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College of Engineering

Laser Communication Testbed

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United States Space Force (USSF)

Mission/SOW

The United States Space Force (USSF) commissioned our NMSU senior engineering capstone design team to support the advancement of high-speed laser communication technologies for space applications.

SOW Parameters:

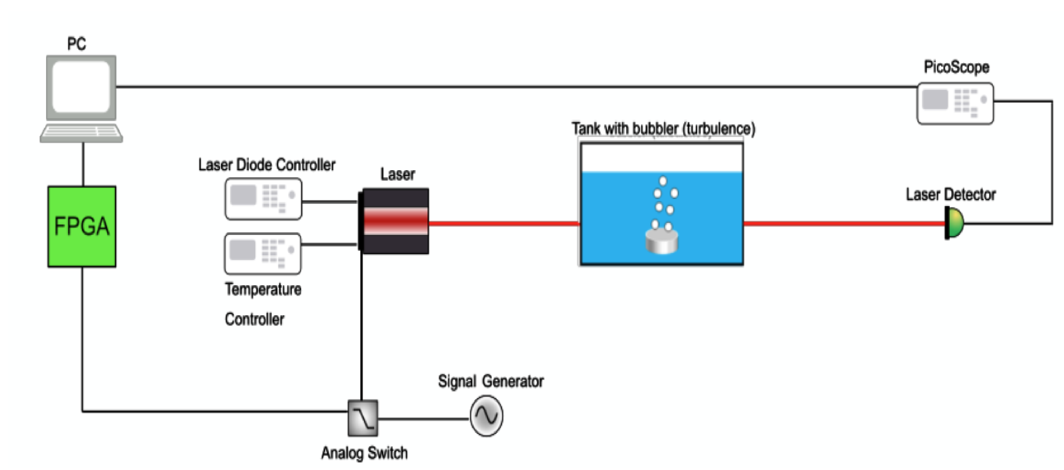
- Simulate atmospheric turbulence
  - Model signal distortion
  - Enable controlled testing environment
- Upgrade to FPGA-based technologies
  - Replace outdated electronics
  - Improve system responsiveness
  - Increase transmission rate

Our team worked with precision and determination to meet and exceed the objectives in support of USSF.

Concept Development

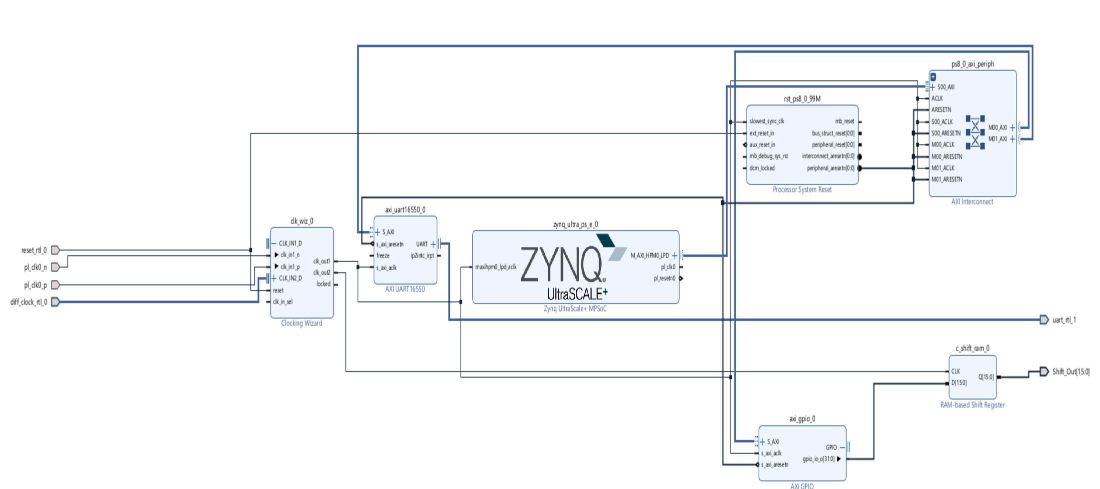
ESR Development

During our time designing the ESR, many different ideas were brought forward. One of the more prevalent designs was using a fan at the bottom of a water tank to generate current. This disturbance and current in the water would then be able to simulate atmospheric turbulence.



