Team Avalanche Final Report

Portland State University
2024 Capstone Team
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https://github.com/PNevins971/ECE585Project

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Executive Summary

Team Avalanche, in conjunction with Galois Inc, is developing a low-cost avalanche transmitter for safety training in winter outdoor conditions. Focused on simulating distress signals, This transmitter will continuously send out a 457 kHz carrier modulated by a 1 Hz square wave (interrupted continuous wave modulation), which rescue teams use to locate individuals trapped in an avalanche. Our design will have an emphasis on affordability, efficiency, and easy assembly, the design aims to facilitate field testing for various mountain rescue groups. The project's key features include cost-effectiveness, operational efficiency, and user-friendly assembly, aligning with the crucial need for effective search and rescue training in avalanche scenarios. The transmitter, designed exclusively for training purposes, represents a valuable tool for outdoor recreation teams to refine their skills in simulated avalanche emergencies.

Our industry sponsor is Galois Inc. Galois is an engineering firm headquartered in Portland, Oregon with offices throughout the country. Galois specializes in the research and development of new technologies in the computer science domain. They have successfully utilized Rigorous Digital Engineering (RDE) practices for the development of complex cyber-physical systems relevant to national security. They develop solutions for clients such as DARPA, Department of Defense, Department of Energy, Department of Homeland Security, Intelligence Community, and NASA, among others. Galois' mission is to transform research into real-world application of systems that achieve a balance between the privacy/cost/speed to ensure reliability and trustworthiness.

We have been asked to deliver a project proposal, project documentation, a user guide, design logs, weekly check-ins, bill-of-materials (BOM), a public Git repository, one working prototype avalanche transmitter, a final report, capstone presentation, a poster for presentation at PSU.

The team's approach to this problem is to divide the system into subsystems. Then we plan to assign each subsystem to a team member to be responsible for. This allows us to rapidly make progress but also be able to become experts in each of our subsystems. This also allows us to pork in parallel and test in parallel while making progress on the entire project and reducing blockers.

Overall this project was a great success for the team. We were able to achieve a fully functioning prototype that is able to transmit our 457 kHz signal with a 1 Hz duty cycle properly. We were even able to pick this signal up with commercial avalanche transceivers up to 10 m away. We were able to achieve many of our requirements but fell short in a few categories. Even though we were not able to achieve every requirement for this project we were able to submit all of the deliverables and objectives laid out in the requirements section.

Background

Team Avalanche is a Portland State University (PSU) senior capstone project group. We will be working alongside Galois as our industry sponsor. Our project will be overseen by Joshua Mendez as the faculty advisor from PSU. Team avalanche has been tasked with creating an avalanche beacon for mountain rescue training.

Avalanche transceivers, sometimes also called avalanche beacons, have been present on the market for roughly 50 years.[1] They are small portable electronic devices that are worn by people in avalanche prone environments, particularly by anyone who enjoys snow sports such as skiing, snowboarding, and mountaineering. Modern transceivers operate on an international standard frequency and are constantly sending out a transmission at 457kHz. In the event of an avalanche burial, search and rescue teams or others in the surrounding area can switch their transceivers into search mode to receive all transmission signals in the area and indicate where a burial victim may be located. Since the first 10 minutes are the most critical in locating and rescuing those buried by an avalanche, the dependability of these devices along with the thorough training of search and rescue teams are of the utmost importance.

The downside of commercially sold transceivers is the cost that ranges between $300 and $600 USD. This makes it cost-intensive for search and rescue organizations to have a sufficient number of transceivers to both simulate multi burial scenarios and search for victims, often relying on team members' personal devices, borrowing from others or using older transceivers.

There exists a need for a low-cost transmission-only device that could be easily produced and acquired in larger quantities. This would primarily aid in simulating multiple burial scenarios where many devices are buried in snow while SAR teams utilize their commercial transceivers to locate them.

Open Source Projects

While no existing open source projects similar to ours are readily available, the team may utilize open source projects to aid in the development of this project. The team is going to use schematics available online or in datasheets for the power supply module, antenna and transmitter circuit. The team will research, select and combine schematics in line with the requirements listed in this proposal and document and align with Galois on all design choices and trade-offs.

Patents, Papers, Articles, Conference Proceedings

The transmitter technical specifications are subject to the European Telecommunications Standards Institute's three part standard for "Avalanche Beacons

[1] History of Avalanche Transceivers (https://en.wikipedia.org/wiki/Avalanche_transceiver)

operating at 457 kHz" ETSI EN 300 718-1 V2.2.1 (2021-06) Technical Standard[2,3] and applicable FCC regulations for non-commercial low power transmitters.

The avalanche transmitter we are making is different from the standard transceivers that are made and used. While a transceiver transmits and receives signals we are only building a transmitter for avalanche search and rescue testing. With the lack of receiving signals for our project,, the patents, papers, and conference proceedings researched are not entirely accurate, however there is an overlap in information applicable to our project.

The U.S. Patent No. 6,484,021 and 6,246,863 of Hereford et al July, 14th, 2005 are relevant to our project design since we are making a transmitter similar to which this patent describes.[4] The patent lays out the apparatus having a housing, a radio signal transmitter, a microcontroller, and a flip lid switch to determine sending or receiving transmitted signals at the specified frequency. Our design will not need a switch to select between transmit or receive, but will have parts similar to those listed. This digital transceiver patent will help guide our team on what a commercial product would need to be operational. Both of these patents come with various strengths and weaknesses which we will weigh and determine the best design for our project.

A factor that was learned though the research was electronic interference (EMI). This interference can be caused by common devices such as cell phones, heated gloves, the biggest interference are smart watches. These devices can cause EMI which will disrupt transceiver searches which we will have to mitigate as much as possible. To test and account for EMI for our final prototype the use of such devices in a testing environment is paramount to making a successful product. Electronic devices as close as 30mm have been tested and proven to disrupt a transmitting signal's integrity.[5] Since the antenna designs have historically been of a magnetic base with copper wire wrapped around it this will be one of the main focuses in our testing along with the PCB's measured EMI and signal integrity.

