ECE
MAJOR DESIGN EXPERIENCE EXPO

April 23, 2025

The Inn at Virginia Tech

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Agenda

Registration	8:30am–9:00am
Welcome	9:00am–9:15am
Tracks	9:15am–11:15am
Posters and Pizza	11:30am–1:45pm
Awards	2:00pm–2:30pm

Presentation Tracks

Welcome to our Spring 2025 ECE Major Design Experience (MDE) Exposition. Each semester, we come together and take a few hours to review and celebrate the accomplishments of our undergraduate student teams. The MDE is intended to be the culmination of the students' entire undergraduate engineering educational journey. Today's MDE Expo showcases the results of 187 students, each working and learning together as a member of a design team finishing their second semester of work on their teams' unique projects.

Today, 36 exciting projects are showcased and each is a unique, open-ended, technical challenge defined by our industry partners. Each student team has engineered their own solution to their project with facilitation from our faculty subject matter experts (SMEs). Whether a student's career takes them to work in industry, to continue towards an advanced degree, or to pursue roles in our national labs, their MDE capstone will impact much of their approach to making contributions to their technical communities and, more broadly, throughout society.

Today's ECE MDE Expo offers us an opportunity to examine and celebrate each project team's outcomes and results. Once you've seen today's demonstrations, posters, and technical presentations, I think you will agree that all our students have learned much and most have delivered some very inspiring and useful projects.

This would not have been possible without the support of our industry partners, our subject matter experts, and a host of other professionals committed to providing our students with these exceptional educational engineering experiences. Thanks to all.

Congratulations to each of the students; their dedication and diligence is evidenced in these 36 projects. On behalf of these students, and from me personally, thanks again to our industry sponsors, our subject matter experts, and our MDE faculty for their tremendous support in developing our next generation of engineers.

Rose Hu
Department Head
Bradley Department of Electrical and Computer Engineering

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We greatly appreciate their support.

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SPECTRAL WARRIOR

CPES
Center for Power Electronics Systems

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MICS

Project Leadership

This class is only possible because of the commitment, dedication, and spirit of the following Customers and Subject Matter Experts. Thank you!

Sponsor	Customer	Project	Subject Matter Expert (SME)
7x24 Exchange **Ashburn, Virginia**	Jeff McWhirt	Data Center Prognostic Noise Sampling Device	
Analog Devices **Greensboro, North Carolina**	Jeff Chambliss	Interactive Phased Array Beam Steering Visualization	Linbo Shao
Annapolis Aquaculture	Richard Young	Autonomous Aquaculture	Alkan Soysal
BAE Systems **Manchester, New Hampshire**	Lu Goncalves-Getty and Jeremy Reeves	Quantum State Generation Using Photonic Integrated Circuits	Yong Xu
Boeing **Blacksburg, Virginia**	Stephen Moyer	Semi-Autonomous Navigation Vehicle	Arthur Ball
DOT&E	Jeremy Werner and Tyler Englestad	Cipher Internet Protocol	Yaling Yang
DOT&E	Jeremy Werner and Tyler Englestad	Applying the Automaton General-Purpose Automated Data Analysis and Visualization Platform	Yaling Yang
DOT&E	Jeremy Werner and Tyler Englestad	Time-Based Evaluation of Cryptographic Security	Yaling Yang
DOT&E	Jeremy Werner and Tyler Englestad	Minimizing Bits for Communications	Yaling Yang
Framatome	Ken Ritchey, Gary Novak and Erich Thurm	FPGA/CPLD Replacement of Deprecated Communication Chips	Linbo Shao
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Christopher Lillard and Kevin Cogley	Saltwater Antenna for Maritime HF Applications	Majid Manteghi
NAWCAD, NAS **Patuxent River, Maryland**	Andrian Jordan	High Speed RF Digitization	

Sponsor	Customer	Project	Subject Matter Expert (SME)
Northrop Grumman	Randy Spicer	Small Satellite Solar Energy Harvester	Ali Mehrizi-Sani
Parsons **Centreville, Virginia**	Peter Rochford	RAG for Codebases	Wenjie Xiong
Parsons **Centreville, Virginia**	Peter Rochford	Performant Prompt Classification in GenAI	Ming Jin
Southwest Research Institute	Todd Veach	CMOS Detector Readout System for Small Satellite Applications	
SSAI **Lanham, Maryland**	Jackie Kendall and Chris Green	3D Printing Toolpath Converter for Multi-Axis Printers	Xiaoting Jia
Virginia Spaceport Authority **Norfolk, Virginia**	Walter Taraila	Supervisory Control and Data Acquisition System for the Virginia Spaceport Authority	Joe Adams
Virginia Tech, CPES **Blacksburg, Virginia**	Rolando Burgos	Electronic Fuse (eFuse) for Auxiliary Power Networks	Ali Mehrizi-Sani
Virginia Tech, ECE **Blacksburg, Virginia**	Kevin Sterne	SuperDARN HF Radar Lab at VT: Transmitter Monitoring	Kevin Sterne
Virginia Tech, ECE **Blacksburg, Virginia**	Luke Lester	Quantum Dot Single-Mode Laser Design and Fabrication	Purv Bavishi
Virginia Tech, ECE **Blacksburg, Virginia**	Wei Zhou and Azahar Ali	Machine Learning Integrated Biosensor for Disease Detection in Milk Samples	Wei Zhou Sook Ha
Virginia Tech, ECE **Blacksburg, Virginia**	Eli Vlaisavljevich	Development of a Novel Multifrequency Focused Ultrasound System for the Non-Invasive, Versatile Treatment of Tumors	Adam Maxwell
Virginia Tech, ECE **Blacksburg, Virginia**	Mantu Hudait	More than Moore: Fabrication of a Germanium FET for Ultra-Fast, Low Power Computing	Muntasir Mahdi
Virginia Tech, ECE **Blacksburg, Virginia**	Mantu Hudait	Design of a Ge and GeSn based Laser For Future Quantum Technologies	Muntasir Mahdi
Virginia Tech, ECE **Blacksburg, Virginia**	Greg Earle	Prototype Development of a Satellite-Based Atmospheric Sensor	
Virginia Tech, ECE **Blacksburg, Virginia**	Kevin Sterne	High Altitude Balloon Venting System	Kevin Sterne

Sponsor	Customer	Project	Subject Matter Expert (SME)
Virginia Tech, ECE **Blacksburg, Virginia**	Scott Midkiff	LoRaWAN Deployment and Demonstration	Alkan Soysal
Virginia Tech, ECE Wireless@VT **Blacksburg, Virginia**	Carl Dietrich	Low-Cost Remote Spectrum Analyzer	Carl Dietrich
Virginia Tech, National Security Institute **Blacksburg, Virginia**	Mark Limes	Portable Controllers for Quantum Sensing Packages	Mark Limes
Virginia Tech, Spectral Warrior **Blacksburg, Virginia**	Brad Davis	Computational Electromagnetic Simulations in Virtual Reality	Chris Headley
Virginia Tech, Walling	Jeff Walling	Design of a High Data Rate Deserializer with 65nm CMOS	Jeff Walling
VPT	Brandon Witcher	Radiation-Hardened LLC Converter	Arthur Ball
Virginia Tech, National Security Institute **Blacksburg, Virginia**	Brad Davis	Beam-Squint Evaluation and Measurement System (BEAMS)	Brad Davis
Wiley Wilson **Lynchburd, Virginia**	Mark Atkinson	Microgrid Design for VT Smart Village	Ali Mehrizi-Sani
Zeta Associates **Fairfax, Virginia**	Michael Drescher and Jared Desai	Personal Locator Beacon Mesh Network	Tim Talty

Project Teams and Posters

Prototype Development of a Satellite-Based Atmospheric Sensor

LEFT to RIGHT: Aditya Bangalore, Raymond Wei, Chinmaya Salinamakki, Haley Strong, Mitchell Chapman

SME:

CHALLENGE

Design, build, and test an electronics prototype for the REDD (Ram Energy Distribution Detector) CubeSat instrument. The instrument is aimed at measuring the dynamics of neutral particles in Earth's upper atmosphere, and the electronics prototype performs all the major functions of the instrument including power distribution, telemetry, control, and sensing. There is currently no go-to space instrument that can make the types of measurements REDD aims to make, so an electronics prototype is a step towards reaching this goal. The data from REDD can provide insights about atmospheric dynamics, solar weather effects (aurora, solar flares, etc), and major weather events on Earth.

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Customer: Greg Earle

Aditya Bangalore Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: My goal is to become an impactful engineer in the aerospace industry. Specifically, I want to work on interplanetary missions that allow humanity to discover more about the universe and our place in it.

Course Comment: This course has been extremely valuable in understanding the practical engineering design process for a complex system. This project has shown me that even if everything looks good on paper, there will inevitably be unforseen issues in the design or manufacturing of the real-life system. It is only after thorough testing and debugging that iteration can occur and a successful design can be achieved. It has also taught me that collaboration and a team-based effort is vital for innovation, and this is something that I will carry with me throughout my career.

Mitchell Chapman Newport News, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I wish to become the best Electrical Engineer I can be in order to obtain a secure career, pay off my loans, and eventually, support a family.

Course Comment: The experiences gained from this course have helped develop the professional skills I will need to succeed in my future career and how important it is to be a lifelong learner.

Chinmaya Salinamakki San Ramon, California

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I want to continue to explore the field of electrical engineering to the best of my ability and constantly learn new things and challenge myself with different engineering problems. I want to work on projects that are going to push me to learn new things on the fly. I am mostly interested in exploring design problems in the field of RF, but am open to learning anything new that a certain project may require.

Course Comment: This project has been extremely valuable for me in learning how to tackle a deadlines and also learn a lot about integrating hardware with software as I took on the role of an embedded systems engineer for this project.

Haley Strong Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I look forward to being part of General Dynamics Mission Systems Engineering Leadership Program starting this summer. I am excited for the doors this program will open for me, and I hope to quickly gain experience and connections which will make me a more well-rounded engineer and effective leader in the engineering professional world.

Course Comment: Having been through multiple electrical engineering internships, I can confidently say this course aptly prepares students for working in the professional world. I have learned lots of practical engineering tips while working through this project, alongside deeper understanding of the engineering design process–including the importance of documentation, testing, iteration, and teamwork.

Raymond Wei Guangzhou, China

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: Solve the most challenging problems, one PCB trace at a time. The buck stops here.

Course Comment: This course was one of the most valuable experiences in my undergraduate journey at VT. It gave me the opportunity to tackle an impactful engineering problem with a team of sharp, driven peers. The hands-on collaboration, technical depth, and problem-solving pushed me to grow as an aspiring engineer and as a person.

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VIRGINIA TECH.
CENTER FOR SPACE SCIENCE AND ENGINEERING RESEARCH

Prototype Development of a Satellite-Based Atmospheric Sensor

Team Members: Aditya Bangalore, Raymond Wei, Haley Strong, Chinmaya Salinamakki, Mitchell Chapman
Customer and SME: Dr. Greg Earle **Mentor:** Prof. Shelley Stover

VIRGINIA TECH.

Motivation

- To design, build, and test a prototype of the Ram Energy Distribution Detector (REDD) CubeSat instrument.
- REDD aims to measure the fundamental characteristics of the neutral atmosphere to inform models of space weather, which can impact long-range radio communications.

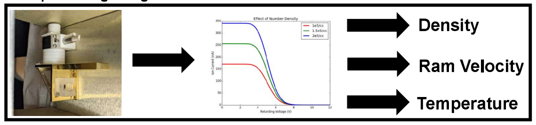


Fig. 1: Overview of motivation for the REDD instrument

Objectives

- Develop electronics and software for controlling thermionic electron emission from a tungsten-alloy filament in vacuum.
- Build and test sensing circuitry for measuring nA to mA level currents generated from neutral particles entering the REDD aperture.
- Develop telemetry software for monitoring instrument status, archiving science data, and controlling instrument operation.

Theory of Operations

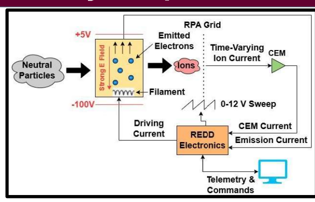


Fig. 2: Simplified REDD instrument block diagram

Instrument Operation

- Neutral particles enter the instrument and are ionized by the controlled electron emission from the tungsten filament.
- The resulting ions enter a retarding potential analyzer[1] (RPA), where they encounter a time-varying potential barrier created by a 0 to 12 volt sweep on a biased grid.
- Depending on the grid voltage, a time-varying ion current is amplified by a channel electron multiplier (CEM) and measured by the REDD electronics.
- Instrument status, emission current, CEM current, and housekeeping data are sent to a flight computer via an output data stream. The flight computer may also command the sweep frequency and emission current level resulting in different spatial resolution modes and ionization rates, respectively.

Electronic Subsystems

- **Power Board:** Powers the system from a +28V bus.
- **Filament Driver Board:** Driving circuitry for inducing emission current.
- **MCU Board:** Houses MSP430, monitors instrument status, outputs data to the flight computer, measures CEM current via an electrometer circuit, and implements control.
- **CEM Board:** Electrical interface for the CEM (not tested due to high voltage -2kV).

Test Setup

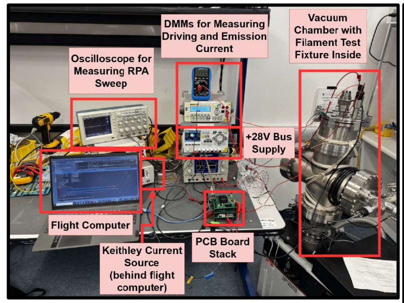


Fig. 3: System level test setup. In addition to the board stack configuration shown, the test was also conducted in a "flat sat" configuration with the PCBs laid out flat and connected with jumper wires.

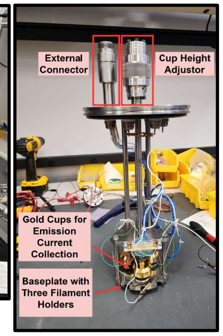


Fig. 4: Filament test fixture

- Digital multimeters (DMMs) are connected for monitoring driving current through the filament and emission current from the filament (R ≈ 1 ohm).
- A Keithley 6220 Precision Current Source is used to simulate the output current from the high-voltage CEM.
- The oscilloscope measures the RPA sweep voltage to monitor spatial resolution mode changes.
- The computer sends commands to the electronics and receives a data stream that is saved as a .csv file.

Test Results

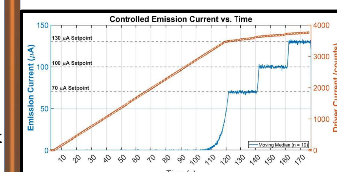


Fig. 5: Controlled emission current for 70, 100, and 130 μA setpoints

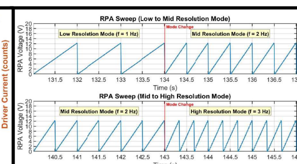


Fig. 6: RPA sweeping voltage in commanded spatial resolution modes

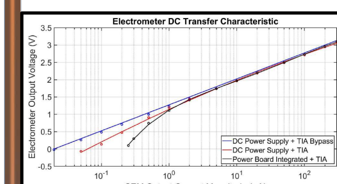


Fig. 7: Electrometer DC transfer characteristic

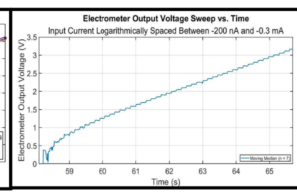


Fig. 8: Electrometer output voltage sweep from system level test

Analysis and Conclusion

1. All boards were built and tested successfully.
2. Fig. 5 shows that emission current is well-controlled and setpoints can be commanded from the flight computer.
3. Fig. 6 shows that the prototype is capable of handling multiple spatial resolution modes which can be commanded. The RPA grid bias voltage responds appropriately to each mode and can vary between sweep frequencies of 1 Hz, 2 Hz, and 3 Hz.
4. Fig. 7 shows that the electrometer circuit covers about 3 decades of input current magnitudes over the expected input range.
5. Fig. 8 shows that the electrometer can respond to time-varying CEM output currents during a holistic system test.
6. Telemetry software provides a data stream, facilitates commanding the system, and saves data in an appropriate file format.

Lessons Learned

- Careful attention to manufacturing procedures and assembly and thorough post-assembly inspection is paramount when building printed circuit boards. Assembly-induced errors can be misdiagnosed as design flaws when solder joints, mechanical stress, or other physical factors are causing the issue.
- When performing tests with complicated test setups, it is crucial to always plan out the test beforehand, drawing pin diagrams and writing careful procedures as needed.
- Before designing a system, it is useful to perform tests that will verify that the given requirements will result in a successful product. For example, during testing it was found that the requirement of 1 A of driving current was insufficient to induce the desired emission current levels.
- Playing to the strengths of each team member optimizes the probability of successfully completing a large-scale project.
- Thermal changes critically influence the performance of electronic components, so circuits must be designed with thermal management in mind.

Future Plans

- The electrometer can be modified with more careful layout practices and part selection to reduce the noise at the inputs, which results in nonlinearities at lower input current levels.
- Using a sturdier interconnect system would allow the board stack to be more resistant to external mechanical forces, like launch vibrations, that would need to be accounted for in a flight-ready CubeSat instrument.
- With a more sophisticated test facility, the CEM can be mounted and tested for its transfer characteristic in environments with varying neutral densities.
- Future iterations of the instrument can be designed with radiation-tolerant hardware to enable science data to be collected during a low-Earth orbit flight.

Acknowledgments

Special thank you to the following for supporting this work:

- Dr. Greg Earle (SME and project advisor)
- Prof. Shelley Stover (Project Mentor)
- Dr. Dan Sable (for providing high-reliability DC/DC converters free of cost)
- Kim Medley (for supporting our procurement logistics)
- Rusty Stewart (for soldering training)

Reference: [1]See "A Versatile Retarding Potential Analyzer for Nano-Satellite Platforms" by L. Fanelli, et al. for more details on RPA measurements.

Beam-Squint Evaluation and Measurement System (BEAMS)

LEFT to RIGHT: Albert Kojo Essiaw Jr., Cole Bednar, Sneha Magadi, Brianna Rodriguez, Charlotte Uehling

SME: Brad Davis

CHALLENGE

Our challenge is to measure and analyze antenna beam-squint, a phenomenon where radio frequency transmission refracts unexpectedly through varying materials. Beam-Squint is a major issue for communication systems because it causes data to be transmitted and received innaccurately. In communications, it is most prominent in devices such as radomes (devices that protect the antenna) and antenna arrays(antennas that can electronically steer the beam peak). Our objective is to create a system to measure beam-squint for antennas in the Ku band (12-18 GHz) so thatfuture design teams can use the measurement system to correct for beam-squint.

Customers: Brad Davis and William Smith

Cole Bednar Abingdon, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: I'm an aspiring RF Engineer with a strong passion for electromagnetics, antenna design, and mathematics. I'm excited by the opportunity to work on cutting-edge technologies and plan to pursue further education in Electrical Engineering. I'm dedicated to lifelong learning and continually building my skills across all areas to grow both personally and pro.

Course Comment: This senior design course does an excellent job at honing your engineering, problem solving, teamwork, and project management skills.

Albert Essiaw Agona Swedru, Ghana

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I plan to begin my career in the tech industry with CACI, to gain hands-on experience and strengthen my engineering skills. After a few years, I intend to pursue a master's in electrical engineering, with the long-term goal of launching a tech hardware company. Ultimately, I also aspire to earn a Ph.D. to contribute to research and innovation in the

Course Comment: This class was a great way to gain exposure to industry standards, collaborate on a project of interest, and refine your presentation and communication skills.

Sneha Magadi Richmond, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to be a cybersecurity executive, leading organizations in managing security risks and inspiring more women to join my field. Addtionally, with my perspective as an integrated security minor, I hope to improve the future of security for my fellow Americans. I also wish to publish and write more novels in my series, To Paint A Rose.

Course Comment: This course offers strong exposure to leadership, industry expectations, and engineering standards in a team-based environment. As a result, I have developed skills in collaborative leadership and effectively communicating complex ideas in an engineering setting.

Brianna Rodriguez Damascus, Maryland

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: My aspiration as a computer engineer is to develop new and innovative AI models that positively impact society. I also wish to earn a masters in computer engineering to contriubte to research and development in the field of AI.

Course Comment: This was a great experince to use the skills I have learned in the past four years and apply it to a real project. It was extremely valuable to me to work with my teammates and collaborate with our customer, mentor, and subject matter expert.

Charlotte Uehling Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: My career aspiration is working in an electrical engineering design role that creates a product that helps people. As of now, I imagine my career having constant learning, problem solving, and circuit design.

Course Comment: Senior Design allows students to apply ECE knowledege and develop relations to industry through deliverables.

Beam-Squint Evaluation and Measurement System (BEAMS)

VIRGINIA TECH

NAVSEA WARFARE CENTERS DAHLGREN

Naval Surface Warfare Center Dahlgren Division, VT NSI, Dr. Bradley Davis

Sneha Magadi, Charlotte Uehling, Brianna Rodriguez, Albert Essiaw, Cole Bednar

INTRODUCTION

What is Beam-Squint?

- **Beam-squint** is the angle difference between the refracted beam and its intended direction.

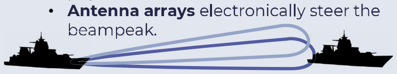
θ: Beam-Squint

Beampeak visual

- A **Beampeak** is the direction of the RF signal from the antenna.

Beam-Squint Impact

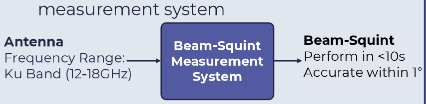
- Communication systems are less precise due to beam-squint.
- Most common in:
  - **Radomes** protect antennas from physical elements.
  - **Antenna arrays** electronically steer the beampeak.

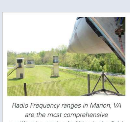


Intended Communication Path
Actual Path due to Beam-Squint

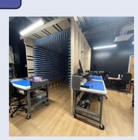
Objective

- Build a compact Beam-squint measurement system





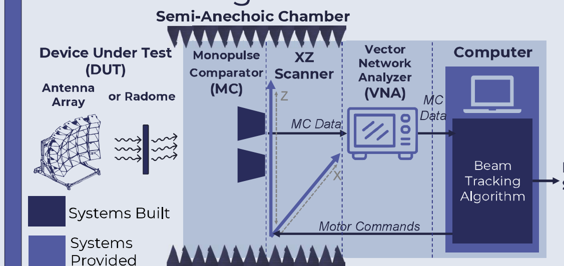
Industry Measurement Solution



Our Measurement Solution

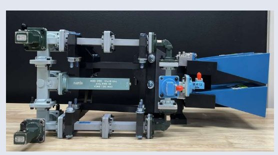
DESIGN

Overall Design



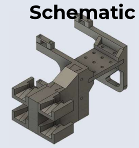
- A **Monopulse comparator (MC)** detects beampeak location
- A **Vector Network Analyzer (VNA)** extracts MC data.
- A **Beam-Tracking Algorithm:**
  - **Adjusts the MC position** until MC finds beampeak
  - **Calculates Beam-Squint** with the beampeak location
- The **Device Under Test (DUT), MC,** and **XZ Scanner** are in a **Semi-Anechoic Chamber**

Hardware: Monopulse Comparator (MC)

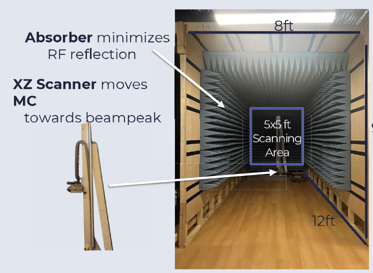


Custom-built MC

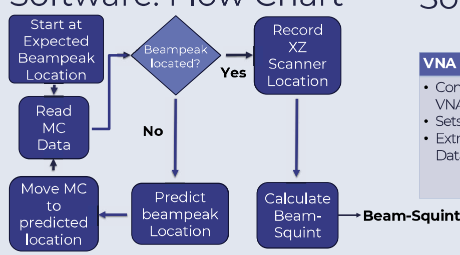
3D Printed Holder Schematic



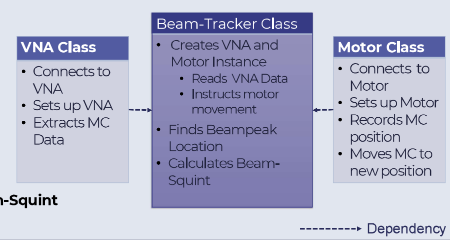
Testing Range



Software: Flow Chart



Software: Class Structure

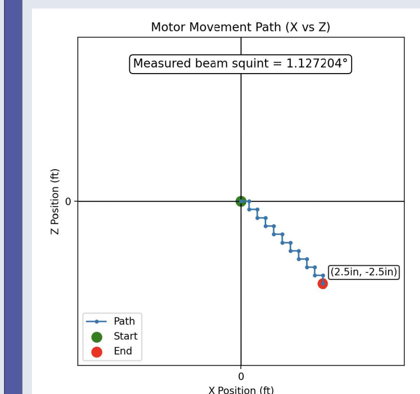


CONCLUSION

Results

The output of our system is a plot showing:

- The movements it took to reach the beam peak
- Final coordinates of the beampeak
- Squint measurement accurate within ~1°



Conclusion

- Measurement system accurately and compactly measures Beam-Squint
- Helpful for future Senior design teams tackling Beam-Squint correction
- Code + Testing Range built have applications beyond Beam-Squint

Acknowledgements

We thank Dr. Bradley Davis of the VT National Security Institute, Dr. Daniel Connors of ECE 4805/6, William Smith @NSWCDD, Dr. Steven Russell @Office of Naval Research (Provided the funds for the scanner). In addition, we thank Virginia Tech for enabling us to explore and advance this topic for future innovation.

Computational Electromagnetic Simulations in Virtual Reality

LEFT to RIGHT: Matthew Gallagher, Ethan Maas, Junior Bonsu, Robert Vaughn, Samuel Philips

SME: Chris Headley

CHALLENGE

Our challenge is to develop and integrate one-dimensional and two-dimensional finite difference time domain simulations into an electromagnetic virtual reality training environment for radio frequency equipment. This is to provide real time simulation functionality to support the existing Spectral Warrior's team's virtual reality experience.

Customer: **Brad Davis**

Kwasi Bonsu Gainesville, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Attain a full-time Software Engineering role focused in AI

Course Comment: It was a rewarding experience to grow alongside my team as we developed the project from initial stages to the final product in VR.

Matthew Gallagher Haymarket, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After graduating, I plan to pursue a graduate degree and continue my ongoing research in the field of Human-Computer Interaction, focusing on the development and use of virtual reality experiences.

Course Comment: This course provided a valuable opportunity to apply engineering concepts in a team environment.

Ethan Maas Tampa, Florida

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I plan to pursue a career in cybersecurity and network engineering after graduation. I want to be part of a field that keeps the world's most powerful and important infrastructure of information and data safe and usable for everyone.

Course Comment: This course does an excellent job at taking engineering students that are inundated with technical material and immersing them in an environment where they learn to value relationships with colleagues and mentors just as much as knowledge of the content.

Samuel Philips Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: Electronic warfare engineer

Course Comment: I learned the importance of communicating with a customer and the importance of having a specification to build to

Robert Vaughn Nokesville, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to continue to learn about electromagnetics and pursue a career where I can apply these skills.

Course Comment: I enjoyed working with my teammates and learned a lot about project management.

Computational Electromagnetic Simulations in Virtual Reality

Team Members: Junior Bonsu, Robert Vaughn, Ethan Maas, Samuel Philips, Matthew Gallagher
Mentor: Dr. Daniel Connors | **Customer:** Dr. Bradley Davis, William Smith
Subject Matter Expert: Dr. William "Chris" Headley

1.Problem Statement

- To design and implement 1-D and 2-D Finite Difference Time Domain (FDTD) code utilized in the creation of electromagnetic (EM) simulations for integration into a virtual reality (VR) environment that visualizes radio frequency (RF) principles in support of the Spectral Warriors.

2. Requirements

- Develop FDTD code to be implemented into both 1-D and 2-D simulations showing electromagnetic principles.
- Simulations needed to be implemented into an Unreal Engine-powered VR space and gamified to create engaging and immersive learning experiences.

3. Background

For FDTD formulation, apply Central Difference Theorem to Maxwell's equations for time and spatial derivatives.

$$\frac{E_x^{n+\frac{1}{2}}(k)-E_x^{n-\frac{1}{2}}(k)}{\Delta t} = -\frac{1}{\varepsilon_0}\frac{H_y^n\left(k+\frac{1}{2}\right)-H_y^n\left(k-\frac{1}{2}\right)}{\Delta x}$$

Then solve for Update Equation to be used in code.

$$E_x^{n+\frac{1}{2}}(k) = E_x^{n-\frac{1}{2}}(k) - \frac{\Delta t}{\varepsilon_0 * \Delta x}\left[H_y^n\left(k+\frac{1}{2}\right)-H_y^n\left(k-\frac{1}{2}\right)\right]$$

This formulation was then applied to coaxial transmission lines and 2-D radomes to allow the user to visualize how changing dielectric properties and geometry of a material affect its interaction with propagating electromagnetic waves.

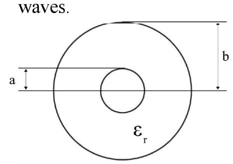


Figure 1: Diagram of coaxial cable with inner (a) and outer diameter (b) and relative permittivity (ε_r) of dielectric material labeled.

4. Simulation Design

- The 1-D simulation applies FDTD formulation to the Telegrapher's equations for transmission lines. The simulation shows the reflected and transmitted voltage waves for mismatched impedances of coaxial lines.
- The 2-D simulation uses a simple horn antenna to give directivity to a sine wave, which allows us to show how waves propagating in a vacuum react when colliding with different geometries and material properties in 2-D.

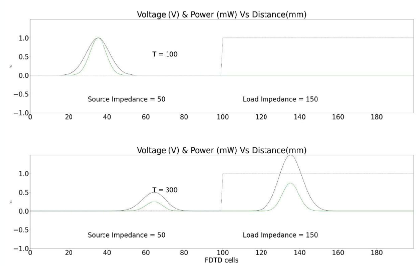


Figure 2: Example of Impedance mismatch between transmission lines of 50 to 75 Ohms shows V and P

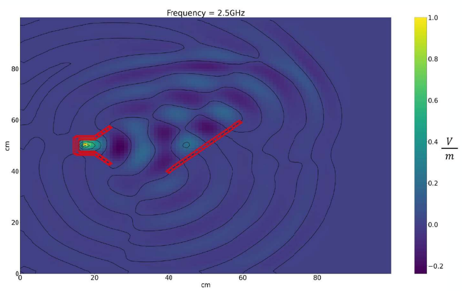


Figure 3: Simulation of a propagating EM sine wave reflecting of an angled dielectric screen in (V/m)

5. Experience Design

- The 1-D experience prompts the user to manipulate the physical properties of a virtual wire to match its impedance to a base wire in a VR simulation.
- The 2-D experience involves the user exploring the behavior of electromagnetic waves propagating from a horn antenna across dielectric materials with different radome geometries.
- Each experience was designed in parallel with game design concepts to maximize engagement, encourage exploration, and provide meaningful feedback to the user throughout their journey.

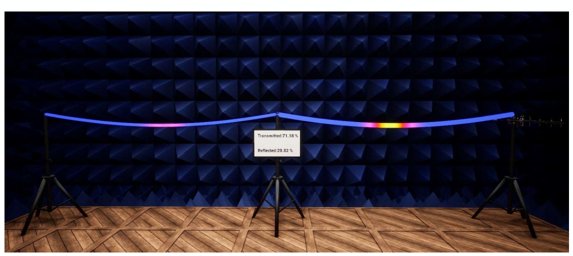


Figure 4: Transmission line FDTD scenario in VR

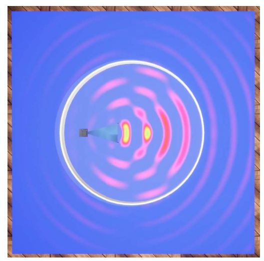


Figure 5: Horn antenna in VR

6. Future Plans

- Optimize the experience to allow for mobile headset usage.
- Create additional simulations within the VR environment featuring more advanced concepts such as array theory.
- Utilize ray tracing for 3-D volumetric simulations.

7. Challenges

- Traditional source control methods proved incompatible with the system due to the binary nature of the various 3-D assets.
- Certain simulation methods including ray tracing proved too complex for implementation within the given timeframe.
- Ensuring all simulations were accurate took an extraordinarily large amount of testing and applied theory.

8. Conclusion

- Tasked with the creation of 1-D and 2-D FDTD simulations in Python which were to be converted to C++ to be integrated into a virtual reality experience.
- Validated the methods with rigorous testing through the use of electromagnetic theory.
- Designed two interactive rooms in Unreal Engine showcasing FDTD simulations, enhanced with user engagement features for gamification.

9. Acknowledgements

We would like to thank our subject matter expert, Dr. William "Chris" Headley, our customer intermediary, Dr. Bradley Davis, our customer Dahlgren, our customer representative, William Smith and our mentor, Dr. Daniel Connors for their support during this project.

LoRaWAN Deployment and Demonstration

LEFT to RIGHT: Nick Meier, Isham Harris, Connor Kramarik, Vijay Mannava, Andrew Budzynski

SME: Alkan Soysal

CHALLENGE

Deploy a functional LoRaWAN network using a Raspberry Pi and ChirpStack open-source software. Design IoT sensor nodes equipped with GPS and CO_2 sensors to collect data over a long range. Then, develop backend and visualization for data.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Customer: Scott Midkiff

Andrew Budzynski Collegeville, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Further my engineering career by supporting DOD interests.

Course Comment: I enjoyed the real world aspect of project developement and working as a team.

Isham Harris Sanderson, Texas

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I would like to further my engineering career with aspirations to move into management in the future.

Course Comment: Thank you to Dr.Midkiff and Dr.Pour for all of their help throughout the year.

Connor Kramarik Williamsburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Pursuing further education at Virginia Tech in the ECE Master's program.

Course Comment: I really enjoyed working on a team to develop unfamiliar technologies.

Vijay Mannava Fairfax, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I would like to pursue a future career as a patent attorney.

Course Comment: I enjoyed my team as well as the project we got to work on.

Nicholas Meier Millstone, New Jersey

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to leverage my technical expertise and innovative thinking to develop impactful solutions to drive a team forward.

Course Comment: I strongly recommed this course to any senior.

LoRaWAN Deployment and Demonstration

Andrew Budzynski, Isham Harris, Connor Kramarik, Vijay Mannava, Nick Meier
Sponsor: Dr. Scott Midkiff
Subject Matter Expert: Dr. Alkan Soysal

VIRGINIA TECH
COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Background

What is LoRa?

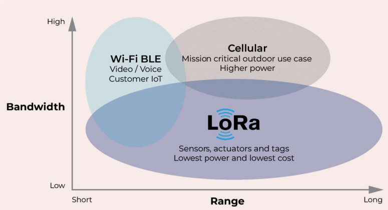
- LoRa is a long-range, low-power radio modulation technique designed to transmit small amounts of data over long distances.

What is LoRaWAN?

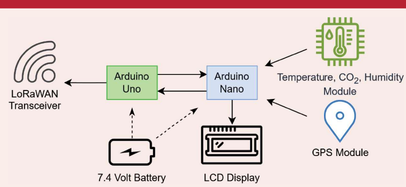
- LoRaWAN is the networking protocol that utilizes the LoRa technology, providing an interface for LoRa-devices to securely interact with certain applications.

Why use LoRa/LoRaWAN?

- In situations where small amounts of information need to be exchanged intermittently, LoRa serves as a more power-efficient solution than Wi-Fi or cellular.
- Wi-Fi and cellular are designed for close range, high bandwidth communication. LoRa is designed for the opposite purpose.
- LoRaWAN is best used in environments where many LoRa devices require secure communication with multiple applications.

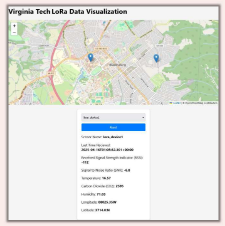


Sensor Hardware



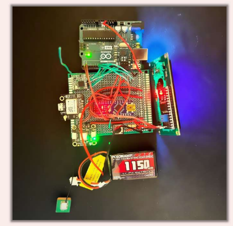
- Comprised of two microcontrollers:
  - One collects, processes, and sends data to the other.
  - The other receives the data and transmits to the LoRaWAN gateway.
- Multi-microcontroller solution enables device modularity and frees computational resources.
- Powered by a 7.4-volt Lithium-Polymer battery for portability.

Final Design

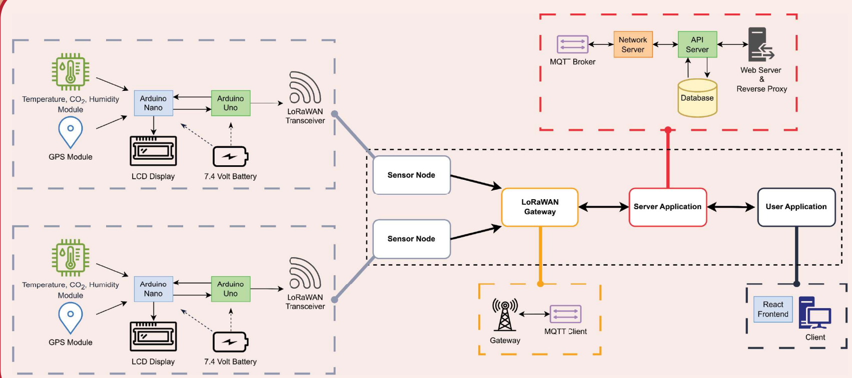


Frontend Application

LoRaWAN Gateway



End Device



Technologies

Frontend

- Developed using the ReactJS framework.
- Served by an NGINX webserver.
- API requests directed to the backend by an NGINX reverse proxy.

