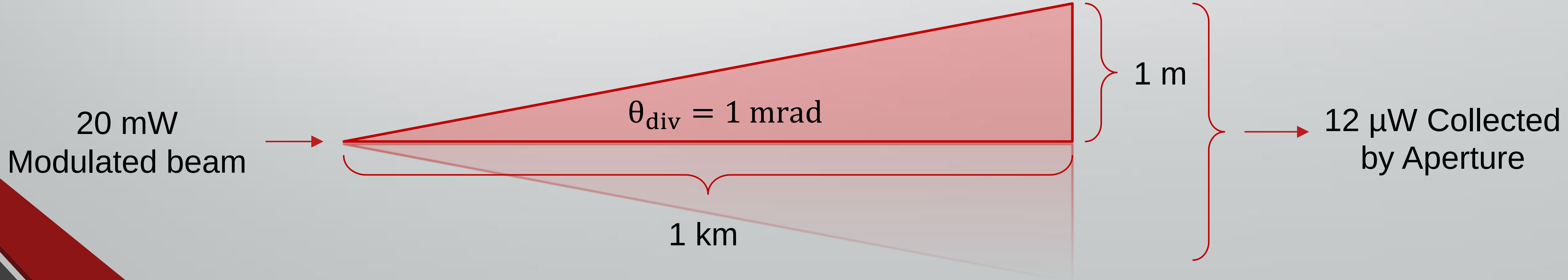
Spectral Filtering

- To counteract broad solar emission spectrum, optical band pass filter will be introduced to receiving module.
  - Filters ± 6 nm spectral band
  - 85% minimum transmission at 1550 nm



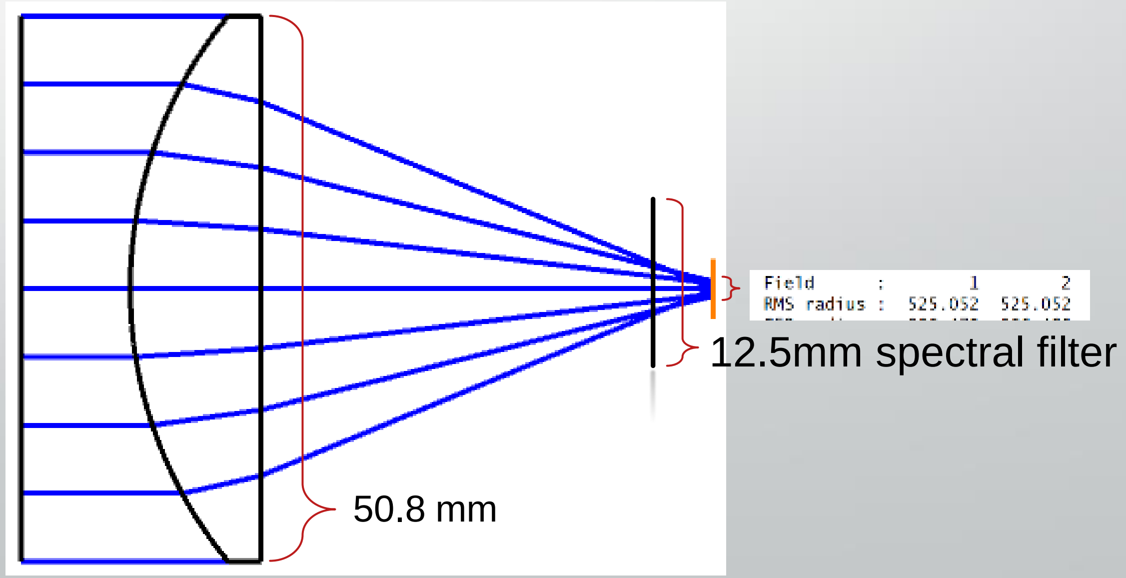
Transmitting Optics

- A minimum beam divergence is required to aid in pointing and link instantiation requirements.
- Collimating optics can be employed to intentionally diverge the beam diameter to a more practical size.
- Divergence is constrained by irradiance requirements