When looking at conference proceedings about new innovations in short-distance data communications, photo-receivers have been a highly studied field. These signal receivers are meant to receive transmitted signals in a fast and low noise environment for short reach photonic applications. The optical range of signal is way outside our operating range for our transmitters, but the silicon-germanium-silicon-heterojunction-based avalanche photodetectors could produce insight into other semiconductor technology and material we can utilize to majorly improve performance, longevity, and energy use of our transmitter.[6]

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[2] ETSI EN 300 718-1 V2.2.1 (2021-06) (https://portal.etsi.org/webapp/workprogram/Report_WorkItem.asp?WKI_ID=57408)
[3] ETSI EN 300 718-2 V2.1.1 (2018-01) (https://portal.etsi.org/webapp/workprogram/Report_WorkItem.asp?WKI_ID=10666)
[4] Abandoned CA patent application referencing patents (https://patents.google.com/patent/CA2443751A1/en)
[5] From: Meister, Dammert "The Effect on Consumer Electronics on Avalanche Transceivers" (https://arc.lib.montana.edu/snow-science/objects/ISSW14_paper_P4.13.pdf)
[6] Silicon-Germanium Avalanche Receivers (https://ieeexplore.ieee.org/abstract/document/9540259)

Concept of Operation

The purpose of the device is to aid search and rescue teams in training for locating individuals buried in avalanches. The device shall emit a signal detectable by avalanche transceivers at the standardized frequency of 457 kHz as established by The European Telecommunications Standards Institute (ETSI).

Existing avalanche beacons have both transmitter and receiver functionality. A transmitter-only device is proposed to provide a lower cost option to be distributed and used in training by SAR teams when searching for simulated victims. This low-cost option will be extremely valuable when training for multi-burial scenarios that necessitate multiple avalanche transmitters.

Ideally after the completion of this project, this product can be manufactured and distributed to local avalanche SAR organizations such as Portland Mountain Rescue (PMR). In order to bring value to these organizations, the device must be low-cost, durable, portable, reusable, and simple to operate. In addition to functioning appropriately, it should also be easily detectable by commercially available avalanche transceivers.

The final design documentation shall be open-source and available for individual non-commercial use. The documentation shall include all the necessary information to manufacture the device, including, but not limited to, circuit diagrams, bill of materials, 3D models, assembly, test documentation, and user guides. Users shall bear all responsibility for creating the actual device and any modifications they introduce.

Requirements

Stakeholders

The stakeholders for this project include:

- Galois - the industry sponsor for the team.
    - Led by Michal Podhradsky, with support from Ethan Lew, Frank Zeyda, and Joe Kiniry.
- Team Avalanche - the project team building the transmitter.
    - Team members: Allen Bakira, Dmitrii Fotin, Phil Nevins, Ken Sutter, Roberto Torres
- Faculty Advisor - Joshua Mendez
- Capstone instructor - Andrew Greenberg
- Portland State University - the institution overseeing the project .
- Search and Rescue Teams - An intended end user of the avalanche transmitter.
- Other snow professionals - Any rescue teams that may use the open source design in the future, including ski patrollers, mountain guides, and others.

RDE Requirements

1. **ETSI EN 300 718-1 Compliance:** The product must abide by the ETSI EN 300 718-1 Standard.
2. **Transmitter/Receiver with Antenna and Battery:** The product must include a transmitter/receiver with an antenna and a battery.
3. **On/Off Switch with Visual Indicator:** The product must have an on/off switch with a visual indicator.
4. **Signal Conveyance to User:** There must be a means of conveying information about the received signal to the user.
5. **Commonly Used Battery with Check Feature:** The product must use a commonly available battery with a check feature to ensure functionality.
6. **200 Hours Transmission at +10°C:** The product must be capable of transmitting for at least 200 hours at a temperature of +10°C.
7. **Positive Check for 20 Hours Transmission at +10°C:** A positive battery check must indicate the capability of at least 20 hours of transmission at +10°C.
8. **Safety Feature Against Accidental Transmission:** The product must have a safety feature to prevent accidental or involuntary transmission.
9. **Carrying System:** The product must include a carrying system that allows easy operation and safe placement, with a joint tensile strength of at least 50 N.
10. **457 kHz Transmission Frequency:** The product must operate at 457 kHz in transmit mode.
11. **FCC Compliance:** The product must comply with FCC regulations for transmitters.
12. **IP65-like Enclosure:** The product must be enclosed in an IP65-like enclosure.
13. **Detection Range of 30-70 Meters:** The product must be detectable by commercial transceivers at a range of 30 to 70 meters.
14. **Prototype Cost Below $200:** The final prototype must cost less than $200.
15. **Broadcast Pattern at 1 Hz:** The product must broadcast the specified pattern at 1 Hz.
16. **Indicator Lights for Transmitter Status:** The product must have indicator lights to determine the transmitter status.
17. **Waveform Transmission:** The product must transmit the specified waveform.

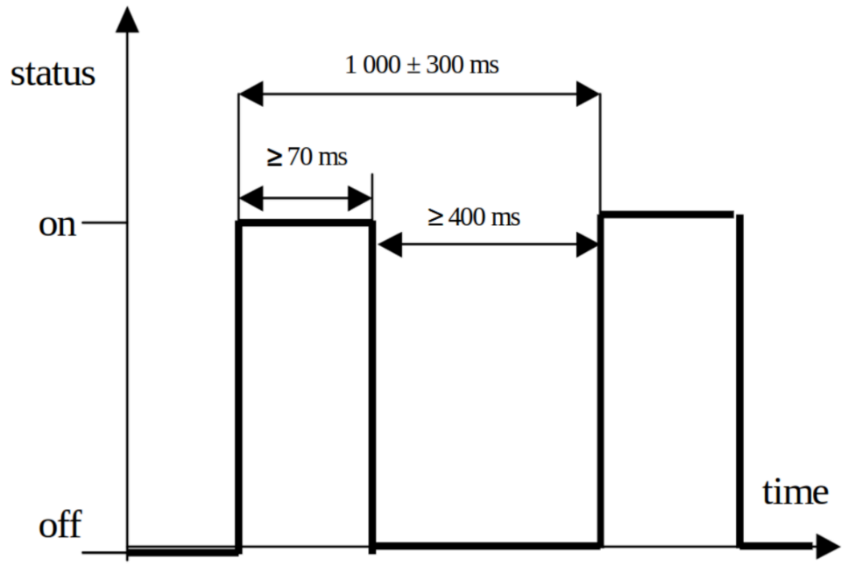


Figure 1

Must Have Requirements

- Ease of Disassembly and Reassembly: The product should be easy to disassemble and reassemble.
- Long Battery Life: The product should have a long battery life.
- Easy to Use Design: The product should have an easy-to-use design.