Backend

- API requests handled by the Flask framework.
- Device data is stored in a MongoDB database.
- Application is fully containerized and deployed using Docker.

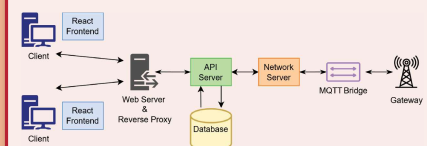
LoRaWAN Network

- Network and end devices managed by Chirpstack.
- Gateway and network communicate via MQTT.

Hardware

- RAK Wireless LoRa gateway interfaces with LoRa devices.
- Arduino Nano and Uno control end device computation.
- Raspberry Pi hosts the containerized full-stack application.

Backend Software



- End devices transmit data using LoRa, which is received by the gateway.
- The gateway forwards this data over the MQTT bridge to the LoRaWAN network server.
- The network server manages devices and forwards data to the API server, where it is stored in a persistent database.
- Device data is made available to end-users through API endpoints exposed by the web server.
- The web application provides an interface for users to view and interact with the devices on Virginia Tech's LoRaWAN network.

Conclusion

Our solution provides Virginia Tech with a LoRaWAN network, giving access to scalable infrastructure for IoT devices. Our software produces an extensible application layer for data management and user interaction. This serves as a foundation for future innovation and provides the necessary infrastructure to build upon.

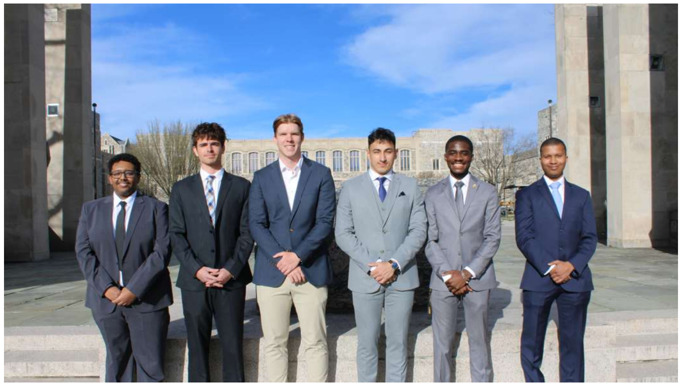
Looking Forward

- Develop fundamental architecture for students at Virginia Tech to utilize LoRaWAN technologies.
- Expand LoRaWAN capabilities to groups that can benefit:
  - Smart, power-efficient control of lighting and HVAC in campus buildings.
  - Tagging and tracking of animals and livestock for the School of Animal Sciences
  - And many other teams across Virginia Tech…

Acknowledgements

We extend our deepest gratitude to Dr. Scott Midkiff for his invaluable guidance and mentorship throughout the Major Design Experience. His extensive expertise in Electrical and Computer Engineering (ECE) has not only enlightened us but also inspired a deeper understanding and passion for the field.

Small Satellite Solar Energy Harvester



LEFT to RIGHT: Abel Tekle, Jacob Manor, Justin Lamberty, Emre Ramiz, Samuel Miller, Jalen Baine

SME: Ali Mehrizi-Sani

CHALLENGE

Northrop Grumman has tasked our team with developing a solar energy harvester circuit for a small satellite. The device must fit within a compact 10 x 10 x 10 cm (1U CubeSat) form factor, harvest solar energy to charge a Lithium-Ion battery, and include a microcontroller to monitor key aspects of the system. This project combines compact design, self-sustaining energy, and circuit monitoring.

NORTHROP GRUMMAN

Customer: **Randy Spicer**

Jalen Baine Moseley, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I want to get a job and work for an engineering consulting firm

Course Comment: This has been a fun and challenging course to take.

Justin Lamberty Daufuskie Island, South Carolina

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Space Systems Engineer

Course Comment: I really enjoyed the real world hands-on experience that Senior design gives

Jacob Manor Milford, Massachusetts

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan on working in the Embedded / FPGA Engineering field post-graduation.

Course Comment: I enjoyed working alongside a repuatable organization on a project with practical applications. On top of that, I love our team.

Samuel Miller Haymarket, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Following graduation, I aspire to pursue a career in Computer Engineering, specializing in Machine Learning applications and the interaction between software and hardware. My goal is to leverage my academic and professional experience to develop innovative, real-world solutions.

Course Comment: This project enhanced my leadership skills in an electrical and computer engineering team while applying knowledge to an industry-like problem. I also gained hands-on experience in PCB design and soldering, which aren't typically covered in class.

Emre Ramiz Mount Olive, New Jersey

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Test Pilot

Course Comment: Important lessons learned for engineering in team environments. Great experience overall.

Abel Tekle Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I want to go into the Naval/robotics feild. Specifically designing and debuging complex electrical system. Later on, I want to work as a PCB engineer.

Course Comment: Well organized course! I enjoyed working on real world applications and testing what I've learned from my courses

Small Satellite Solar Energy Harvester

Sponsor: Dr. Randy Spicer

Mentor: Professor Kelley Andrews

SME: Professor Ali Mehrizi-Sani

Team: Samuel Miller, Abel Tekle. Jalen Baine, Jacob Manor, Emre Ramiz, Justin Lamberty

Problem Statement

Develop a robust energy management circuit that efficiently harvests solar power from one or more solar cells to charge a Li-Polymer battery.

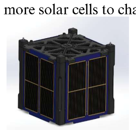


Figure #1: 1U CubeSat

Key Impacts:

- Enables self-sufficient power for small satellites
- Lowers cost barriers to space exploration missions
- Extends battery life for consistent and reliable mission performance
- Real-time monitoring improves subsystem efficiency and safety
- Supports future satellite innovations and sponsor-driven applications

Key Objectives

- Develop a circuit to harvest solar energy from onboard solar cells
- Safely charge a Li-Polymer battery using the harvested energy
- Integrate a microcontroller to monitor and control:
  - Battery voltage
  - Battery status (e.g., state-of-charge)
  - Charge and discharge currents
- Ensure the entire system fits within a 10 × 10 × 1 cm form factor to meet 1U CubeSat constraints

Challenges

During the development of our project, the team faced several significant challenges:

- PCB Manufacturing: Export tariffs made it difficult to source PCBs from overseas. To address this, we shifted to domestic manufacturing through OSH Park.
- Bluetooth Interference: An external Bluetooth module interfered with the Arduino's operation. To resolve this, we transitioned to an Arduino Nano with built-in WiFi and Bluetooth capabilities.
- Boost Converter Startup: Properly initializing the boost converter IC proved challenging due to its minimum startup voltage requirements, which required temporary startup from the Arduino's power source.

Design Implementation

The Small Satellite Solar Energy Harvester is composed of six key subsystems, each designed to fulfill a specific function that contributes to the system's overall efficiency and reliability. Together, these subsystems manage energy harvesting, power conversion, battery charging, and system monitoring—ensuring continuous and safe operation in a compact CubeSat environment. A detailed overview of each subsystem is provided below:

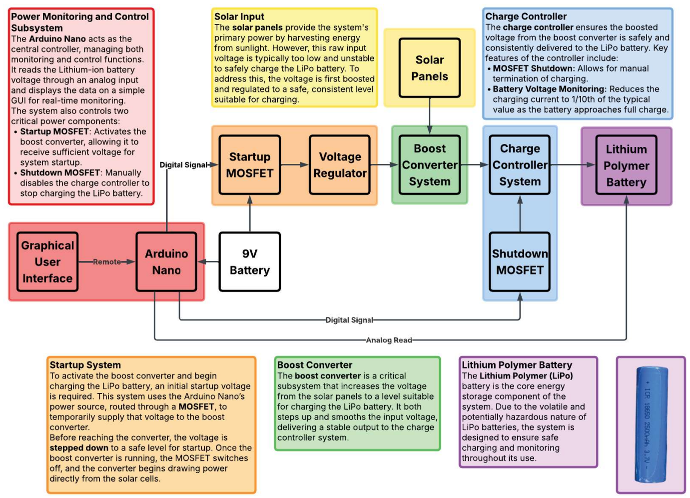


Figure #2: High level System Design

Test Results

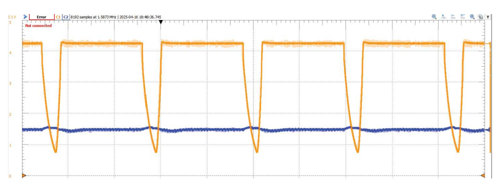


Figure #3: Input/Output Voltage of the System

C2	Maximum	1.5598 V
C2	Average	1.4712 V

Figure #4: Channel 2 Represents Vin

C1	Maximum	4.2942 V
C1	Average	3.7583 V

Figure #5: Channel 1 Represents Vout

Conclusion

This solution offers an efficient and maintenance-free method for charging and monitoring a Li-Po battery in CubeSat applications. By ensuring safe operation and enabling battery recharging in space, the system enhances satellite longevity and reliability without the need for manual intervention post-launch.

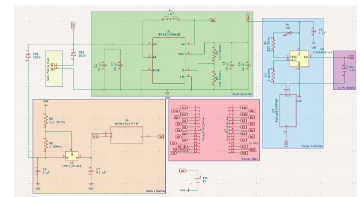


Figure #6: Final Circuit Schematic

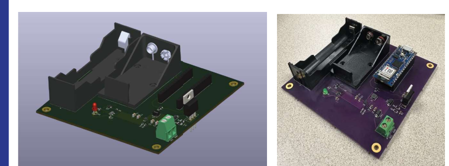


Figure #7: Final PCB design

Future Work

- Integrate a rechargeable 9V battery to ensure the entire system operates using only renewable energy sources
- Further reduce PCB size to support seamless integration with additional CubeSat subsystems while staying within the 1U form factor

Acknowledgement

We would like to take a moment to sincerely thank the following individuals. Your guidance, support, and encouragement have been instrumental in helping us reach this point. We truly couldn't have done it without you:

- Mentor: Prof. Kelley Andrews
- Customer: Dr. Randy Spicer
- SME: Prof. Ali Mehrizi-Sani
- Professor: Joe Adams

Thank you all for your invaluable contributions to our project.

CMOS Detector Readout System for Small Satellite Applications

LEFT to RIGHT: Justin Winn, Dawsyn Schraiber, Noah Welenteychik, Archit Chavan, David Encarnacion

SME:

CHALLENGE

Our goal is to design a control system for a CMOS detector that minimizes noise, size, weight, and power consumption. This effort supports the Southwestern Research Institute's suborbital and orbital missions by delivering a compact, efficient imaging detector readout system which can be tweaked for a number of desired applications.

SwRI® SOUTHWEST RESEARCH INSTITUTE

Customer: Todd Veach

Architsingh Chavan Richmond, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Get my master's degree in the field of Quantum Computing

Course Comment: Excited for the opportunity to be working on a CubeSat

David Encarnacion Denville, New Jersey

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I will start my career right out of undergrad working either along the space coast or out west

Course Comment: Enjoying the opportunity to contribute to a project from a higher level with the experience I gained working on another cubesat project

Dawson Schraiber Loves Park, Illinois

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: To be an avionics engineer for aerospace applications

Course Comment: I wish we has an SME

Noah Welenteychik Richmond, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: Placeholder for Aspirations

Course Comment: Placeholder for Course Comment

Justin Winn McLean, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering
Bachelor of Arts
Music

Aspirations: To work in embedded systems and eventually obtain a Master's in Embedded Systems

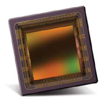
Course Comment: Enjoying the work on a networked CubeSat device, as well as learning from a team with a diverse skill set

CMOS Detector Readout System for Small Satellite Applications

Team Members: David Encarnacion, Dawsyn Schraiber, Noah Welenteychik, Archit Chavan, Justin Winn
Customer: Dr. Todd Veach, SwRI **Mentor:** Dr. Shelley Stover, NASA

Motivation

To develop a low-cost and adaptable CMOS image sensor readout system capable of converting LVDS output into a readable format for data transfer and storage. This system will support integration into satellite payloads deployed in low-earth-orbit (LEO), enabling SwRI to gather orbital image data for internal research and potentially share with the scientific community. Comprehensive documentation will ensure the system's replicability for future missions, allowing the deployment of multiple satellites equipped with versatile imaging capabilities.



ams CMV4000 CMOS Detector

Objectives

- Create a low-form-factor, low-power, and low-noise image readout system
- Reach a data capture speed of 15 frames per second at a 2048x2048 image resolution
- Ensure the system survives a low-earth-orbit (LEO) thermal environment and launch vibration

High Level Block Diagram

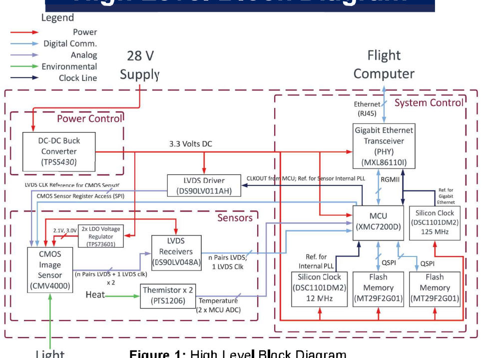


Figure 1: High Level Block Diagram

Software

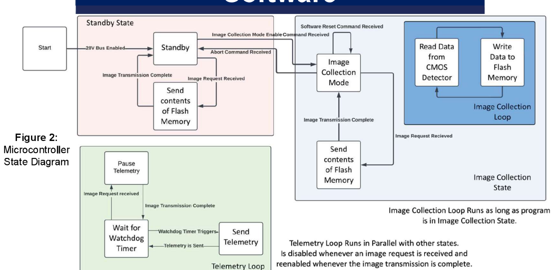


Figure 2: Microcontroller State Diagram

Layout

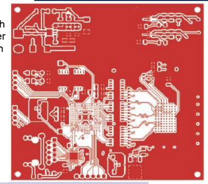


Figure 3: Top Signal layer with 3.3 PWR copper pour in between traces.

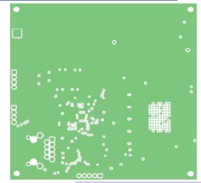


Figure 4: Second layer as one of three GND planes

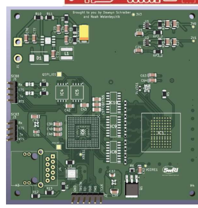


Figure 5: 3D view of top side of PCB

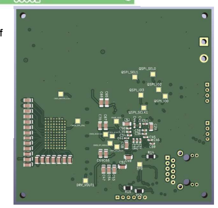


Figure 6: 3D view of back side of PCB

6-layer PCB with alternating SIG/PWR and GND layers for noise isolation

Experimental Setup

Validation testing utilized the following:

- 28V DC Power Supply
- Host Computer running Test Software
- Readout System

After verification testing, operational and survivable environmental conditions were tested. The following equipment was used:

- PWS4323 DC Power Supply
- DM3068 Digital Multimeter
- LACO Technologies Thermally Controlled Vacuum Chamber and HVC-3500 control unit

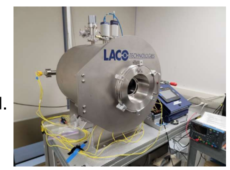


Figure 7: TVAC used for environmental testing

Test Results

Ethernet communications were able to be established via the Test Software and the development board using the FreeRTOS software stack on the microcontroller to manage CPU time. Telemetry, commands, and responses were able to be exchanged between the host computer and the primary microcontroller.

Three boards were assembled to aid in testing and debugging with varying degrees of functionality. This has been completed to allow for subsystem testing. The first board revision featured a linear regulator that was replaced with a switching regulator in the second revision to accommodate higher power dissipation. The microcontroller also features an external regulator for its core voltage that was able to regulate the 3.3V to 1.1V and operate nominally, indicating minimal microcontroller functionality.

Analysis and Conclusion

This project has shown the feasibility of developing an extensible, low-cost, 1U Cube-Sat CMOS image sensor readout system with high-speed communications via Gigabit Ethernet despite their typical high price points. It must be emphasized that the amount of work that has gone into this project to develop the PCB and software as it currently stands has been significant, and considering future plans, the design was at the brink of completion. Combining the successes of the first and second board revisions and some reconsiderations regarding the Ethernet Transceiver subsystem, the system likely would have seen full functionality with a third board revision. Additionally, the software as tested on the development board meets all desired functionalities and goals set in the Fall semester. With a few adjustments, this software likely could have been flashed onto our board and performed as expected.

Challenges

- Gigabit data speeds over Ethernet
- Software designed for a development board environment adjusted for PCB
- Having no subject matter expert to consult
- PCB Routing for ball and micro-pin grid array components

Future Plans

Future opportunities to improve device functionality include:

- Ensure SPI lines are broken up such that data can be written and read from flash simultaneously
- Reorient PCB components to include a center mounting hole for mechanical stability
- Utilize different PCB materials for better suitability for LEO environment
- Add a USB Debugger and other more user-friendly means of debugging
- Better noise suppression

Acknowledgements

We would like to thank the following people for their support throughout the project:

- Todd Veach, SwRI (Customer Point of Contact)
- Sowmya Muthurangan, VT ECE (T-Vac Point of Contact)
- Alec Salvetti, AMP Lab Soldering Mentor

Microgrid Design for VT Smart Village

LEFT to RIGHT: Shahad Alfaraj, Emerson Rodriguez, James Mercer, Parus Hundal, Daniel Klumpp

SME: Ali Mehrizi-Sani

CHALLENGE

Our team was tasked with designing a reliable, cost effective microgrid for the Virginia Tech Smart Village to power its current and future research buildings, primarily using renewable energy. We presented a cost benefit analysis of two systems, each with solar panels, biogas generators, battery energy storage, human machine interfaces, and electrical protection devices to our customer Wiley Wilson.

Customer: Mark Atkinson

Shahad Alfaraj Dammam, Saudi Arabia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to complete my master's degree in electrical engineering and pursue a career in the power industry. My goal is to become a power systems engineer and contribute to the development of reliable and sustainable energy solutions.

Course Comment: This course gave me the opportunity to work on real-world engineering problems. It provided valuable insight into the engineering industry and helped me grow both academically and professionally.

Parus Hundal Vienna, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to be an entrepreneur with a Robotics consulting company. I also have a great interest in musical instruments and DJing, thus I'd like to use my engineering knowledge to help create custom DJ equipment on the side for personal interest.

Course Comment: This class has given me a great opportunity to act as a consultant given the nature of our project. Since we have been proposing certain systems and solutions to the microgrid problem to Wiley Wilson I have built a basic knowledge of researching and pitching products to a customer.

Daniel Klumpp Reinholds, Pennsylvania

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: As a Power and Energy Electronic System Major, I hope to continue the reliability and sustanability of our National Grid. Following Graduation, I will be a System Protection Engineer for Dominion Energy in Richmond, VA.

Course Comment: This class has further developed my customer interaction and system planning skills, as well as public speaking. I would like to thank our SME for supporting us, and Wiley Wilson for the rewarding project.

Robert Mercer Newark, Delaware

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal after graduating is to gain experience in the industry and to find a particular field that interests me, before continuing to graduate school and pursuing an academic career.

Course Comment: This course was an excellent opportunity to gain experience communicating with real clients on solutions to the technical and economic challenges of a real-world engineering project.

Emerson Rodriguez Sterling, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After I complete my degree, I will be a consulting engineer for MPR associates in Alexandria VA, working on electric generation, transmission, and distribution projects. I hope to continue America's transition to renewable energy.

Course Comment: I have enjoyed learning how protection systems work on my own, and I learned how to work with people who I don't have immediate contact with, such as power vendors.

Virginia Tech Smart Village Self – Sustaining Energy District

Sponsor: Wiley Wilson | **Mentor:** Dr. Kelley Andrews | **SME:** Dr. Ali Mehrizi-Sani

Team Members: Shahad Alfaraj, Parus Hundal, Daniel Klumpp, James Mercer, Emerson Rodriguez

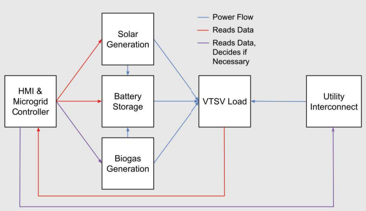
Background

1. Virginia Tech's goal: 100% renewable electricity by 2030
2. Virginia Tech plans to increase peak load for Smart Village from 0.5MW to 1.5MW

VT Smart Village requires a *reliable, sustainable,* and *self-sufficient* microgrid

Requirements

- Enough stable power for future loads
- Primarily solar, with backup generation and connection to VTES
  - Decided on biogas for backup



High Level System Diagram

- Solar contained North Field
- All systems within VTSV boundaries

Testing

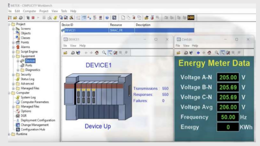
Soil Resistance Testing in North Field

Cost Benefit Analysis Results

System 1 | System 2

HMI/SCADA

System 1: GE VERNOVA CIMPLICITY



Specs:
- Customizable UI
- Configurable alerts
- Historian for data logging

Analysis:
- Alerts for basic automation
- Optional subscription service ($600/yr)

System 2: Eaton Power Xpert

Specs:
- Control functions for automation
- Islanded mode
- Historian for data logging

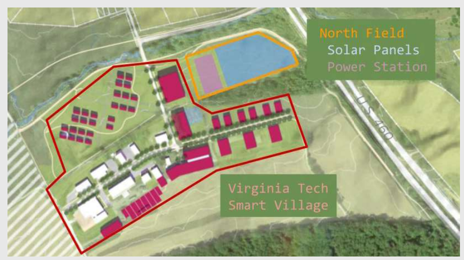
Analysis:
- Already in use by VTES
- Islanded mode + certain controls useful for microgrids

Solar

Grid-following Inverter

Specs:
- Grid-Following inverters
- High-power panels

Analysis
- Inexpensive & simple operation
- Lacks robustness
- Needs another power source for inverters



VT Smart Village Location

Grid-forming Inverter

Specs:
- Hybrid inverters
- 2nd transformer to remove harmonics

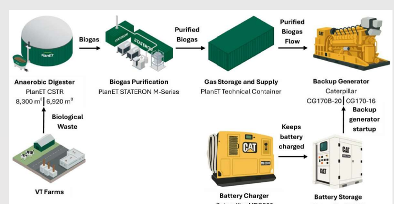
Analysis:
- Works independently
- Higher price
- All domestic products to avoid tariffs

Biogas Generation

Caterpillar CG170B-20

Specs:
- Power Output: 2,300 kW
- Digester Volume: 8,300 m³

Analysis:
- Higher power output & efficiency
- Higher cost and larger footprint
- Supports future load expansion



Biogas Generator Equipment

Caterpillar CG170-16

Specs:
- Power Output: 1,560 kW
- Digester Volume: 6,920 m³

Analysis:
- Lower cost and smaller footprint
- Less pressure on biomass supply
- Lower power output and efficiency

Utility Interconnection

GE Multilin 850

Analysis:
- More robust cybersecurity
- Synchrocheck, undervoltage monitoring in one package

Comparable Specs:
- Both feeder protection relays
- Optional Arc Flash Protection, Reclosing functionality
- Supporting equipment: 3 phase voltage and current transformer

ABB REF615 ANSI

Analysis:
- More monitoring options
- Synchrocheck and undervoltage monitoring in separate packages

Results (cont.)

System 1 | System 2

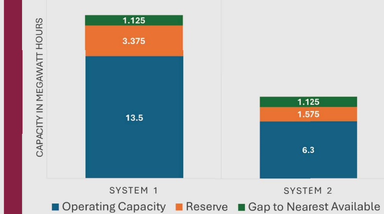
BESS

Symtech Megatron 1.6MW x 3MWh

System 1: High capacity
13.5 MWh - 6 units
- Full workday's energy
- Facilitates more use of solar power
- Twice the cost of low capacity

System 2: Low capacity
6.3 MWh - 3 units
- Enough power for longest night of the year
- Relies more on backup generation
- More load per unit

BESS CAPACITY BREAKDOWN



Total Cost

$15.8 Million – $11.2 Million

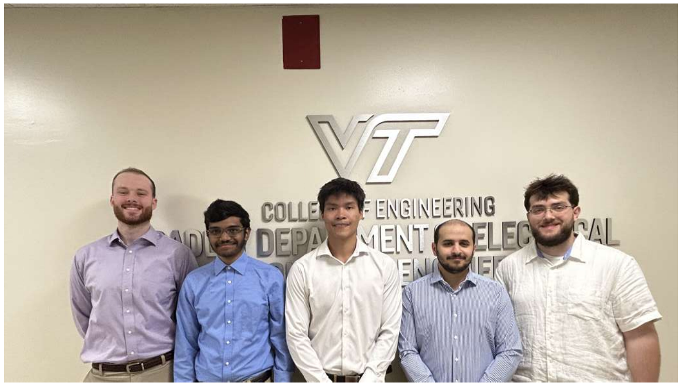
Future Work

- System 3 Cost Benefit Analysis
- Simulation of VTSV microgrid
- Determine how system affects current electrical infrastructure

Acknowledgements

- **Gary Li**, **Mark Atkinson**, and **Chuck Niedermayer** of Wiley Wilson
- **Prof. Kelley Andrews,** Mentor
- **Dr. Mehrizi-Sani, PHD**, SME

High Altitude Balloon Venting System



LEFT to RIGHT: Josh Dunn, Rahul Shanmugam, Ty pho Dang, Ali Alnukhali, Harun Adiyaman

SME: Kevin Sterne

CHALLENGE

Our objective is to develop a long-range communication system capable of remotely controlling a venting mechanism on a high-altitude balloon operating at altitudes exceeding 80,000 feet, using control commands sent from a ground station.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Customer: Kevin Sterne

Harun Adiyaman Aldie, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Become 1% bettter than I was yesterday

Course Comment: This course combined several aspects of engineering into one. From problem solving to interacting/managing customers to practicing presenting. In all, I've gained more practical experience in this course than any other before.

Ali Alnukhali Jeddah, Saudi Arabia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Travel the world & Meet new people

Course Comment: The project provided an accurate simulation of real-world problem-solving. I particularly enjoyed exploring new topics, deepening my understanding of the tools involved, and collaborating as a team to deliver a quality product.

Ty pho Dang Lorton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Retire and live on a farm

Course Comment: This course is has taught me a great deal about team work and being responsible. There are expectations of you from your teammate, they keep you in check if you are slacking or delivering poor quality product.

Joshua Dunn Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: In the short term, I want to focus on completing my final coursework successfully while recovering from my leg injury. I eventually want to earn a master's of engineering degree and have a stable enough career where I'm able to travel to different places like Scotland.

Course Comment: This was a good course experience and well worth the effort. I enjoyed learning more about the topics this design project covers and getting to apply my course knowledge to a tangible outcome.

Rahul Shanmugam Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Complete my Master's Degree here at Virginia Tech and have a successful career in doing what I love.

Course Comment: Senior Design Project has taught me a lot about how to work as a team, communicate with customers and experts, and even time management. This course bridges the gap between academics and industry by allowing me to apply theoretical knowledge to practical problems. Furthermore, it simulates real-world constraints like deadlines, budgets, and client expectations which helped me prepare for my career.

High Altitude Balloon Venting System

VIRGINIA TECH

Sponsor: High-Altitude Ballooning at Virginia Tech, Kevin Sterne **Mentor:** Joe Adams
Team: Rahul Shanmugam, Typho Dang, Harun Adiyaman, Josh Dunn, Ali Alnukhali

Background

Current high-altitude balloon systems face limited flight durations due to uncontrolled ascent and eventual bursting. These limitations restrict the time available for data collection and reduce mission efficiency, especially at high altitudes.

Problem Statement

To overcome these limitations, our project goal is to extend the flight duration of a high-altitude balloon by achieving near-neutral buoyancy at approximately 80,000 feet. This will be accomplished through a remotely operated **venting mechanism**, controlled via a **ground station**, allowing real-time altitude adjustments and prolonged stable flight.

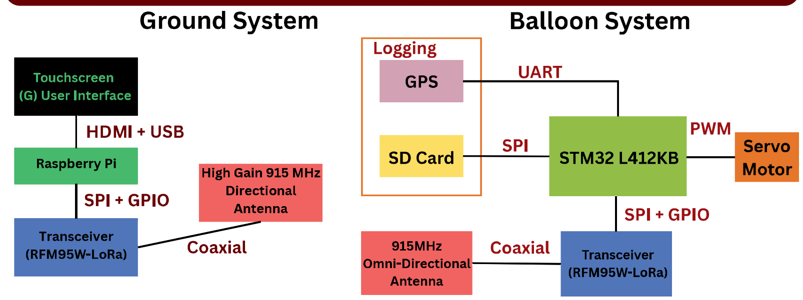
Features

Remote Operation via Ground Station

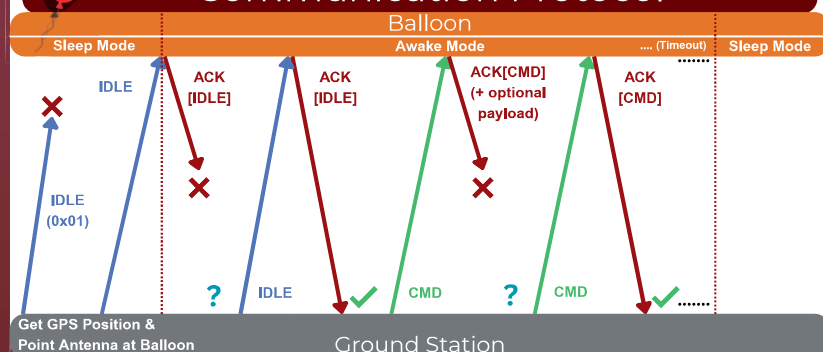
Extended Flight Duration

Target Altitude: 80,000 ft

System Block Diagram



Communication Protocol



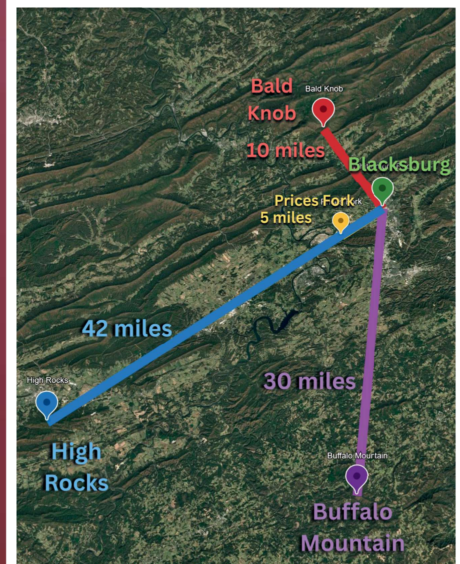
Packet Format

Seq # 1 byte	Ack# 1 byte	CMD 1 byte	Len 1 byte
Data (*len* bytes)			

Improvements

- Use a patch antenna on balloon
- Implement Geofencing for cutdown
- Reimplement the ground station interface using C++ instead of Python.
- Extend the command set

Testing Results



Conclusion

In conclusion, we have developed and tested a high-altitude balloon venting system capable of receiving remote commands from over 40 miles away to actuate a motor and maintain near neutral buoyancy at high altitudes.

Acknowledgments

We would like to thank our customer **High Altitude Ballooning at Virginia Tech**, our SME **Mr. Kevin Sterne**, our mentor **Dr. Joe Adams**, and the facilities manager, **Mr. Rick Johnston**, for providing resources and support throughout the course of our project.

SuperDARN HF Radar Lab at VT: Transmitter Monitoring

LEFT to RIGHT: Corey Carpenter, Tanner Beamer, Dagmawi Theodros, William Betz, Wesley Flynn

SME: Kevin Sterne

CHALLENGE

Before this project, SuperDARN had no current method to tell if the transmitter or antenna has faulted. This leads the SuperDARN team travel to the site multiple times to determine fault and repair the site. This project aims to design a scalable method to lower maitnence costs by determining the cause of the fault at their sites.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Customer: Kevin Sterne

Tanner Beamer Culpeper, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: After graduating, I will be converted to a full-time positon with the Department of the Navy in the Electromagnetic and Sensor Systems Department. There, I intend to study to become a Radar Engineer/Specialist.

Course Comment: This course is a very unique experience to enable a better understandying of industy-style engineering and development. Working with a team is also extremely valuable and prevolant.

William Betz Lynchburg, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: Following this semester, and gradaution, I will be heading off to grad school here at Virginia Tech for a masters through their accelerated grad program. After I graduate with a masters, I intend to go into the power industry to help improve renewable power integration.

Course Comment: The course is a good way to present us with a unique project with no determinant solutions. That way we can get a work-like experience while still having the support of our teachers and mentors.

Corwin Carpenter Severn, Maryland

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: After graduation, I hope to continue my studies in grad school here at Virginia Tech; going for a masters degree. I intend to stay in the field of RF and communication systems

Course Comment: I enjoyed how this course provided a structured approach to breaking down and tackling a real-world problem. It gave us the opportunity to work on an actual industry project, while also providing a safety net to let us explore diffrent approaches and ideas.

Wesley Flynn West Chester, Pennsylvania

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: Upon graduation, I will commission as an officer in the United States Air Force. My first assignment will be to pursue a Master's degree at the Air Force Institute of Technology in Dayton, Ohio. Following that, I will serve as a developmental engineer, helping develop technology for the Air Force.

Course Comment: I enjoyed how the course walked us through the common practices that large organizations use for engineering projects. I also loved the opportunity to apply the knowledge from class in a practical setting.

Dagmawi Theodros Silver Spring, Maryland

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Upon graduation I will be moving to Atlanta to continue my work with Siemens through their eMobility Experience Program. There I will be assisting in Creating, testing, and implementing products and applications for EV's and EV charging stations.

Course Comment: Through the course I have been able to get first hand experience in working through a professional task with a customer. Making sure that as a group we stayed on pace with our assigments to show signifigant progress.

SuperDARN HF Radar Lab at VT: Transmitter Monitoring

Designed by: Tanner Beamer, William Betz, Corwin Carpenter, Wesley Flynn, Dagmawi Theodros
Sponsor: Kevin Sterne, Virginia Tech
Professor: Dr. Adams and Dr. Connors, Virginia Tech

What is SuperDARN?

SuperDARN is an acronym for the Super Dual Auroral Radar Network. The network consists of over 30 low-power radar arrays that observe the Earth's atmosphere for plasma motion in the ionosphere; providing key insight into Earth's space environment. This is accomplished by sending bursts of pulses through a transmitter and connected antenna, then receiving the returned signal and interpreting it.

While our project focuses on the site in Blackstone, VA, SuperDARN is an international collaboration between 19 universities. Virginia Tech, Dartmouth College, Penn State University, and the John's Hopkins University Applied Physics Laboratory (APL) represents the U.S. component of the network, which is funded by the National Science Foundation (NSF).


Figure 1: View of the SuperDARN antenna array at Blackstone, VA. Source: http://vt.superdarn.org/gallery

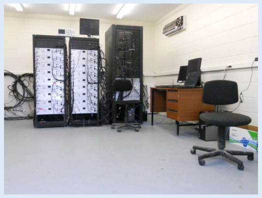


Figure 2: Image of the transmitters and computer at the Blackstone, VA site. Source: http://vt.superdarn.org/gallery

The Problem and How Can We Help?

Problem

- SuperDARN sites are located in remote areas
- The health of the 18 transmitters onsite is unknown without a technician traveling to the site
- This uncertainty and inaccessibility makes maintenance time consuming and costly

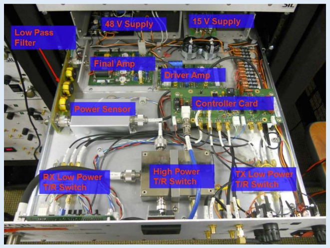


Figure 3: Labeled image of a transmitter at the Blackstone, VA site

Project Objectives

- Create a cost-effective system that monitors SuperDARN transmitters at the Blackstone site
- System must measure status voltages and temperature from all 18 transmitters on-site
- System must use the existing site computer to make measurements remotely accessible to technicians

System Design

System Overview

Our system consists of 18 Sensor Units, one inside each transmitter, and a Sensor Unit connected to the site computer. The Sensor Units communicate to the Sensor Hub using Wi-Fi, and the Sensor Hub is connected to the computer via USB. Below is an example of one Sensor Unit and Sensor Hub connected to the transmitter system.

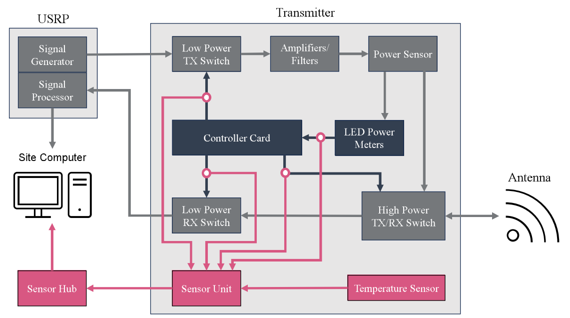


Figure 5: A flow chart of the implemented measurement system

Sensor Units

Each unit, driven by an ESP32 microcontroller, reads status voltages from the transmitter in which it is installed. These voltages are carried by jumper wires between the signal path components and the transmitter's controller card:

- High SWR Flag
- Low Power RX/TX Switch Pulses
- 400V High Power Switch Supply

Each unit also contains a temperature sensor for in-case thermal readings.