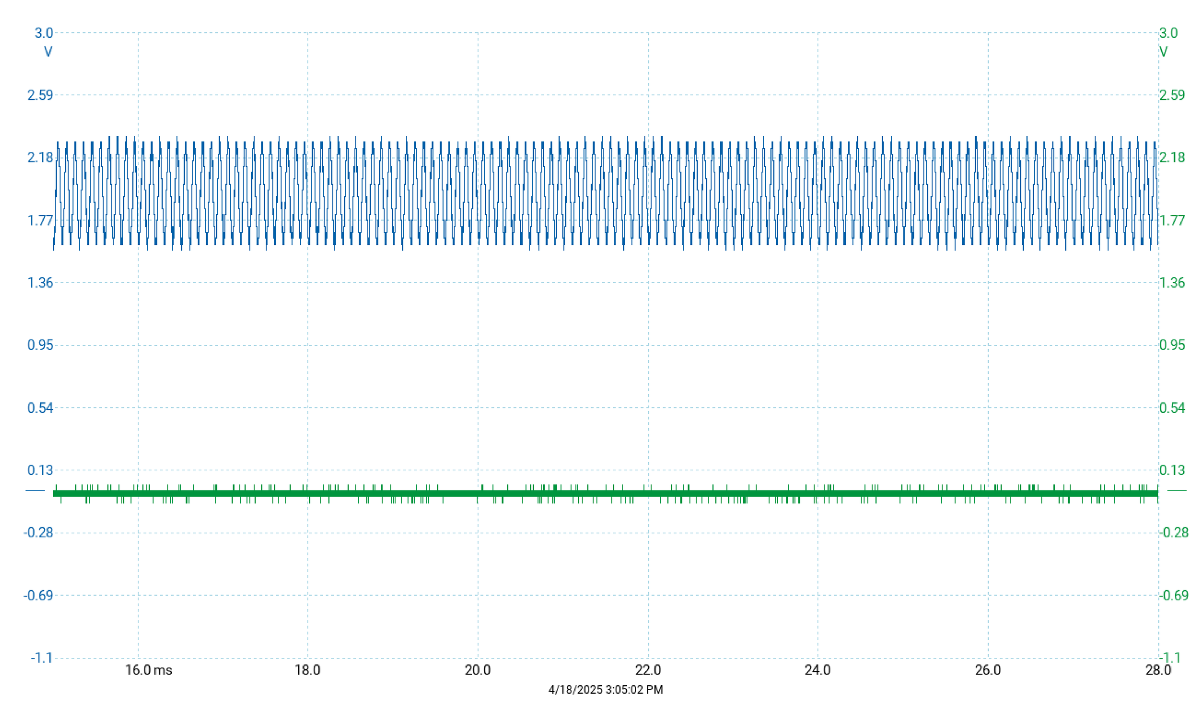
FPGA Development

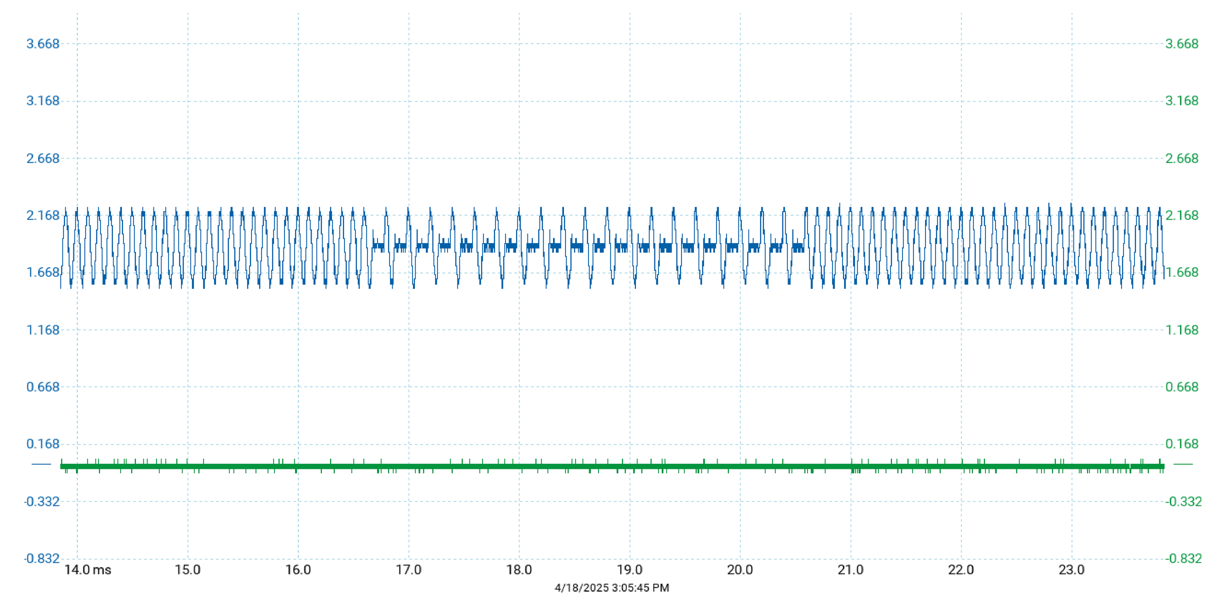
The FPGA has gone through many iterations, similar to the ESR. These iterations mainly revolve around changes to the actual hardware itself. We started with an Xilinx FGPA and then changed to an Enculstra. The Enclustra never arrived so afterwards, we switched to a Terasic DE10—Lite.