Optional Requirements

- Manufacturability on a Large Scale: The product may be manufacturable on a large scale.
- Advanced Signal Processing: The product may include advanced signal processing for high-end signal transmission.
- Sophisticated Display: The product may have a sophisticated display.
- Upgradability and Firmware Updates: The product may support upgradability and firmware updates.

Intellectual Property

For the Avalanche transmitter project Galois will own the intellectual property. The project will be open source and use BSD-3 license. The use of the BSD-3 license was requested by Galois.

Reasons for choosing BSD-3 license:

- Requested by Galois
- It is easy to implement and has few requirements.
- It is a free license to use by any team.
- Limited restrictions placed on use modification, and redistribution.

- It does not impose any liability or warranty on the original authors of the software.
- Compatible with every major copyleft license

Objectives and Deliverables

Our project objectives include:

- Develop a cheap avalanche transmitter that can be easily assembled and used for training purposes.
- A properly trained rescuer can locate a victim with our transceiver even under several feet of snow,
- Both the victim and a rescuer can operate the transceiver and efficiently. T
- Applying RDE techniques on a small scale project

Our project deliverables include:

- Project Proposal document to act as an agreement between the industry sponsor and the team for scope of work and deliverables.
- Documentation that describes the transmitter function, a user guide, user warnings/safety from outside elements and interference.
- Design logs weighing the pros and cons of each iteration that lead to our final prototype.
- Weekly check-ins with weekly progress reports.
- Bill-of-Materials (BOM) with sourcing and pricing of various components and functionality behind each part for easy future reference and redesigns. Throughout this project we will make notes of the updates, upgrades, and manufacturing services needed to make the product in the event that any manufacturing services used today are unavailable in the future.
- A public Git repository containing all aforementioned documentation.
- At least one working prototype avalanche transmitter, to be given to the industry sponsor.
- A final report on our capstone project. This document is to serve as the final report for the 2024 Team Avalanche capstone project.
- Capstone presentation at Portland State University with a poster for presenting the prototype

Design

Existing Design

When we started on this project there were no pre existing capstone projects to start from. However there are alot of commercial products available to use as a guide and to build off of. Our team ended up renting a commercial avalanche transceiver for testing. This was to ensure our prototype would work with the existing technology.

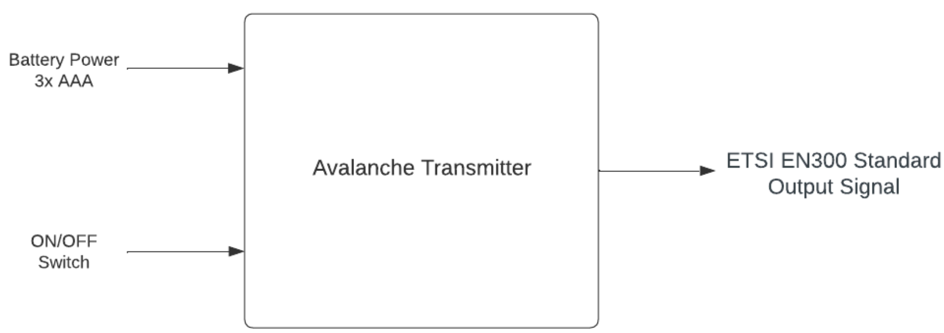
Initial product design

Our approach to designing this avalanche transmitter included breaking the project into smaller portions and working in parallel as a team on the various subsystems. Below we will discuss each subsystem and the development process throughout the project.

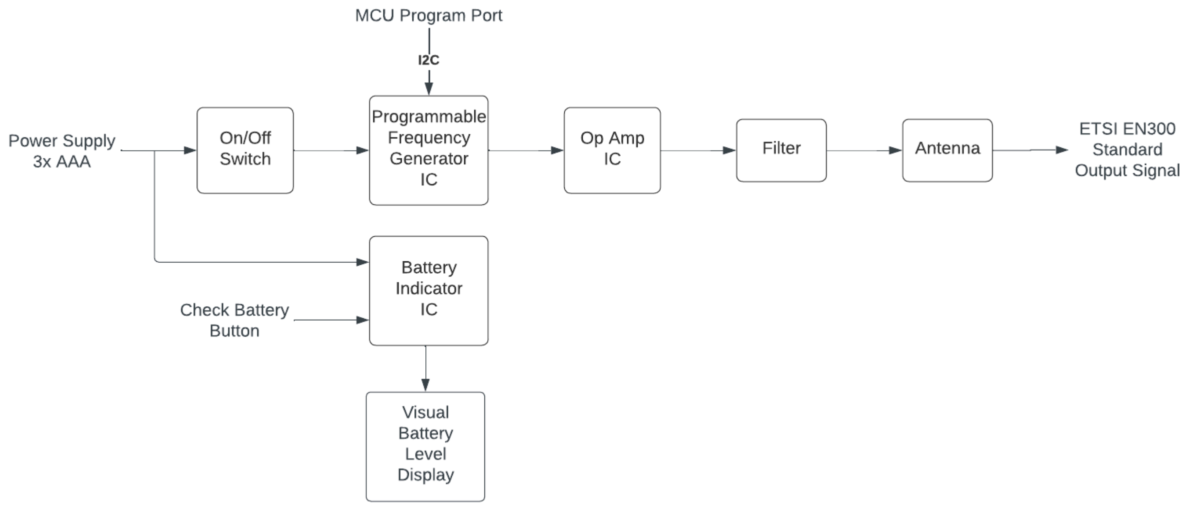
We first started with research and just trying to understand the project as best we could. During the research stage, we focused on putting together a more detailed concept of the final device. We scheduled interviews with members of Portland Mountain Rescue to better understand the expectations SAR teams might have for the design of the avalanche beacon. We also actively discussed the potential circuit designs with our academic advisor to identify possible approaches and their trade-offs and present our findings to Galois and determine the final design.

After the research stage we began the planning and implementation stage. During this stage we were able to create block diagrams and lay out the overall plan for the project. In this stage we created our schedule for production and assigned each team member the subsystem they were responsible for. Below we have included out block diagrams as well as a brief explanation of our plan for both hardware and software implementation.

Hardware architecture



L0 Block Diagram



L1 Block Diagram

Subsystems

Battery and Indicator Subsystem

The battery and indicator subsystem consists of the power source for the transmitter and a user interface to display the remaining battery level of the transmitter using a button and leds as indicators. The battery based power supply consists of 4 common alkaline AA batteries in series, housed in a COTS battery pack holder. This produces about 6.3V when new batteries are used, and should continue to provide power as low as about 3.3V. This battery pack is connected to the BATT power input pin of the Pro Trinket.