After assembly, all one must do to install a Sensor Unit is:

- Disconnect the jumper wires from the controller card
- Connect the jumper wires to the Sensor Unit
- Use additional jumper wires to connect the Sensor Unit to the controller card, allowing for signal passthrough
- Attach the Sensor Unit's power leads to the existing 15V supply terminals

Sensor Hub

- The central system to the entire sensor system
- Consists of single ESP32 running a Real Time Operating System (RTOS)
- Connected to site computer via USB

Software

- The Sensor Hub uses FreeRTOS to handle connecting to and reading the data send from the Sensor Units every 500ms.
- The Sensor Units themselves also employ FreeRTOS to handle the simultaneous reading of status signals.
- The collected data is sent from the Sensor Hub to the site computer to be stored in a CSV file.

Measurement Data Handling

Sensor Unit
- Analog Voltages
- Boolean Flags
- Ambient Temperature

WI-FI ↓

Sensor Hub
- Verify MAC address of Sensor Units
- Collect readings from all Sensor Units
- Append readings to UART stream

USB ↓

Site Computer (Linux x86)
- Verify serial readings
- Adds timestamp
- Save to CSV log file

Outcome

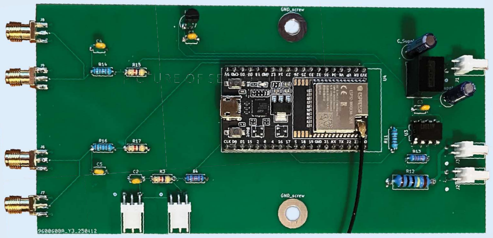


Figure 5: A picture of the PCB design of the Sensor Unit

Cost

- The total cost of components for an 18-transmitter radar site is **$496.63**, equivalent to **$27.59 per transmitter.**
- This cost excludes the price of external wires and cables, but includes the necessary connectors and crimping materials.

Fault detection

- The following table of scenarios give examples of fault events and how they are detected by the sensor units. The flag lets the user know if the transmitter or antenna faulted.

Cause of Failure	Response	Result
Lightning strikes the antenna causing it to fail	high reflected power is detected by the power sensor and the transmitter shuts off	The Sensor Unit reports the opening of the low power switches and the high SWR flag
A transistor fails in the High Power TX/TX Switch	The 400V high-power switch supply drops to a low voltage	The Sensor Unit detects the voltage drop and changes the value sent to the log accordingly
The air conditioning system for the transmitter room fails	The transmitter begins to heat up	The Sensor Unit measures the increase in temperature and records it to the log

Future Steps

Compactness

The PCB (Figure 5) has a lot of unused space. Given more development, a more compact PCB layout could be developed, saving on space.

Signal Measurement

We only learned the true nature of the control signals after gaining access to a transmitter about a month before the end of the project. With the knowledge gathered from hands-on testing, we realized more optimized methods of status reporting can be deployed. For example, we learned that the control signals for the low power TX and RX switches are the same. This means that one of the signals currently measured is redundant and can be ignored.

We also determined many of the control signals behave more like pulses, as the transmitter restarts itself within milliseconds of detecting a fault. Circuit-based sample and hold techniques could be used instead of software-based ones, allowing for more efficient operation of the ESP32.

Supervisory Control and Data Acquisition System for the Virginia Spaceport Authority

LEFT to RIGHT: Rami Benhamida, Daniel Alexander, Adam Bowman, Brian Lee, Jack Gurley, William Brown

SME: Joe Adams

CHALLENGE

As the Virginia Spaceport Authority (VSA) continues to expand operations by bringing new launch pads and processing facilities online, it is crucial to develop a Supervisory Control and Data Acquisition (SCADA) system that provides a unified architecture for all facilities. This SCADA system will serve as a common interface for launchpad technicians and engineers offering full visibility, data logging, and user control features for a rocket launchpad located at the Mid-Atlantic Regional Spaceport (MARS).

Customer: Walter Taraila

Daniel Alexander Gainesville, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After I graduate, I plan to pursue a career as a software engineer. I wish to work with a combination of hardware and software solutions, being able to work with physical components and implement them using software.

Course Comment: I enjoyed my time in this course because of how unique it was compared to my other courses. Being able to work with an external customer with little direction from a professor was a great experience and helped me to think about the many different factors going into a project. Working with a team and generating a solution to this problem together was also a good experience.

Rami Benhamida Fairfax, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: After I graduate, I will start my career as a Software Engineer for a company called QRC Technologies located in Fredericksburg, VA. They specialize in producing RF and SIGINT equipment for both commercial use and the military.

Course Comment: I enjoyed this course because it mimicked what it's like to work in a real team to produce a useful product. It allowed me to work on my communication skills and gain more experience working in a professional environment. The project we got to work on was also incredibly interesting and allowed me to explore possible career paths outside of my internship and job.

Adam Bowman Sterling, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After I graduate, I plan to pursue a career in software engineering in Northern Virginia.

Course Comment: I enjoyed this course because I got to use skills to provide a deliverable for a real company and not just a class. The project provided its own unique challenges and learning opportunities that I found really fun to navigate.

William Brown Pittsburgh, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I plan to pursue a career in developing autonomous systems and robotics. I am eager to engage in hands-on work that focuses on designing and developing innovative technologies.

Course Comment: My favorite part of the course was the collaboration of ideas with my teammates in order to find solutions to tough problems. This course is mostly self-motivated and requires taking initiative in order to deliver a great project.

Jack Gurley Manhattan, New York

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After I graduate, I plan to pursue a career in software engineering. I plan to work with both AI and Machine Learning technologies as well as low level system programming in C and C++.

Course Comment: Working in this class as showed me what its like to work with a team in a real production setting where I am able to exercise my knowledge of engineering skills. It has tought me proper communication skills and how to manage conflicts.

Brian Lee Springfield, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I aspire to pursue a career as a software engineer, focusing on embedded systems and FPGA (Field-Programmable Gate Array) applications. I'm excited to work with the complex hardware-software integration of embedded systems and the flexibility FPGAs offer in customizing hardware solutions.

Course Comment: I enjoyed this course because it allowed me to work as part of a team on a project with dynamic customer requirements, closely simulating the real-world experience of an engineer. Adapting to these changes and finding solutions was both challenging and rewarding, helping me better understand the importance of teamwork, communication, and problem-solving in engineering.

Supervisory Control and Data Acquisition System for the Virginia Spaceport Authority

Team Members: Brian Lee, Will Brown, Rami Benhamida, Daniel Alexander, Adam Bowman and Jack Gurley

Customer: Mr. Walter Taraila | Mentor: Dr. Joe Adams

Background

As the Virginia Spaceport Authority (VSA) continues to expand operations and bring new launch pads online, the development of a unified Supervisory Control and Data Acquisition (SCADA) system is essential.

The interface will provide:

- Remote data monitoring of all devices
- Faster anomaly detection
- Decreased Mean Time to Repair (MTTR)

Key Requirements

- **Robust and reliable network topology**
  - Ensure reliable communication and data flow
- **Dedicated server environment**
  - Develop and configure primary and redundant virtual machines for SCADA operations
- **Control system interfacing**
  - Utilize data communication protocols for use between control systems and SCADA system
- **User friendly UI / UX**
  - Utilize Inductive Automation's Ignition software suite to monitor and control SCADA operations
  - Provide clear visibility of system status to launchpad technicians and engineers

Design Process

The testbench models a rocket fuel control system located at Pad 0B:

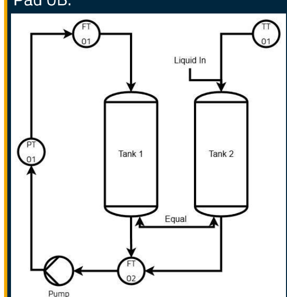


Fig. 1: P&ID Schematic

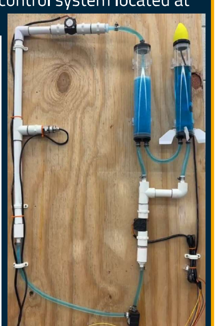


Fig. 2: Testbench

System Overview

The system consists of four major subsystems, the **physical testbench** with sensors and the control system, the **ring network** with two ethernet arduinos, the **Open Platform Communications (OPC) server**, and the **virtual machine** hosting primary and redundant copies of the Ignition gateway, and historical database. All communication between devices such as the process controllers are on the same subnet using a network switch.

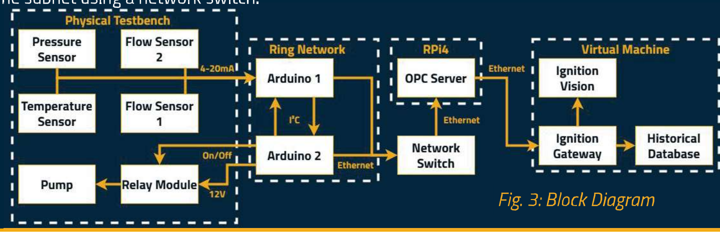


Fig. 3: Block Diagram

Detailed Implementation

Hardware

- **Ethernet/IP Network Communication**
  - Follows Ethernet/IP protocol to simulate industrial communication between 4-20mA devices and Allen Bradley PLCs
- **Ring Network**
  - Each device has dual contact points between the two Arduinos
  - Redundant links allow for data transfer with one broken link
- **Relay Logic**
  - Translates Ignition user commands to the Arduino controller into a Relay module
- **Data Collection Sensors**
  - Water Pressure (0 – 1.5 MPa)
  - Flow Rate (0 – 500 mL/sec)
  - Water Temperature (-55 – 125°C)
  - Derived values using 4-20mA current
  - Values written to JSON format to be received at the network switch

Software

- **Arduino Code**
  - Contains logic needed for pump control and for formatting data collected from sensors
- **OPC UA Server**
  - Used to format raw sensor data collected by the Arduinos into individual OPC tags
- **Historical Database**
  - PostgreSQL database is used to archive sensor data collected by the SCADA system
- **Ignition**
  - Displays all the equipment and sensors and updates their values in real-time. On-page controls provide control over the pump
- **Virtual Machines**
  - Primary and redundant copies of Ignition Gateway and historical database
  - Serves as an air gapped system between Gateway and Ignition Vision

Results (Ignition UI)

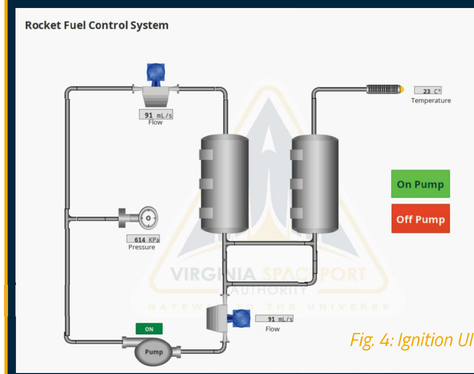


Fig. 4: Ignition UI

Conclusions

VSA now has a SCADA system blueprint that is:

- **scalable,** for both multiple launchpads and multiple sensors
- **user friendly,** for use by both engineers and technicians
- **reliable,** achieved using an integrated and redundant ring network topology

Future Work

- Automated program to perform maintenance predictions, scheduled shutdowns, and electronic work order tracking
- Network status page for monitoring PLC connections
- Deploy OPC UA server and Ignition features on launchpads to connect to all devices on Pad 0B

Acknowledgements

We would like to thank the following individuals for their support throughout the project:

- **Walter Taraila**, *Virginia Spaceport Authority*
- **Sidnee McGee**, *Virginia Spaceport Authority*
- **Brian Bishop**, *Virginia Spaceport Authority*
- **Dr. Joe Adams**, *Virginia Tech*
- **Roosevelt "Ted" Mercer, Jr.**, *Virginia Spaceport Authority*

Autonomous Aquaculture

LEFT to RIGHT: Logan Mathews, Daniel Reeves, Jayson De La Vega, Zachary Chu, Nathan Skirvin, David Watson

SME: Alkan Soysal

CHALLENGE

Our objective was to design a system to automate the lifting and lowering of offshore oyster cages from a remote server via cellular or LoRa communications. The system is controlled from a graphical user interface which displays sensor data regarding the system and its surrounding environment.

Customer: Richard Young

Zachary Chu Atlanta, Georgia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I plan on using my winnings from the 2028 International Wanko Soba Noodle Eating contest to cultivate a lotus garden.

Course Comment: Inheriting a project is always more work than designing it from scratch. I hope more teams get the opportunity to solve what their peers worked on, mostly for developing a more thoughtful design and accountability reasons.

Jayson De La Vega Dumfries, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Bachelor of Science
Mathematics

Aspirations: I aspire to pursue a career working on autonomous vehicles for the benefit of humanity.

Course Comment: This course was a great opportunity to apply all the skills and knowledge I acquired throughout my time here at Virginia Tech.

Logan Mathews South Hill, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to find gainful employment in a field related to my chosen degree program.

Course Comment: Hard assignments will keep testing us, always helpful.

Daniel Reeves Roanoke, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Seek treatment.

Course Comment: "Knowing that you do not know is the best. Not knowing that you do not know is an illness." ~ Lao Tzu

Nathaniel Skirvin Chesapeake, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Find a job I'm passionate about and travel the world while doing it.

Course Comment: A fun class full of practical experiences I'll use beyond the classroom!

David Watson Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to build electric drift vehicles.

Course Comment: Good class overall. The project really pushed us to learn independently and think critically. It also provided valuable experience with teamwork and real-world problem solving

Communication and Control Equipment and Processes to Improve Remote Operation of Aquaculture Equipment

Sponsor: Annapolis Aquaculture **Mentor:** Dr. Joe Adams

Team: Zachary Chu, Jayson De La Vega, Logan Mathews, Daniel Reeves, Nathan Skirvin, David Watson

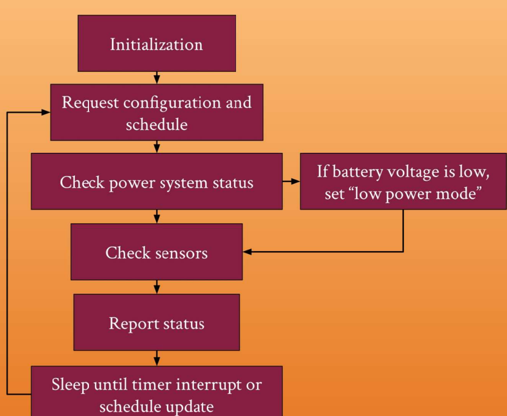
Background

Oysters are both economically and environmentally beneficial due to their function as filter feeders which help improve water quality and eliminate agricultural runoff. Outside of a manufactured farm environment, oyster cultivation often employs a low-intervention approach; however, this can lead to the accumulation of biofouling organisms that hinder oyster growth and reduce overall yield. One common mitigation strategy involves periodically removing the oyster cages from the water, allowing harmful organisms to be eliminated through desiccation. This process is physically demanding due to the weight, quantity, and distribution of the cages. Implementing automated lifting and environmental monitoring systems can reduce labor demands and improve management efficiency.

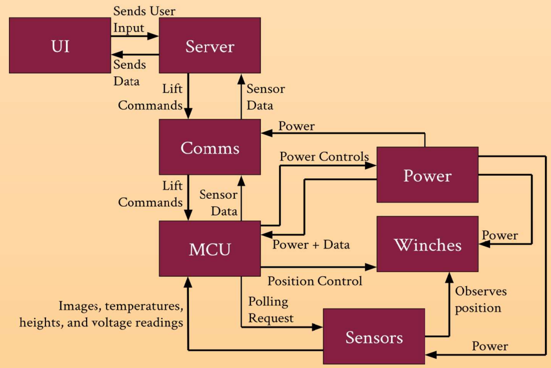
Features

- Web server based graphical user interface for scheduling lifts and viewing sensor data
- Local database for long term storage of acquired sensor data
- Long range wireless communication via LoRa with a cellular fallback
- Remote monitoring of:
  - Power management system
  - Cage height
  - Water temperature
  - Crane camera
- Solar power generation and battery storage for up to four cranes capable of lifting a collective 4500 lbs

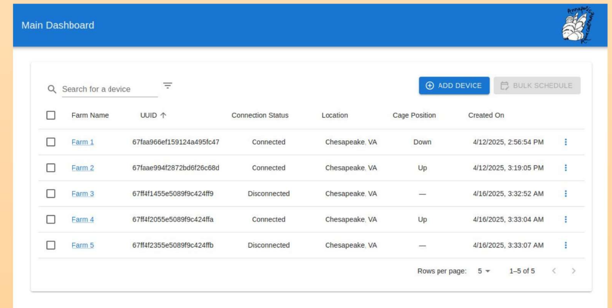
Finite State Machine



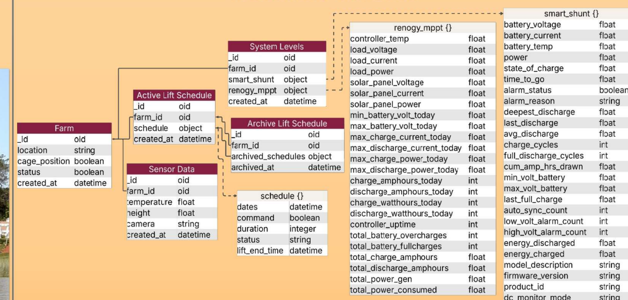
System Block Diagram



User Interface



Database Schema



Conclusion

The system we designed provides reliable remote control and monitoring of the oyster cranes, reducing labor upkeep in exchange for minimal upfront material costs, increasing the proliferation of oyster cultivation, and reducing pollution in our local waterways and ecosystems.

Future Work

- Custom PCB work for our system
- Improved waterproofing for system components
- Improvement of communications using a LoRaWAN gateway and a mesh network
- Addition of external storage and real time clock modules
- Installation of weather sensors for automatic lift deferrals

Acknowledgements

We would like to offer our heartfelt gratitude to Mr. Richard "Dickie" Youngk, Dr. William "Joe" Adams, and Dr. Alkan Soysal for advising and supporting us throughout this project.

Portable Controllers for Quantum Sensing Packages

LEFT to RIGHT: AJ Dempsey, Adam Dillingham, Tyler Wells, Andrew Merdes, Marc Nguyen

SME: Mark Limes

CHALLENGE

Design and test a set of PCBs for low noise open-loop operation of quantum sensors. The project will interface with some of the best portable magnetic field measurements in the world. This system is low cost and smaller in size, which is highly beneficial to practical applications.

NATIONAL SECURITY INSTITUTE
VIRGINIA TECH.

Customer: Mark Limes

AJ Dempsey Huntington, West Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to apply the skills I have acquired while in school to the real world while also deepening my knowledge through real-world experience.

Course Comment: This course has given me the opportunity to apply the knowledge and skills I've gained during my time at Virginia Tech. It has also challenged me to deepen my understanding of various subfields within electrical engineering and refine my problem-solving abilities.

Adam Dillingham Midlothian, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan on first finalizing my degree in Electrical Enginnering here at Virginia Tech and use my obtained school and workforce experience to impact and innovate our current industry.

Course Comment: This course allowed me to have hands on experience with project development, PCB design, customer management, and technical writing. These experiences have helped me grow, not only as a student, but as a communication-lead team member and future engineer.

Andrew Merdes Mequon, Wisconsin

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan on pursuing a masters degree in computer engineering to improve my knowledge in the machine learning and embedded systems aspects of the field. I want to use my knowledge in these fields to work in industry to apply what I have learned to real applications to problem solve and improve the quality of life.

Course Comment: This course has pushed me forward in achieving my career goals by giving me experience in working with a team of engineers in an industry-like environment. It has helped improve my team management and communication skills. I was also able to learn about PCB development.

Marc Nguyen Ashburn, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan on going into industry working on either networking or embedded systems. Once I have gained valuable experiences, insights, and connections, I hope to eventually pursue a masters degree so that I may end up working in my dream field of optical computing. I also hope to one day have a job where my commute is 15 minutes or less.

Course Comment: This course has given me a valuable opportunity to learn PCB design for a professional project. It has also allowed me to develop the necessary skills to effectively collaborate and work with my peers while handling feedback from our mentor and customer.

Tyler Wells Midlothian, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I strive to improve my knowledge after leaving university and to travel the world.

Course Comment: This course has taught me the values of being on a team and learning to collaborate with individuals that are from different walks of life than me. It's good to gain insight on how people approach different solutions in order to solve a problem.

Portable Controllers for Quantum Sensing Packages

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

NATIONAL SECURITY INSTITUTE
VIRGINIA TECH.

Customer: Dr. Mark Limes **Mentor:** Dr. Daniel Connors

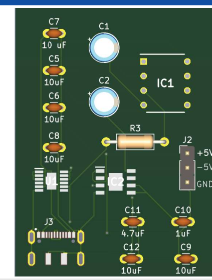
Team: Tyler Wells, Adam Dillingham, AJ Dempsey, Andrew Merdes, Marc Nguyen

Motivation

- Current quantum sensing controllers for atomic magnetometers are:
  - Expensive
  - Overly feature packed
  - Use case limited
- We have innovated these commercial controllers to account for these faults while also keeping them:
  - Photon shot noise limited
  - At a fraction of the original cost
  - Similar performance metrics

Power Supply

- Responsible for powering the other subsystems
- Connects to a computer using a USB-C connector
- Provides +5V and -5V output
- Uses a low dropout regulator to ensure a clean signal



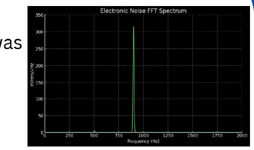
Challanges and Solutions

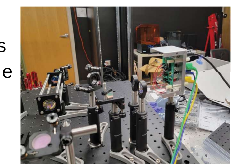
Technical Challenge: Electronic Noise

- Ensuring that our system was photon-shot noise limited

Project Solution Additions:

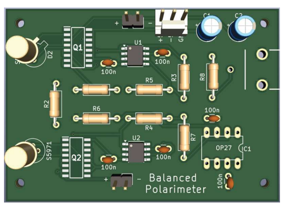
- Ceramic capacitors to Op-Amp rails
- Polarized capacitors at the balanced polarimeter inputs
- Low dropout regulator to the power supply



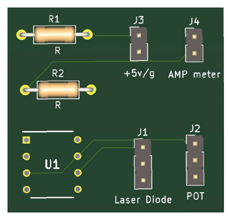


Balanced Polarimeter

- An optical setup that splits rotated light to detect changes in polarization rotation
- FDS015 photodiodes, MAT04FY matched transistors, ADA4898, OP27 operational amplifiers
- Mountable hardware



VCSEL Driver

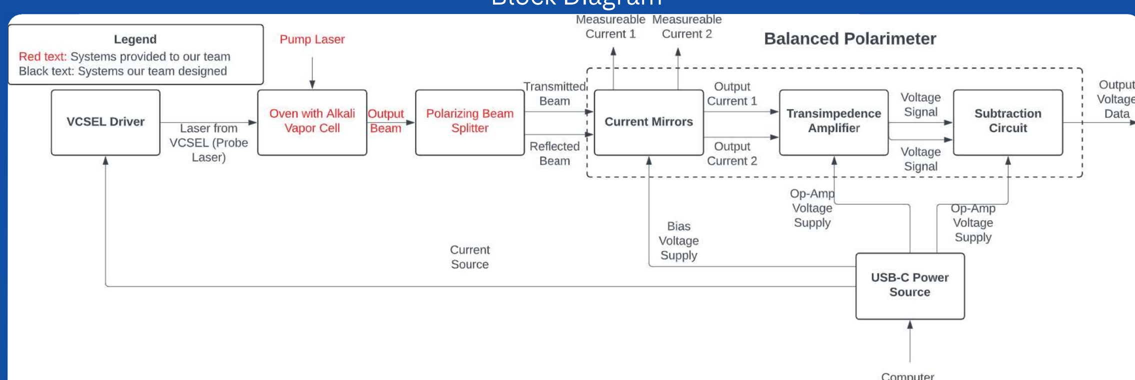


- Controls the power of the probe laser by varying its current with a potentiometer
- Has provisioning for laser current measurement on board
- Equipped with a current regulator to provide a stable current signal

Conclusion

- Our setup can replicate scalar magnetometer experiments:
  - At a noise level of 350 nV/√Hz
  - At a reduced price from a commercial balanced polarimeter ($1,778.88 → $171.76)

Block Diagram



Future Work

- Create aluminum enclosures to resemble a faraday cage and reduce electromagnetic interference
- Design ADCs, DACs, and microcontrollers to interface with the front end of the controllers
- Additional power noise isolation with ferrite beads

Acknowledgements

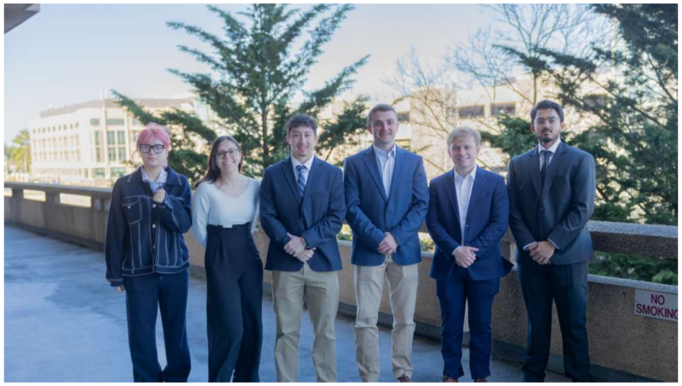
A Special Thanks to:

Sponsor: **Virginia Tech National Security Institute (VTNSI)**

Customer/SME: **Dr. Mark Limes**

Mentor: **Dr. Daniel Connors**

Semi-Autonomous Navigation Vehicle



LEFT to RIGHT: Guixian Lyu, Kiara Klevar, Alex Trevino, Tyler Doyle, Jack Bacon, Shahmeer Shaikh

SME: Arthur Ball

CHALLENGE

Our team was tasked with designing and building a semi-autonomous, modular line-following robot to address the lack of cost-effective solutions for mobile material transport. The robot features a custom 3D-printed chassis, custom PCBs, and a real-time wireless user interface via WiFi. It supports remote user input and can carry a 10 lb payload, all for under a $1,000 budget.

Customer: Stephen Moyer

Jack Bacon Marriottsville, Maryland

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: After college, I aspire to leverage my skills in cybersecurity, computer engineering, and reverse engineering to contribute to innovative and impactful solutions in the tech industry, focusing on system security and vulnerability research.

Course Comment: The MDE experience was incredibly rewarding, providing real-world engineering exposure through hands-on collaboration with an industry sponsor and fostering valuable technical, professional, and problem-solving skills.

Tyler Doyle Hopedale, Massachusetts

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: Upon graduation, I aspire to utilize my hands on skills combined with my theoretical knowledge to make a mneaningful impact in the aerospace or automotive industry. I also plan to continue my education to grow as an engineer.

Course Comment: Throughout this couse I was able to gain a great amount of hands on knowldege and learn more about the importance of communication. This project allowed me to better my problem solving skills in a number of different areas and allowed me to be more open minded.

Kiara Klevar Richmond, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Once I graduate, I plan to continue my studies at Virginia Tech Innovation campus in Alexandria, VA focusing on Machine Learning. I aspire to become a Machine Learning Engineer. I am dedicated to making meaningful contributions and aid in real world issues in tech industry.

Course Comment: This course allowed me to work on a project I am interested in and being able to experience industry standards through working with a client. I was able to expand my skills and experience things not many people get the opportunity to.

Guixian Lyu Xi'an, China

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I am committed to a career in AI-related fields, working on the development of smarter and more adaptive interactive robotic systems. In the future, I will continue to learn related knowledge.

Course Comment: Through this course, I have had the opportunity to work hands-on on real projects, allowing me to apply what I have learned in reality. The process gave me a deep appreciation of hardware and software integration. It not only enhanced my hands-on skills, but also gave me a rich experience.

Shahmeer Shaikh Blacksburg, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After graduation, I aspire to apply my background in Control, Robotics, and Autonomy to develop intelligent and reliable robotic systems that address real-world challenges. I am especially interested in advancing automation in the aerospace and automotive industries.

Course Comment: This course has been both challenging and highly educational. It offered valuable hands-on experience through a project closely aligned with my top area of interest and future career goals in robotics. It also enabled me to furether my understanding and acquire new skills in both hardware and software.

Alex Trevino Dinwiddie, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Upon graduation, I aspire to use my knowledge and experience in Electrical Engineering to make an impact in the aerospace and defense industry. I am currently pursuing a track in power electronics, and I hope to continue learning in industry.

Course Comment: Senior design has provided me with the experience of going through a long-term project as a member of a team. This project has provided me with hands-on learning as well as a need for communication and resiliency in problem-solving issues with the project.

S25-18

Semi-Autonomous Navigation Vehicle

Sponsor: Stephen Moyer, on behalf of the VT ECE Department
Mentor: Joe Adams, Ph.D. & Arthur Ball, Ph.D.
Team: Jack Bacon, Tyler Doyle, Kiara Klevar, Guixian Lyu, Shahmeer Shaikh, Alex Trevino

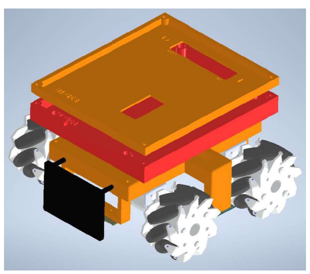
COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Background

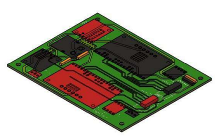
Our team was tasked with designing and building a low cost, user configurable, mobile navigation platform capable of real time human intervention. The interest is to address the lack of cost-effective solutions for mobile material transport in commercial environments. The robot features a modular 3D-printed holonomic drive chassis, custom PCBs, and a real-time wireless user interface via WiFi. It supports remote user input and can carry a 10 lb payload, with a total unit cost of $831.

Features

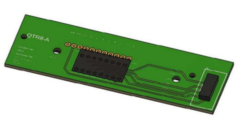
- Real time user interface for user-defined motion control, performance configuration, and data collection
- Wireless control, enabling remote and untethered UI
- Custom PCB's for ease of manufacturability, robot unit reliability, modularity of components, and future capability extensions and customizations
- 3D printed chassis to support payload, ease of manufacturing and modularity



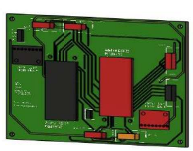
3D Model



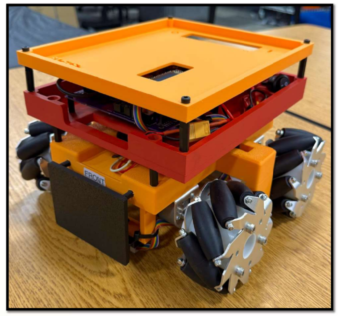
Control PCB



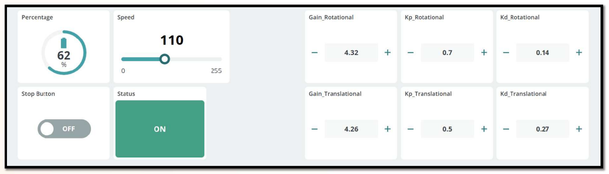
Sensor PCB

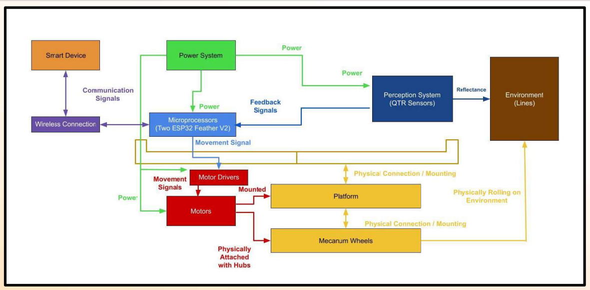


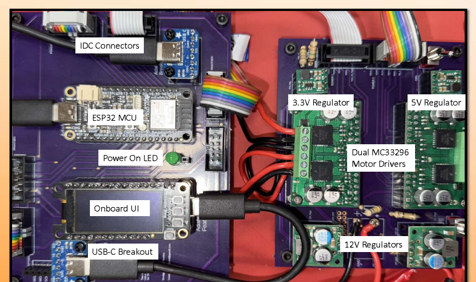
Power PCB



User Interface via web-based Arduino Cloud







Use Cases

- Transportation of materials in manufacturing and other environments
- Future MDE Project for additional capabilities such as manipulator and end-effector for mobile pick-and-place application
- Educational learning aid for autonomy, feedback control, real-time PID performance adjustment and monitoring, and holonomic motion demonstration

Conclusions

Our solution delivers precision control through its real-time user input system, enabling dynamic tuning of PID parameters and speed on the fly. This provides immediate feedback and fosters a deeper understanding of control systems. With a modular architecture, the robot is easily expandable, making it ideal for education, manufacturing, and prototyping.

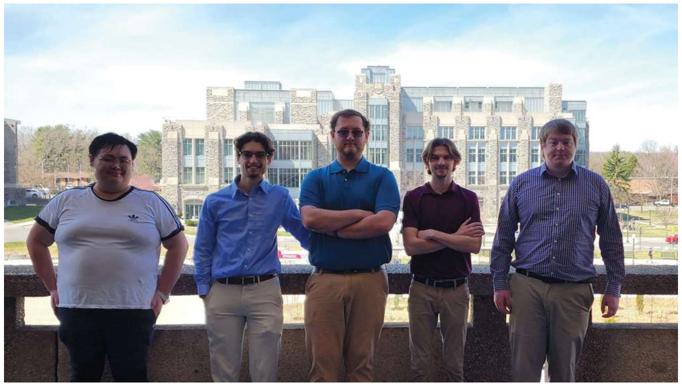
Next Steps

- Add on an end effector for pick-and-place applications in manufacturing environments
- Intersection detection to allow for a que system of pick up and drop off locations

Acknowledgements

We would like to thank Dr. Adams, Dr. Ball, and Stephen Moyer for their support in completing this project. We would also like to thank the VT CRO team for their assistance with coding examples and 3D printing support. We would also like to thank OSHPark for expediting our shipping.

Data Center Prognostic Noise Sampling Device



LEFT to RIGHT: Jiaqi Mo, Vasili Konstantinakos, Hunter Greene, Drew Salley, Tyler Baker

CHALLENGE

Create an offline noise sampling device that records audio data in a data center electrical room and detects any abnormalities. Detected abnormalities are displayed on a human-machine interface, which alerts workers to the issue.

7X24 XChange Washington, D.C. The end-to-end reliability forum.

SME:

Customer: Jeff McWhirt

Tyler Baker Basye, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I hope to create entire factorys with my expertise and education.

Course Comment: From start to finish this course has allowed me to finally spread my wings and work on a meaningful project in any way I see fit. It has inspired me to work on EE projects in the future on both company time and my personal time. It also gave lots of experience with working in a team.

William Greene Baskerville, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to work in research and design in the future doing hands on work with my degree.

Course Comment: I think this class has been a great experience giving hands on practice for future jobs.

Vasili Konstantinakos Midlothian, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to be an important part of any future engineering team that I partake in. I strive to improve upon my current communication skills and learn as much as I am able to so that I become a flexible and adaptable engineer in a team.

Course Comment: Overall, I believe that the ECE4805/6 class has been a positive experience that gave students insights into solving a problem laid out by a customer. My team and I have learned the importance of teamwork, communication, and adapting to a project scope to accomplish our given tasks.

Jiaqi Mo Hunan, China

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I hope to accumulate experience and become an expert in the field.

Course Comment: The course provided experience for problem solving in real world senario.

Andrew Salley Halifax, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: My career goal is to work and become an expert in renewable energy. I want to be a big part in the design and implementation of new technologies in this field. Following graduation, I will be working at Dominion Energy in System Protection.

Course Comment: This class is really taught me how to take a big problem and break it down into smaller achievable objectives, as well as gave me experience that was similar to the industry. It also got me outside of my comfort zone forcing me to code.

Data Center Prognostic Noise Sampling Device

VIRGINIA TECH

Sponsor: Jeff McWhirt, Jason Clark **Mentor**: Kelley Andrews **SME**: Ben Kim

Team: Vasili Konstantinakos, Tyler Baker, Drew Salley, Hunter Greene, Jiaqi Mo

Background

Data centers are the backbone of the digital world. Powering everything from cloud storage to critical financial systems and business operations. With the growing digital world ensuring the reliability and safety of data center infrastructure is more important than ever.

This project aims to develop a system that continuously monitors sound in a data center electrical room to detect abnormal noises in real-time. By identifying issues early, this system could help prevent costly downtime, reduce maintenance costs, and improve overall safety and equipment lifespan.

Features

Continuous Audio Recording
The system captures live audio from the electrical room 24/7.

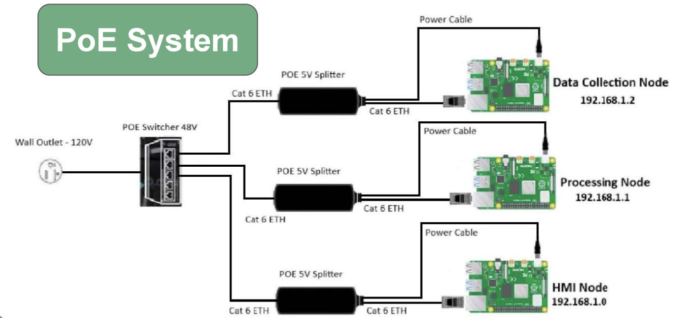
Ethernet-Based Audio Transmission
Captured audio is transmitted via Ethernet to a central processing unit for analysis. This also ensures the system is offline for security and safety purposes.

Abnormal Detection Using Statistical Analysis
The processor uses standard deviation and normal distribution to flag audio signals that deviate from the normal range. This is the "catch all" detection for our device.