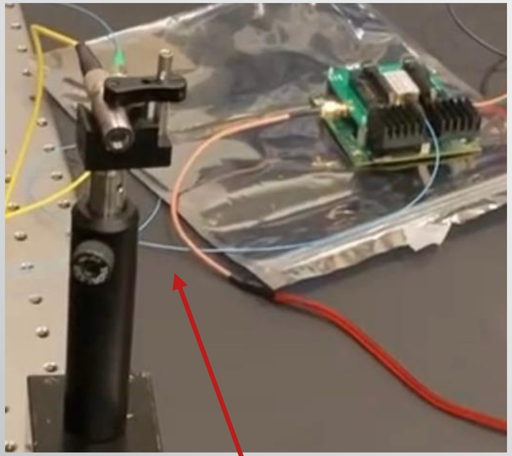
Receiving Optics

- Receiving module optics will focus light collected over a 2 in. aperture.
- Larger area collecting aperture enables collection of lower irradiance light.
  - Larger permitted divergence
    - Aids pointing requirements
- Selected N-SF11 Lens
  - Good 1550 nm transmission
  - Short focal length (F/~1, compact)



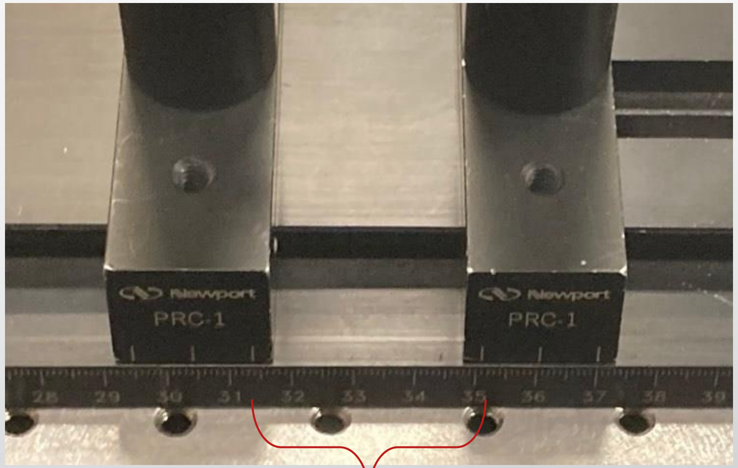
Functional Prototype

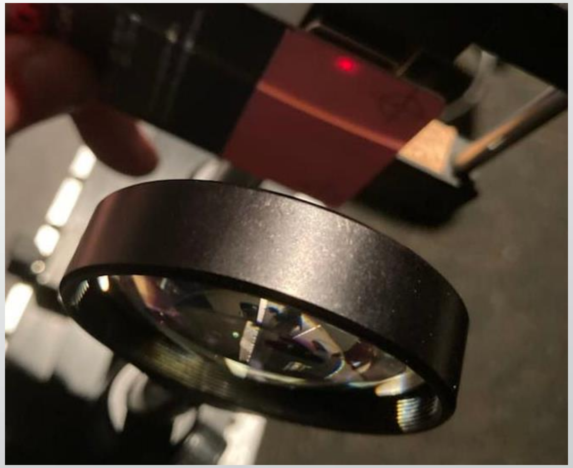
- Transmission Optics



Compact Fiber coupled collimator aids in achieving form factor goals

- Receiving Optics