The battery indicator circuit consists of 4 red LEDS connected to 4 digital output pins of the Trinket Pro and a push button switch connected to an input pin of the Pro Trinket. A voltage divider circuit consisting of two 100k resistors connected in parallel to the BATT input pin and then connected to analog input pin on the Pro Trinket divides the input voltage by two so that the voltage can be read in at a safe range to the Trinket.

When the user activates the button switch, the voltage of the power source is read in via the analog pin, and a corresponding number of LEDs light up to indicate (25%, 50%, 75%, 90%). The calculation from voltage to percentage is accomplished by the “checkBattery” function running on the Pro Trinket.

Microcontroller clock generator subsystem

The microcontroller clock generator subsystem utilizes an Si5351 clock generator break-out board. This clock generator is programmed at start-up by the Adafruit Pro Trinket 3V, using a Processing script uploaded to the Trinket. The Si5351 is chosen due to its flexibility and open-source support, including Etherkit libraries that facilitate the use of its PLLs. The clock generator produces the required clock frequencies for the system, specifically generating a 457 kHz signal needed for the subsequent subsystems. This approach provides a precise and programmable clock source that aligns with open-source requirements.

Transistor switching subsystem

The clock frequency of 457 KHz from the clock generator chip and the duty cycle signal from the microcontroller are fed to an AND gate, which only outputs the 457 KHz signal when the duty cycle is on. The signal is fed to the transistor, the transistor enables the current at the 457 KHz frequency at the given duty cycle through the antenna. The current through the antenna determines the magnetic field strength of the antenna based on the gain ratio of the transistor. The circuit uses a potentiometer to adjust the gain ratio to reach the desired field strength.

Antenna subsystem

The Antenna subsystem will be a ferrite rod aerial antenna. We created this antenna ourselves for cost savings. This is a small magnetic loop antenna made of a ferrite rod with a coil of wire wrapped around it. This antenna makes an inductor that can be matched to a specific capacitance and propagate a signal at the desired 457kHz frequency. It also uses approximately 12.5mH should so that the capacitor can resonate with the ferrite rod. The parts can be purchased from off the shelf manufacturers and constructed by Team Avalanche. We will include instructions on how to build this in Appendix I.

Enclosure subsystem

The team then used an off the shelf enclosure and decided to use an IP65 rated Pelican M50 Case. This decision was based on how much time we had left and lead time on printing and creating our own enclosure.This case is small and fits in the hand well. It also holds all of our circuitry safely from the elements. If we had more time we would have designed and crafted our own enclosure but we wanted to focus on having an operational transmitter. Future iterations could easily see a smaller PCB using only SMD components and custom battery housing, this would allow for an enclosure primarily limited by battery and antenna size, making it about palm sized.

Once we were able to have each subsystem operational and pass out testing protocols. We then had time to print and solder all of our subsystems to a PCB. The circuit and the PCB was designed and simulated by Team Avalanche in KiCAD. The PCB was manufactured by OshPark. Team Avalanche soldered the PCB together using components purchased online from DigiKey or Mouser.

The main risks we ran into for this project is deviation from the ETSI EN 300 718 standard, especially as we found deviations during the final testing stages. Our goal was to examine what factors may cause deviations during the design stage, and build prototypes of regulated systems as soon as possible in order to have time for multiple rounds of testing and fixing as needed. Some of our subsystems took much longer than expected and thus we were not able to meet all of the standards but we were able to meet as many as possible.

Commercial Off-the-Shelf Products

The primary commercial off-the-shelf (COTS) product to be used throughout this project will be a modern functioning commercially available avalanche transceiver. This will be used as a source for product design, as well as to test and verify the ability of commercial transceivers to detect and locate our transmitters.

Team Avalanche plans to investigate the use of off the shelf components for the project. Currently the team has not chosen any specific components, only general classes of components and examples of existing components. Below is a list of the current proposed off the shelf components:

- Integrated frequency synthesizer - This would be a great way to produce the frequency at a low cost with high reliability compared to building the circuit.
- Crystal oscillator - This is used to provide a stable frequency. This would require more work and time to source and build if used as the primary frequency generator. However one would still be utilized as an external reference for the previous IC.
- Medium Wave Radio Transmitter - unlikely to be COTS, but will be constructed using COTS parts
- Bandpass or low pass filter to filter out unwanted harmonics.
- Antenna to send the signal out of the integrated circuit - made using COTS components
- Amplifier to amplify the signal from the integrated circuit to achieve the range noted in the requirements section - utilizing COTS components

Test Plan

We took a bottom up approach for testing of our project. While we created a test plant for top down and bottom up testing. We felt the bottom up approach fit our system much better so we proceeded to use the bottom up method. Both of our test plans can be found in Appendix III. In our bottom up test plan we analyzed each subsystem individually. We also analyzed each subsystem's corresponding inputs and outputs to ensure proper functionality and reliability of each subsystem. This allowed us to work in parallel but also test in parallel without being reliant on each other's systems for testing progress. We did complete a final top down test. In the top down test we analyzed the system as a whole and tested based on the assumption the system is working. There were also subtests to test the system in various test points to ensure proper signal tracing through the system. The top down test was nice to ensure the system was working as a whole once we were all able to bring our subsystems together for testing.

Results

This section will cover the results portion of our project. We will cover deliverables achieved and not achieved as well as the various successes and failures we encountered. We will go over the tests we performed and the results of these tests.

Overall this project was a great success for the team. We were able to achieve a fully functioning prototype that is able to transmit our 457 kHz signal with a 1 Hz duty cycle properly. We were even able to pick this signal up with commercial avalanche transceivers up to 10 meters away. We were able to achieve many of our requirements but fell short in a few categories. Even though we were not able to achieve every requirement for this project we were able to submit all of the deliverables and objectives laid out in the requirements section.