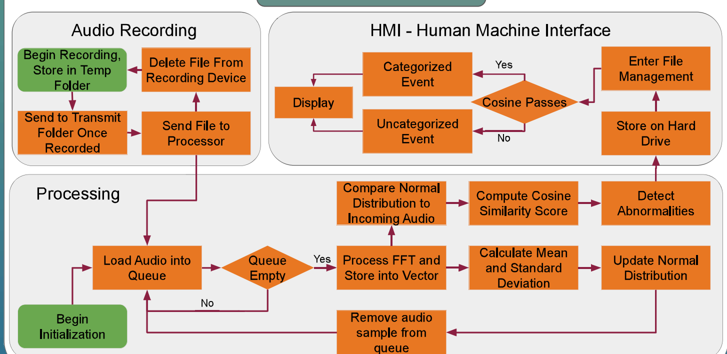
Abnormal Sound Classification with Cosine Similarity
Our system compares new abnormal sounds to a database of labeled examples using cosine similarity to identify the type of issue (fan failure, buzzing breaker, etc).

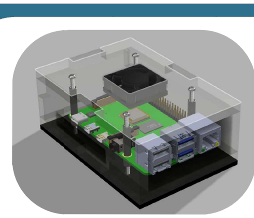
Human-Machine Interface (HMI) Display
Displays detected anomalies and their classifications to on-site personnel through an HMI interface for immediate awareness and response.

PoE System

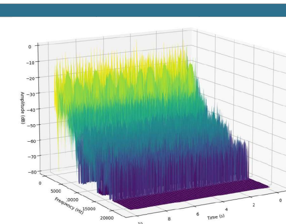


Data Flow



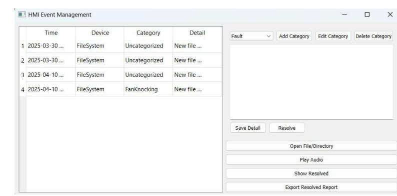


Case and Housing Design
Intended to house the Data Collection Nodes for easy access to ports for data acquisition and a fan for regulating device temperatures.



3D Model of Processed Data
3D representation of Fast Fourier Transform applied to audio sample

Machine Interface



Conclusion

This solution provides a low-cost, real-time solution for detecting and identifying abnormal events in a data center electrical room. By automating the detection process and notifying staff through a HMI, the system enhances preventative maintenance efforts, reduces the risk of unexpected failures, and improves overall equipment uptime and safety.

Future Work

- Incorporate Mel-Frequency Cepstral Coefficients (MFCC) to obtains a more detailed comparison technique.
- Dynamic Time Warping (DTW) to better compare and detect similarities that are not occurring at the same time interval in audio samples
- Collect data to add to a database for eventual self diagnosis

Acknowledgements

We would like to thank Kelley Andrews, Ben Kim, Jeff McWhirt, and Jason Clark for their assistance and advice throughout the project. We also want to thank 7x24 Exchange for sponsoring this project.

Low-Cost Remote Spectrum Analyzer

LEFT to RIGHT: Kidus Melaku, Ivin Biju, Puneeth Vangumalla, Craig Schichtel, Alena Anderson

SME: Carl Dietrich

CHALLENGE

Our team was tasked with developing a SCPI and Python web-based interface for the tinySA Ultra (Sub-$200 spec-trum analyzer). The interface should allow users to write and run scripts remotely to control observations or measurements made by the tinySA. The successful project should also demonstrate use of the interface by automating and demonstrating one or more measurements that use the interface.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

WIRELESS@VIRGINIATECH

Customer: **Carl Dietrich**

Alena Anderson Tewksbury, New Jersey

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: In the future, I hope to work on a more hands-on, robotics-based project in the workforce and eventually transition into a role as a STEM teacher. For now, I have a System Administrator position lined up in the IS department at the Virginia Spaceport Authority.

Course Comment: The Major Design Experience course provided a valuable opportunity to develop both soft and hard skills. As I got to collaborate with a customer and a hard-working, skilled team, it offered hands-on experience that will be highly applicable in future work environments.

Ivin Biju Chesterfield, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I aim to become an electrical engineer specializing in embedded systems, building efficient and innovative hardware-software solutions. After gaining experience in the field, I plan to pursue a master's degree in machine learning to explore how intelligent systems can enhance embedded technology.

Course Comment: I really enjoyed the Major Design Experience, especially the freedom we had to shape our project and make key decisions. Being held accountable for our work made the experience feel very close to what I imagine working in the industry is like. It was a great opportunity to apply what we've learned in a realistic and meaningful way.

Kidus Melaku Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to be an embedded systems engineer that contributes to interesting/groundbreaking work. I hope to apply my skills to many different fields and some day maybe even start my own tech company. I also hope to go back to graduate school and partake in innovative research.

Course Comment: This course has helped me hone my skills in python and programmable instruments. Through the development of our project, I've learned how RF instruments can be programmed and the standards in structuring said program. As an embedded software engineer, I can defenitively see the skills gained from this MDE project translating to future projects.

Craig Schichtel Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan to become an embedded engineer that works in the automotive, aviation, or defense industry. I hope to one day become a project manager.

Course Comment: The biggest takeaway from this course is learning how to manage customer and team meetings. The project gave me hands-on experience with standard commands for programmable instruments, Raspberry Pis, linux, and project budgeting. This course is valuable for having a mini "industry project".

Puneeth Vangumalla Glen Allen, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Driven by a passion for Machine Learning technology, I strive to contribute to advancements in the field. After graduation, I plan to join GE Vernova's Digital Technology Leadership Program, where I will further develop my technical and leadership skills.

Course Comment: This course has provided me valuable insight into effective customer interaction and the dynamics of working within a team under tight deadlines. The experience of managing complex project requirements has strengthened my problem-solving abilities and prepared me for future challenges in the industry.

Low-Cost Remote Spectrum Analyzer

VIRGINIA TECH

Sponsor: Carl Dietrich **Mentor**: Kelley Andrews

Team: Kidus Melaku, Puneeth Vangumalla, Ivin Biju, Alena Anderson, Craig Schichtel

Background

Problem:
- Professional spectrum analyzers are expensive and often inaccessible for students/educators.

Solution:
- Our project offers an affordable alternative using the TinySA Ultra, a compact spectrum analyzer.

Key Features:
- Supports SCPI (Standard Commands for Programmable Instruments) — standard used in professional RF tools.
- Web-based interface for remote access and control.
- Enables scripted measurements, real-time visualization, and data capture.

Educational Impact:
- Students gain hands-on experience with real-world tools and industry-standard protocols.

System Breakdown

Web GUI (Flask, HTML/JavaScript)
- User login and session control
- Tabs for uploading SCPI files, running commands, and viewing results
- Dynamic updates for logs, images, and graphs

Web GUI

Raspberry Pi Backend (Python)
- Hosts the Flask web server
- Parses and executes SCPI commands
- Manages user sessions and access
- Interface to tinySA Ultra

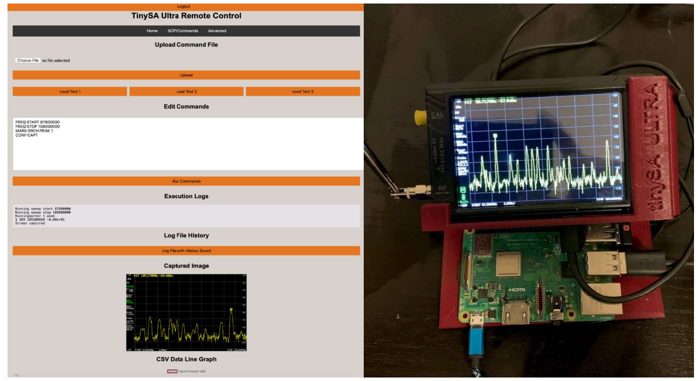
Raspberry Pi Backend

USB SCPI Interface to tinySA
- Sends commands over USB to the tinySA Ultra
- Supports start/stop frequency sweeps, screenshot capture, raw data reads, etc.
- Handles response parsing and error logging

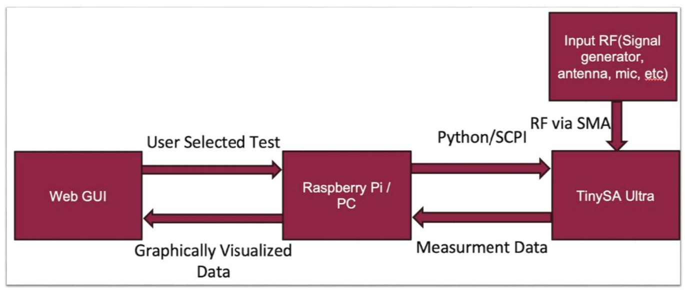
USB SCPI Interface

Data Logging & Visualization
- Logs each command with timestamp and output
- Stores trace data as `.csv` files
- Displays line graph using Chart.js

Data Logging & Visualization



System Diagram



Software/Hardware Tools

Software:
- Python (backend)
- Flask (web server)
- HTML/CSS/JS

Hardware:
- TinySA Ultra
- Raspberry Pi 4
- USB Connection

Challenges

- **File Overwriting & Data Management**

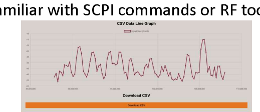
To avoid storage issues, we implemented auto-overwriting for logs and captures. Plotting CSV data also brought formatting and syncing challenges.

- **Remote Access Security**

Campus-wide access over open Wi-Fi required careful handling of login security, session isolation, and multi-user conflicts.

- **User Interface Simplicity**

Designing a functional yet intuitive interface was challenging, especially for students unfamiliar with SCPI commands or RF tools.



Conclusion

Low-Cost & Remote:
- Successfully built a budget-friendly, remotely accessible RF analysis system using TinySA Ultra + Raspberry Pi.

Core Features Replicated:
- Web-based GUI with SCPI command support.

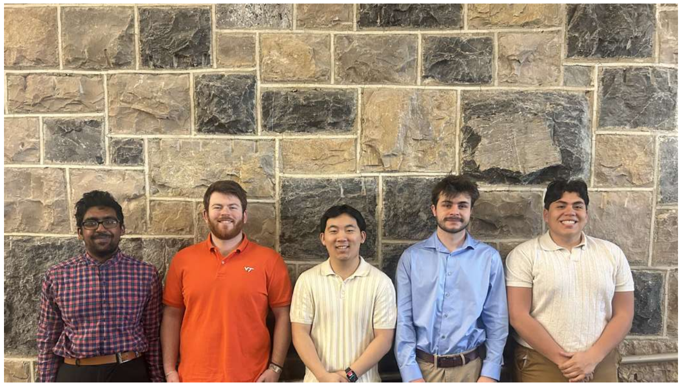
Command logging and data graphing, mirroring commercial analyzers.

Future Work:
- Cloud Integration: Store GUI on cloud for everyone to access
- Automated Calibration & Diagnostics
- Curriculum Integration Tools: Build modules that plug directly into course materials

Acknowledgements

We would like to thank Dr. Carl Dietrich and Kelley Andrews for their mentorship and support, as well as the Virginia Tech ECE department.

RAG for Codebases



LEFT to RIGHT: Abhay Raghavan, Patrick Mountcastle, Justin Liang, Ben Scoppa, Raphael Rodriguez

SME: Wenjie Xiong

CHALLENGE

Our project was focused around developing a retrieval augmented generation (RAG) model that was able to retrieve programming files that were relevant to a natural language user prompt. In todays age, retraining an large language model to be up to date with company files and information is an expensive task. Our goal was to design a solution that would eliminate this need for expensive re-training, while also increasing efficiency in the workplace and increase the recyclability of previously developed programs.

PARSONS

Customer: **Peter Rochford**

Justin Liang Ellicott City, Maryland

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Grad school and big tech

Course Comment: great team!

Patrick Mountcastle Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Continue Edicuation and find job within technology industry

Course Comment: Course has been very helpful and the team works well together

Abhay Raghavan Marlton, New Jersey

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: A career in either Machine Learning or Cybersecurity Next year - Accelerated Master's at Virginia Tech

Course Comment: Course has provided a good balance of working on a team but also stepping out into industry

Raphael Rodriguez Hometown, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: To Create a Successful Startup Company

Course Comment: Course has helped in teamwork, and talking with investors!

Benjamin Scoppa Mount Airy, Maryland

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Grad School and then a Career in Machine Learning

Course Comment: Course has been great for teamwork skills and I have enjoyed working with everyone!

RAG for Codebases

Justin Liang, Patrick Mountcastle, Abhay Raghavan,
Raphael Rodriguez, Ben Scoppa

VIRGINIA TECH

PARSONS

Motivation

- Large Language Models (LLMs) are a very powerful technology, but with great power comes great consumption
- Parsons (our company sponsor) wanted to find a more efficient and reliable means of updating a code base without having to constantly retrain a model
- Solution to be used within Parsons GPT to improve efficiency and productivity in the workplace

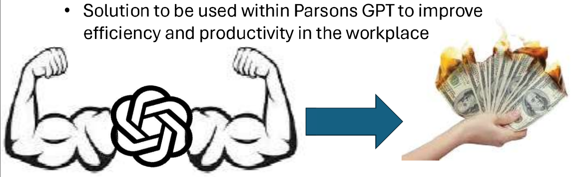


Figure 1: Depicting how training LLMs translates into spending a lot of money

Challenges

- Retrieval Augmented Generation (RAG) is a method for enhancing the quality of a response generated by an LLM through connection to an external data source
- RAG is known for using text documents, but applying it to Code Bases gets more complex
- The biggest questions arise: How to properly retrieve code from a RAG methodology, and how to properly store code in a database to make search easier

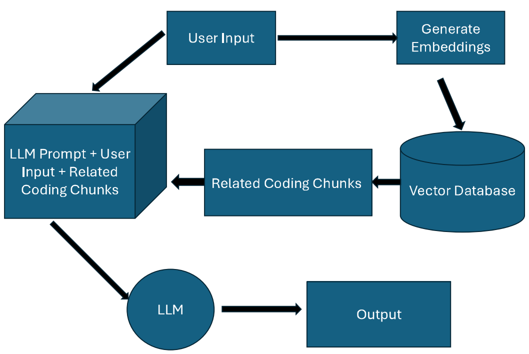


Figure 2: High Level Architecture for RAG Model

LLM Code Description Pipeline

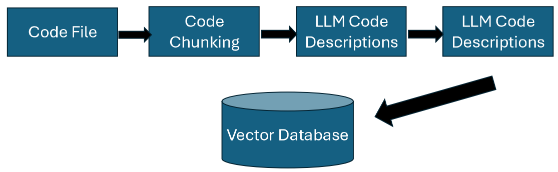


Figure 3: LLM Code Description Generation Pipeline

Results

- Cross-encoder Re-ranker model used to evaluate the relevancy with a scalar from 0 to 1
- Generated descriptions scored well when compared to human written descriptions
- Scoring was used to determine if retrieve results were relevant with scores for both description and code
- Threshold can be used remove non relevant results which is adjustable to fit user needs

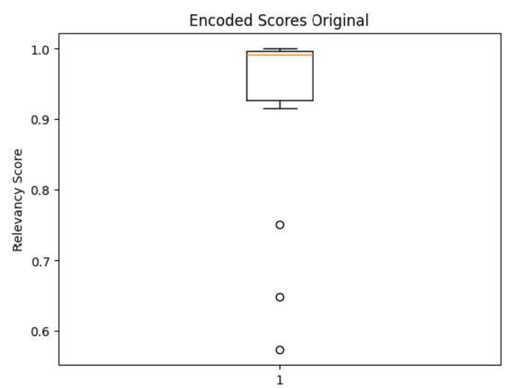


Figure 4: Encoded Scores comparing generated vs human written descriptions. Used to determine sentiment similarity.

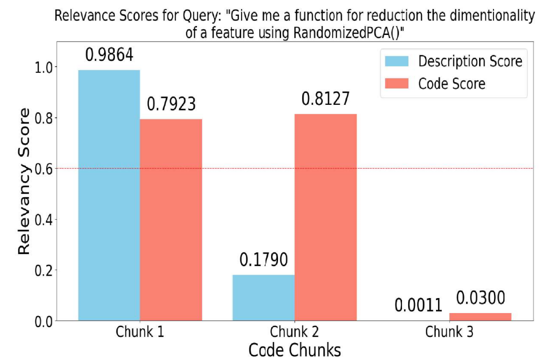


Figure 5: Comparison of scaler scores from description and code embeddings with cutoff line

Conclusions

- Creating descriptions using an interim LLM to embed along with code chunks is useful for improved codebase retrieval
- Embedded descriptions are helpful for performing similarity search during vector search
- Search results can be refined further post retrieval using a cross-encoder re-ranker model

Future Work

- Edge case refinement should improve the effectiveness of system for vaguer prompts
- More files need to be added to the database to improve the amount of code that can be retrieved
- The pipeline needs to be optimized to handle a diverse set of languages in addition to Python

Acknowledgements

We would like to thank our mentor Dr. Nagender Aneja, our SME Wenjie Xiong, and our customer Will Cole for advising and supporting us throughout the project. Special thanks to Parsons for making this project happen.

VIRGINIA TECH

This project was sponsored by Parsons Corporation and the Bradley Department of Electrical and Computer Engineering at Virginia Polytechnic Institue and State University

Performant Prompt Classification in GenAI

LEFT to RIGHT: Shanoor Verma, Chase Smaker, David Arnold, Jacob Shatto, Kim Junsung

SME: Ming Jin

CHALLENGE

Develop a lightweight prompt classification and customizable guardrails system for Parsons' in-house generative AI models. The system uses a fine-tuned BERT model to accurately classify and route image and text prompts to the appropriate model, while the adaptable guardrails enforce evolving policy requirements.

PARSONS

Customer: Peter Rochford

David Arnold Roanoke, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Aspiring Software Engineer, Interested in ML

Course Comment: Enjoyed working with my team towards an end goal and interacting with a customer and mentor to achieve a finished prototype

Junsung Kim Yeosu-Si, South Korea

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Aspiring Software/ML engineer, passionate in building efficient products

Course Comment: Enoyed working with a team towards long term goal

Jacob Shatto Eldersburg, Maryland

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Aspiring Software Engineer, Interested in ML/Embedded Systems/3D Graphics

Course Comment: Enjoyed learning about the applications, and safety mechanisms of modern LLMs

Chase Smaker Ladera Ranch, California

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Aspiring Controls Engineer, interested in ride engineering

Course Comment: Enjoyed getting the opportunity to work on a long term project in a team environment

Shanoor Verma Blacksburg, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Software Engineer, majoring in ML.Interest in Digital twins

Course Comment: Had alot of great experience and learned alot about reinforcement learning.

Performant Prompt Classification in Gen-AI

Team: Chase Smaker, Junsung Kim, Shanoor Verma, Jacob Shatto, David Arnold

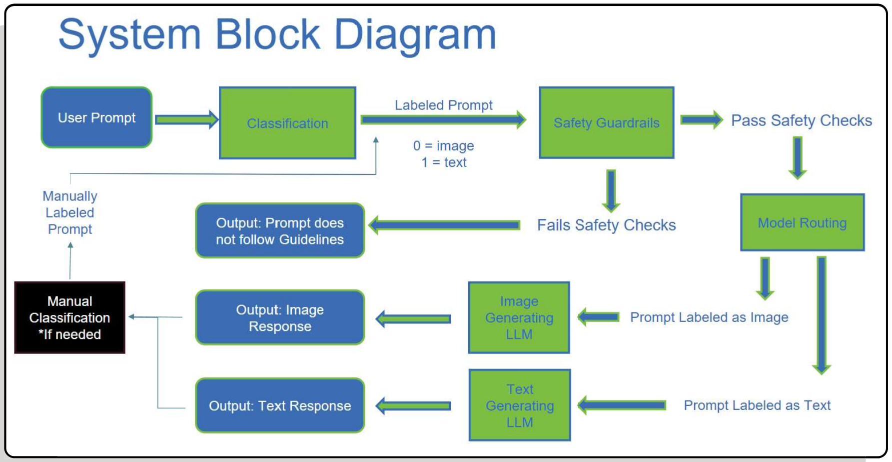
Mentor: Nagender Aneja
SME: Jin Ming

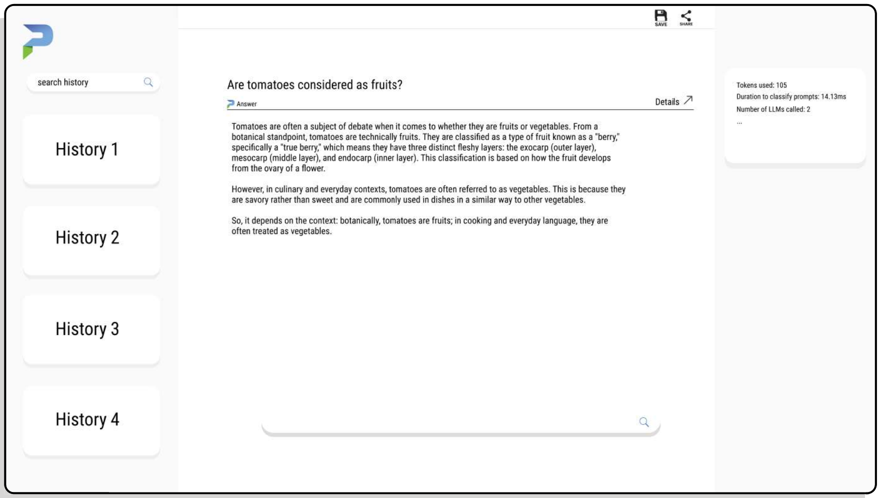
Background

To enhance real-time interactions with Generative AI, there is a need for an efficient and reliable prompt classification system. This system must balance performance and resource constraints while ensuring safe, policy-compliant prompt handling through lightweight models and built-in guardrails.

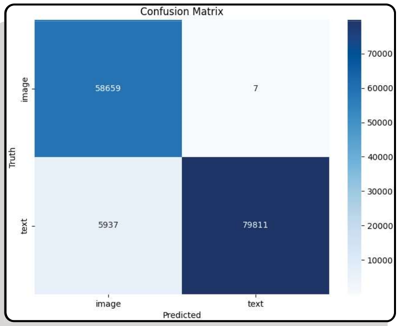
Features

- Classification system with ability to classify image and text prompts
- Model Routing, making our system the optimal entry point for use of multiple models
- Nemo Guardrails preventing unsafe or irrelevant prompts from being answered
- Manual Reclassification: if our model incorrectly classifies a users prompt, they can manually select the correct classification.
  - The prompt will be saved with the correct classification to a database for further tuning





Confusion Matrix: Heat Map



Conclusion

We achieved 95% accuracy when classifying prompts...
0.2s of guardrails overhead
Successful guardrails configuration for off topic or unsafe prompts

Next Steps

The prompt classification system that we have created can be set as a fundamental system that is fully customizable by our sponsor Parsons. With their custom guardrails, and multiple LLM routings, the system can be fully configured to Parsons needs.

Acknowledgements

We would like to express our sincere gratitude to Professor Aneja Nagender for his unwavering support throughout the year, Professor Jin Ming for his input, and our sponsor, Caleb Wagner, for his valuable guidance and feedback.

3D Printing Toolpath Converter for Multi-Axis Printers

LEFT to RIGHT: Isaiah Amir Saclayan, John Otooni, Theo Barrett-Johnson, Bozhidar Dimov, Alvin Chung, Andrew Viola

SME: Xiaoting Jia

CHALLENGE

Our project relates to the manufacturing of printed electronics via multi-axis 3D printers. These machines require specialized toolpath files to coordinate their movement. We implement a software system to convert from one toolpath format into other formats.

Customers: Chris Green and Jackie Kendall

Theophillus Barrett-Johnson Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to work in the machine learning field, bringing the power of machine learning and ata analytics to more fields, beyond generative AI.

Course Comment: This course has given me a good understanding of what it is like to develop a project based off of a customers needs, as well as how to lead such a team in meeting deliverables and functioning cohesively.

Alvin Chung Burke, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aim to work with embedded systems to facilitate the development of innovative hardware. I will continue to dedicate myself to refine and expand my capabilities as an engineer.

Course Comment: It certainly has been a journey to get here. I've definitely gained insight into how things operate in industry. Also, I've learned a few things from working on a team that I'll take with me as I transition to working professionally.

Bozhidar Dimov Stara Zagora, Bulgaria

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to start working into the cybersecurity field to help enhance defense systems for the DoJ.

Course Comment: This course showed me different ways to look into a project. Also it taugh what our work as engineers would like in the real world.

John Otooni Warrenton, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to start working in the machine learning field, focusing on developing solutions to enhance signal processing techniques and their various applications.

Course Comment: This course has given me a lot of experience in organizing and designing an extensive project for a company. This industry-like experience offers a great insight into the real world challenges that we will face in our careers.

Isaiah Amir Saclayan Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to continue my education while working full-time to become a leader in the field of software development and cybersecurity.

Course Comment: Senior Design has given me an industry-like experience that expanded my technical and interpersonal skills immensely.

Andrew Viola Monroe Township, New Jersey

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to continue my education into the graduate program to further enhance my knowledge in machine learning and additive manufacturing.

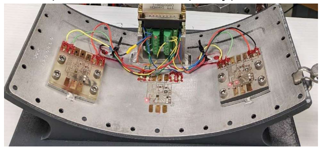
Course Comment: Senior Design has taught me how to be adaptable and patient with any challenge thrown at me.

3D Printing Toolpath Converter for Multi-Axis Printers

Customers: Chris Green, Jackie Kendall **Mentor:** Shelley Stover **SME:** Dr. Xiaoting Jia
Team: Alvin Chung, Andrew Viola, Bozhidar Dimov, Isaiah Amir Saclayan, John Otooni, Theo Barrett-Johnson

Motivation

This project relates to 3D printed electronics for space applications, which require specialized machines to fabricate them. These machines use toolpath files to direct their movement on multiple axes. Since the technology is developing, the current processes have high overheads to generate a toolpath for a design, moving between multiple software. Our project aims to minimize overhead by providing a single tool to generate toolpath files for multiple types of machines.



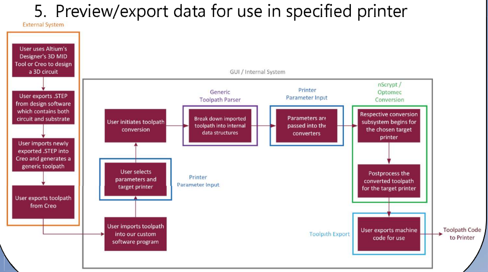
Example of printed electronics placed on a door panel
https://ntrs.nasa.gov/citations/20230008696
https://ntrs.nasa.gov/citations/20230014746

Objectives

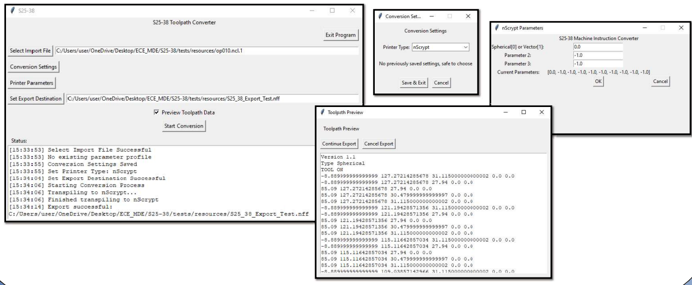
- Design and implement a software system to convert from one toolpath format to other toolpath formats
- Support specific printer types: nScrypt and Optomec
- A modular system implementation to facilitate future development
- Provide a good user experience
- Minimal hardware requirements

Conversion Process

1. Export an unprocessed toolpath file from Creo
2. Import and select parameters/printer type
3. Parser extracts all relevant information
4. Converters utilize information to generate printer-specific toolpath data
5. Preview/export data for use in specified printer



Graphical User Interface



Results

Target Multi-Axis Printers

nScrypt 3Dx-700

Optomec Aerosol Jet 5X

Testing

- Subsystem Testing
  - Automated test scripts were implemented to test functionality of each subsystem independently.
  - Manual tests were written for more complex testing of the GUI.
- System Verification Testing
  - Tests procedures were written and followed to test the implementation of the entire system against requirements.
- System Validation Testing
  - The software is demonstrated to our customers and they validate the outputs from our system by inspection.

Conclusion

To support the manufacture of printed electronics, we developed a software system to convert from one toolpath format to other toolpath formats. Our goal was to minimize overhead moving from design to fabrication. We communicated with our customers and other contacts for information about the existing software and machines used for these printed electronics and we implemented our system with the information we were able to obtain.

Future Plans

- Improve implementation of printer parameters to be more intuitive and user-friendly
- Integrate safety features to check for incompatibilities with printers
- Develop a post-process script for use within Creo
- Develop a tool simulation feature for user visualization
- Adapt implementation for additional multi-axis printers

Acknowledgments

Special thank you to:

- Margaret Samuels (NASA)
- Matthew Minogue (NASA)
- Tristan Epp Schmidt (NASA)
- David McBride (SSAI)
- Sameer Bahethi (SSAI)
- Md Alamgir Hossain (Florida A&M)
- Brandon Dickerson (nScrypt)
- Paul Deffenbaugh (nScrypt)
- Mike Renn (Optomec)
- Andrew Kirzeder (Optomec)

Cipher Internet Protocol

LEFT to RIGHT: Davis Cardiff, Ajani Nembhard, Nolan Attreed, Jomar Roque, Daniel Jacobson

SME: Yaling Yang

CHALLENGE

Network enumeration is the first step in reconnaissance for an attacker to identify weak points against targets. Our protocol investigates and deploys a new IPv4 assignment scheme following the usage of a one-time pad cipher mapping devices in a smaller subnet to a larger one. By utilizing Ephemeral Elliptic Curve Diffie Hellman and AES-128 we can securely share Cipher IPs to hosts forcing attackers to scan larger subnets hindering their ability to effectively scan a network.

Customers: Tyler Englestad and Jeremy Werner

Nolan Attreed Manassas, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Next fall, I plan to continue academia here at Virginia Tech by pursuing my Master's of Engineering. Following that, I hope to pursue a career in network penetration testing and one day work in cybersecurity management.

Course Comment: This course provided me with new insight into team leadership and management that I haven't received in other activities. It also strengthened my ability to communicate ideas and design choices to a broader audience.

Davis Cardiff Moseley, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My aspiration is to work in the cybersecurity field and enhance digital security for organizations.

Course Comment: This course has given me the opportunity to gain hands-on experience in participating in a group project that spans over a longer period of time, which will be done throughout our careers.

Daniel Jacobson Vienna, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I would like to continue learning and growing my skillset as a network engineer so that I can be a valuable part of an organization I care about.

Course Comment: This course has given me a useful preview for what working in this industry and on real-world teams generally will be like and has shown me my own strengths and weaknesses as a teammate.

Ajani Nembhard Leesburg, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I want to continue learning in the field of engineering and become a responsible, independent adult. I want to gain experience in working for companies and eventually become a project manager or even manage my own company.

Course Comment: This course gave professional experience for developing real life applications and working on a collaborative team.

Josemari Roque Alexandria, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I want to be able to learn more about computer and network security and work for a government entity to help ensure that the public is able to continue to use the internet with little risk from malicious actors.

Course Comment: This class allowed me to grow in experience of working with a team through the design and development of a project, similar to what engineers will be doing in the workforce.

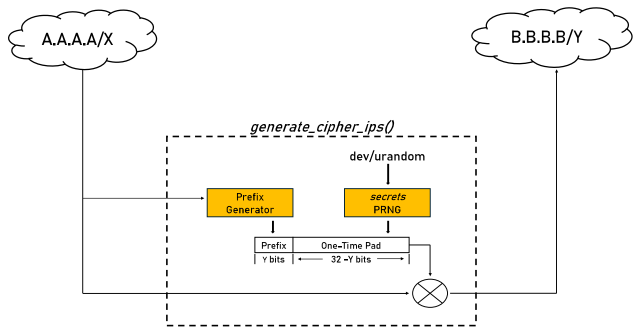
Cipher Internet Protocol

Sponsor: Dr. Jeremy Werner Mentor: Dr. Daniel Connors
Subject Matter Expert: Dr. Yaling Yang
Team Members: Nolan Attreed, Davis Cardiff,
Daniel Jacobson, Ajani Nembhard, and Jomar Roque

Background Information

- Network reconnaissance is the first step in gathering information about a network.
  - Typically done with tools like *nmap*.
- This enumeration helps identify targets and their vulnerabilities.
- Our protocol hinders this by extending the Dynamic Host Configuration Protocol (DHCP).
  - Responsible for IP assignment.
- Clients traditionally follow the DORA procedure (Discover, Offer, Request, Acknowledge).
- Deployed with smaller subnet, allowing attackers to quickly scan the subnet.

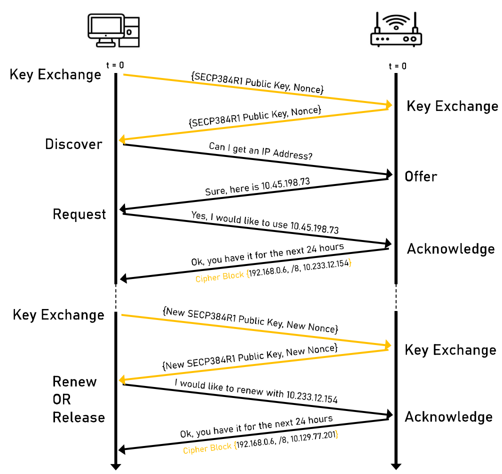
Cipher IP Generation



Protocol Implementation

- Cipher IP utilizes a client-server architecture.
- Server listens for broadcast messages on port 10067 then handles packets according to packet type – either a key exchange, or DORA packet.
- Each client has a client lease object, which links their hardware address to their IP information.
- Server supports the generation of real and cipher IPs.
- Threading allows for safe access and modification of server data structures and for execution/monitoring of client lease timers.
- The server differentiates renewal requests from regular requests using client lease; for a renewal, new Cipher IPs get generated.

Protocol Timing Diagram



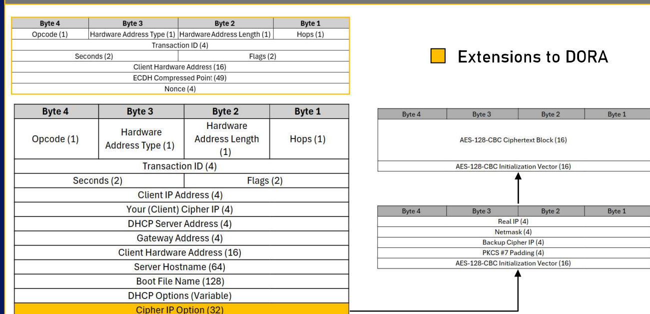
Extensions to DORA

Network Scanning Results

Subnet Scanned	Finish / Cutoff Time	Address Coverage	Hosts Discovered
192.168.0.0/24 (No Cipher IP)	4.04 Seconds	100%	5/5
10.0.0.0/8 (W/ Cipher IP)	77 Hours	40.9%	2/5

- A simple ping scan was run against two VirtualBox networks containing the router, DHCP server, and three desktops.
- In the Cipher IP network, the only devices identified were the router and server.
- The desktop machines had shuffled through seven IP addresses each and were undetected.

Protocol Packet Structures



Conclusions

- By successfully utilizing a one-time pad to map smaller subnets into a larger subnet, we hinder an attacker's ability to quickly scan networks.
- This forces attackers to scan faster, which can alert an IDS/IPS and block their scan altogether.
- Constant changing of IP addresses adds confusion to network scan results they receive.

Future Work

- Implement protocol into real router | server firmware as well as host operating system network stacks.
- Extend the protocol to ensure authentication in client server communications mitigating man-in-the-middle attacks.

Acknowledgements

Our team would like to thank Dr. Daniel Connors and Dr. Yaling Yang for their assistance and mentorship in the development of our solution. We would also like to thank Dr. Jeremy Werner and DOT&E for their support of our project, and Carl Harris for his insight on Virtual Box networking.

Minimizing Bits for Communications

LEFT to RIGHT: Richard Martinez, Nate Sawitzki, Kylan Montgomery, Jacob Ramirez, Michael Volkman

SME: Yaling Yang

CHALLENGE

In remote environments, limited bandwidth and low data rates often hinder the effective use of digital communication infrastructure. To address this challenge, we have developed an innovative encoding scheme that optimizes bit efficiency while preserving message readability. The potential use cases include military field operations and commercial scenarios where efficient and reliable point-to-point communication is critical.

Customers: Tyler Englestad and Jeremy Werner

Richard Martinez Reston, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I will leverage my knowledge and experience to develop next-generation solutions in the fields of digital signal processing, machine learning, and autonomous systems.

Course Comment: MDE has been an invaluable learning experience, particularly in understanding the importance of building strong customer relationships. This course strengthened my technical background and soft skills, such as teamwork and communication, making this project key to my professional growth.

Kylan Montgomery Mascoutah, Illinois

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan to pursue a career in Cybersecurity and use my knowledge to help prevent digital attacks.

Course Comment: The team aspect of MDE was extremely helpful for me to see how a common goal can be achieved when working together.

Jacob Ramirez Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I plan to continue with Virginia Tech and complete my master's in Fall 2026. Afterwards, I would like to create things that make day-to-day life easier and more enjoyable.

Course Comment: MDE was a great experience in working as a structured team with a clear goal in mind.

Nathaniel Sawitzki Richmond, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I hope to use my CPE degree and expertise to build real world tools that help people bring their own ideas into reality.

Course Comment: MDE helped me build real world teamworking skills and helped me gain experience working with customers.