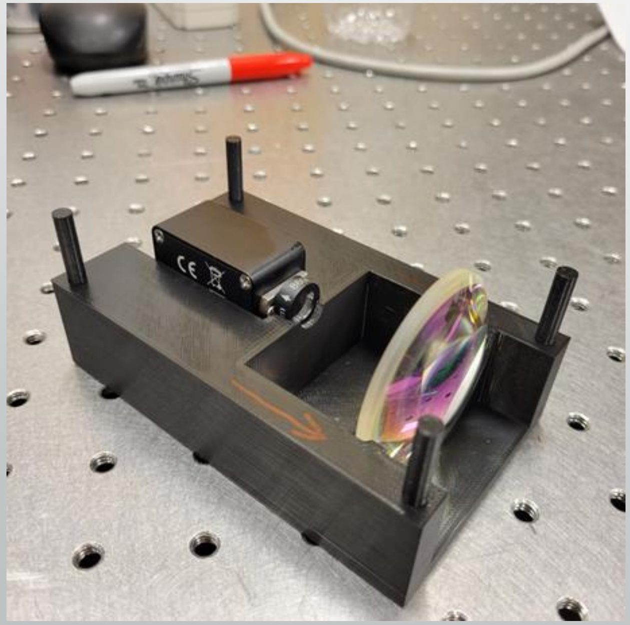


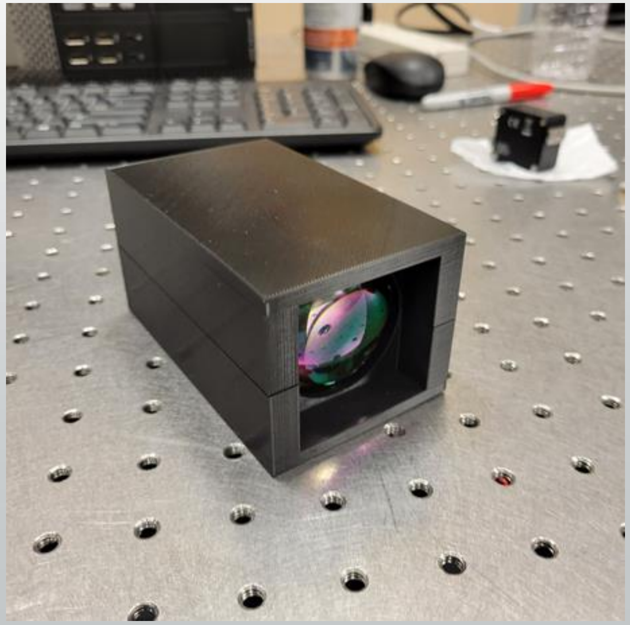


Free space optical alignment (First using optical table and later 3D printed housing) spacing determined and optimized for focal spot size using Zemax

Functional Prototype

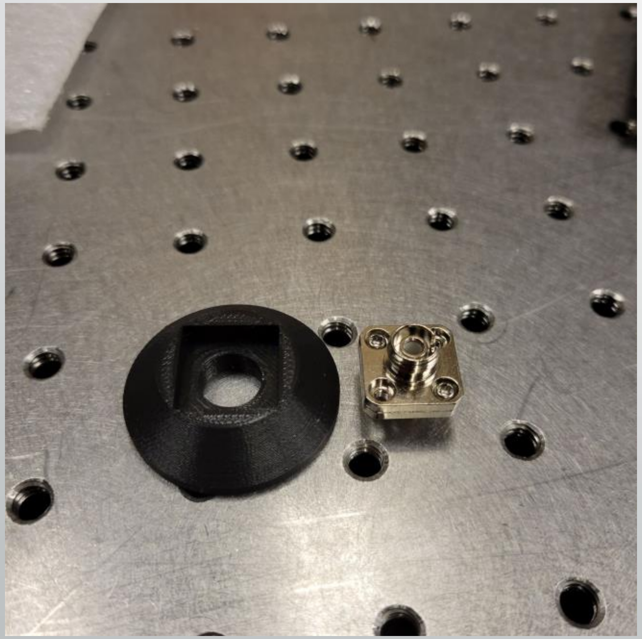
- 3D Printed housing for the receiving end of the optical system.
  - Contains a 2-inch lens that focuses the incoming light beam onto a photodetector with an active area of Ø80 µm.
  - 1550 nm bandpass filter positioned directly in front of the photodetector to block any undesired wavelengths.