When we look at the deliverables laid out for this project we were able to meet and submit all of these deliverables for the project. For the project proposal document that acts as an agreement between the industry sponsor and the team for scope of work and deliverables. We were able to submit this and get approval early on in the project. The documentation that describes the transmitter function, a user guide, user warnings/safety from outside elements and interference will be included in this report when submitted at the end of the term. Design logs weighing the pros and cons of each iteration that lead to our final prototype are included in the Github repository associated with this project. Weekly check-ins with weekly progress reports were completed and submitted throughout the course of this project. We created a bill-of-materials (BOM) with sourcing and pricing of various components and functionality behind each part for easy future reference and redesigns. This BOM is included in this final report in the resources section. Throughout this project we took notes of the updates, upgrades, and manufacturing services needed to make the product in the event that any manufacturing services used today are unavailable in the future. We have populated a public Git repository containing all aforementioned documentation. We have completed a working prototype avalanche transmitter, to be given to the industry sponsor. This document will serve as the final report on our capstone project. We will be giving a capstone presentation at Portland State University with a poster for presenting the prototype

Now taking a look at the objectives laid out for this project. We were able to achieve all of the objectives laid out below during the time frame of this project. The team was able to develop a cheap avalanche transmitter that can be easily assembled and used for training purposes. We believe our buried transmitter would be detectable for 5-10m in real conditions, and while this range is not comparable with commercial transmitters (stated range of 70m, but closer to 30-40m in real conditions), it can still be valuable for training purposes, as the shorted detection range forces rescuers to search and practice more diligently even in a smaller training area. The transmitter is simple to operate so that both the victim and a rescuer can operate the transceiver and efficiently. We applied various RDE techniques on this small scale project including feature modeling and Clafer projections, discussed in detail at the end of this section.

Through testing we were able to identify some areas where we failed or fell short on this project. We used both bottom up testing methods as well as top down testing methods. In our tests we were able to find various bugs and issues throughout the iterations of the project. One area we have fallen short is the ability to pick up the signal from 30 M to 70 M away. We have only been able to achieve a signal response from about 10 meters away. This is due to antenna tuning and if we had more time we would have been able to tune our antenna to be able to precisely hit the range of 30 m to 70 m. We also believe if we would have had time in a RF chamber for testing in a non noisy environment we would have been able to see a bit more range than we had seen in the park we tested in. This would have been extremely expensive and out of the scope of this project. Another area where we failed or fell short was the 200 hrs of operation. We were only able to achieve around 80 hrs of operation. This is due to inefficiency in our circuit. We are ok with this failure because these are not intended to be used in real situations only training scenarios and batteries will be able to be changed after multiple rounds of testing. To fix this we could make our circuit more efficient or add more batteries. We also were experiencing quite a bit of signal drift over long periods of operation. We could fix this by using better, more expensive components. But this whole project was supposed to be cheap and used in training scenarios only. So we are ok if the signal drifts over a long period of time. Overall we feel like this project was a major success and we delivered what we set out to deliver. If we had more time we would have been able to achieve 100% of this project and the requirements. Our industry sponsor is happy with the work and design we came up with and so is our academic advisor.

Hardware Feature Modeling Using Clafer

Galois Inc frequently uses Clafer to model features throughout their software development process. “Clafer is a general-purpose lightweight structural and behavioral modeling language developed by GSD Lab, University of Waterloo, and MODELS group at IT University of Copenhagen. Clafer can be used for modeling of static hierarchical structures and for modeling the change of the structures over time (behavior). Clafer allows for naturally expressing variability in both the structure and behavior. The main goal of Clafer is to make modeling more accessible to a wider range of users and domains.”[7] Galois was interested in seeing how Clafer could be used for hardware feature modeling. We utilized Clafer Multi Objective Optimizer Visualizer (Moo

[7] Clafer Lightweight Modeling Language (https://github.com/gsdlab/clafer),(clafer.org)

Visualizer)[8], a web front end, to develop a Clafer program that would allow us to compare the set of Pareto-optimal variants based on possible features and components in our prototype. This included modeling component variables such as: cost, availability, reliability, ease of implementation, size, weight, and power consumption.

Using Clafer Moo Visualizer was an interesting exercise in early feature modeling in product design. This allowed us to see all the variants of component combinations and pick which direction we would take when designing our prototype. Some of the limitations of using Clafer had more to do with the team's inexperience using this program and our lack of base knowledge about proposed components going into this project. While it was very useful to gain experience with this language and with feature modeling, this level of thoroughness in feature modeling may not have been necessary on a project with less complexity in features and component selection like ours. Essentially since our deciding factors for features in this project were our short development time, cost, part availability, and ease of implementation for an end user, there weren't a large amount of features and variants to choose from and design decisions were fairly clear without the use of this tool.

However, as a case study in whether or not Clafer would be a useful tool in modeling complex hardware with more variability in features, this exercise very much supported that idea. We believe Clafer could be an extremely useful tool when making design decisions in the development of hardware. If a potential hardware had the possibility for many different ICs, passive components, and other physical components all with their own variance in quality, cost, reliability, etc., then Clafer would make quick work of visualizing and deciding the best design approaches to pursue. When scaled up to larger systems including multiple subsystems, all with their own complexity of design, implementation, manufacturing, software, and support, a tool such as Clafer would be necessary in order to track and make sense of the near endless combinations of potential design decisions. We believe that if a tool such as Clafer was used with discipline from the beginning of the hardware development process that many of the common design mistakes organizations make could be entirely avoided and as unforeseen issues arise the next best decision would already be modeled and ready to implement.

The Clafer model made for this project along with the visualization results can be found in Appendix VI and on Github.

[8] Clafer Moo Visualizer (https://github.com/gsdlab/ClaferMooVisualizer)