Michael Volkman Burke, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I will be continuing my education at Virginia Tech, working towards a master's degree in computer engineering with the intention of graduating in 2026. Afterwards, I intend to take the knowledge I've obtained and experiences I've had to work in the control systems or robotics fields in industry.

Course Comment: This course provided an excellent opportunity to work with peers in a product development team, coordinate with industry partners, and complete an engineering task where the solution hasn't already been determined by an instructor. This course was a true culmination of all that we learned throughout our time as undergraduate students.

Minimizing Bits for Communications

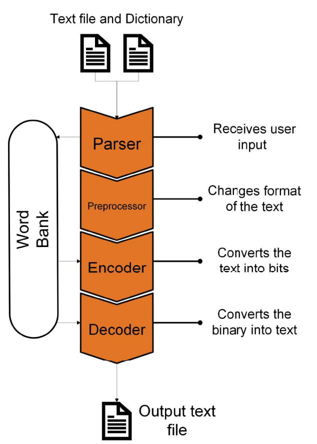
Sponsor: U.S. Director, Operational Test and Evaluation **Mentor**: Dr. Joe Adams

Team S25-11: Richard Martinez, Kylan Montgomery, Nate Sawitzki, Jacob Ramirez, Michael Volkman

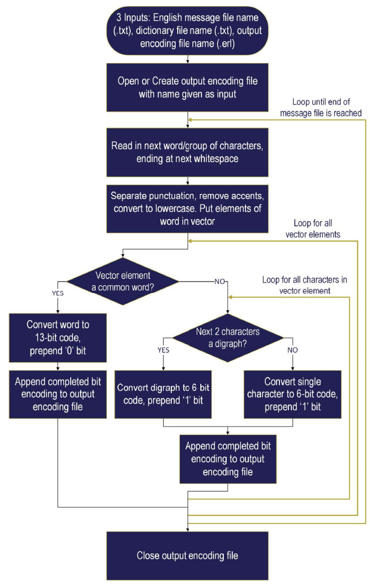
Background

- ASCII is the standard method for encoding text files, assigning an 8-bit code to represent each individual character
- A typical English message, however, uses very few of these characters, and each word likely comes from the ~10,000 that make up a native English speaker's vocabulary
- By directly encoding these words with their own unique bit codes and providing bit codes for only the most useful characters, the size of an encoded English message can be greatly reduced

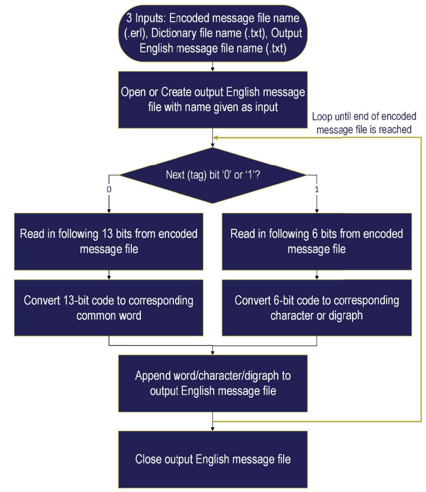
Solution



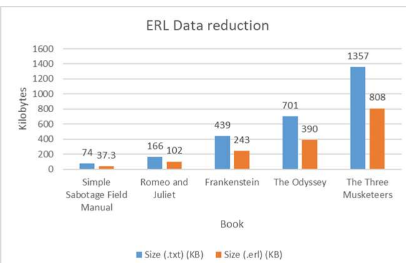
Encoding Algorithm

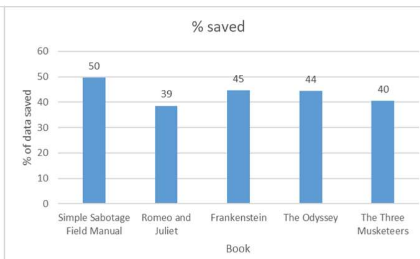


Decoding Algorithm



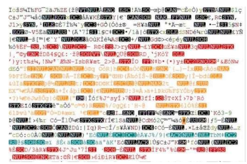
Results of Encoding & Decoding Sample Texts





What is ERL?

English Reduced Language (ERL) is a binary file format designed to optimize text storage using the team's new bit format. Compared to pre-processed files, ERL files are typically 40-50% smaller.



Conclusion

By using 6-bit and 13-bit codes, ERL offers a more efficient solution than standard ASCII, enabling easier communications.

Future Work

A dynamic word bank that adapts to its domain and supports other languages would enable broader applications.

Acknowledgments

The team would like to thank the project sponsor, Dr. Jeremy Werner and the U.S. Director, Operational Test and Evaluation, the project mentor, Dr. Joe Adams, and subject matter expert, Dr. Yaling Yang, for their guidance throughout the project

Time-Based Evaluation of Cryptographic Security

LEFT to RIGHT: Ralph Nehme, Duncan Anthony, John Green, Mahdi Mountassir, Jacob Fast, Daniel Aspesi

SME: Yaling Yang

CHALLENGE

Design and implement a program to estimate the time and computational power required to crack various encryption and hashing algorithms using consumer-grade hardware, with results presented through accurate and consistent tables and graphs. Develop a separate tool that allows users to explore different encryption schemes to better understand how they function.

Customers: Tyler Englestad and Jeremy Werner

Duncan Anthony Herndon, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to work on a product I'm passionate about, creating pentesting tools and contributing to game development.

Course Comment: This course taught me the effort required to be part of a team and expanded my understanding of encryption, decryption, and encryption attacks.

Daniel Aspesi San Diego, California

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aspire to design more secure kernel and operating systems. While applying my skills to Cybersecurity in order to advance XNU kernel research.

Course Comment: This course provided a great amount of value towards desiging a real world project with real world expertise.

Ralph Nehme Sterling, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to become a Software Engineer and understand how AI can be harnessed to enhance our sense of security and well-being.

Course Comment: This course helped me better understand how to collaborate with a team to tackle real world problems.

Jacob Fast Herndon, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I am eager to apply my knowledge and skills to real-world problems, contriubintg to my field and developing solutions that make a difference.

Course Comment: This course strengthend my skill in encryption and hashing by providing hands on experience with algorithm implementation and security analysis.

Jonathan Green Poquoson, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Contribute to our understanding in the Cybersecurity field

Course Comment: A solid crowning experience of everything I've learned that measured both competency and cooperation.

Mahdi Mountassir Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I will be pursuing a MEng in Computer Engineering at Virginia Tech and I hope to have a meaningful career in the networking and cybersecurity field where I am able to make a difference.

Course Comment: This course provided great exposure for how industry projects are designed and implemented. I enjoyed having the oppertunity to apply the skills I have learned and learn new things along the design process.

Time-Based Evaluation of Cryptographic Security

VIRGINIA TECH

Client: Dr. Jeremy Werner **Mentor:** Dr. Joe Adams **SME:** Dr. Yaling Yang

Team: Duncan Anthony, Daniel Aspesi, Jacob Fast, John Green, Mahdi Mountassir, Ralph Nehme

Problem Statement

- The DOT&E wants to study and characterize the time and resources needed to break adversary encryption schemes on consumer-grade systems.
- Considering the recent chip embargoes placed by the US, it is essential to understand how strong our computing power is compared to others.

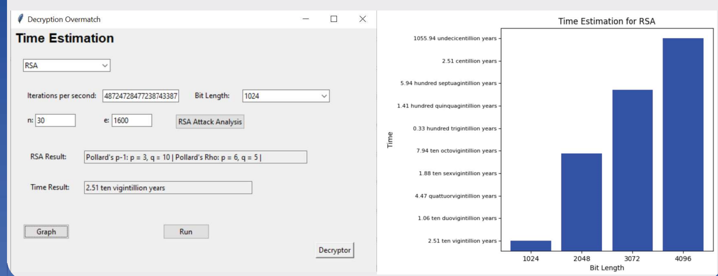
Objectives

- Estimate the amount of time and power needed to break encryption and hashes
- Create an interactive tool to explore encryption algorithms
- Showcase results via tables or graphs
- Support AES, RSA, and modern standards
- Generate accurate and consistent outputs
- Run offline on low-power machines

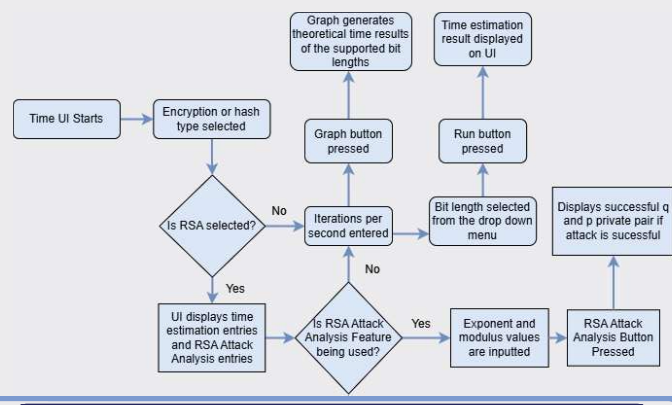
Approach

- Researched encryption algorithms (RSA, AES, hashing)
- Designed modular UI components for time estimation and decryption testing
- Calculated theoretical decryption times using iterations per second
- Integrated RSA attack analysis based on known private key weaknesses

Time Estimation UI



Time Estimation

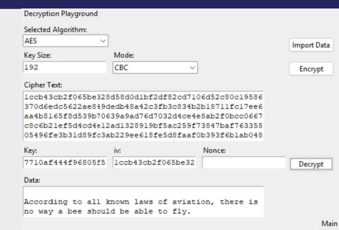


Future Work

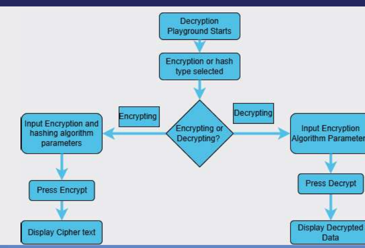
There are multiple avenues of future work for this project that include:

- Investigate and implement how specific vulnerabilities influence time estimation
- Compare results of our time estimation with quantum computing methods
- Expand the program to include more hashing algorithms and encryption schemes

Decryption Playground UI



Decryption Playground



Conclusion

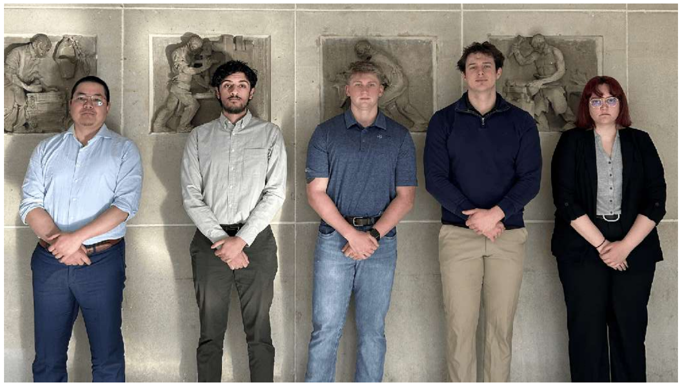
- Problem: Investigate the computational power and time required to break encryption and hash algorithms
- Solution: Developed software that estimates time to break encryption or hash based on computational power (iterations per second)

Acknowledgments

We would like to express our gratitude to the following individuals for their support and guidance throughout the course of this project:

- Dr. Joe Adams (Mentor)
- Dr. Jeremy Werner (Customer)
- Dr. Yaling Yang (SME)

Applying the Automaton General-Purpose Automated Data Analysis and Visualization Platform



LEFT to RIGHT: Thonsith Roongsang, Humza Khalil, Ryan Kluttz, Brayden Gardner, Katie Martin

SME: Yaling Yang

CHALLENGE

DOT&E's Automaton is a program capable of taking in a dataset with any data types, performing complex statistical analyses on the dataset, and outputting a web-based GUI of the results. Due to Automaton's current R implementation, program scalability attempts are hindered. To resolve this, the team has reimplemented a portion of this project in C++ to ensure scalability for any future DOT&E endeavors.

Customers: Tyler Englestad and Jeremy Werner

Brayden Gardner Leesburg, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Post-graduation I plan to be working as a Research & Development Software Engineer at Leidos with focus on Machine Learning practices and how it can be used to better our daily way of life. I hope this opportinuty allows me to further understand what aspect of this field I truly find to be passionate about and therefore grow my experience from there while also continuing to always be learning.

Course Comment: This course has provided me with a lot of real-world prepation into what its like to collaborate with a team in agile development like environment. I was also able to gain experiecne with working on and improving an already estasblished codebase, which is also what I plan to see in the industry.

Humza Khalil Leesburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Over my career I want to be in positions that contribute to the well-being of others. Whether that be in software role in the private-sector, or working to create better policy in the federal government.

Course Comment: This course has taught me life-long lessons in project management, team dynamics, and working on software with a team. I will never forget what I've learned and the people I've worked with during the Major Design Experience.

Ryan Kluttz York, Pennsylvania

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Post-graduation I plan to continue my current work as a Software Engineer for Innovative Defense Technologies contributing to software solutions for the US Navy.

Course Comment: This class has taught me how to work through a team-based software project.

Katie Martin Lynchburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Post-graduation I want to pursue a master's degree in Materials Science to later work as a Semiconductor Processing Engineer.

Course Comment: This course has given me invaluable experience in project management that is relevant in any work environment.

Thonsith Roongsang Bangkok, Thailand

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After graduation, I'll be launching into my next chapter at Leidos as a DevOps/Cloud Engineer, where I'll keep building and breaking things in the cloud. A few months in, I plan to dive back into academia to pursue a master's degree in machine learning, with a research focus on bridging the gap between AI and real-world security — both physical and digital. Here's to chasing curiosity, securing systems, and never stopping learning!

Course Comment: This course gave me valuable hands-on experience applying technical skills to a real-world problem. Working with my team taught me how to collaborate effectively and solve complex challenges under deadlines. I'm grateful to our mentor and SME for their guidance, and to DOT&E for giving us a rewarding project.

Applying the Automaton General-Purpose Automated Data Analysis and Visualization Platform

Team: Katie Martin, Ryan Kluttz, Humza Khalil, Thonsith Roongsang, Brayden Gardner
Customer: Dr. Jeremy Werner - Director Operational Test and Evaluation (DOT&E)
Mentor: Dr. Daniel Connors | Subject Matter Expert: Dr. Yaling Yang

What is Automaton?

Automaton is an R-based program capable of performing complex statistical analyses on data sets that provides a web page dashboard of results.

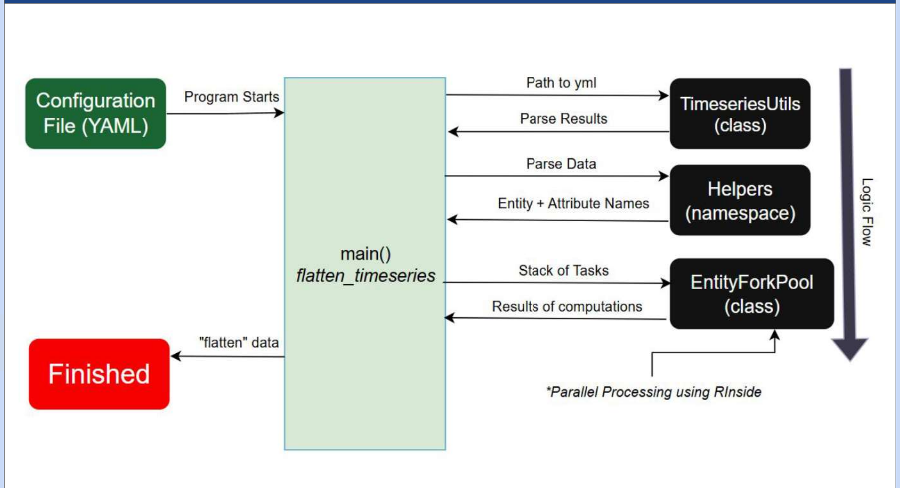
Objective

Re-implement Automaton's data flatten logic in C++ to ensure program scalability for future DOT&E endeavors.

Requirements

- Single C++ executable replaces existing data flattening R script
- C++ implementation produces identical results to R version
- C++ conversion integrates with other layers of Automaton

System Diagram



Improving Performance (Parallel Processing)

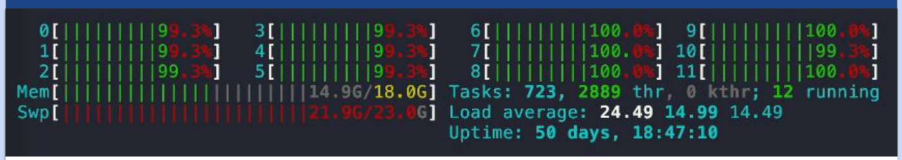


Image: CPU Cores fully loaded using the C++ version EntityForkPool class

- C++ Implementation distributes task entity by entity
- Pipes are used to send/receive tasks along with attribute values
- EntityForkPool class requires less overhead than R's "mcapply" parallel processing function leading to faster runtime
- Select is used to send new tasks to children as soon as they become available

Challenges

- Migrating configuration files from R to YAML
- Utilizing RInside with parallel processing
- Optimizing parallel processing

Tools Used

- CMake
- Linux
- RInside
- Boost C++ libraries
- Python
- Bash scripts
- Htop

R Benchmarks

Passed "diff" test

- **Runtime Average Over 15 Runs-6 core**
  - 4.291 s
- **Runtime Standard Deviation Over 15 Runs**
  - 0.0596 s

C++ Benchmarks

Passed "diff" test

- **Runtime Average Over 15 Runs-6 core**
  - 4.078 s
- **Runtime Standard Deviation Over 15 Runs**
  - 0.0491 s

Future Work

- Add GUI
- Real-time results via web application
- More attribute / statistics / insights from datasets
- Containerized for deployment (cloud-ready)

Acknowledgements

Our team would like to thank these individuals for their support:

- Dr. Daniel Connors
- Dr. Yaling Yang
- Dr. Jeremy Werner

Development of a Novel Multifrequency Focused Ultrasound System for the Non-Invasive, Versatile Treatment of Tumors

LEFT to RIGHT: Abigail Dillard, Marlyn Ngembus, Peter Costescu, Maxwell Kawada, Thomas Lu, Steven Roccia

SME: Adam Maxwell

CHALLENGE

To enable versatile non-invasive treatments of cancer, we developed a novel focused ultrasound system with multifrequency capabilities. We designed 32 modular channels of high-voltage drivers, an FPGA controller, and MATLAB software to generate and control histotripsy, which is a focused ultrasound technique that precisely destroys targeted cells. Our system provides multifrequency, multicycle capabilities that current histotripsy systems lack, enabling new experiments and treatments in the field.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Customer: Eli Vlaisavljevich

Peter Costescu Falls Church, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration
Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After I graduate, I will study RF IC design at the master's level in the MICS group at Virginia Tech. I will pursue a research degree in both industry and academia.

Course Comment: This course has taught me to balance planning, prototyping, debugging, and team needs. I have enjoyed working on both the analog and digital sides of the project and getting a lot of PCB design experience.

Abigail Dillard Arlington, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I plan on pursuing a master's in engineering, and after aspire to apply what I have learned in making innovative solutions to world problems.

Course Comment: I am grateful for this opportunity to work on such a profound, meaningful project with an incredible group of accomplished fellow engineers.

Maxwell Kawada Woodbridge, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy
Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After graduation, I am enrolled into a Biomedical PhD program at Purdue University to research surgical robotics and improve the boundaries of patient care.

Course Comment: In this course I have learned how to be a professional engineer while developing an advanced medical device, an experience that you cannot find anywhere else.

Thomas Lu Burke, Virginia

Bachelor of Science in Computer Engineering
Machine Learning
Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I am pursuing a Ph.D. in Biomedical Engineering. I hope to advance minimally/noninvasive treatments for nervous system diseases through ECE technologies.

Course Comment: This course has been my favorite engineering experience in college. I was able to combine my research passion with robust ECE design work, and I have learned so much from my amazing teammates that I will carry into future engineering projects.

Marlyn Ngembus Dumfries, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I am pursuing a masters in computer engineering. I hope to advance my knowledge in the networking and cybersecurity discipline and apply it in industry.

Course Comment: This course has taught me how to work effectively on a team. I am grateful to have been able to work on such a rewarding project that opened my eyes to ECE applications in other engineering fields.

Steven Roccia Newtown Square, Pennsylvania

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My career goal is to work in the industry and gain valuable experience as a power engineer to set me up for future success.

Course Comment: This course expanded my knowledge in a field I was previously unaware of. I am grateful for the increased interest that this project has brought me. I am appreciative of the amazing teammates I worked with.

Development of a Novel Multifrequency Focused Ultrasound System for the Non-Invasive, Versatile Treatment of Tumors

Thomas Lu[1], Peter Costescu[1], Abigail Dillard[1], Maxwell Kawada[1], Marlyn Ngembus[1], Steven Roccia[1], Joe Adams[1] (Mentor), Adam Maxwell[2] (SME), Eli Vlaisavljevich[2] (Customer)

[1]*Electrical and Computer Engineering,* [2]*Biomedical Engineering and Mechanics,* [1-2]*Virginia Tech*

Contact Information: Thomas Lu (thomaslu21@vt.edu); Eli Vlaisavljevich (eliv@vt.edu)

BACKGROUND

Histotripsy is an emerging non-invasive focused ultrasound technique for the treatment of cancer [1].

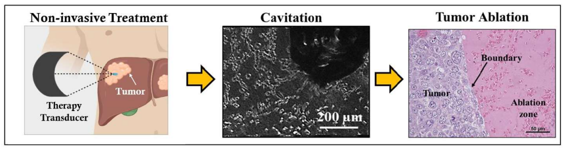


Figure 1. Histotripsy uses focused ultrasound to precisely destroy (ablate) cancer cells.

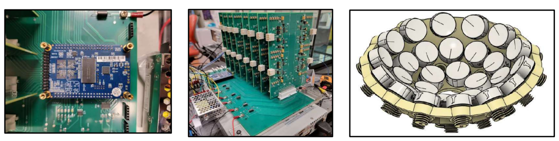
PROBLEM

Frequency changes histotripsy's effects (**Fig 2, Left**). However, current histotripsy systems and treatments are limited to a single frequency.

Figure 2. **(Left)** Frequency changes histotripsy precision [2]. **(Center)** Diseases like sarcoma require varied precision. **(Right)** Photograph of a sarcoma [3].

SYSTEM OVERVIEW

Our system achieves multifrequency histotripsy using 32 high-voltage drivers. Pulsing is controlled through MATLAB and an FPGA.



DE0-Nano FPGA **8 Driver Boards** **Ultrasound Transducer Array**

Figure 3. Overview of system components.

SIMULATION

Transducer configurations are accepted via a GUI. The pressure output is simulated via the Rayleigh-Sommerfield Integral method in MATLAB.

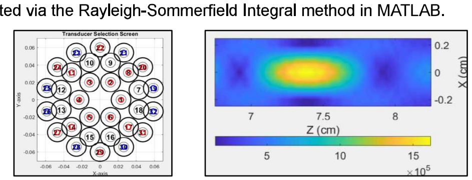


Figure 4. **(Left)** Transducer frequency selection **(Right)** Output pressure heatmap.

TREATMENT BUILDING SOFTWARE

MATLAB is used for treatment building and transmission. Treatments consist of instructions and pulsing patterns ("trajectories").

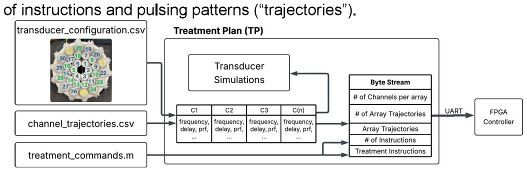


Figure 5. Treatment building program block diagram.

FPGA CONTROLLER

The FPGA acts like a video card and "renders" trajectories onto the array. It connects to the gate drivers, triggers, status LEDs, and FTDI chip.

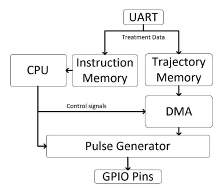


Figure 6. FPGA block diagram.

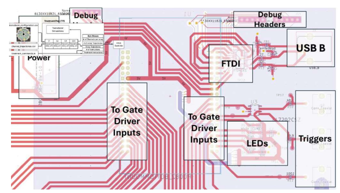


Figure 7. FPGA GPIO breakout.

DRIVER BOARD DESIGN

The FPGA toggles the gate driver inputs, turning the power FETs on and off. A full-bridge topology allows for doubled voltage. Bootstrap circuits enable the use of an NMOS-only transistor circuit.

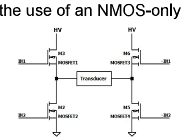


Figure 8. Full-Bridge diagram.

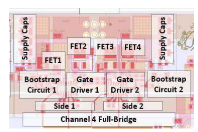


Figure 9. Full-Bridge layout.

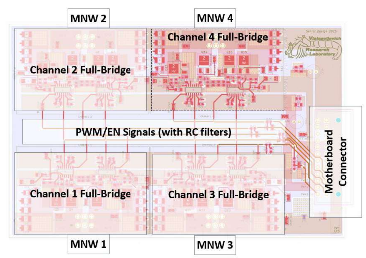


Figure 10. Driver board layout.

MATCHING NETWORKS

We designed LC matching networks to drive 500 kHz, 1 MHz, and 3 MHz transducer elements, minimizing reactive components in the load.

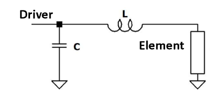


Figure 11. Network schematic.

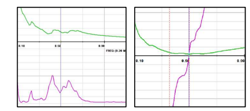


Figure 12. 500 kHz impedance plots: **(Left)** Before matching **(Right)** After matching.

TRANSDUCER ARRAY AND VALIDATION

We designed a three-frequency transducer array. We validated our system using pressure measurements and optical imaging. Results show our system can drive each frequency and produce the required pressure outputs.

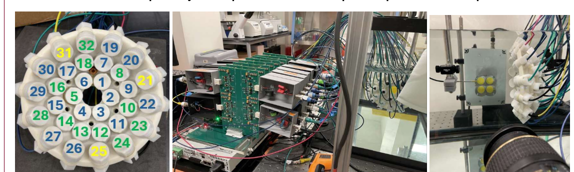


Figure 13. Transducer Array Configuration (Blue = 500 kHz, Green = 1 MHz, Yellow = 3 MHz). **(Center)** Full system set-up. **(Right)** Hydrophone and camera testing set-up.

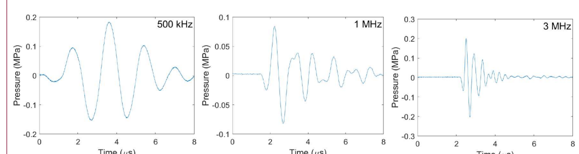


Figure 14. Pressure output measurements for three elements with different frequencies.

CONCLUSIONS AND ONGOING WORK

- Our system met key requirements for multifrequency histotripsy, enabling new treatments and experiments.
- Future work includes:
  - Scaling to 64+ channels and multiple FPGA controllers
  - Improving driver power capabilities
  - Adding channel-by-channel amplitude control
  - Adding more rigorous checksums and FPGA safety checks

ACKNOWLEDGEMENTS: The authors would like to sincerely thank Dr. Joe Adams, Dr. Eli Vlaisavljevich, and Dr. Adam Maxwell for their invaluable mentorship. This work was supported by the Virginia Tech Department of Electrical and Computer Engineering and the Vlaisavljevich Research Lab. REFERENCES: **[1]** Z. Xu et al., Int. J. Hyperthermia, 2021. **[2]** Edsall et al., PMB, 2021. **[3]** Ruger et al., IEEE Trans. Biomed. Eng., 2023.

Machine Learning Integrated Biosensor for Disease Detection in Milk Samples

LEFT to RIGHT: Mason Young, Saket Pendharkar, Benji Adjepong, Jonathan Ravid, Volkan Akkale, Ryan Recupero

SME: Sook Ha and Wei Zhou

CHALLENGE

Our challenge was to develop a proof-of-concept for a real-time, dual-modal biosensor system integrated with machine learning for early disease detection in milk samples. Subclinical mastitis, which affects nearly 50% of dairy cattle, often goes undetected until it progresses into more severe stages. Early identification is crucial to maintaining herd health, ensuring milk quality, and improving overall farm efficiency.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Customers: Azahar Ali and Wei Zhou

Benji Adjepong Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Upon graduation, I plan to complete a Master of Engineering degree at Virginia Tech, further developing my expertise in machine learning. I aspire to build a career in this field, leveraging my skills to drive innovation while continuing to explore side projects that challenge me and expand my technical knowledge.

Course Comment: This course provided valuable insight and experience in real-world team scenarios, including managing deliverables, meeting customer expectations, and working in a fast-paced environment. It was also particularly beneficial as it allowed me to further develop my skills in machine learning algorithms, an area of strong interest for me.

Volkan Akkale Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduating, I plan to work as a data engineer in the Richmond area. I want to use my experience from this project and my education in general to eventually work in the biotech industry and develop systems and devices to help people.

Course Comment: Major Design Experience was immensely valuable, providing hands-on problem-solving, teamwork, and project management skills in a field I aim to enter after graduation. It challenged me to apply my technical knowledge in real-world scenarios, preparing me for industry-level engineering work.

Saket Pendharkar Nassau, The Bahamas

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am eager to apply my skills in a challenging setting, and to contribute fresh ideas, and work collaboratively to drive innovation. I look forward to joining an organization where I can grow professionally and help shape the future of the industry.

Course Comment: Major Design Experience was a transformative introduction to practical, industry like work environments. The course's blend of structured milestones with a flexible framework allowed me to refine my time management and project coordination skills. Through lab and work sessions, I built a solid foundation in software development, debugging, and problem solving. I am excited about using these skills later in my career.

Jonathan Ravid Roswell, Georgia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: After graduating, I'm planning on working for a couple of years in the at the DoD, then I would like to pursue a Masters in Bioelctronics

Course Comment: This course gave me real-world experience similar to working with a team in a professional setting. I learned how to engage collaboratively, divide tasks effectively, and work toward a shared goal. It challenged both me and my team to operate simultaneously, leveraging our strengths while improving on our weaker areas.

Ryan Recupero Summit, New Jersey

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduating, I'm currently planning on working for one year in the defense industry, before going back for a masters in embedded systems. After that, I would like to work abroad as an embedded software or testing/validation engineer.

Course Comment: Major Design Experience gave me my first real experience with lab work and research. Although there were scheduled deliverables, the loose nature of the course allowed me to improve my time management skills. In the lab I gained valuable experience with embedded software development and debugging, two areas that I believe will be very important in my career.

Mason Young South Brunswick, New Jersey

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: After graduating, I plan to utilize my education in the professional field with the potential to work in a variety of disciplines. I will mainly focus on the digital design and FPGA fields. In the future I am also considering network engineer roles and embeded systems engineering.

Course Comment: Major Design Experience provided a tangible experience in working with a team to achieve a long term goal. The year-long nature of the project helped me learn how to work on a greater goal with the future in mind. The interdisciplinary features of our project opened my mind to more career path choices.

Machine Learning Integrated Biosensor for Disease Detection in Milk Samples

Benji Adjepong, Volkan Akkale, Saket Pendharkar, Jonathan Ravid, Ryan Recupero, Mason Young

VIRGINIA TECH

U.S. National Science Foundation

Commonwealth Health Research Board

Background

- Subclinical mastitis (SCM) is a bacterial infection that affects many cattle globally
- SCM negatively affects dairy production and milk quality, and cattle health overall
- Current SCM detection is **slow**, **expensive**, and **impractical** for continuous monitoring

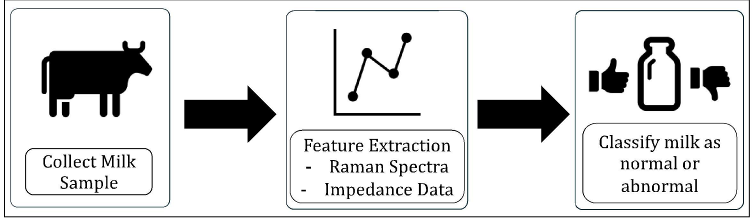
Objectives

- Design a **portable, scalable, and real-time detection** device for use in dairy farm environments
- Develop a **dual-modal biosensor** system combining Electrochemical Impedance Spectroscopy and Raman Spectroscopy.

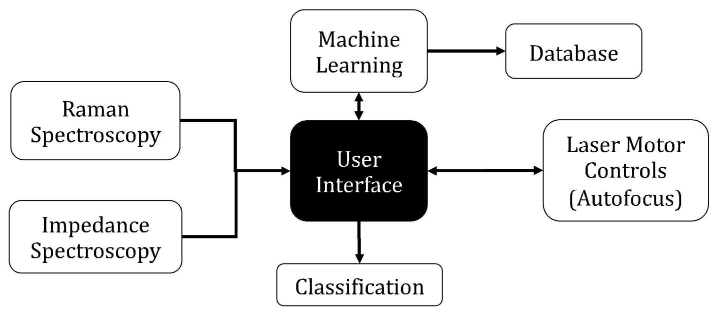
Solution

- A proof-of-concept, **real-time**, dual-modal biosensor system enhanced with **machine learning** to demonstrate a more efficient approach for early SCM detection
- Utilizes **Electrochemical Impedance Spectroscopy** and **Raman Spectroscopy** paired with machine learning capabilities for **milk classification**

Demonstration



System Overview



Milk Classification

- We mimicked diseased milk conditions by treating milk samples to make them distinguishable in under Impedance and Raman Spectroscopy
- Milk samples were treated with different concentrations of NaCl and EDTA to alter the impedance for classification under spectroscopy
- Milk serum samples were treated with Rhodamine 6G and lysed E. Coli bacteria to alter Raman signature for multiclass classification

Results

- Implemented autofocus module capable of 3D axis control of portable Raman laser
- Constructed classification script which performed with over 90% accuracy in multiclass supervised learning environment
- Developed local database to store classification results, timestamps, etc.
- Integrated user interface with autofocus, input, classification and database

Future Work

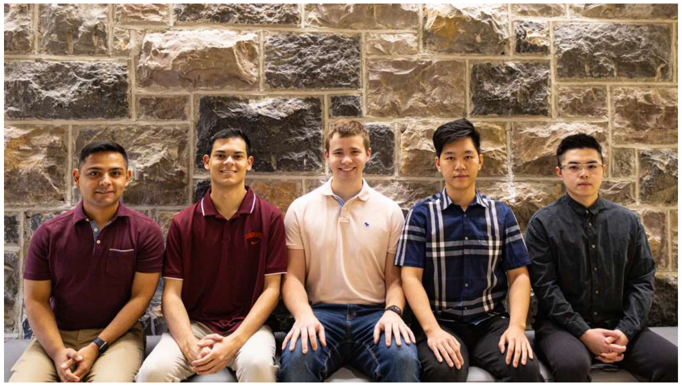
- Develop impedance sensing functionality with our current detection codebase
- Further validation on more diverse dataset of milk to make milk classification more robust
- Integration into automated milking system on a large-scale milking farm

Acknowledgements

We'd like to say thank you to the following:

- Customers: Dr. Wei Zhou, Dr. Ali Azahar
- SME: Dr. Sook Shin
- Mentor: Dr. Joe Adams

Interactive Phased Array Beam Steering Visualization



LEFT to RIGHT: Nate Guevara, Rob Weaver, Raymond Drewry, Howard Yu, Pei Fu

CHALLENGE

Our challenge was to design and develop a real-time visualization system that displays X-band (10 GHz) RF beam intensity and steering using a custom-built 30x30 LED matrix and RF power detectors. This system lights up LEDs according to the pattern created by a steered beam, providing an interactive and intuitive representation of RF propagation and phased array behavior. The project aims to enhance understanding of RF beamforming concepts for educational and demonstration purposes by translating invisible electromagnetic signals into an engaging, visual display.

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

SME: Linbo Shao

Customer: Jeff Chambliss

Raymond Drewry Colonial Heights, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I have accepted a job as a Network Engineer with ASRC Federal upon graduation.

Course Comment: This course has given me the oppurtonity to use my skills to build a quality product for a customer. I have enjoyed applying my skills from my time here at VT to a real a world deliverable.

Pei Fu ChangSha, China

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Become a network engineer at a technology company

Course Comment: This class gave me a clear understanding of how companies collaborate and manage projects. It was a really valuable hands-on experience for me.

Nate Guevara Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: Once commisioned into the Space Force, I hope to explore developmental engineering, closely working with DoD partners and engineers to create innovative solutions for complex challenges.

Course Comment: The Major Design Experience challenged me to apply my engineering skills to a real-world problem creatively. With a clear vision and the freedom to choose our methods, my team and I sharpened our problem-solving and collaboration abilities. I am thankful for my teammates and the support from Analog Devices which pushed us to have a strong project. This course gave me practical design and management experience that will benefit my future career.

Robert Weaver Severna Park, Maryland

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: I have signed a job offer to work for Northrop Grumman upon graduation. There I will work to improve the power and signal integrity of systems. I hope to progress and learn enough to work on radar/sonar systems.

Course Comment: This course taught me many things about what to consider when starting a major project from scratch. While not on the syllabus, learning to anticipate and overcome problems is essential.

Howard Yu Centreville, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I will continue my computer engineering journey in grad school upon graduation.

Course Comment: The course has provided me a clear insight in real world applications and collaboration among multi-disciplinary majors. It has taught me how to communicate efficiently and effectively with my colleagues.

Interactive Phased Array Beam Steering Visualization

Designed by: Raymond Drewry, Pei Fu, Nathan Guevara, Rob Weaver, Howard Yu
Mentor: Dr. Daniel Connors | **Customer:** Jeff Chambliss | **SME:** Dr. Limbo Shao

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Problem Statement

Challenge and Issue:
Beamforming is an invisible technology and can be difficult for unfamiliar parties to grasp.