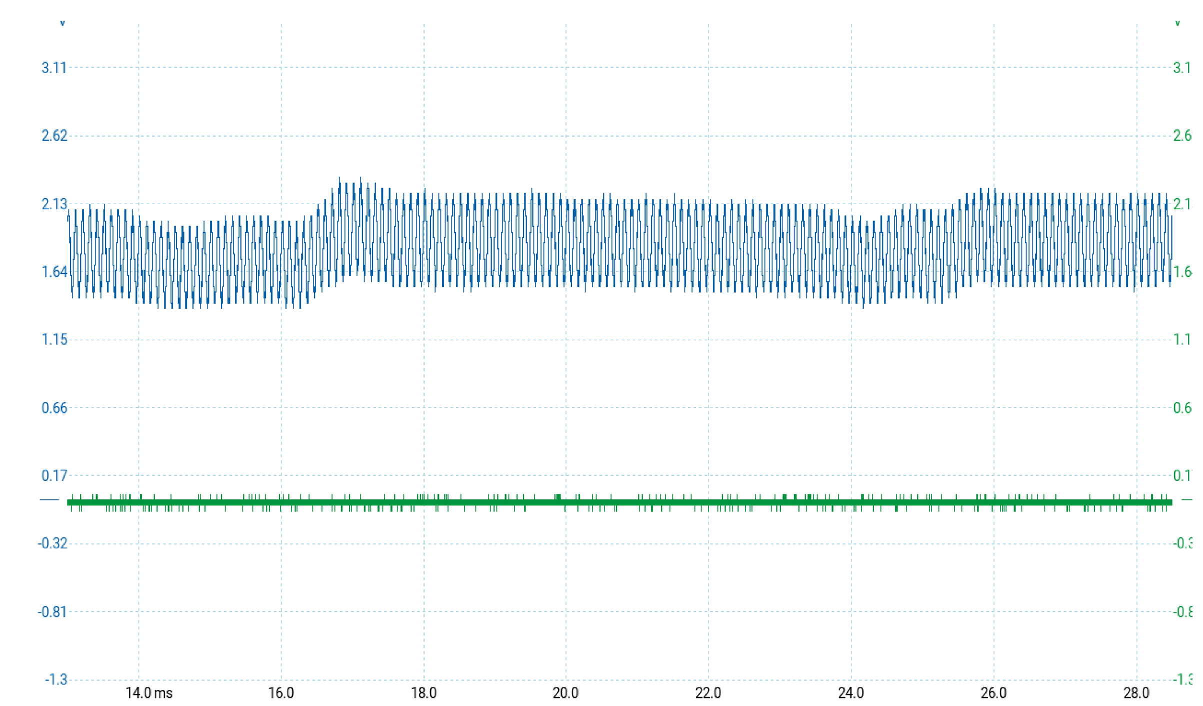
Final Results

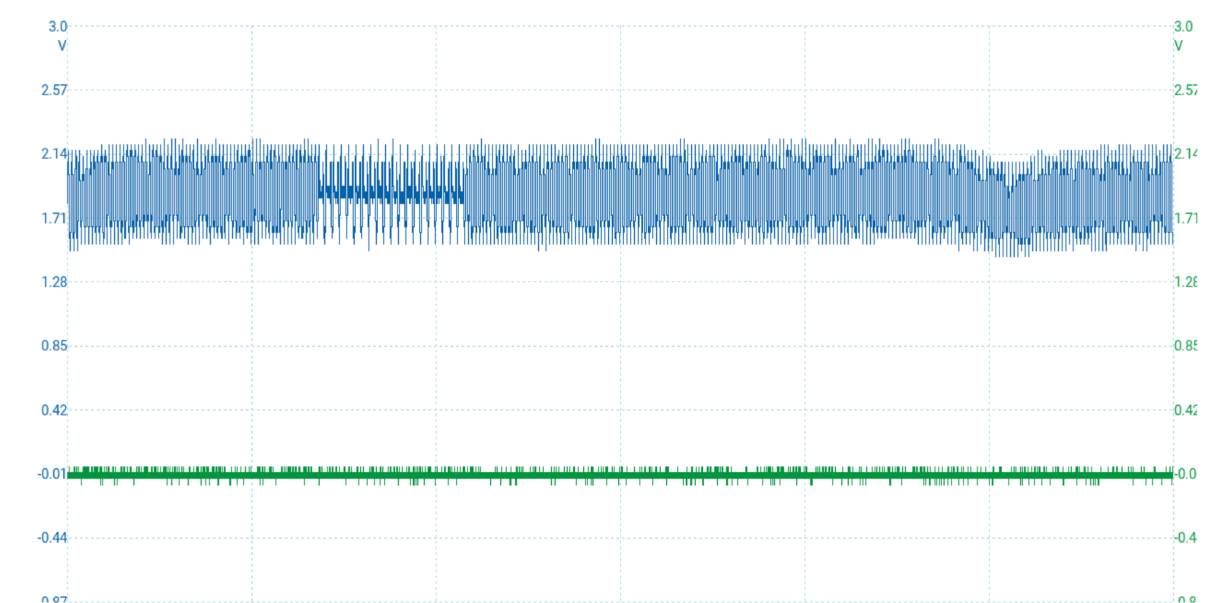
Before Turbulence





After Turbulence





Our final system integrates two major subsystems: the Environmental Simulation Rig (ESR) and the Laser Communication FPGA Setup. The laser used in testing is an 850 nm diode laser (IR) with a 10 mW power output and a diode diameter of 5.6 mm. The receiver is designed to capture signals with a diameter up to 13 mm.

FPGA Communication System:

- Utilizes a Terasic DE10-Lite FPGA programmed through Quartus Prime to transmit binary data over a laser diode.
- The FPGA is configured to generate accurate bitstreams representing digital messages, which are converted into laser pulses.
- A high-speed receiver collects the laser pulses, which are then analyzed to ensure data integrity and minimal signal loss.

Environmental Simulation Rig (ESR):

The ESR simulates Earth's atmospheric turbulence using disturbed water and bubbles.

- It is a 3D-printed PETG container, redesigned after three failed prints to improve durability and watertightness.
- The ESR includes forward and lateral acrylic (PMMA) panes with fitted BOROFLOAT® borosilicate windows, providing over 90% transmissivity for wavelengths up to 2000 nm.
- Final sealing was done using epoxy and silicone, passing initial water testing.
- A bubbler inside the ESR agitates the water, creating turbulence for the laser beam to pass through.
- The design allows comparison testing with and without environmental disturbances to evaluate signal degradation.