RDE Requirements

1. **ETSI EN 300 718-1 Compliance:** [Not Fulfilled] - The device was designed as an open source project and kit. Without extensive and expensive testing, we could not meet all of the compliance requirements.
2. **Transmitter/Receiver with Antenna and Battery:** [Fulfilled]
3. **On/Off Switch with Visual Indicator:** [Fulfilled]
4. **Signal Conveyance to User:** [Fulfilled]
5. **Commonly Used Battery with Check Feature:** [Fulfilled]
6. **200 Hours Transmission at +10°C:** [Not Fulfilled] - WIth our calculations on battery life compared to the need for it to be hand held led us to sacrificing this compliance requirement.
7. **Positive Check for 20 Hours Transmission at +10°C:** [Fulfilled]
8. **Safety Feature Against Accidental Transmission:** [Not Fulfilled] - Not applicable for the intended purpose of the device,
9. **Carrying System:** [Not Fulfilled] - Not applicable for the intended purpose of the device,
10. **457 kHz Transmission Frequency:** [Fulfilled]
11. **FCC Compliance:** [Not Fulfilled] - The device was designed as an open source project and kit. Without extensive and expensive testing, we could not meet all of the compliance requirements.
12. **IP65-like Enclosure:** [Fulfilled]
13. **Detection Range of 30-70 Meters:** [Not Fulfilled] - This is due to antenna tuning and if we had more time we would have been able to tune our antenna to be able to precisely hit the range of 30 m to 70 m. We also believe if we would have had time in a RF chamber for testing in a non noisy environment we would have been able to see a bit more range than we had seen in the park we tested in.
14. **Prototype Cost Below $200:** [Fulfilled]
15. **Broadcast Pattern at 1 Hz:** [Fulfilled]
16. **Indicator Lights for Transmitter Status:** [Fulfilled]
17. **Waveform Transmission:** [Fulfilled]
18. **Ease of Disassembly and Reassembly:** [Fulfilled]
19. **Long Battery Life:** [Fulfilled]
20. **Easy to Use Design:** [Fulfilled]
21. **Manufacturability on a Large Scale:** [Not Fulfilled] - The device was designed as an open source project and kit. Without extensive and expensive testing, we could not meet this requirement.
22. **Advanced Signal Processing:** [Not Fulfilled] - Only the transmission side of the original device was made, so this requirement was ruled out.
23. **Sophisticated Display:** [Not Fulfilled] - The device needed to be simple and easy to use.

24. **Upgradability and Firmware Updates:** [Fulfilled] - Using the Arduino Trinket and SI5351, updates can be run to the device.

Post Mortem

Overall this project was a positive experience with a lot of great learning aspects. Some of the following aspects went particularly well. We worked very well as a team throughout the six months we worked on this project. The team had excellent communication and work ethic. Each team member acted as an expert on their part of the project for the rest of the team. We also worked in parallel throughout the majority of this project. This was particularly effective because we were all able to take a smaller piece of the project and make it our own and master that part. Everyone worked well individually. Each team member showed up and performed well when ever called upon. Our design process worked very well throughout this project. We chose to each design a smaller subsystem then integrate them at the end. Sometimes this can make the integration stage challenging but it worked fairly seamlessly for our team. On the technical side of things that went well for the team. We felt using microcontrollers for the heavy lifting of signal generation was key to our success in this project. It allowed us to be able to fall on our extensive coding background to do some of the more complicated signal generation work. As a team we followed an iterative design process and this was very effective. We were able to have something working early then add to it instead of having an extremely difficult time integrating at the end. We also tried to have rapid prototypes throughout the process. This was helpful in maintaining the vision and seeing the project come to life.

While the majority of the project was very positive and had a lot of great things. As a team we recognized some areas that could have gone better or didn't go as well. One of the big things was having only one electrical engineering student and 3 computer engineers on an RF analog heavy project like this. It meant we had to rely on Allen to be the antenna expert and keep us informed on everything antenna related. As the antenna was one of the more difficult pieces of the project we recognize we should have started this first as it took the most amount of time. We vastly underestimated the amount of work that went into designing and tuning a custom antenna. Some of the other areas that did not go as well include trying to organize for team meetings and having extended work sessions. Everyone on the team either works a full time job or has a family and kids. This made meeting and working for extended periods as a group tough. We had to rely heavily on communication and online meetings.

If we could do this project over again there are some things we would change or do differently. First off if we could we would start meeting, researching, and brainstorming as soon as possible. We waited until the term in winter started to be greeted with a snowstorm that took a week or 2 away from working on this. We also would have laid out our objectives sooner to help us form the vision of the final project sooner. There are alot of things we wish we would have known at the beginning of the project. This includes how long building and tuning an antenna from scratch would take. Also how complicated building and tuning an antenna from scratch would be and labor and testing intensive it would be. Also we wish we would have known exactly how long it would take for each portion of the project. This would have been helpful for making timelines and planning.

If we had more time to work on this project there are many things we would add, change or present with this project. First we would have designed and built a custom case and enclosure. We would have had a logo or design on it, made it ergonomic to hold in your hand, and safely store and operate the transmitter. Second we would ensure it meets all required standards for a commercial project. This way we could sell ours for much cheaper than the commercial products already out there. We also would have built more prototypes to share and show off. We also would have done more testing and tuning. We would have used a much bigger RF chamber for testing as well as live scenario testing in the mountains.

Creating a smaller version of the PCB using all SMD components would allow for a smaller enclosure and making it more handheld. Only one set of the AND gates on the 74HC08 were utilized so this could be a smaller IC as well if available. Incorporating the battery pack into the case would also allow for a smaller footprint.

If there is another team to pick this project up in the future. Our current design works and is a great starting point for this project. The circuit could be optimized and so could the antenna. After you're able to optimize this circuit I would then begin testing and implementing changes to begin to make this compliant to all standards. From there they should start designing and packaging new production ready PCBs and enclosures. From there implementing a better battery system or even a custom rechargeable pack could be extremely helpful. Overall this project could be taken much further but currently it is in a great operable condition.

Project Resources

All major tooling and software used for this project is listed and described in Appendix II. Below is the Bill of materials for the project which includes everything we purchased throughout the time we worked on this project.

Item	Link	Link 2	Component Unit Cost	Qty Per Tx	Component Cost per Tx	Project Qty Purchased	Project Cost	Totals
Ferrite Rod	https://www.digik	-	$2.86	1	$2.86	6	$17.16	Final Per Transceiver Cost
Adafruit Si5351A Clock Generator Breakout Board	https://www.adaf	https://www.digik	$7.95	1	$7.95	7	$55.65	$56.89
Adafruit Pro Trinket - 3V 12MHz	https://www.adaf	https://www.digik	$9.95	1	$9.95	7	$69.65	
Battery Holder 4 x AA, On/Off Switch with Case	https://www.adaf	https://www.digik	$2.95	1	$2.95	7	$20.65	Total Galois Project Cost
(x) AWG Wire (x ft)				1	$0.00		$0.00	$390.84
AND Gate SN74HC08AN				1	$0.00		$0.00	
Transistor				1	$0.00		$0.00	Total Team Project Cost
Variable Capacitor				1	$0.00		$0.00	$12.76
Capacitor Ceramic 100pf				1	$0.00		$0.00	
Potentiometer				1	$0.00		$0.00	Total Rob Project Cost
Resistor (value for red led)				4	$0.00		$0.00	$0.00
Resistor (value for green led)				1	$0.00	1	$0.00	
Resistor (value for button)				1	$0.00		$0.00	Total Allen Project Cost
Push Button				1	$0.00		$0.00	$0.00
Red LED				4	$0.00		$0.00	
Green LED				1	$0.00		$0.00	Total Phil Project Cost
Slide Switch	https://www.digik		$0.76	1	$0.76	1	$0.76	
Pelican M50 Case				1	$0.00		$0.00	
O-rings?					$0.00		$0.00	Total Ken Project Cost
OshPark PCB			$32.42	1	$32.42	6	$194.52	$0.00
					$0.00		$0.00	
					$0.00		$0.00	Total Dmitrii Project Cost
					$0.00		$0.00	$0.00
Project Supplies Not in Final Tx								
Magnet Wire	https://www.digik	-	$12.00	0	$0.00	1	$12.00	
Proto Board (5x7cm) - 3pack	https://www.adaf	-	$2.95	0	$0.00	2	$5.90	
Ferrite Rod Smaller	https://www.digik	-	$0.85	0	$0.00	3	$2.55	
Transceiver Rental - PSU - Rob			$12.00	0	$0.00	1	$12.00	
Transceiver Rental - PSU - Allen				0	$0.00	1	$0.00	
OshPark PCBs					$0.00		$0.00	
EPL PCBs					$0.00		$0.00	