Need:
A hands-on demonstration that simplifies the complex principles of phased array technology.

Objectives

RF Beam Power Measurements:
The power received over the air from the signal source is what will be measured and be the data used for visualization.

Real-Time Display Updates:
The LED matrix should update quickly to changes in RF beam direction and intensity.

Heat Map Interpretation:
Power values are displayed on the LED matrix using a color spectrum. "Warm" colors indicate high power intensity, and "cool" colors indicate low power intensity.

Expo Setting Demonstration:
The LED matrix and RF source distance should accommodate an expo setting and be portable for use by Analog Devices.

Technical Requirements

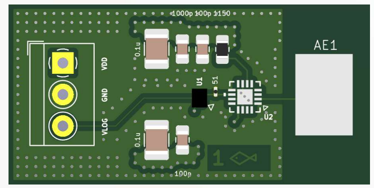
Requirement	Units	Acceptable Range	Achieved Value
Source Frequency	GHz	4-18	10.5
Source Distance	ft	1-20	1-20+
LED Array Dimensions	ft^2	2+	3
LED Matrix Resolution	LEDxLED	10x10+	30x30
System Response Time	ms	20-100	30

Acknowledgments

Our team is grateful to the following people for supporting our project:

Mr. Jeff Chambliss, Our customer at Analog Devices
Dr. Daniel Connors, Our mentor
Dr. Linbo Shao, Our SME
Dr. Majid Manteghi, for his help with RF design

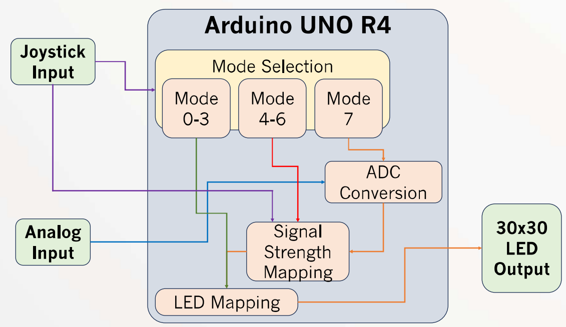
Hardware Design



PCB:
- Patch antenna designed for 10.5 GHz
- A low noise amplifier (ADL8102)
- A log detector to convert signal power to a corresponding voltage (ADL5507)

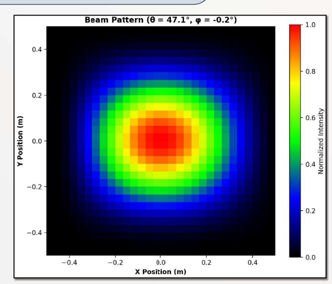
LED Array:
- 900 addressable WS2812B LEDs
- Controlled by a single data channel
- Powered by a 350W power supply.

Software Design



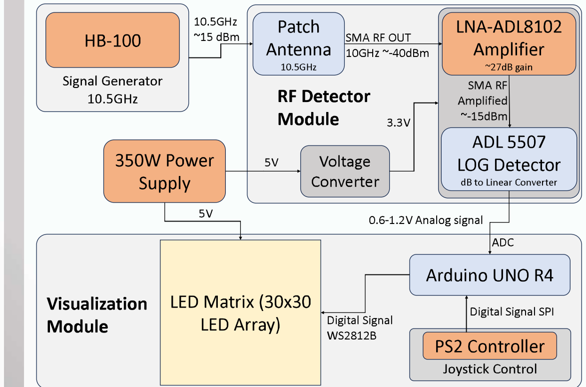
Modes:
- 4 Test Modes
- 4 Interactive Modes
  - 3 Simulation
  - 1 Real-time

Design:
- Compute signal values for each LED
- FastLED Library for LED Control



Simulated Board

System Overview



Results

Performance:
Single LED mode shows real RF beam power intensity, joystick modes are interactive and educational.

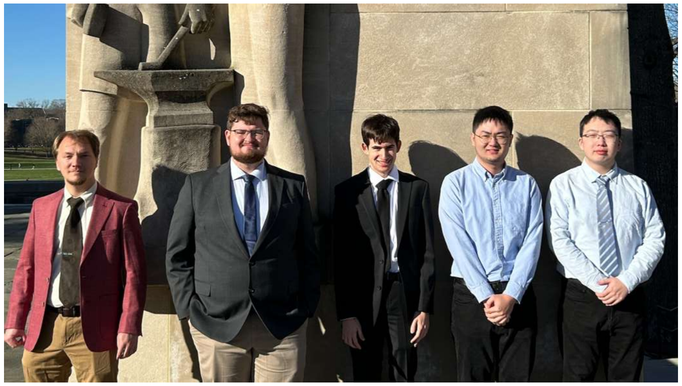
Visuals:
Diffused lights shine clearly, modes switch seamlessly for different visual interpretations.

Lessons Learned:
- Designing a PCB for RF signals is much different than DC/ low frequency systems.
- Microstrips can sometimes act as antennas and cause interference.
- Do not solder all parts until everything has been properly tested.

Future Work

Phased Array Testing:
Currently, the RF source is the HB100 microwave motion sensor. It emits a wide, 10.5 GHz beam. By testing with a real phased array, we can achieve:
- A true electronically steered beam
- Improved directivity measurements and visualization

Electronic Fuse (eFuse) for Auxiliary Power Networks



LEFT to RIGHT: Brennan Sebastian, Alex Callahan, Jack Simmons, Qihao Yang, Rui Xie

CHALLENGE

Develop a solid-state circuit breaker for auxiliary power networks in power electronics converter systems, capable of protecting 48 V, 1 A, DC systems from line and ground faults, and of operating in harsh electro-magnetic interference environments. The efficiency and power density should be maximized and be comparable to that of commercial off-the-shelf components.

CPES Center for Power Electronics Systems

SME: Ali Mehrizi-Sani

Customer: Rolando Burgos

Alexander Callahan Laurel, Maryland

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I plan to graduate with a Bachelor's in Electrical Engineering in May. After graduation, I will relocate to Richmond, Virginia working for Dominion Energy as a System Protection Engineer.

Course Comment: This course helped me grasp the concepts of working in a research and development team. I have gained practical skills regarding design of power electronics and protection systems.

Brennan Sebastian Palmyra, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan to graduate with a Bachelor's in Electrical Engineering, return home, and find work locally to help support my family.

Course Comment: This course taught me about the challenges of balancing the technical end and the business end of a design project. I also learned about surface mount PCBs and how to order electrical parts (including the many parameters in doing so). Overall, an exciting first foray into power electronics design.

Jack Simmons Moseley, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I plan to pursue a career in power electronics design for power systems. I intend to continue at Virginia Tech for a master's degree to this end.

Course Comment: I learned a great deal about the practical elements of engineering design. In particular, marrying theoretical concepts of electronic design from my degree with details such as ordering parts and creating a PCB gave a satisfying finish to my academic journey in electrical engineering.

Rui Xie Nanjing, China

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I would like to pursue a master's degree in power electronics and gain further research experience afterward.

Course Comment: This course offers a glimpse of the real career life and helps students to prepare for their future by building practical skills and professional awareness.

Qihao Yang Wuxi, China

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: Pursue a mater degree in power electronics and gain more experience and knowledge in Virginia Tech.

Course Comment: Great course overall and I learned a lot about how to work as a team, its nice to have a team that everybody is in the same page and working together to solving the problem. The first ever experience of design and assemble a PCB is great.

S25-03: Development of Electronic Fuse (eFuse) for Auxiliary Power Networks

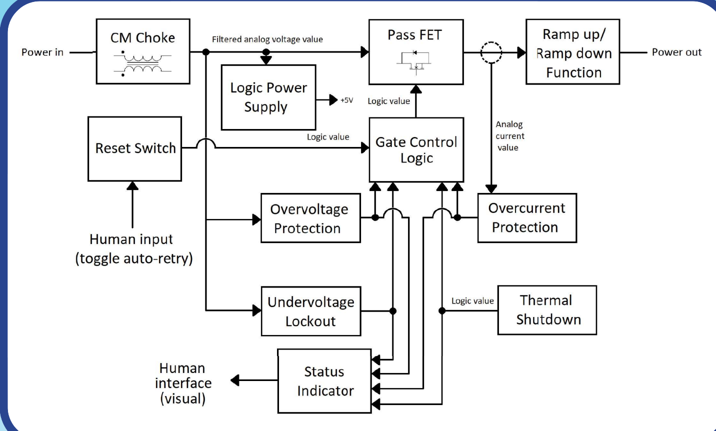
Customer: Dr. Rolando Burgos
SMEs: Ashkan Barzkar, Dr. Ali Mehrizi-Sani
Mentor: Janice Burr
Team: Alex Callahan, Brennan Sebastian, Jack Simmons, Rui Xie, Qihao Yang

VIRGINIA TECH

CPES Center for Power Electronics Systems
The Bradley Department of Electrical and Computer Engineering
College of Engineering
Virginia Tech, Blacksburg, Virginia, USA

BACKGROUND

Power systems, comprised of complex and expensive electrical equipment, require swift and accurate protection to ensure safe operation. Conventional circuit breakers are well-established for grid-level use, but protection at lower power levels is rarely fully featured. The Center for Power Electronic Systems (CPES) needs a device to tunably and repeatably isolate electrical and thermal faults in medium-voltage power converters in their lab, which has high levels of electrical noise. This eFuse should address voltage, current, and thermal faults under these conditions as well as include tunable protection and retry mechanisms to facilitate flexible operation in various converter use cases.



WHAT'S AN eFUSE?

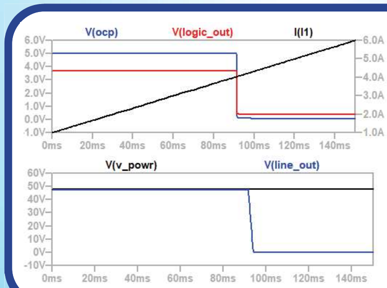
An **electronic fuse (eFuse)** is a device which can cut power to a device using a transistor to break the circuit, as opposed to a broken wire like a fuse or a mechanical armature like a circuit breaker. By monitoring the current and voltage of the power path, the eFuse will either bias the transistor into saturation region to pass power or bias the transistor into cutoff region to cut power.

The eFuse includes protection against:

- Overvoltage
- Undervoltage
- Overcurrent
- Overheating
- Harsh EMI conditions

LOGIC-LEVEL OPERATION

- **Fault Detection** – Tunable comparator circuits monitor conditions on the power path.
- **Reset Switch** – A reclosing circuit prevents temporary faults from stopping power transfer longer than necessary.
- **Gate Control Logic** – Logic gates make decisions on how to react to signals from fault detection sensors.

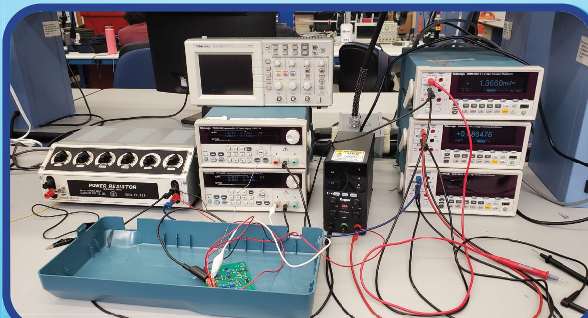


Pictured: A simulation of overcurrent testing with respect to time.

- I(1) represents varying current from 1 A to 6 A.
- V(ocp) represents the voltage output of the overcurrent protection subsystem.
- V(logic_out) represents the voltage output of the Gate Control Logic subsystem.
- V(v_powr) represents input voltage to the eFuse.
- V(line_out) represents output voltage.

POWER PATH

- **Pass FET** – Transistor which either passes power or cuts it off based on DC bias from its gate to source. Power path flows from drain to source in no-fault condition.
- **CM Choke** – A common mode filter is placed on the power path to reduce CM noise, a known source of interference with off-the-shelf eFuses.
- **Ramp up / Ramp down** – A few components are added to soften the voltage transient of the eFuse in the event of a cutoff, protecting the load from current spikes.



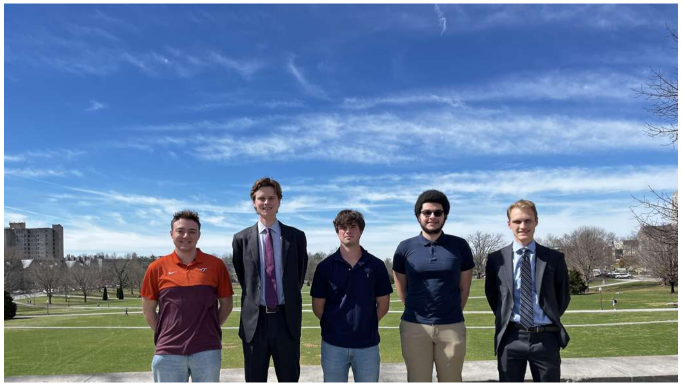
CONCLUSIONS & FUTURE WORK

- We developed a method of electrical and thermal fault detection using comparator circuits, a Hall effect sensor, and a thermistor.
- Future work should modify the gate driver topology to address challenges found during testing, improve the filter performance by adding additional components, and upgrade the tuning and usability of the auto-retry timer.
- Further testing should confirm eFuse operation when connected to laboratory medium-voltage converters as well as determine whether the device functions under higher thermal and/or mechanical stress.

ACKNOWLEDGEMENTS

We would like to give thanks to Dr. Rolando Burgos, Ashkan Barzkar, Dr. Ali Mehrizi-Sani, and Janice Burr for their insights on this project. We would also like to thank the Center for Power Electronics Systems at Virginia Tech.

High Speed RF Digitization



LEFT to RIGHT: Braden Schickler, Declan Rymer, Ryan Stewart, Trey Livesay, Chris Cox

CHALLENGE

In high frequency military RF systems speed is of the essence and ADCs are often a bottleneck in these systems. Our team was tasked with researching and performing a conceptual design of a high speed and high resolution ADC and designing a MATLAB testbench for the simulated testing of future ADCs. In addition to this the team opted to create a physical prototype of an ADC as a proof of concept.

SME:

Customer: **Andrian Jordan**

Christopher Cox Not Blacksburg, United States

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: graduate with a degree in communications

Course Comment: An enlightening experience: I learned a bit about research strategy. We had moments of satisfying competence and terrifying moments of incompetence; the scope of this project went deeply into graduate material which impacted the feasibility possible. We have a lot to learn, especially when it comes to novelty and pushing devices to their extremes. Even if the class was at 8AM, I appreciated seeing all my friends before we drift into different worlds.

James Livesay Stafford, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: Get a job, preferably in RF or communications.

Course Comment: Overall, I thought this was a pretty neat experience, but I have a few regrets from my time in this course. I still feel like I have plenty to learn about communicating with teammates and researching materials, but it was cool to work on a larger project with a team larger than two. Regardless of what happens to me, I'm proud of what my teammates have accomplished, and I wish them the best of luck in their future endeavors.

Declan Rymer Downingtown, Pennsylvania

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Use machine learning to increase accuracy and effciency of RF communications systems.

Course Comment: This course has tough me valuable lessons and skills, especially when it comes to research and project planning. As a CE major instead of EE I did not have some of the technical background of my teammates, but we all worked together to use our different skill sets to solve the problem. As the project manager I had to do my own research to understand what each member was working on so we could make sure it all fit together and figure out how to complete the project in the end.

Braden Schickler Ellicott City, Maryland

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: Work with high end computers/ gaming computers and design and manufacture parts for these computers

Course Comment: A great experience learning how to work with a long-term team to complete a project over a long period of time.

Ryan Stewart Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Design systems for renwable energy, whether it is implementation on devices such as cars (solar cars) or power plants OR communication systems (networking)

Course Comment: From this course, the main thing I got out of it was time management on large projects. A few times I have struggled with close deadlines because of poor time management (I still got the tasks done, however with more time I would have been less stressed and could have strategized my outcome better). However, as time has gone on, I have realized that certain deadlines need to be considered in advance, as well as not to count on certain things to be puncutal (ie parts coming in when you need them to).

High Speed RF Digitization

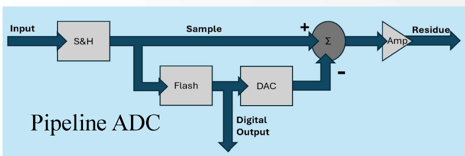
Declan Rymer, Braden Schickler, Trey Livesay, Ryan Stewart, Chris Cox
Mentor: Professor Janice Burr Sponsor: Naval Air Warfare Center Aircraft Division

Problem

- The Navy operates at high frequencies and needs fast and accurate digitization
- Precisely analyze 50GHz spectrum with 10bit, 5GHz bandwidth
- Analog to Digital Converters (ADCs) impede digital processing

Solution

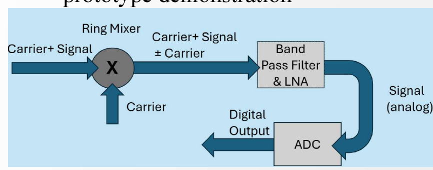
- Simulate Existing ADCs: MATLAB tool
- Design faster ADC's: component & MATLAB
- Improve receiver performance



- S&H – Sample & Hold
- DAC – Digital to Analog Converter

Receiver Design

- Analog superheterodyne receiver
- Two Different Implementations due to cost
  - Theoretical (LTspice only)
    - Using original frequency specs
  - Physical (Implemented on PCB)
    - Smaller frequency specs for real prototype demonstration



High-speed ADC Design Choices

General
- Integrated Circuit design
- 1.5-bit stages
- Switches & capacitors
- Parallel stages

S&H
- Integrate into other stages
- Sampling strategies (bootstrap, bottom plate sampling, differential)

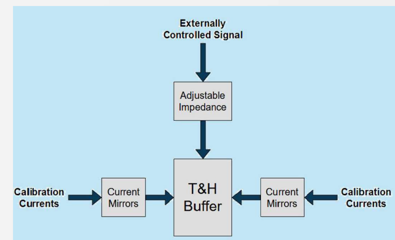
DAC
- Flip around configuration
- Residue amplifier (Multiplying DAC, Subtraction, Amplify)

Calibration, Error Correction

Error
- Jitter, Offset mismatch, gain mismatch, nonlinearity, clock feedthrough, charge injection

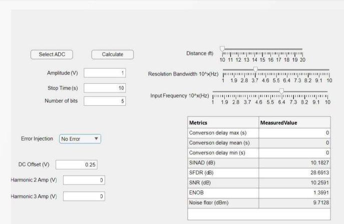
Current Mirrors
- Adjusts ADC offset with calibration currents

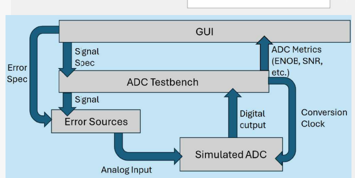
Adjustable Resistance
- Adjusts Gain with a resistance dependent calibration signal

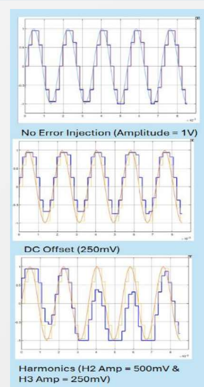


Matlab tool for testing

- ADC design and testing can be expensive and slow
- Simulation speeds up design and testing by giving accurate feedback and allowing quick modification of designs
- Required to create a Matlab/Simulink based tool to test ADC design.
- Customize input signal and parameters in GUI implementation
- The testbench outputs signal traces and ADC performance metrics







No Error Injection (Amplitude = 1V)

DC Offset (250mV)

Harmonics (H2 Amp = 500mV & H3 Amp = 250mV)

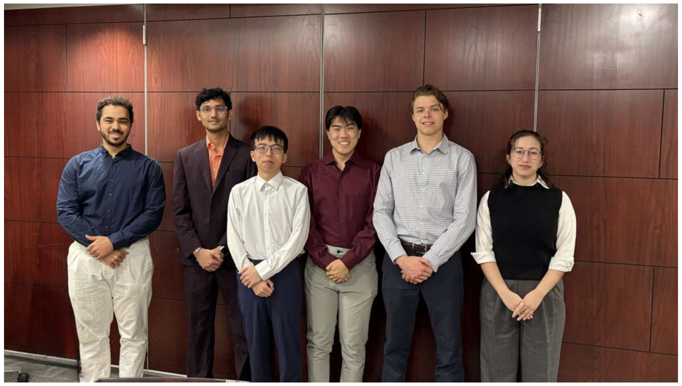
Conclusion

- Designed ADC test tool in Simulink
- Implemented Simulink ADC
- Simulated pipeline ADC implementations
- Built Receiver

Acknowledgement

•Thanks to our mentor, Professor Burr
•Thanks to our sponsors, Israel and Adrian Jordan at Naval Air Warfare Center Aircraft Division

Personal Locator Beacon Mesh Network



LEFT to RIGHT: Braden Greene, Muhammad Athar, Jason Huang, Matthew Chang, Aj Anderson, Victoria Wagner

SME: Tim Talty

CHALLENGE

Design and implement an updated personal locater beacon system to incorporate mesh network capability. New beacons in this system will be capable of transmitting, range-extending, or both to strengthen the range and proficiency of the PLB Mesh Network. The main focus of this system is to act as a locating system without the reliance on traditional cellular service for relevant third-parties.

ZETA ASSOCIATES

Customers: Jared Desai and Michael Drescher

AJ Anderson Richmond, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to use the knowledge and skills I have developed at Virginia Tech to design and create innovative and efficient power systems that drive reliability and sustainability in energy infrastructure.

Course Comment: This course has allowed me to practice and further develope my soft skills while working in a fast paced design team

Muhammad Athar Woodbridge, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to work in the world of FPGAs and Embedded Systems. I am also planning on pursuing Graduate School in the near future.

Course Comment: MDE has shaped me into a well-rounded engineer, enhanced my soft skills, and equipped me with professionalism applicable to any industry.

Matthew Chang Oakton, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Persuing ECE at Virginia Tech made me appreciate the relationship hardware and software have with each other. I hope I can continue working close to hardware in my future.

Course Comment: MDE has helped me become more accustommed to working in teams on more realistic projects. It has given me valuable insight on coordination and time management for my future endeavors.

Braden Greene Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I hope to get a chance to move abroad to practice engineering in a new country

Course Comment: This course has provided me with great experience of working with a team for a long period of time and how to manage responsibilities and a communal work enviornment

Jason Huang Fairfax, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: After graduation, I hope to also get my M.S. in Computer Engineering here at Virginia Tech. In industry, I would like to find something that deals with embedded systems or software systems.

Course Comment: MDE has gave me valuable experience that can be applied to industry. I have learned how to work in a team, how to have good time management, and how to present milestones in a professional manner.

Victoria Wagner Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: While finishing my degree at Virginia Tech, I learned valuable lessons in work ethic and how to use technical knowledge to create high-quality projects. As I transition into industry, I want to apply these lessons into my passion for Networking & Cybersecurity.

Course Comment: The MDE course has prepared me for how to efficiently work in a team environment. It has taught me how to divide a grand task into equal parts, how to communicate progress to superiors, and how to appropiately manage my time to deliver a professional product.

Personal Locator Beacon Mesh Network

AJ Anderson, Muhammad Athar, Matthew Chang,
Braden Greene, Jason Huang, Victoria Wagner
Sponsor: Jared Desai, Michael Drescher, Zeta Associates
Subject Matter Expert: Dr. Timothy Talty
Mentor: Dr. Daniel Connors

Background

- A communication system that allows a base station user to geographically locate and track beacon users.
- Allows beacon users to travel or work in remote locations while still being able to notify the base station user if they are in distress.

First Responders Providing Aid

Objectives

- Develop mesh protocol for beacons to have additional functionality
- Standardize beacon hardware to have transmit, extender, and mesh capability
- Ensure backwards compatibility with legacy beacons so that current beacons can also function with old hardware

Approach

We standardized the beacon software by developing a state machine for each beacon mode in C++, primarily using the Arduino **RadioHead** library.

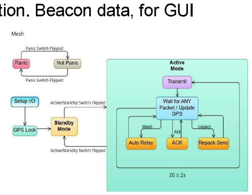
- **Transmit-Only:** Transmit GPS Location of Device
- **Range-Extender:** Passively Forward Packets (Pass-Through)
- **Mesh:** Transmit GPS Location of Device and Forward Packets

Beacon Data Packet								
Data Name	Radio ID	Panic State	Message ID	Latitude	Longitude	Battery Life	UTC time	Total
Number of bits	8	1	15	32	32	8	32	128

Beacon Packet Data

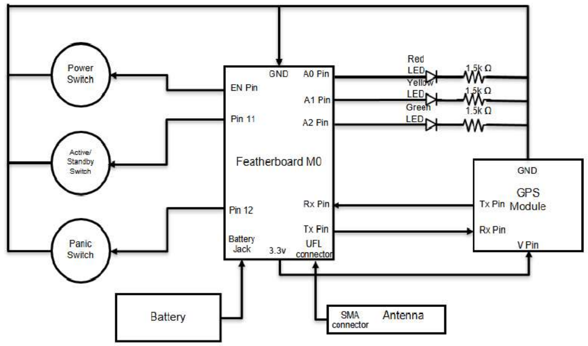
A **Folium** map was embedded in a **PyQt5** application to allow for interactive geographical data visualization. Beacon data, for GUI purposes, is stored in a **JSON** file.

GUI functionality includes:
- Beacon Location Markers
- Packet Data
- Beacon Filtering
- Play/Pause

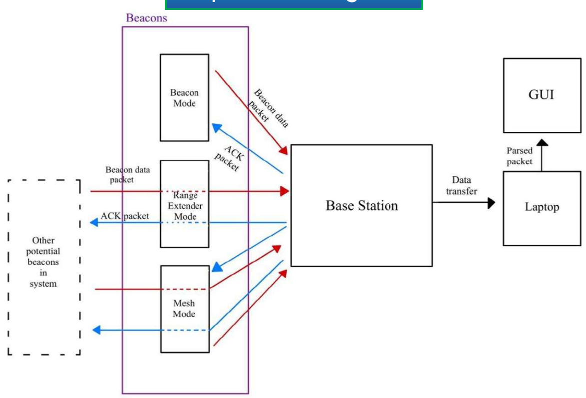


Mesh Mode Protocol

Hardware Diagram



Top-Level Diagram

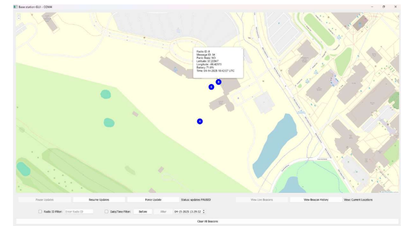


Challenges

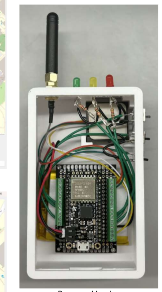
- Backwards Compatibility with Legacy Beacons
- Implementation of Mesh Networking
- Hardware Standardization and physical constraints
- Budget Constraints
- GUI Visualization and Functionality
- Testing Network at Scale

Testing Results

- Testing was conducted on campus across multiple buildings and line-of-sight blockages



GUI Example Showing Current Beacon Locations



Beacon Hardware

GUI Example Showing Beacon's Past Location

Conclusion

- New system has standardized hardware along with mesh capability
- GUI can display path history along with filtering to observe individual beacons
- Range of transmission has minimum of 400 meters line of sight
- Physical barriers remain the biggest obstacle for successful transmissions

Future Work

- Develop database to host long-term storage of beacon data
- Implement integrated display to show acknowledgment information to users

Acknowledgement

The Personal Locator Beacon Mesh Network Team would like to thank:
- **Jared Desai**: Sponsor
- **Michael Drescher**: Sponsor
- **Dr. Daniel Connors**: Mentor
- **Dr. Tim Talty:** SME
- **Kim Medley**: Project Accountant

Saltwater Antenna for Maritime HF Applications

LEFT to RIGHT: Aaron Clark, Brendon Bennett, Jandre Erwee, Preston Pitzer, Nate Carter

SME: Majid Manteghi

CHALLENGE

Create an antenna capable of communications in the high frequency radio band that uses seawater as the radiating element. The antenna must have operational characteristics sufficient to avoid damage to a connected transever.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

Customers: Kevin Cogley and Christopher Lillard

Brendon Bennett North Kingstown, Rhode Island

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I aspire to be have a career in sports and/or music, utilizing my education to further enhance the experiences for people in these field.

Course Comment: N.A.

Nathanyal Carter Richmond, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: My career aspiration is to continuously develop my skills and become an expert, then move into a leadership role where I can make a positive impact.

Course Comment: This course gave me the opportunity to solve a real-world problem, preparing me for the critical thinking skills necessary for being a valueable asset in the future.

Aaron Clarke Lynchburg, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I hope to use my career as a way to provide valuable contributions to the amateur radio community and grow my skills in RF electronics and wireless communications.

Course Comment: MDE was valuable experience in learning to turn failure into progress.

Jandre Erwee Ringoes, New Jersey

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: My goal is to become an electrical engineer focusing on the design of RF circuits and antennas

Course Comment: Great experience and an excellent way to introduce students to the real world.

Preston Pitzer Lynchburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering
Bachelor of Science
Mathematics

Aspirations: I hope to design cutting-edge digital circuits for software defined radio applications

Course Comment: This course gave me the opprotunity to apply skills from my courses and learn new skills from interesting fields.

Saltwater Antenna for Maritime HF Applications

Team Members: Aaron Clarke, Brendon Bennett, Jandre Erwee, Nate Carter, Preston Pitzer
Customer: Chris Lillard, NSWCDD **SME:** Dr. Majid Manteghi **Mentor:** Prof. Shelley Stover **GTA:** Muntasir Mahdi

NAVSEA WARFARE CENTERS DAHLGREN

VIRGINIA TECH.

Motivation

High Frequency (HF) antennas take up significant space and have limited multi-band capabilities. A fluid antenna can have precise tunability across the entire HF band and takes up minimal space when not in use.

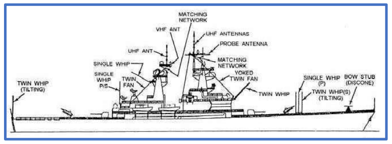


Fig. 1. *Typical Antenna Configuration on a Naval Vessel [1]*

Objectives

1. Produce an antenna capable of HF communications that uses seawater as the radiating element
2. The antenna should function across the entire HF band (3-30MHz)
3. The antenna shall have performance sufficient to avoid equipment damage (VSWR < 1.5:1)

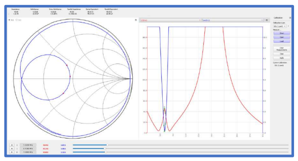


Fig. 2. *Acceptable VSWR*

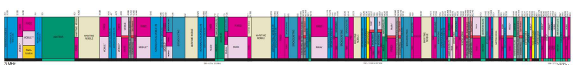


Fig. 3. *Wireless Services in the HF Spectrum [2]*

Methods of Excitation

Modeling and Simulation

To find an effective current injection method, we modeled multiple ways of injecting RF current into seawater in Ansys HFSS. We found that direct current injection using a copper pipe was the most effective.

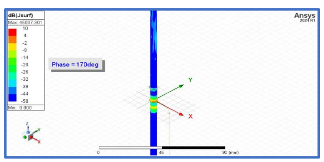


Fig. 4. *Seawater and Copper Pipe Surface Current Density in HFSS*

Building and Testing

The excitation was constructed using copper refrigerant tubing, which had coaxial cable soldered directly to it. The tubing diameter was selected to match the internal diameter of our soft tubing, producing a watertight seal. We tested the ability of the excitation to inject RF into saltwater at various frequencies and geometries before integrating it into the final system.

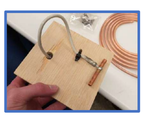


Fig. 5. *Copper Pipe with Coaxial Connection*

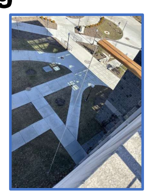


Fig. 6. *10m Vertical Tube Testing*

Electronic Tuning Control

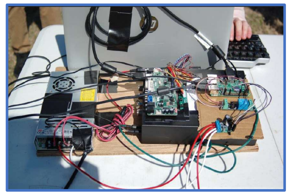


Fig. 7. *Control Electronics*

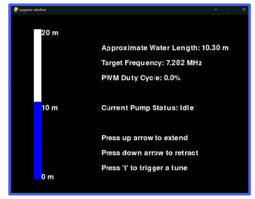


Fig. 8. *Graphic User Interface*

Tuning is achieved by modifying the length of the excited water, targeting a length of λ/4 for a vertical monopole and λ/2 for an end-fed half-wave.
Two software modes are available, one to fill and empty a static tube, and the other to pump various lengths in free space. Both use PWM control from a Raspberry Pi 3, controlled from Python software. An H-Bridge steps-up the 3.3VDC voltage to 12VDC PWM, usable by the pump.
An antenna tuning unit (ATU) is connected between the transceiver and the antenna to eliminate imaginary current components that lead to loss. Remote triggering of the tuner is achieved by shorting its control pins using a relay.

Test Configuration

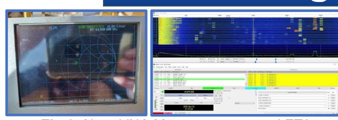


Fig 9. *NanoVNA Measurements and FT8 Software (WSJT-X)*

FT8 (Franke-Taylor 8-FSK) is a digital amateur radio mode based on 8-FSK modulation. It is used for minimal communication over long distances using low power (~5W) [3]. We transmitted and received FT8 packets via our prototype antenna using a Xiegu G-90 HF Transceiver to test transmit range. We also used a NanoVNA to measure VSWR and impedance.

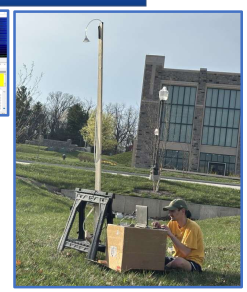


Fig 10. *Fixed Monopole Test*

Test Results

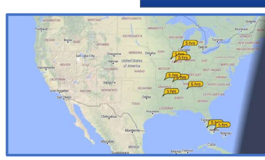


Fig. 11. *Our FT8 transmissions heard across the eastern US*

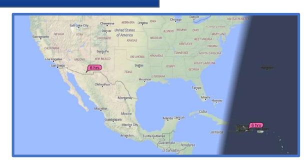


Fig. 12. *Our FT8 transmissions heard in Santo Domingo*

While band conditions did vary significantly over the course of our testing, we did achieve multiple DX (international) contacts. The antenna made long-distance contacts on amateur HF bands (40m, 20m, 15m, 10m), indicating its ability to communicate.

Analysis and Conclusion

While our antenna does achieve the baseline performance metric of "capable of communications", it suffers significant performance penalties associated with both the high impedance at the feed point and the extremely low conductivity of seawater compared to copper (approximately 5 S/m vs. 5.96E7 S/m [4]). This results in non-resonant behavior, indicated by the narrow match from tuning (i.e. our instantaneous bandwidth). Unfortunately, the latter is an unavoidable consequence of our required material and indicates that this choice of fluid for a fluid antenna is suboptimal. Other materials choices such as liquid mercury would give many of the same benefits (namely tunability), with fewer performance downsides. However, this would not allow the same conveniences for maritime use that seawater does.

Fig. 13. *Corrosion on Current Injector*

Fig. 14. *Dahlgren Testing Setup*

Additionally, we concluded that much more sophisticated pumping hardware is required to achieve free-air antenna geometry. A pump capable of producing resonant geometries was outside of our budget and would have required much greater support resources (i.e. an ocean and significant power). A fixed-tube solution was ideal for our proof-of concept testing. It provided us more flexibility with geometry, the ability to use a less expensive pump, and the ability to operate in windy weather.

Future Plans

Fig. 15. *Early Attempt at a Water Stream RF Choke*

While our success using a free-space solution was limited, there is academic precedent for free-space fluid antennas on higher frequency bands [5]. However, to get acceptable performance for our given system requirements, a much wider stream diameter and hence, extraordinarily stronger pump, would be required. An equivalently robust RF choke would be needed to prevent electrical interaction with the source of water as well as RFI from the pump. A balun could be beneficial in both free space and fixed-tube solutions to reduce high feed-point impedance. For longevity, corrosion due to the saltwater exposure would also need to be accounted for. This issue could potentially be avoided by using a different type of metal, or coating the existing copper with a material that still allows it to efficiently capacitively couple to the saltwater.

Acknowledgements

The team would like to acknowledge the assistance of our SME, Dr. Majid Mantghi, our Mentor Prof. Shelley Stover, and especially our customer Chris Lillard. We also acknowledge the Virginia Tech Amateur Radio Association for loaning various HF equipment. We acknowledge the volunteers who maintain pskreporter.info and the network of receivers it aggregates.

https://www.navy-radio.com/ant-ship.htm [1]
https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf [2]
https://www.sigidwiki.com/wiki/FT8 [3]
https://www.thoughtco.com/table-of-electrical-resistivity-conductivity-608499 [4]
https://ieeexplore.ieee.org/abstract/document/7374349 [5]

FPGA/CPLD Replacement of Deprecated Communication Chips

LEFT to RIGHT: Alec Neps Alvarado, Liam Boyle, Eric Li, David Dojcinovski, Kofi Ofosu-Tuffour

SME: Linbo Shao

CHALLENGE

Framatome's SUSI submarine uses the U6050B and U6052B chips to control the on-board camera's pan-tilt-zoom movements. These chips, however, are now obsolete and to continue the service of the SUSI submarine we must create FPGA emulations of these chips. The design must use PCBs that interface with a CPLD chip while being fully compatible with each other and the original chips.