Integration & Testing:

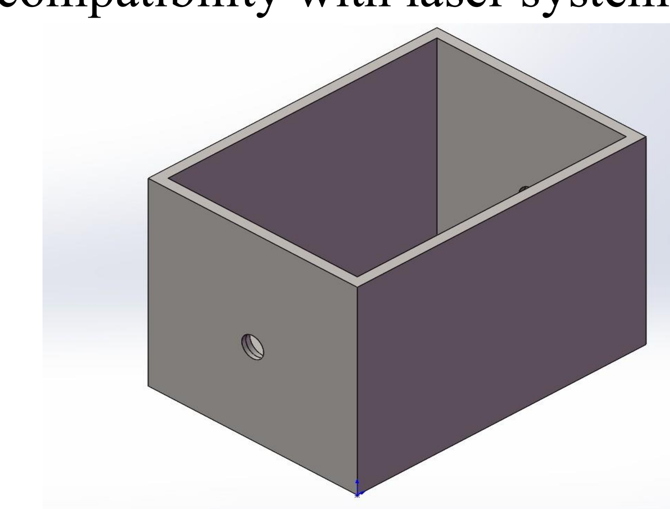
- The FPGA and ESR operate together as a functional testbed.
- Testing was conducted at Goddard-Annex Lab and in controlled outdoor settings.

Research

The team conducted targeted research to replicate realistic atmospheric effects on laser communication systems. Efforts were focused on tuning the system to emulate dynamic turbulence conditions, calibrating the intensity and frequency of optical distortions, and ensuring the testbed could generate meaningful signal disruption data. Component selection and system architecture were also validated to maintain full compatibility with the existing laser hardware.

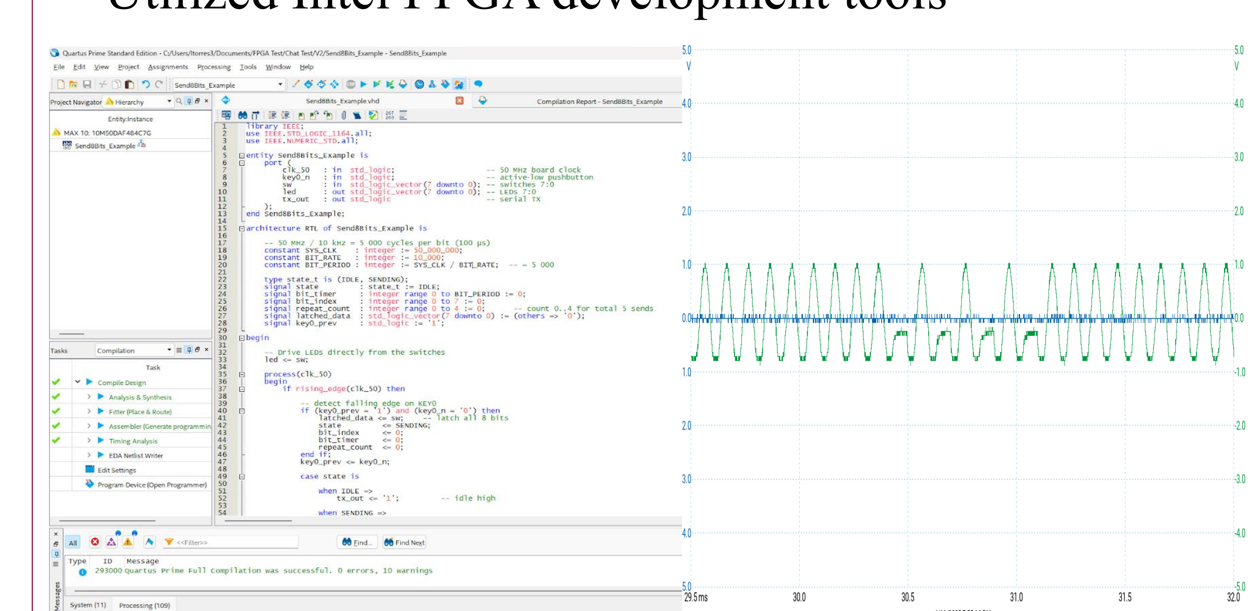
Key Research: ESR

- Tuned system for dynamic conditions
- Calibrated turbulence intensity and patterns
- Focused on realism in signal disruption
- Ensured compatibility with laser systems



Key Research: FPGA

- Deployed VHDL on FPGA board
- Integrated software–hardware communication links
- Utilized Intel FPGA development tools



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