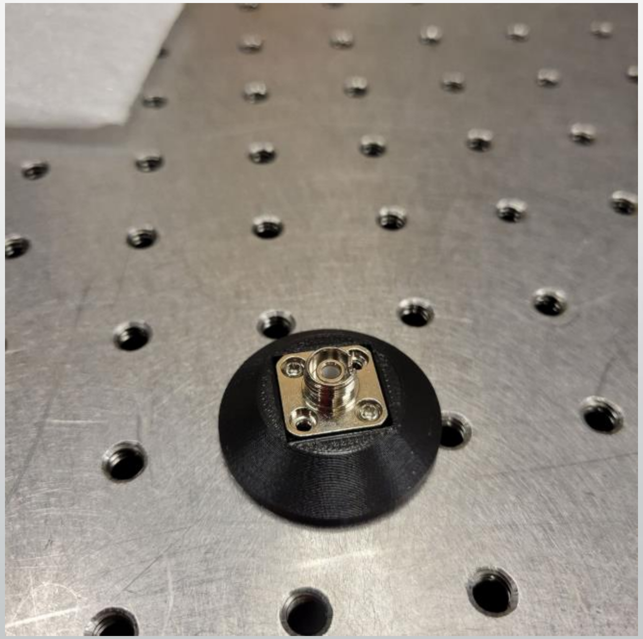


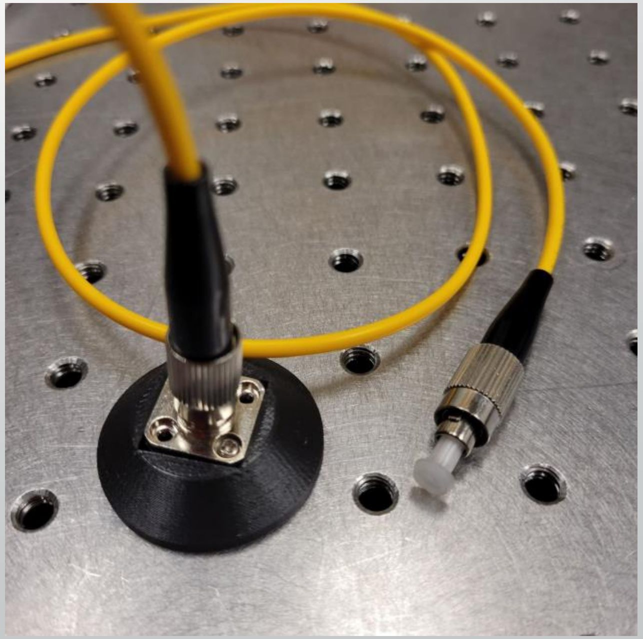


Functional Prototype

- Fiber coupler UAV fuselage mount.
  - Mounted on the inside bottom surface of the fuselage, so as to protect the laser and its related components. Laser fiber is coupled to cheaper and more easily replaceable cable.







Budget and Financing

- Project is fully financially supported by Dr. Kyle Renshaw with Night Vision Lab.

	Parts	# of Parts	Discipline	Cost	Total
1	Laser	2	Optics	$ 900.00	$ 1,800.00
2	Photo Diodes	2	Optics	$ 45.00	$ 90.00
3	Photo Detectors	2	Optics	$ 300.00	$ 600.00
4	Band pass filter	2	Optics	$ 200.00	$ 400.00
5	Lenses	2	Optics	$ 80.00	$ 160.00
6	Collimator	2	Optics	$ 300.00	$ 600.00
7	Electrical PCBs	6	Electrical	$ 70.00	$ 420.00
8	Procured PCBs	4	Electrical	$ 30.00	$ 120.00
9	Serializers	2	Computer	$ 200.00	$ 400.00
10	Computer PCBs	2	Computer	$ 100.00	$ 200.00
11	Laser Driver	2	All	$ 700.00	$ 1,400.00
12	Laser Mounts	2	All	$ 250.00	$ 500.00
13	Miscelanious Parts	N/A	All	$ 200.00	$ 200.00
				Total	**$ 6,890.00**

Work Distribution

Team Member	Optical	Electrical	Computing	PCB	3D Printed Housing	Website
Austin B.	X					X
Austin H.	X				X	
Wyatt		X		X		
Moises			X	X		

Thank You

The S.T.E.A.L.T.H. team would like to offer a special thanks to Dr. Renshaw and Knight Vision Lab for supporting this project, as well as to our other faculty reviewers, Dr. Mhibik and Dr. Li for their time and feedback.

We would also like to thank Dr. Wei and Dr. Kar for their instruction and guidance through Senior Design 1 and 2.