Customers: Gary Novak, Ken Ritchey and Erich Thurm

Liam Boyle Bellmore, New York

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: My goal is to contribute to major breakthroughs in electronics and the semiconductor industry while continuously expanding my knowledge and expertise. I aim to excel in my field and become highly skilled in my craft. Also, I'd like to have enough money to support myself and my family, comfortably fund my passions, and live a well-rounded life.

Course Comment: I appreciated the need to learn on our own and come up with unique solutions. Exploring new areas of electrical and computer engineering that our classes haven't covered was very valuable, as I believe that this is an important skill that contributes to success. Also, this was the longest project I have worked on so far, and it taught me how to navigate and manage a long-term goal.

David Dojcinovski Parsippany, New Jersey

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My goal is to continuously learn and hone my skills in the world of electrical engineering so I can become a eventually become an expert in my field.

Course Comment: The course has allowed me to understand how different types of engineers and various programs, resources, and companies can be used to build a complete and tangible product using knowledge from all my college classes.

Eric Li Penn Laird, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I hope to use my knowledge of digital design and FPGAs to contribute to the next generation of computing hardware.

Course Comment: This course has given me experience working on a large, long-term project and having to refine the design based on customer feedback, which I appreciate.

Alexander Neps Alvarado Lynchburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Work as an embedded systems engineer allowing me to use both hardware and software to solve problems.

Course Comment: It was very important to undertake a project of this scale and scope. The lessons learned from managing our own project cannot be learned anywhere else but in industry.

Kofi Ofosu-Tuffour Chesterfield, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My career aspirations are in Embedded Engineering and ASIC Design.

Course Comment: The course allowed me to take in a real-world problem and use the knowledge and strategies from courses to propose a solution.

FPGA/CPLD Replacement of Deprecated Communication Chips

Liam Boyle, David Dojcinovski, Eric Li, Alec Neps Alvarado, Kofi Ofosu-Tuffour

Customers: Ken Ritchey, Erich Thurm, Gary Novak

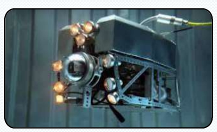
Subject Matter Expert: Dr. Linbo Shao

Company Background

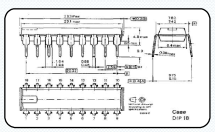
Framatome is an international leader in nuclear energy recognized for its innovative, digital and value added solutions for the global nuclear fleet. With worldwide expertise and a proven track record for reliability and performance, the company designs, services and installs components, fuel, and instrumentation and control systems for nuclear power plants.

Problem Statement

- Framatome's Submarine System for Inspections (SUSI) inspects submerged reactor components
- The SUSI uses the U6050B and U6052B chips to control the system's camera
- The U6050B and U6052B are no longer being produced, and are difficult to find
- We must emulate these chips so Framatome can continue the service of the SUSI system



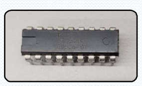
Framatome's SUSI



U6050B/U6052B Package

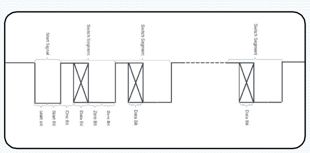
U6050B and U6052B Chips

U6050B transmitter



U6052B receiver

- 18 input 'dual inline package' chips
- Transmit 16 bits when cascaded
- Unique transmission protocol, low frequency
- Transmission over a serial data line, not RF



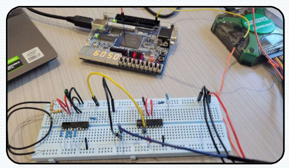
Data word:
- 2 low start bits
- 16 data segments:
  - 1 high bit
  - 1 data bit
  - 2 low bits

Requirements

- Our transceiver emulations must communicate with each other as well as the obsolete chips
- Final product must be a standalone PCB; no microprocessors or FPGA developer boards
- Must be made with modern, procurable components

Emulation Prototyping

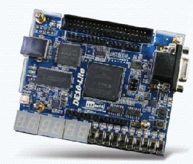
- Verilog models were written to emulate our transmitter and receiver
- Models were flashed onto developer boards and connected to the obsolete chips
- Eventually working models were created that were able to communicate with the obsolete chips



Communication between U6050B and Developer Board

Solution

- Since PCBs can take up to a week to print and ship, we used FPGA developer boards to prototype Verilog designs
- Once we verified our Verilog emulations, we could move on to PCB design
  - The PCB would include a CPLD chip that could be programmed with a Verilog model
  - This allows for a low-cost hardware-only solution

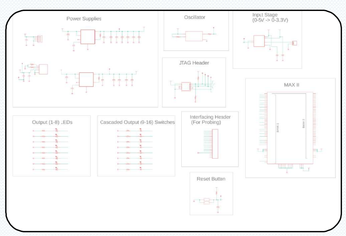


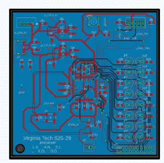
DE10-Lite Developer Board with MAX 10 FPGA

- With the FPGA developer board emulations validated, we could then create our PCBs

PCB Design

- PCBs allow us and Framatome to customize the design and test each part of the system.
- Both communication components are contained in a two-layer, top-side assembly, 100mm x 100mm board which keeps manufacturing low-cost and fast





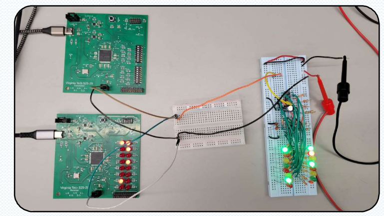
Receiver PCB Layout

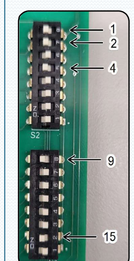
Assembled Receiver PCB

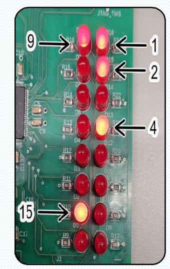
- The primary components on the PCBs include:
  - MAX II CPLD (programmed w. Verilog models)
  - USB-C power connector
  - Linear voltage regulators
  - Level Shifters
  - Oscillators
  - Switches (inputs) and LEDs (outputs)
- While the transmitter PCB has switches for inputs and the receiver PCB has LEDs for outputs, the boards are mostly the same otherwise.

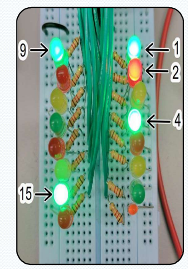
Conclusion

- PCBs successfully demonstrate functionality of original chips
  - Original transmitter communicates properly with our receiver PCB
  - Our transmitter PCB communicates with both the original receiver and our receiver PCB
  - Toggling a switch on either transmitter toggles the corresponding LED on either receiver
- Framatome can now continue the service of SUSI









Future Work

- PCB must be adjusted to better fit the needs of the SUSI
  - The current solution is designed to demonstrate the functionality of the project
  - PCB layout can be changed to be a smaller footprint
- Our customer plans to repackage our solution

Acknowledgments

We would like to thank our mentor Dr. Connors, our SME Linbo Shao, and our sponsor Framatome for enabling our success on this project.

More than Moore: Fabrication of a Germanium FET for Ultra-Fast, Low Power Computing

LEFT to RIGHT: Xiaorui Liu, Jacob Miller, Samuel Abernathy, Mia McConathy, Ryan Pham

CHALLENGE

Our goal was to explore and optimize the geometry of a Germanium nanosheet FET and integrate a ferroelectric layer into the gate to develop a low-power and ultra-fast transistor. This involved researching suitable ferroelectric materials, implementing them in simulation software, analyzing performance relative to other transistors, and evaluating key parameters to enhance overall device behavior.

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BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

SME: Muntasir Mahdi

Customer: Mantu Hudait

Samuel Abernathy Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After college, I plan to start my career in digital signal processing by working full-time in the field as a government contractor. In addition to my professional work, I aspire to stay active in music by playing in a community orchestra and serving as church organist

Course Comment: This course had its share of ups and downs, but it was a valuable experience in collaborating with a team of fellow engineers and working directly with a customer to ensure our work met their needs. The challenges we encountered along the way gave me insights that I'll carry with me into my career, helping me navigate teamwork, problem-solving, and real-world project expectations.

Xiaorui Liu Beijing, China

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I want to work in something I enjoy, and spend the rest of the time traveling.

Course Comment: This course offered an unexpected journey into the semiconductor realm, guiding me through next-generation transistors, nanoelectronics, and even the intricacies of cleanroom fabrication. I acquired a wealth of interdisciplinary insights, though I sometimes mused about the circuitous route we were asked to take. Ultimately, it's a collection of experiences I'll undoubtedly reflect on as I navigate my future career.

Mia McConathy Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After college, I plan on traveling and working for an environmental engineering firm in the water industry. I am excited to pursue this path because it will allow me to improve infastructure and have a positive impact on people's lives.

Course Comment: This course was my first opportunity to take on a leadership role, and it helped me discover both my strengths and areas I could improve in as a leader. I also gained valuable knowledge related to the semiconductor industry, which I will keep in mind as I plan my career.

Jacob Miller Marshall, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering
Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: After graduation, I aspire to work in a research lab focused on cutting-edge robotics and biomimicry or in the audio hardware and music industry, where I can merge my technical expertise with my passions. Beyond my professional goals, I also hope to travel extensively and experience as much of the world as possible.

Course Comment: This course has presented challenges I did not anticipate, pushing me beyond my comfort zone as a computer engineer. However, it has also deepened my interest in nanoelectronics, as well as material science, physics, and chemistry. Through this project, I have gained valuable knowledge and interdisciplinary insights that I hope to apply in my future career endeavors.

Ryan Pham Newport News, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I want to work on cutting-edge techology in the semiconductor industry and hopefully make a real positive impact on people's lives. Outside of that, I'd love to travel, see the world, and keep learning through new experiences.

Course Comment: I really enjoyed learning about next-generation transistors and getting insight into the research happening in the field. Visiting the cleanroom and seeing how the fabrication process works was also a great experience. Overall, this course taught me a lot that I'll carry with me moving forward.

More than Moore: Fabrication of a Germanium FET for Ultra-Fast, Low-Power Computing

Samuel Abernathy, Xiaorui Liu, Mia McConathy, Jacob Miller, and Ryan Pham

Mentor: Ken Schulz **Subject Matter Expert(s):** Dr. Rutwik Joshi and Muntasir Mahdi

VIRGINIA TECH

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Background

Moore's Law has been a driving force in the semiconductor industry for the past several decades. It predicted an exponential increase in transistor density, requiring smaller, faster, and more power-efficient devices [1]. As silicon FETs reach their scaling limits, new materials and architectures are needed. The nanosheet FET (NSFET) is a promising successor, offering improved short channel effects and gate sizing flexibility [2]. Adding a negative capacitance layer, such as a ferroelectric material like Hafnium Zirconium Oxide (HZO) can reduce power consumption by internally amplifying gate voltage and lowering the subthreshold slope (SS) [3]. While both NSFETs and negative capacitance had been explored individually, no prior research combined them with a germanium channel. Germanium's high carrier mobility made it ideal for boosting speed and efficiency which was the aim of our project.

Objectives

- ✅ Determined optimal effective width (*Weff =2N(Wch+Hch)* for a single NSFET
- ✅ Identified most effective device geometry associated with optimal *Weff*
- ✅ Converted the optimized NSFET into a negative capacitance FET (NCFET), incorporating a ferroelectric material into the gate structure
- ✅ Simulated device behavior using Synopsys' Sentaurus TCAD
- ✅ Extracted simulation data, analyzed results, and determined best performance metrics
- ✅ Designed a fabrication-compatible process flow for the device

Structural Changes

Weff values of 8, 16, 24, 32, 40, 48, 56, 64, and 80 nm were simulated. A square channel provided the best on-current, and a rectangular channel provided the best subthreshold slope (SS)

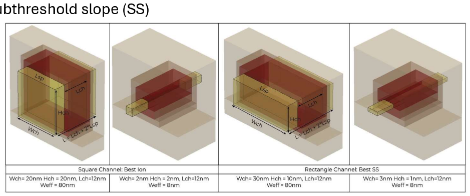


Figure 1: From left to right, the NSFET with no ferroelectric layer at Weff of 8 and 80 with a square channel and Weff at 8 and 80 with a rectangular channel

Weff values of 24 nm and 32 nm were selected for further geometric exploration due to high Ion current with subthreshold swing (SS) below 65 mV/dec

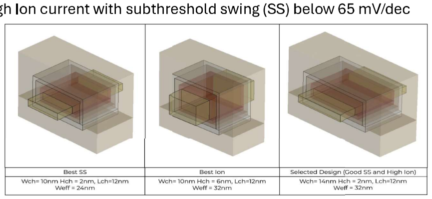


Figure 2: From left to right, the physical NSFETs with the added ferroelectric layer (silver) showcasing the geometries with the best SS, Ion, and overall performance. The rightmost graphic displays the combined best SS and Ion

Gate Layer Changes

Advantages of HZO:

- CMOS compatibility, scalability, thermal stability, and lead-free [4]
- Creates a controlled interface between HZO and the high-k dielectric (HfO_2)
- Using uniform thickness in gate stack simplified the simulation
- Polarization v. gate voltage curve showed clear ferroelectric switching, stable remnant polarization, and a small loop area
- Confirmed successful integration of HZO into the gate stack
- Can withstand high (~600°C) temperatures without degradation

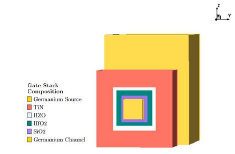


Figure 3: Cross-sectional view of the simulated gate stack with the integrated ferroelectric layer

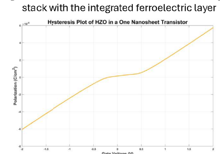


Figure 4: The polarization v. gate voltage curve demonstrating ferroelectric switching behavior

Simulation

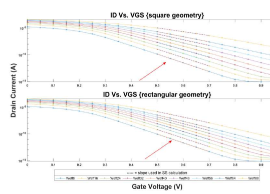


Figure 5: IDS Vs. VGS for different Weff values. Arrows highlight slope used in SS calculation. Ion and Ioff extracted at 0V and 0.5V respectively

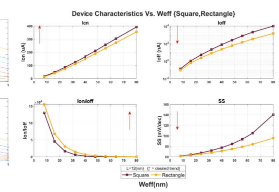


Figure 6: Device metrics for Square and Rectangle geometry study. Arrows indicate optimal/desired trend

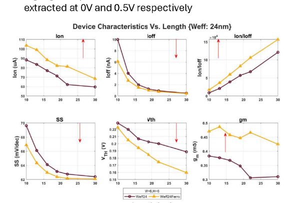


Figure 7: Device metrics vs. Length. Width & height are constant at 6nm. Arrows indicate optimal/desired trend

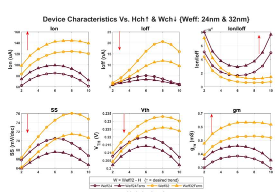


Figure 8: Device metrics vs. Hch↑ and Wch↓. Length is constant at 12nm. Arrows indicate optimal/desired trend

References

[1] G.E. Moore, "Cramming more components onto integrated circuits," *Electronics*, vol 38, no. 8, pp. 114-117, Apr. 1965.
[2] A. S. Bhat, M. S. Bhat, and M.S. Bhat, "Nanosheet field effect transistors-A next generation device to keep Moore's Law alive," *Microelectronics Journal*, vol. 114, p. 105141, Aug. 2021, doi: 10.1016/j.mejo.2021.105141.
[3] H. Amrouch, V. M. van Santen, G. Pahwa, Y. Chauhan, and J. Henkel, "NCFET to rescue technology scaling: Opportunities and challenges," *Proc. IEEE/ACM Int. Conf. on Computer-Aided Design (ICCAD)*, pp. 1-8, Nov. 2020, doi: 10.1145/3400302.3415621.
[4] M. B. Hachemi et al., "Study of structural and electrical properties of ferroelectric HZO films obtained by single-targetsputtering," *AIP Advances*, vol. 11, no. 8, p. 085004, Aug. 2021, doi: 10.1063/5.0058656.
[5] Q. Zhang, J. Gu et al., "Optimization of structure and electrical characteristics for four-layer vertically-stacked horizontalgate-all-around Si nanosheets devices," *Micromachines*, vol. 12, no. 3, p. 309, Mar. 2021, doi: 10.3390/mi12030309.

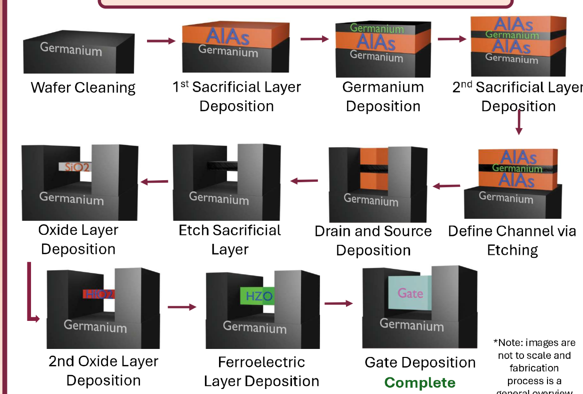
Results

Best Values		Improved %	FET Type	Height (nm)	Width (nm)	Length (nm)	Weff (nm)	Supply (V)
Ion	144.112 µA	+17.05 %	NCFET	6	10	12	32	0.5V
Ioff	0.923 nA	-34.3 %		10	2		24	
Ion/Ioff Ratio	8.028×10^4	+79.5 %		2	14		32	
Subthreshold Slope (SS)	62.08 mV/dec	-4.43 %		6	6	30	24	
Threshold Voltage (Vth)	0.202112 V	-2.74 %		10	2	12	24	
Transconductance (g_m)	0.633735 mS	+20.37 %		6	10		32	
Overall	**Ion:** 98.6 µA **Ioff:** 0.923 nm **SS:** 64.1757 mV/dec **Vth:** 0.20426 V **Gm:** 0.477 mS			2	14		32	

Conclusion

The integration of a ferroelectric material significantly enhanced the device's I-V characteristics. While the original structure with the best SS exhibited a relatively low on-current, the addition of the ferroelectric layer increased Ion by 17%, reduced Ioff by 34%, and reduced SS by 4.4%. There were no noticeable performance drawbacks, other than the addition of HZO would be difficult to fabricate. These results highlight the potential of ferroelectric materials to simultaneously achieve low SS and high Ion in advanced device structures.

Fabrication Process Flow



Future Work

- Simulate Multi-nanosheet NCFETs
- Study ferroelectric thickness scaling at 5 and 10nm
- Test HZO in integrated circuit applications, including inverters and SRAM cells

Acknowledgements

The team would like to thank our mentor, Ken Schulz, as well as our two SMEs, Dr. Rutwik Joshi and Muntasir Mahdi, for their knowledge and advice.

Design of a Ge and GeSn based Laser For Future Quantum Technologies

LEFT to RIGHT: Benjamin Pittelkau, Adam Hammond, Jared Houseman, Gobran Hanna, Tiernan Barber

SME: Muntasir Mahdi

CHALLENGE

Improve upon existing strained-Germanium quantum well laser design with tin-doped Germanium. Perform physics-based simulations of several configurations of barrier thickness, carrier doping and tin concentration and to maximize gain, minimize necessary current, and tune wavelength.

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VIRGINIA TECH.

Customer: Mantu Hudait

Tiernan Barber Lititz, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Hardware and Software Design

Course Comment: Great opportunity to learn high-level photonics design principles and adjust to leadership in an engineering context.

Adam Hammond Radford, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Working in power generation and control

Course Comment: Course was very interesting and allowed me to learn how lasers are designed.

Gobran Hanna Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: Product Engineering within the Semiconductor Industry

Course Comment: This course has taught the importance of team organization and delegation, as well as the ins and outs of low level semiconductor simulation and design.

Jared Houseman Riner, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I plan to pursue a career designing and repairing audio and studio equipment.

Course Comment: This course helped me better understand lasers and the semiconductor fabrication process. I also gained valuable experience coordinating with teammates, advisors, and customers.

Benjamin Pittelkau Round Hill, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: Biomedical device R&D

Course Comment: Very engaging project and learned way more than I thought I would about lasers.

Design of a Ge and GeSn based Laser for Future Quantum Technologies

Customer: Dr Mantu Hudait of ADSEL at Virginia Tech **SME:** Rutwik Joshi and Mahdi Muntasir
Team members: Tiernan Barber, Adam Hammond, Gobran Hanna, Jared Houseman, and Benjamin Pittelkau

Background

Why Germaniam-Tin (GeSn)? Germanium is an element very similar to silicon, meaning it can easily be fabricated into semiconductors and chip-scale integrated circuits.

- Germanium doped with tin: Direct band gap material capable of lasing.
→ Allows an **affordable, small laser** source fabricated using existing semiconductor infrastructure.
- Tunable lasers: Modifiable laser materials and structures for specific application.
→ Allows for **lasers of different wavelengths, power levels, and efficiencies.**
- Low loss operation in optical computing: **Optimize for low threshold current**
- High gain necessary to map environments: **Optimize for high net gain**

Optical Computers

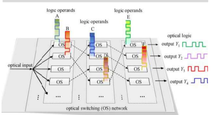


Figure 1 – Optical logic gates
Ideal: low threshold current

Environmental Imaging

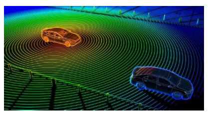


Figure 2 – Automotive LiDAR
Ideal: very high gain

Biomedical Imaging

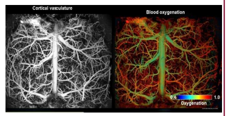


Figure 3 – Photoacoustic Microscopy
Ideal: high gain

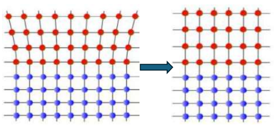


Figure 4 – Lattice Mismatched crystal structure (left) and lattice matched crystal structure (right)

- **Previous** Ge lasers used **crystal lattice mismatching to modify Ge bandgap** (left).
→ **Material degrades ('relaxes') over time** and leads to frequent manufacturing defects.
- **Our GeSn maintains a lattice match** (right).
→ Creates a **more stable material.**

GeSn Laser Modeling & Simulation

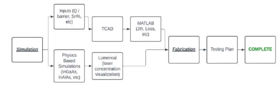


Figure 8 – GeSn laser simulation process flow.

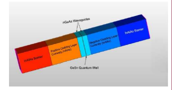


Figure 9 – The simulated structure in TCAD. Color indicates doping concentration where the left has more positively doped regions (red & orange), and the right has more negatively doped regions (blue and navy).

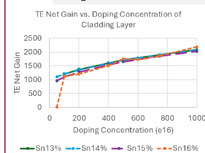


Figure 10 – Effect of doping concentration in the cladding layer on the net gain of the laser.

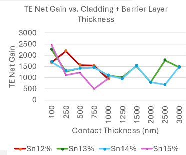
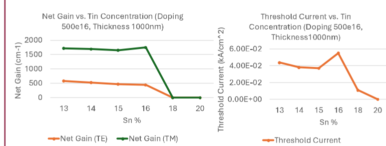


Figure 11 – Effect of cladding & barrier thickness on the net gain of the laser.



Figures 12 – Effect of varying Sn concentration on Net Gain (left) and threshold current (right) for a configuration with a doping concentration of 500×10^{16} cm^{-3} carriers and a cladding thickness of 1000 nm.

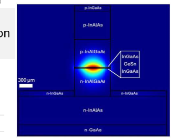


Figure 13 – |E|-Field mode profile simulation for our 6% tin configuration. The highlighted region demonstrates beam confinement within the GeSn QW by the InGaAs waveguide.

Simulation Results

PREVIOUS TEAM (e-Ge)	Material Loss (lower is better)	Jth density (kA/cm2) (lower is better)	Gain (cm-1)	Net Gain (cm-1) (higher is better)	Wavelength (µm)
Waveguide Indium Composition = 16%	**1935**	10.7	3042	**1107**	1.799
Waveguide Indium Composition = 16%	2202	3	3009	807	2.137
Waveguide Indium Composition = 16%	2475	**2.4**	2974	499	2.500

CURRENT TEAM (GeSn)	Material Loss (lower is better)	Jth density (kA/cm2) (lower is better)	Gain (cm-1)	Net Gain (cm-1) (higher is better)	Wavelength (µm)
Sn=6%, Doping 500e16, Thickness 2500nm	**1027**	0.0313	2214	1186	2.160
Sn=13%, Doping 500e16, Thickness 200nm	1338	0.0121	3212	1874	3.092
Sn=13%, Doping 500e16, Thickness 1500nm	1338	**0.00973**	3272	1934	3.092
Sn=15%, Doping 50e16, Thickness 100nm	1475	0.0266	3950	**2475**	3.601
Sn=15%, Doping 500e16, Thickness 1000nm	1475	0.0154	3116	1545	3.601

When **compared to previous strained-Ge designs** in Transverse Electric (TE) Mode, **all 5 GeSn designs:**

- Produce **higher net gain** (produce light more efficiently)
- Have **lower threshold current** density (less current required to operate the laser)

We highlight five configurations:

- One with a **low tin percentage** (easier to fabricate)
- Two with a high tin concentration and **high gain**
- Two **low-threshold-current-density** configurations at 13% tin.

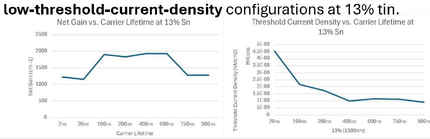


Figure 14 – 1500 nm 13% Sn configuration's carrier lifetime (how long the QW can retain carriers), gain, and threshold current.

Design of a GeSn QW Laser

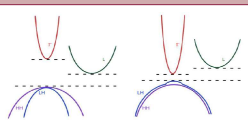


Figure 5 – Band structures of unstrained Ge (left) and GeSn (right)

- **Ge doped with Tin** lowers Γ-valley & increases L-valley **→ decreases bandgap energy to allow lasing** (Figure 5)
  - Electrons in lower Γ-valley require less energy to jump from the conduction band to the valence band (and vice versa)

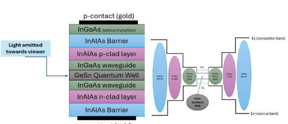


Figure 6 – Theoretical **ternary structure** for the GeSn laser used in electrical simulations [1].

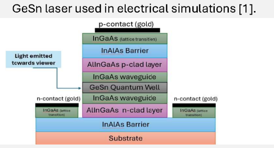


Figure 7 – Theoretical **quaternary structure** for the GeSn laser used in optical simulations.

GeSn laser structure

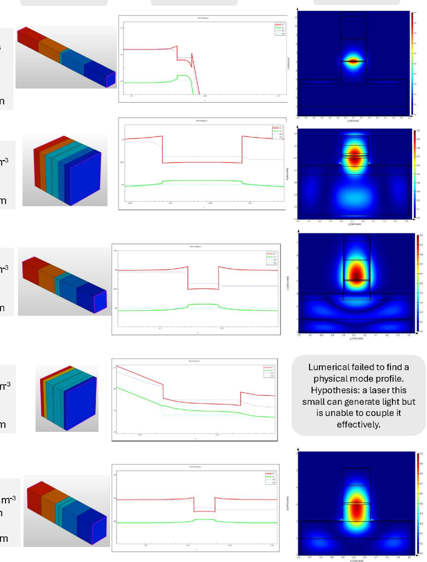
- **Step-like energy progression to easily funnel carriers** (electrons and holes) **into the quantum well** (QW) (Figure 6)
- **Confinement of carriers** creates a better-quality laser
- Our laser design for **optical simulations adds a cladding layer to** increase carrier and optical confinement (Figure 7).
- Final material stack includes a lattice transition layer to aid in the deposition of gold contacts.

Acknowledgements

We would like to thank our subject matter expert **Rutwik Joshi** for thoroughly introducing us to the optical physics of chip-scale lasers, our other subject matter expert **Mahdi Muntasir** for guiding us in the cleanroom, our mentor **Professor Schulz** for his instruction on presenting to an engineering audience and our customer **Dr. Hudait** for an opportunity to be a part of his research.

Device Configurations

Configuration
Sn = 6% Doping = of 500×10^{16} cm^{-3} Thickness = 2500nm Wavelength = 2.160um
Sn = 13% Doping = 500×10^{16} cm^{-3} Thickness = 200nm Wavelength = 3.092um
Sn = 13% Doping of 500×10^{16} cm^{-3} Thickness = 1500nm Wavelength = 3.092um
Sn = 15% Doping = of 50×10^{16} cm^{-3} Thickness = 100nm Wavelength = 3.601um
Sn = 15% Doping = of 500×10^{16} cm^{-3} Thickness = 1000nm Wavelength = 3.601um

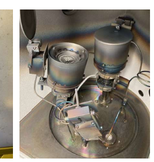


Prototyping

Strained Germanium Sample

Spin coating

Photolithography



Vapor deposit of contacts

Practiced and begun developing a process on pure Ge wafer, eventually to be used for GeSn

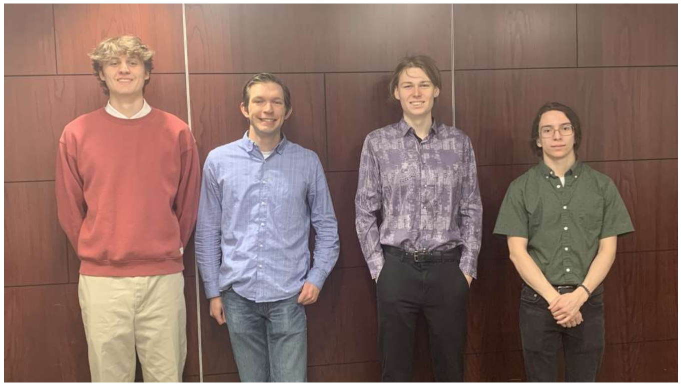
Conclusions

We have found that GeSn is promising in the field of optoelectronics: higher net gain and lower threshold current density compared to e-Ge. For future research: GeSn is an *expensive* wafer, and difficult to fabricate. Lower tin percentages are more practical. Larger concentrations of tin tend to homogenize causing crystalline defects.

References

[1] R. Joshi, L. F. Lester and M. K. Hudait, "Lattice Matched Tunable Wavelength GeSn Quantum Well Laser Architecture: Theoretical Investigation," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 31, no. 1: SiGeSn Infrared Photon. and Quantum Electronics, pp. 1-12, Jan.-Feb. 2025, Art no. 1500612, doi: 10.1109/JSTQE.2024.3434581.

Quantum State Generation Using Photonic Integrated Circuits



LEFT to RIGHT: Quinton Clark, Andrew Richardson, Russel Stewart, Sean Sechtman

CHALLENGE

Design and simulate a feasible on-chip quantum state generator and fully model two components of the system; an on-chip Hadamard gate, and an on-chip superconducting nanowire single photon detector. The models we design will undergo thorough testing under stress of non ideal temperatures, different power throughputs, and physical strain to test the efficacy of the photonic components in different conditions.

BAE SYSTEMS

SME: Yong Xu

Customers: Lu Goncalves-Getty and Jeremy Reeves

Quinton Clark Ithaca, New York

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspirations are to continue to learn and create as an engineer, using my experience to develop technology I can be proud of.

Course Comment: This course has challenged me to learn a subject matter at a more rapid pace than any course I have taken at Virginia Tech. This experience will serve as proof to myself that I can succeed even when I start from nothing.

Andrew Richardson Midlothian, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: I intend to pursue a master's degree in electrical engineering and then later work in the communications industry.

Course Comment: This course has given me the opportunity to work on a project that is beyond my realm of expertise, conducting research and developing software skills along the way.

Sean Sechtman Chesapeake, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to work in controls and robotics industry developing technologies that benefit society.

Course Comment: I have been challenged by this course to learn material independently of a traditional class outside of my major. As well as work as a team on an advanced project without clear guidance.

Russell Stewart Chesapeake, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I hope to enter the industry as an FPGA or ASIC engineer before returning to VT to pursue a Master's degree.

Course Comment: This senior capstone project has challenged me to work in a subject matter far outside of my degree's primary focus, and because of this I have proven to myself that I can learn just about anything.

QUANTUM STATE GENERATION USING PHOTONIC INTEGRATED CIRCUITS

VIRGINIA TECH | BAE SYSTEMS

Sponsor: BAE Systems - Jeremy Reeves and Jane Heyes **Subject Matter Expert:** Dr. Yong Xu **Mentor:** Professor Kenneth Schulz **Team Members:** Quinton Clark, Andrew Richardson, Sean Sechtman, Rusty Stewart

BACKGROUND

Quantum computing offers the potential to solve certain problems much faster than classical computers, particularly in AI, optimization, and cryptography. One promising approach involves using photonic circuits to create and manipulate quantum states, making them a key focus for developing high-speed quantum technologies.

In this context, our project focuses on designing and simulating a basic quantum state generator within a photonic integrated circuit, along with the components needed to test its functionality outside of simulation. The core elements we worked with include waveguides, which direct light to desired locations; optical couplers acting as Hadamard gates, which are fundamental to quantum state generation; and single photon detectors, which generate an electrical signal when detecting a photon.

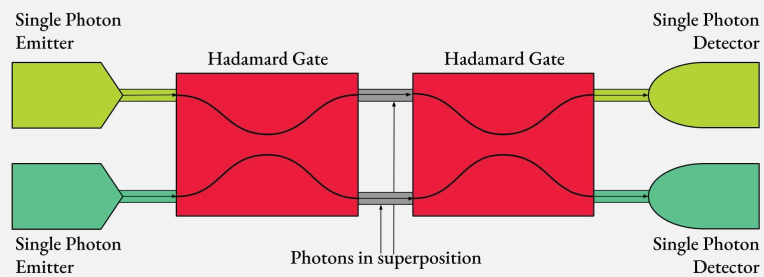
DELIVERABLES

- Full system simulation in Ansys INTERCONNECT
- 3D models of waveguides, Hadamard gate, and single photon detector using Ansys varFDTD, FDTD, and CHARGE
- Characteristics of waveguides, Hadamard gate, and single photon detector (losses, efficiency ratios, etc)
- Testing data for waveguides, Hadamard gate, and single photon detector under non-ideal temperatures and physical stresses

SYSTEM DESIGN

Our full system is not just a quantum state generator, but everything that is required to test a physical implementation of our quantum state generator. This includes external single photon inputs, waveguides to route photons, optical couplers acting as Hadamard gates, and single photon detector. Hadamard gates have the ability to take a known quantum state, such as 0 or 1, and turn it into an unknown state. Hadamard gates also have the ability to return an unknown state to its previous known state, and this is the main metric we used to prove that our optical couplers have the same functionality as Hadamard gates.

To test the system, one photon is injected into either the top (logic 0) or the bottom (logic 1) waveguide. The photon will then reach the first coupler, where it will be put into a state of superposition. The path it follows after passing through the first coupler is only known if the photon's modal type is also known. The photon then reaches the second coupler, where it should always return to the same waveguide it starts on. A photon detector should detect the photon as it leaves the second coupler and shows that the photon ended on the same waveguide that it started on.

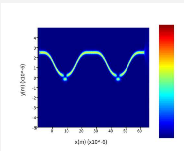


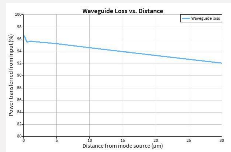
CHALLENGES

- Our biggest challenge by far was our lack of photonics knowledge prior to MDE.
- We overcame our slow start to simulation even though we didn't gain access to the Ansys Lumerical multiphysics software until December.
- Software learning curve
- Abysmal simulation times and hardware requirements
- Software Physics Limitations
- System redesigns and part changes lead to late stage pivots in project direction.

CONCLUSIONS

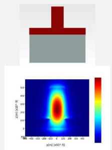
- We were successful in creating and testing a quantum state generator, as well as proving our conceptual design of a photonic IC is feasible through full system simulation and testing, and the development of an on-chip single photon detector model in our SPAD design.
- Our testing showed, as expected, that higher temperatures and physical stresses increase the losses in our system and decrease the efficacy of each component.



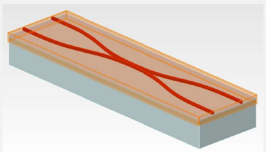


WAVEGUIDES & HADAMARD GATE

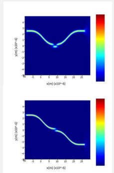
- Waveguides were implemented in Si_3N_4 using a "ridge" structure consisting of a 380nm tall, 220nm wide channel, and a 120nm tall slab beneath the channel.
- The slab layer beneath the channel allows light to couple between nearby waveguides.
- Transverse Electric and Magnetic (TE/TM) "modes" couple differently and allow the separation of light based on its "modal type".
- The Hadamard gate takes advantage of this property of light, bringing two waveguides close together to change the path of a photon using its modal type.



Waveguide cross section



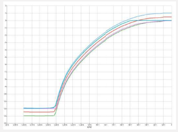
Optical coupler / Hadamard gate structure



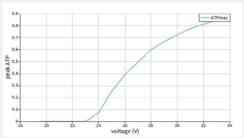
Optical power through coupler

SINGLE PHOTON AVALANCHE DIODE

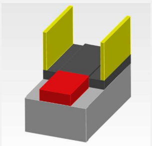
- Single photon avalanche diodes(SPADs) function by detecting individual photons through avalanche multiplication. This process creates a voltage drop across the diode which can be measured and interpreted as a photon being detected.
- The chance of a photon triggering an avalanche is known as the SPAD's Avalanche Triggering Probability(ATP). We can also interpret it as the probability of a photon being detected.
- Our design features a ~2x2 micron waveguide-coupled silicon diode reverse biased into its breakdown region



Diode Band Gap With Reverse-Bias Voltage of 15V



ATP vs. Reverse Bias Voltage



Single Photon Avalanche Diode

ACKNOWLEDGEMENTS

Jeremy Reeves, for the opportunity to work on this project and for his guidance throughout the year.

Jane Heyes, for sponsoring our project and offering valuable insight at critical points during our project.

Dr. Yong Xu, for his advice to most successfully create our demo.

Professor Kenneth Schulz, for mentoring us on how to clearly and confidently present our work.

Radiation-Hardened LLC Converter

LEFT to RIGHT: Bao Nguyen, Will Graham, Sam Craver, Zachary Rogers, Nguyen Nguyen

SME: Arthur Ball

CHALLENGE

The objective of the project is to develop a radiation-hardened, constant-frequency, constant-output GaN-based LLC resonant converter as a part of two-stage buck-fed LLC converter for space-grade power applications. The goal is to achieve high efficiency, compact design, good thermal management and reliable performance in a harsh environment and all the components are radiation-hardened.

Power Your Critical Mission Today

Customer: Brandon Witcher

Sam Craver Salem, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: Work with implementing renewable energy in the power grid

Course Comment: It was interesting creating a custom DC-DC converter that's not yet common in industry

William Graham Purcellville, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: Work on large scale projects, such as infrastructure, and have a direct positive impact on the communities around me.

Course Comment: This project has challenged my knowledge and helped me understand the importance of team work and communication.

Bao Nguyen Hanoi, Vietnam

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I want to expand the renewable energy industry to become more available and affordable for my hometown

Course Comment: It was an interesting, but one of the most complex projects that I have ever done; however, I was grateful that my team got received many great supports from our Mentor, SME and customer along the way.

Khoa Nguyen Hanoi, Vietnam

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Work with subjects related to power system and power electronics

Course Comment: Learned a lot regarding the design of DC-DC converter

Zachary Rogers Lexington, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My goal is to implement my skills and experience into real world applications, solving problems and forming solutions. As I continue to challenge myself, I want to develop more as an engineer by making improvements and generating new ideas throughout my career.

Course Comment: This course has given me the opportunity to experience a work-like environment by providing challenges as a real-world engineer. Furthermore, this made me learn how important time management and communication is essential to accomplish a project.

Radiation Hardened LLC Converter

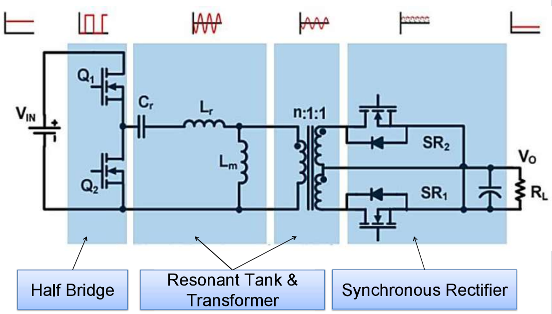
Sponsor: VPT, Inc. / Brandon Witcher **Subject Matter Expert:** Dr. Arthur Ball
Team: Sam Craver, Will Graham, Bao Nguyen, Zack Rogers, Nguyen Nguyen

Industry Relevance

DC-DC Power converters are essential in every kind of device, especially space & military applications where stability, voltage regulation, isolation, and protection are required for mission critical instruments.

Problem Statement

VPT would like to experiment with replacing their current phase shifted DC-DC buck converter implementation with a two-stage cascade Buck-LLC alternative. Team S25-23 mission is to design and implement the LLC stage to act as a constant frequency DC-DC transformer (DCX) for the two-stage system.

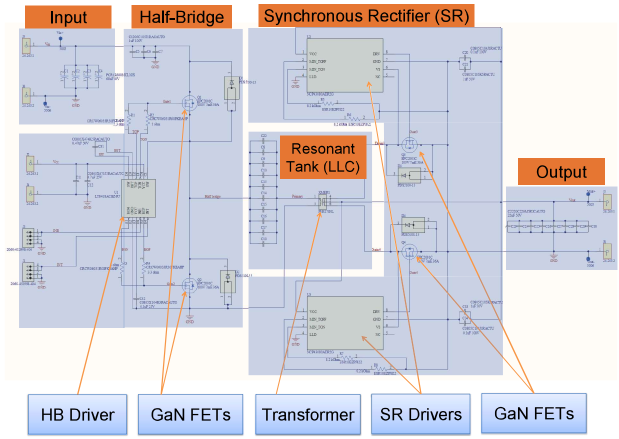


General LLC Converter Topology

Requirements

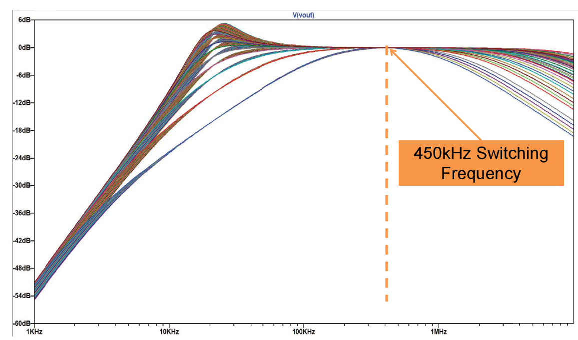
Specifications	Value
Output Voltage	20V
Max Load Power	400W
Full-load Efficiency	95%
Output Voltage Ripple	~ 100mV
Component Temperature Rise	≤ 40°C
Operating Temperature	-35°C to +85°C
Operating Switching Frequency	450kHz
Synchronous Recitification	N/A
Radiation Hardened	TID ≥ 100 krad(Si) SEE ≥ 80 MeV-cm2 /mg

Schematic



Shown above is our LLC converter schematic broken down by subsystem as denoted by the blue blocks in the schematic.

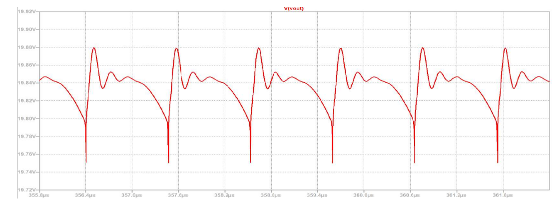
Monte Carlo Simulation



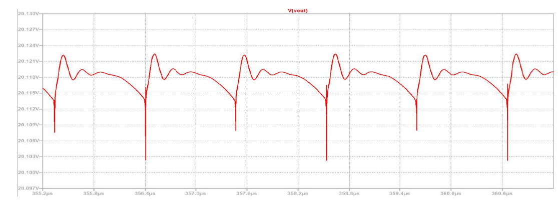
Frequency vs. Gain for the Resonant Tank with Load Variation and Component Tolerances

Shown above is the Monte Carlo sweep of the resonant tank gain from 10% to full load with a step of 10% and ± 20% tolerance for all resonant tank components with a step of 5%.

Results



Simulated output voltage with full load (113mV ripple)



Simulated output voltage with 10% load (20mV ripple)

Conclusion

LLC converters provides high efficiency, high power density, and operate at constant frequency which reduces the complexity of the overall system control compared to other DC-DC converters.

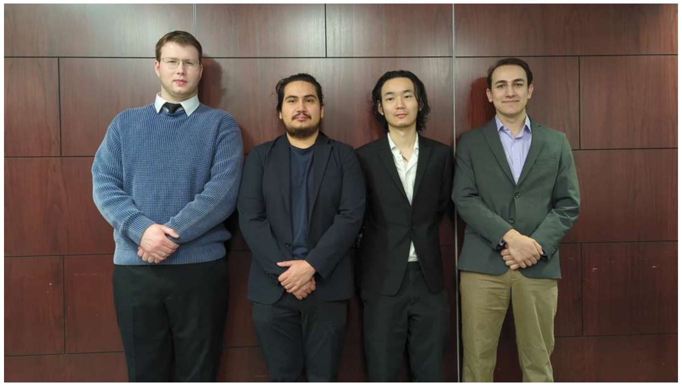
Future Work

- Incorporating rad-hard parts
- Decreasing board size and increasing power density
- Improve efficiency

Acknowledgments

We are grateful to Dr. Arthur Ball, Brandon Witcher, and Professor. Kenneth Schulz for advising and supporting our team throughout the whole project. We greatly appreciate the Bradley Department of Electrical & Computer Engineering for providing parts and equipment for the project.

Quantum Dot Single-Mode Laser Design and Fabrication



LEFT to RIGHT: Connor Kadel, Anthony Diaz, Zunyuan Wang, Sanjiv Chokshi

CHALLENGE

Design and fabricate a quantum dot laser diode with large contact pads that exhibits single-mode emission. Develop multiple cavity structures to suppress higher-order modes through integrated waveguide features, validating designs using Ansys Lumerical. Fabricate at least one functional laser diode using the Micron Technology Semiconductor Processing Lab.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

SME: Purv Bavishi

Customer: Luke Lester

Sanjiv Chokshi South Windsor, Connecticut

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I plan to pursue a career working with electric vehicles.

Course Comment: This course helped me to work collaboratively with others, enhanced my communication, and learn more about the semiconductor industry.

Anthony Diaz Massapequa, New York

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: In the future, I hope to utilize my degree to to its fullest. I hope I find a good company with fulfilling work, and to potentially go back to school after some years of industry experience.

Course Comment: This course is unlike anything I have experienced before. I am thankful for the opportunity and appreciate all the skills and lessons learned from it.

Connor Kadel Henrico, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: I aspire to develop my knowledge of Communications Engineering and RF systems in industry while pursuing a master's degree.

Course Comment: The hands-on approach of this course, particularly our time spent in the cleanroom, gave me valuable insight into semiconductor fabrication while also improving my teamwork skills.

Zun Yuan Wang Shanghai, China

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: I look forward to working in industry as an equipment engineer, where I will apply what I have learned in school to produce Photonic devices.

Course Comment: This course was an enriching experience that not only strengthened my engineering knowledge but also prepared me for future teamwork in the industry.

VIRGINIA TECH

Quantum Dot Single-Mode Laser Design and Fabrication

Team Members: Connor Kadel, Sanjiv Chokshi, Anthony Diaz, Zunyuan Wang
Customer: Dr. Luke Lester **Mentor:** Dr. Daniel Connors **SME:** Purv Bavishi

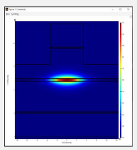
UPWARDS for the Future Network
micron | TEL | VIRGINIA TECH

Background

Introduction

Single-mode lasers play a crucial role in the telecoms industry, where they enable long-distance data transmission with fiber-optics. We have been tasked with designing and fabricating laser diodes with enlarged contact pads for simple probing and testing. However, these larger pads can support higher-order modes. Our team has developed special waveguide structures to attenuate higher-order modes.

Important Concepts



Cross-Section of Waveguide Showing Fundamental Mode

- Propagation Modes
Patterns that EM fields can travel through a waveguide. Each mode is only supported above a certain cutoff frequency.
- Fundamental Mode
Has the lowest cutoff frequency and is usually the most efficient for transmission.
- Quantum Dot (QD) Lasers
A type of laser that amplifies light travelling in it with layers of special nanocrystals, which are called quantum dots.

Applications

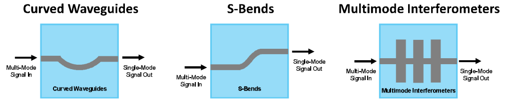
- Single-mode NIR lasers used in telecoms.
- Found use as laser scalpels for surgery.
- Better noise and temperature performance relative to other semiconductor lasers.

Specifications

- Wavelength: 1211nm (NIR)
- Probing Pad Area: At least 50um x 50um
- Cavity Length: 2mm
- Output: Single-Mode Beam

Proposed Solution: S-Bends

There are several options for waveguide structures that attenuate higher-order modes within the device. However, each type has distinct advantages and limitations. Three that were under consideration are featured below:

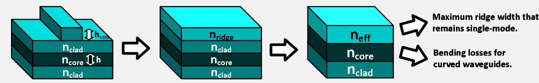


Advantages of S-Bends:
- Less sensitive to process variations compared to MMI's.
- Retains fundamental mode better than curved waveguides.
- Improved confinement of guided light.

Simulating the Structure

Analytical Models

By approximating the complex structure of the ridge as a four-layer slab waveguide, we could quickly estimate single-mode ridge dimensions and bending losses.



Model of ridge waveguide. Ridge height represented by h_{upp}, core thickness represented by h.

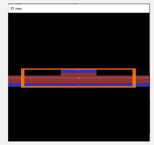
Waveguide approximated as a four-layer dielectric slab waveguide. Effective index of ridge shown as n_{ridge}.

The upper two layers are merged together to find the effective index of the etched cladding, n_{eff}.

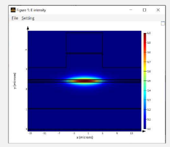
Analytical model of three-layer dielectric slab waveguide is well-defined, allowing for prediction of ridge behavior.

Simulated Approaches

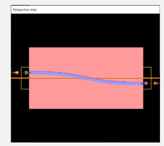
Modeled structure in Ansys Lumerical to account for material properties of wafer. Used the FDE solver to determine modes supported by waveguide, and FDTD solver to determine propagation effects.



Cross-section of ridge waveguide in FDE solver of Ansys Lumerical. The solver determines what modes are supported within the waveguide.



Analytical solutions for ridge dimensions were validated using the FDE solver. The figure depicts the FDE output of a single-mode waveguide.



Model of s-bend in the FDTD solver of Ansys Lumerical. The solver determines the s-parameters of the structure for specified modes.

- Using a combination of analytical and simulated methods, the team designed several waveguide structures to suppress higher-order modes.

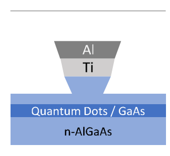
Fabrication Overview

Overview

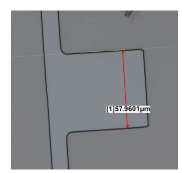
- Using contact lithography to obtain feature widths as small as 12um
- All etching processes rely upon wet etching
- Aluminum etched by MF-319
- Titanium etched with H_2O_2 warmed to 50°C
- AlGaAs etched with H_3PO_4/H_2O_2/DI using a volumetric ratio of 3:1:50

Materials Used

- Titanium Etch: H_2O_2
- Aluminum Etch: MF-319
- AlGaAs Etch: H_3PO_4 and H_2O_2
- Photoresist: Shipley 1813
- Developer: MF-319
- Deposition Machine: Kurt Lesker PVD75
- Mask Aligner: Karl Suss MA6
- Plasma Etcher: Samco RIE-1C



The ridge will become undercut during etching. To prevent this from affecting its optical properties, the feature widths were designed to be oversized.



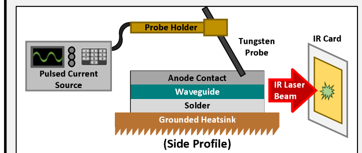
Microscope image of contact pad for fabricated laser. The measurement shows that it is within specification, as its smallest end is greater than 50um.

Testing the Device

Challenges

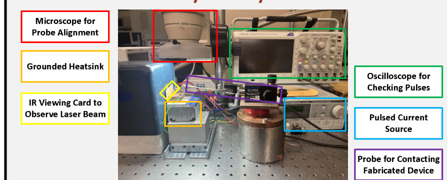
- The cathode of our devices are not metallized, complicating the process of testing the diodes.
- A thin layer of solder is applied between the bare side of the device and the heatsink.
- The small area of each contact pad requires a microscope for aligning the probe.
- Need to determine the threshold current for our fabricated devices.
- Pulsing current with a 1us period and 10% duty cycle to prevent thermal damage to laser diode.

Block Diagram



Simplified block diagram of test setup for our fabricated laser devices. Because the cathode of our devices are not metallized, we need to apply solder between the heatsink and diode.

Physical Layout



Physical layout of our test setup in the ADSEL lab.
As shown in the block diagram, the diode lays on top of the copper block and emits a beam towards the IR viewing card.

Conclusion

By the end of our project, the team has demonstrated:
- S-Bend waveguide structures are promising for attenuating higher-order modes.
- Created a process to fabricate laser devices using deposition and wet etching.
- Demonstrated that devices could be successfully tested using measurement setup.

Future Work

Several steps could be taken to improve the performance of our laser diode, including:
- Metallizing cathode of device for easier testing.
- Packaging the laser diode.
- Determine how FDTD simulations could be performed faster.

Acknowledgements

We would like to thank Dr. Luke Lester, Dr. Daniel Connors, and Purv Bavishi for supporting us throughout the project.

Special thanks to Don Leber, manager of the Micron Technology Semiconductor Processing Lab, for providing training and assistance to the team in the cleanroom.

Design of a High Data Rate Deserializer with 65nm CMOS

LEFT to RIGHT: Trent Fox, Jacob Kawada, Sean McShane, Jackson Andrew, Lucas Hartmann

SME: Jeff Walling

CHALLENGE

Design a high speed deserializer using TMSC 65nm CMOS technology. The device will allow throughput of 5 Gbps of serial data while keeping signal integrity intact. The device will work within size and power constraints and be able to be implemented as part of a larger CMOS device.

Customer: Jeff Walling

Jackson G. Andrew Goldens Bridge, New York

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: After I graduate I expect to pursue my masters in radio systems engineering. Once I complete my masters I hope to rise just high enough in where ever I work to be a engineering manager.

Course Comment: Senior design was able to accommodate every engineering student in getting a project and preparing the students for real work. However, I found that our project which didn't follow the standard engineering design cycle was inhibited by the course pacing.

Trent Fox Gloucester, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: Post graduation I will be working in the public sector to put my family in a better position financially and geographically.

Course Comment: This class was unique and challenging in a way that really drove me to put in late nights to prove to myself I could do it. Portions of the class with mentors and assignments felt mildly dissconnected however.

Lucas Hartmann Kensington, Maryland

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: After I graduate I hope to work at the at intersection of hardware and software, applying all the skills I have learned over my time in ECE.

Course Comment: I greatly appreciate this course and the freedom/uniqueness of the projects offered. I think the mentor/customer system works great for this course elevates it above a typical undergraduate capstone project.

Jacob Kawada Woodbridge, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: Throughout my time in college, I've fostered a deep passion for the endless applications of Radio Frequency (RF) and have made lifelong friends within the ECE majors. Being able to graduate with the unique major of Space Systems, I have been able to study an area deeply interesting to me. Through the collaborative effort of myself and my peers, friends, professors, and future employers, I hope to advance the field of human space exploration and allow mankind to venture the stars.

Course Comment: While working with peers, mentors, and SMEs, the course has allowed me to deep dive into electrical engineering concepts and tools that are not regularly taught at undergraduate levels and to learn how to effectively communicate complex questions/topics to those more and less knowledgeable in the subject than myself. I would like to thank Dr. Walling and Dr. Lohrabi Pour for their mentorship during this project and for giving us the keys to our success.

Sean Thomas Nicaretta McShane Vienna, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave
Bachelor of Science
Mathematics

Aspirations: Having pursued an undergraduate degree in Radio Frequency & Microwave (RF), I hope to advance the overall knowledge of humanity by completing a thesis. I am excited to do so in the field of RF, in at Virginia Tech Blacksburg campus.

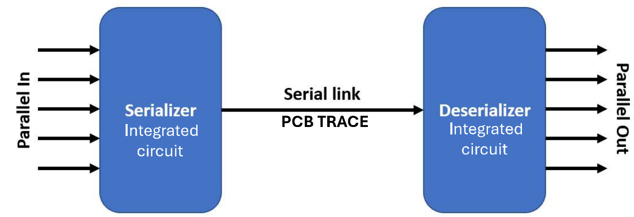
Course Comment: This course has been a rewarding journey of growth, learning, and Radio Frequency Integrated Circuit (RFIC) design. It has taught me how to dive into a subject with little to no prior knowledge and how to effectively read papers to understand the workings behind complex concepts. I am also deeply grateful to Dr. Walling for providing us with the opportunity and guidance throughout this project, and to Dr. Lohrabi Pour for his invaluable assistance in helping me understand the intricacies of this project.

Design of High Speed Deserializers

Jacob Kawada, Sean McShane, Jackson Andrew, Lucas Hartmann, Trent Fox
Virginia Polytechnic and State University, Department of Electrical and Computer Engineering

VIRGINIA TECH

SerDes System



Background

SerDes systems allow devices to communicate with each other high speed. Parallel traces lead to greater distortion between signals over long ranges. SerDes systems convert many parallel inputs to a single serial trace to avoid this, then convert back at the destination.

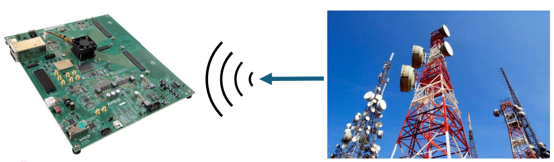
This deserializer is designed with our customer's needs and applications in mind.

Requirements (Simulation)

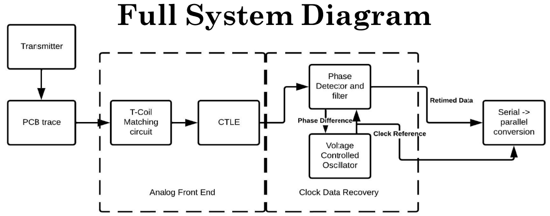
Data Throughput	Error Rate	Max. Jitter
5 Gbps	1e-12%	10ps pk-pk

The Problem

The MICS lab requires a 65nm process deserializer design to talk with a ZCU670 FPGA for 5G data applications. Our final deliverable is a Process Design Kit (PDK), containing simulations, layouts and documentation, to be produced at a later date.

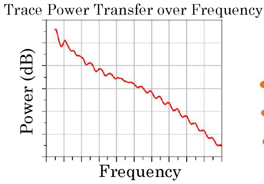


Full System Diagram

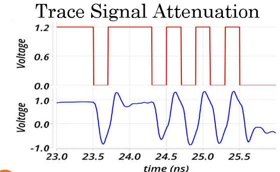


Problem Breakdown

At high frequencies, the PCB trace distorts and attenuates the data due to parasitic capacitance and inductances.



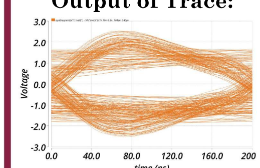
The goal of the analog front end is to convert the distorted analog signal to discretized bits of 0 and 1.



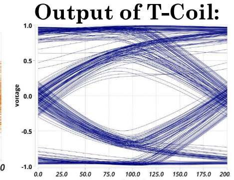
Analog Front End (T-Coil + CTLE)

The Analog Front End (AFE) amplifies and equalizes the incoming data. This is shown by eye diagrams, a statistical overlay of every bit passing through the channel representing signal clarity. Horizontal lines at the top and bottom represent bits 1 and 0, with crosses showing signal transitions. From full AFE testing it was found additional filtering would be needed to reduce symbol overlap.

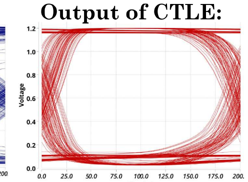
Output of Trace:



Output of T-Coil:

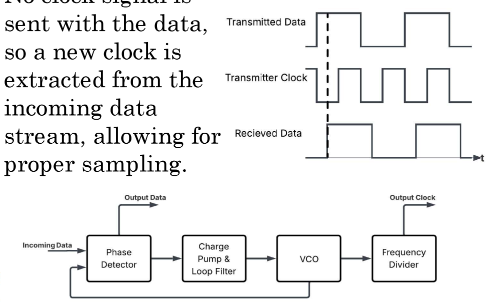


Output of CTLE:



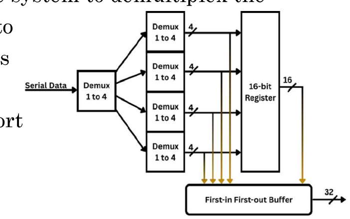
Clock & Data Recovery

No clock signal is sent with the data, so a new clock is extracted from the incoming data stream, allowing for proper sampling.



Series-to-Parallel

The analog signal is processed into digital data, deciding between 1 and 0 at high speeds. Synchronized data and clock signals from the CDR allow the system to demultiplex the series data into 32 parallel bits that will be stored in a short term buffer.



Results (Maximum Achieved)

Data Throughput	Error Rate	Max. Jitter
4.68 Gbps	In testing	In testing

Acknowledgements

A huge thank you to our Mentor Dr. Fariborz Lohrabi-Pour, and our Subject Matter Expert Dr. Walling, both of whom are part of the MICS Lab at Virginia Tech.

Guest Speakers

In addition to our project sponsors and subject matter experts, there were many others that significantly contributed to the success of this class. We want to take this opportunity to express our deep-felt appreciation and thanks for their contributions.

Dr. Creed Jones and Dr. Tim Talty, Virginia Tech ECE Graduate Programs

Best in Course Recognition for Base Course Performance

Fall 2024

ECE 1004–Introduction to ECE Concepts

- Michael Welborne

ECE 2024–Circuits and Devices

- Arjun Jayakumar
- Ryan Jeronimus
- David Mathews

ECE 2214–Physical Electronics

- Timothy Estrada
- Michael Liang

ECE 2514–Computational Engineering

- Noah Chin
- Justin Santana
- Sam Squier

ECE 2544–Fundamentals of Digital Systems

- Noah Chin
- Jun Elbert
- Hannah Petersen
- Elisabeth Presley

ECE 2564–Embedded Systems

- Sean Chan
- Yi Teng Ma
- Anthony Mai

ECE 2714–Signals and Systems

- Timothy Estrada
- Shaan Gupte

ECE 2804–Integrated Design Project

- Youssef Chebil
- Timothy Estrada
- Walter Lin
- Sebastian Marrufo

Digital Blood Pressure Cuff

LEFT to RIGHT: Timothy Estrada, Walter Lin

CHALLENGE

Our task was to create a fully functional arm blood pressure cuff capable of measuring mean arterial pressure, systolic pressure, diastolic pressure, and heart rate. This was accomplished through various stages of analog filtering and amplifying, as well as digital processing. We built our design using basic electronic components and an Arduino as well as a provided pressure sensor, pump, valve, instrumentation amplifier, and inflatable arm cuff. To validate our design, we had to get within 4% difference of a commercially available BP cuff for our output values.

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Timothy Estrada Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Bachelor of Science
Physics

Aspirations: After graduation, I plan to get a job in photonics, space systems, or signal processing, and I plan to work with cutting edge technology.

Course Comment: Despite being very challenging, this course provided valuable insight on what independent design is like, guided by restrictions, not instructions, forcing us to come up with solutions on our own.

Walter Lin Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I hope to work within the photonics or power systems field after graduating.

Course Comment: This course was an excellent way to explore the dynamics of working as a group. In addition, IDP provided an excellent opportunity to apply the knowledge acquired from other courses.

Blood Pressure Cuff Project

Team: Timothy Estrada & Walter Lin

Instructor: William Baumann

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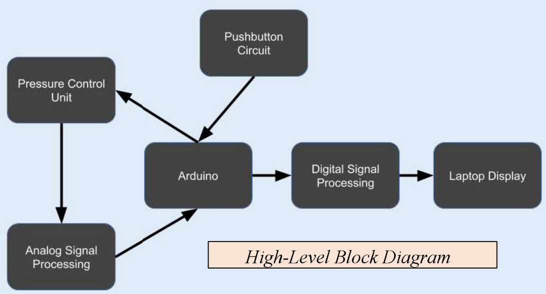
Background

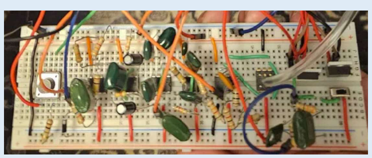
In this project, we built a fully functioning blood pressure cuff that was capable of measuring mean arterial pressure, systolic pressure, diastolic pressure, and heart rate.

The entire project was created using components from the first-year ECE take home kits and a given pressure sensor, instrumentation amplifier (INA), and blood pressure cuff.



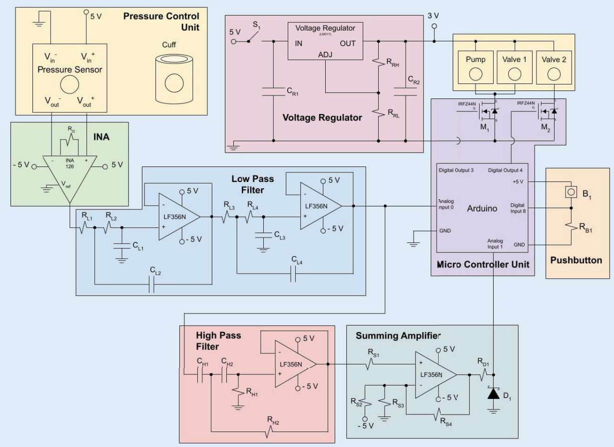
High-Level Block Diagram

Constraints



- A **4 V** pressure signal from the instrumentation amplifier (INA) corresponds to **200 mmHg**.
- **Filter** transfer functions should **match design** accurately.
- The **60 Hz wall noise** does **not exceed 1%** of the maximum **amplitude** of the **oscillometric signal**.
- The cuff should not exceed a **4% difference** from the cuff in blood pressure and bpm.

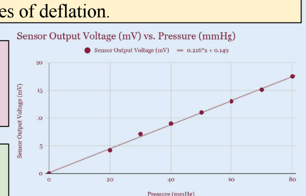
System Design



Pushbutton
Starts cuff inflation through the arduino.

Pressure Control Unit
Includes the cuff, motor, and valves which are used to inflate and deflate the cuff. Two valves for two rates of deflation.

Voltage Regulator
Steps down supplies from 5V to 3V as to not damage the pump. Includes kill switch for emergencies.



Pressure sensor gain measured with sphygmomanometer to properly calibrate INA gain.

INA
Allows the pressure signal to be amplified from a source of high impedance.

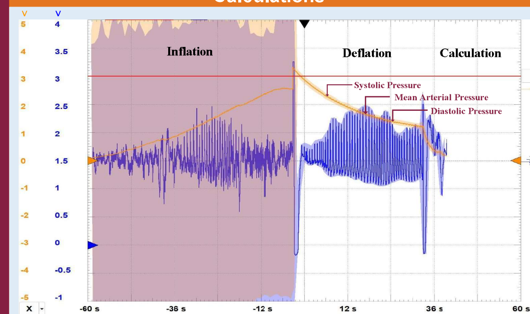
Low Pass Filter
Used to remove high frequency noise, such as 60 Hz wall noise, with a break frequency at 30.11 Hz (to include hearts rate below 180 bpm and 10 harmonics of heart rate). Outputs Pressure Signal.

High Pass Filter
Used to remove excess low frequencies comprising the decaying exponential offset with a break frequency at 0.496 Hz (to include heart rates above 30 bpm).

Micro Controller Unit
1. Starts/stops pump and opens/closes valves through MOSFETs
2. Used in digital signal processing to isolate desired signals

Summing Amplifier & Clipper
Used to increase the magnitude of the output signal and to keep oscillometric voltages between 0 V and 5 V so the arduino can process them. Outputs Oscillometric Signal.

Calculations



Pressure Signal (orange) representing the pressure within the cuff, and the Oscillometric Signal (blue), representing oscillations in the pressure signal due to the heart pumping blood.

Values recorded during deflation period (30 seconds).

- **Mean Arterial Pressure**: Pressure signal value when Oscillometric signal amplitude is at a maximum.
- **Systolic Pressure:** Pressure signal value when Oscillometric signal amplitude is 50% of maximum, before maximum.
- **Diastolic Pressure:** Pressure signal value when Oscillometric signal amplitude is 80% of maximum, after maximum.
- **Heart Rate:** The frequency of the Oscillometric signal.

Accomplished with peak2peak detection algorithm, storing each peak2peak and corresponding Pressure signal value in arrays, and comparing after deflation period has passed. Values outputted on serial terminal of arduino.

Test Results

- **4 V** pressure signal corresponds to **199.73 mmHg.**
- All measured filter **transfer functions matched** attenuation and break frequencies of **design calculations**.
- Using Fast Fourier Transform tool, found 60 Hz noise to be 2.5 mV at max (varied under different conditions). After analog signal processing, **60 Hz noise is at max 0.43% the amplitude of the oscillometric signal**.
- Systolic and Diastolic Pressures and Heart Rate compared with those provided by a store-bought BP cuff, immediately after each other for most accurate measurements.
  - For 3 trials at different times of day, all three values fell **within 4% difference**.

	Commercial Cuff Measurements			Our BP Cuff Measurements			Cuff Percent Difference		
Trial	Systolic Pres. (mmHg)	Diastolic Pres. (mmHg)	Heart Rate (BPM)	Systolic Pres. (mmHg)	Diastolic Pres. (mmHg)	Heart Rate (BPM)	Sys. Difference (%)	Dia. Difference (%)	Heart Rate Difference (%)
1	125	78	75	123.98	79.27	78	0.819	1.615	3.922
2	111	67	74	111.19	66.23	76	0.171	1.156	2.667
3	118	72	74	119.2	73.17	76	1.012	1.612	2.667

Future Steps

- Changing the display from a laptop to an **OLED Display**.
- Shrink design into a more **compacted** form.
- Invest in **faster pump and valve** and more **airtight tubing**.
- **Pulse width modulate** valve to accurately control deflation rate.
- Remove reliance on an oscilloscope by providing a **battery** as a **power supply**.

Home Audio System Design

LEFT to RIGHT: Sebastian Marrufo, Youssef Chebil

CHALLENGE

The goal of this project was to build a complete audio system that allows a user to adjust the equalization of an audio input and then directly drive a high-power load. Additionally, the system includes an OLED display for a spectrogram, providing real-time feedback on band adjustments. This is achieved using three sets of filters - one each for bass, mid-range, and treble - for the equalizer, along with a Class-D amplifier for a maximally efficient output. The system must minimize harmonic distortion caused by modulation, as well as limit the gain in order to maintain a stable output.

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Youssef Chebil Carthage, Tunis, Tunisia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspiration after graduation is to work on cutting-edge developments in robotics and AI/ML.

Course Comment: This course was incredibly valuable as it demonstrated how theoretical concepts from our ECE classes translate into practical applications, deepening my understanding and making previously abstract ideas much clearer.

Sebastian Marrufo Blacksburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation, I hope to stay at VT to pursue a master's degree in Electrical Engineering.

Course Comment: This course gives students the opportunity to apply what they have learned in class, as well as motivation to research and experiment with solutions outside of the usual curriculum.

Home Audio System Project

Team: Sebastian Marrufo & Youssef Chebil

Instructor: Dr. Tyler Milburn

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Objective

In this project, we designed and built a complete home audio system.

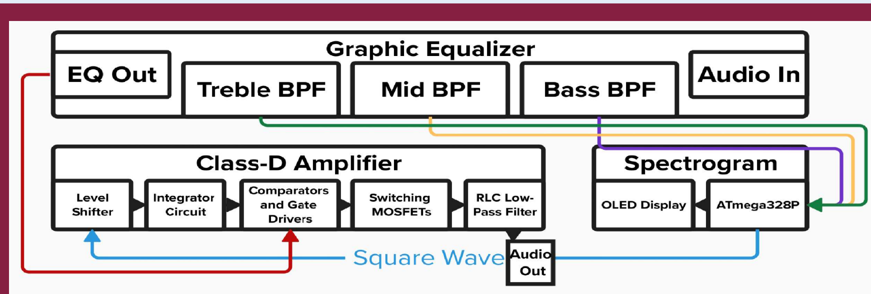
This system consists of:

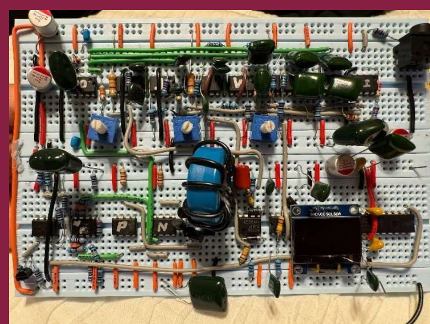
- Graphic Equalizer to boost or cut different audio frequency ranges.
- Class-D Amplifier to be able to drive high power audio outputs with maximum efficiency.
- Spectrogram on OLED display to visualize the frequencies present in the input audio and the effect of the equalizer.

Requirements

We were tasked with completing this project to at least the following specifications:

- The equalizer can achieve greater than, less than, and equal to 0dB on each of the three frequency bands.
- The equalizer has a ripple within 2dB at equal potentiometer settings across entire 100-8kHz audio range.
- At least 80kHz PWM Frequency for the amplifier.
- Deadtime in the switching circuit to prevent shoot-through current.
- Below 50mV ripple in the output and low harmonic distortion.
- No DC component to the output.
- Stable output with any potentiometer configuration.





Specifications

Graphic Equalizer:

- 3 Band-pass filters, with output controlled by potentiometers.
- Max/min gain limited to +/- 10dB to ensure stability.

Class-D Amplifier:

- 800kHz switching frequency for near-perfect modulation of input and -80dB attenuation at RLC Low-pass stage.
- Symmetrical 100ns deadtime so only one MOSFET is conducting at a time.
- Zero DC bias at RLC output.

System:

- Onboard ATMega328P, only connections required are power supplies, no computer needed.

Spectrogram

Results

(Top Right) – 2dB ripple at target full-range 6dB gain.

(Middle) – 800kHz PWM output of Class-D amplifier, successful operation of MOSFETs purely in saturation region to behave as a switch between power supply rails. MOSFETs operate passively with no heatsink.

(Bottom Right) – Output (Blue) after passing PWM through RLC Low-Pass filter perfectly recreates and amplifies the input (Orange) with no ripple/harmonics.

(Bottom Left) – Symmetrical dead-time added to the MOSFET gate signals, 100ns delay to turn-on edges to allow complementary MOSFET to fully turn off.