Budget and Resources

Galois' budget for this project is approximately $500 to research, design, test, and produce a final device that can be used in avalanche testing. Throughout this project we needed to purchase components and parts as well as manufacture PCBs and enclosures to meet the design requirements of the project.
The purchasing process involved team members sending a shopping list to Galois and upon approval, parts will be ordered by Galois either for a team member to pick up or delivered to a team member's address.

Galois will also provide a functioning avalanche transceiver for testing as well as access to a team of engineers with knowledge of system architecture and years of experience in project work. The Team will provide approximately 8-10 hrs of time per week per member towards the development of this project. As students we will utilize the Electronic Prototyping Lab (EPL) as a component store, as well as various CAD, simulation, and VCS's systems accessible under student licenses. We will also discuss design methodology, and FCC regulations and standards with faculty at Portland State

University to ensure adherence to the standards. We may utilize the RF lab to perform product testing as well as a team locker to house parts as needed. The capstone lab, a lab containing measurement, testing, and prototyping equipment will be utilized to prototype and manufacture the transmitter. Team members may also utilize their personal labs and workstations in the development of the transmitter. Some team members have standard electronic testing equipment, soldering stations, and 3d printers.

Conclusion

Overall this was an extremely positive and educational experience for the entire team. We had ups and downs throughout the process but mostly successes. We started slowly and then ramped up as time went on throughout the project. We were able to achieve the majority of our requirements and created a great project that could be used by mountain rescue teams for practice. This would also be at a much cheaper cost for practicing especially with multi burial situations. We hope to distribute this project as a DIY kit to various mountain rescue teams for use in practice. If we had more time we would have added a bit more functionality. We also would have added some exciting designs for the enclosure and PCB. Moving forward this project is basically plug and play for anyone looking through this document in the future. We are extremely proud of what we created in just six months. We worked well as a team and really came together when we needed to complete this project.

Appendices

Appendix I: User’s Manual

Users operation manual

Program Setup

1. Download the Arduino IDE. This will be needed to upload the code to the Adafruit Trinket Pro. (https://www.arduino.cc/en/software)

2. Install and update (if needed)

3. Open Arduino

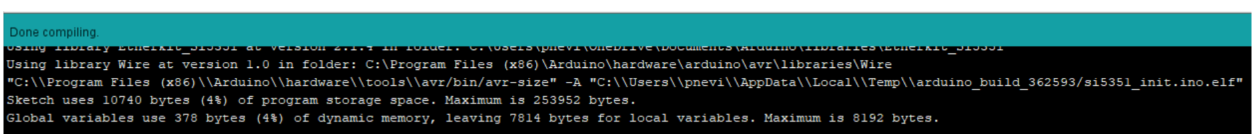
4. Connect the Adafruit Trinket Pros USB cord that came with it, from the Trinket to one of the USB ports on your PC

4. Copy the given code from the “AdafruitTrinketCode” file into the Arduino IDE window that is open

5. Now add the libraries for the SI5351. To do this, go to Sketch > Include Library > Manage Libraries… Search for and install: Etherkit SI5351.

6. Now go to Tools > Port: … This should be connected to your USB port, so it should be on any COM with a number. Select that one. It is different for each USB port on your PC.

7. Next, press the check mark  to verify the code is correct. If there are no



```
Done compiling.
Using library Wire at version 1.0 in folder: C:\Program Files (x86)\Arduino\hardware\arduino\avr\libraries\Wire
"C:\\Program Files (x86)\\Arduino\\hardware\\tools\\avr/bin/avr-size" -A "C:\\Users\\pnevi\\AppData\\Local\\Temp\\arduino_build_362593/si5351_init.ino.elf"
Sketch uses 10740 bytes (4%) of program storage space. Maximum is 253952 bytes.
Global variables use 378 bytes (4%) of dynamic memory, leaving 7814 bytes for local variables. Maximum is 8192 bytes.
```

errors, after compiling the sketch, you should see:

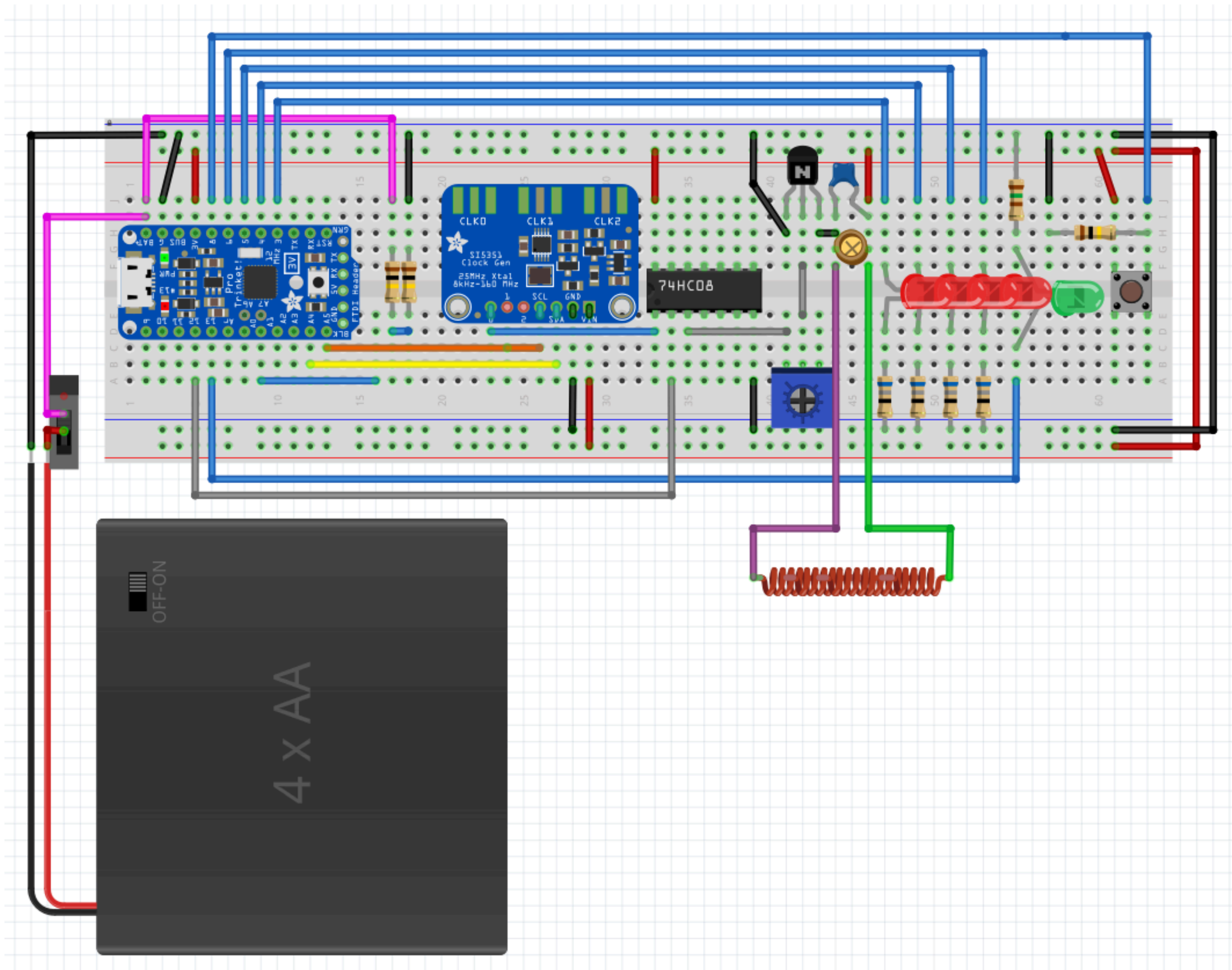
8. Next, if you see Done Compiling with a similar message about memory, press the upload code button . This may take a few minutes. You will see messages in red and scrolling text. When you see “Done Uploading” in place of “Done Compiling” on the IDE, you are ready to go. Now you can unplug your Adafruit Trinket Pro, and anytime you turn it back on, it will run the setup code we just uploaded. This setup code will program the SI5351 to produce a 457kHz square wave that is required for the Avalanche Transmitter to receive the signal. At this point, you should be able to receive the signal from the newly made transmitter, by your avalanche transceiver. If you are not picking up a signal, there was either an error that was missed while uploading the program to the Arduino Trinket, or there is a defect in one of the solder points made in the previous steps. Double check all of the solder points and start over at Step 1 of the “How to program” section.

Breadboard/Protoboard Setup

Connect all components as shown in the diagram below. Using a breadboard is an excellent way to verify the layout and ensure component functionality. For a more secure and field-ready product, you can use a soldered protoboard. The diagram applies to both setups. Additionally, a PCB prototype version is available on GitHub and can be found in the appendix. Following either this diagram or the circuit schematic will yield the same results.

An extra switch is optional and can be used if mounting the case upside down to allow access to the batteries or if the battery pack does not include a switch.

The Fritzing file and a higher-quality image are available on GitHub.



Antenna subsystem

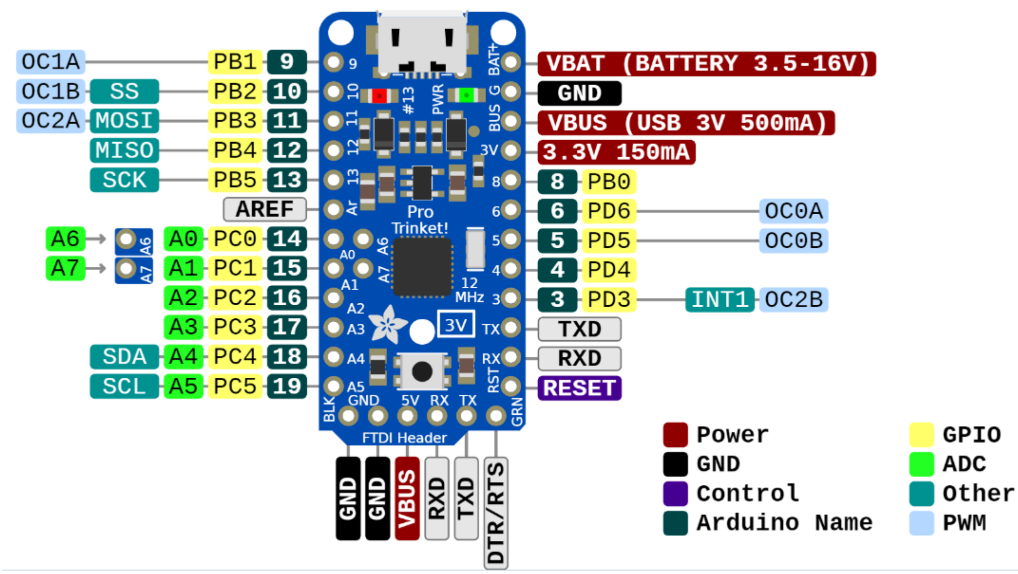
- The antenna will be made by having the ferrite rod, 36 AWG wire, 10pF capacitor and mechanical counter all together.
    - You will attach the ferrite rod to the mechanical counter, wrap a few loops of wire around the ferrite rod to prevent the wire from slipping, and rotate the mechanical counter about 500 times
- No programming required
- You will put the capacitor in parallel with the ferrite rod and create a tank circuit.
- Test the ferrite rod with wire windings by connecting each leg to an LCR meter to measure the inductance. Approximately 12.5mH should be the target goal for the capacitor to resonate with the ferrite rod.
- To disassemble this subsystem remove the capacitor and unwind the coil around the ferrite rod.

Adafruit Pro Trinket - 3V 12MHz

The trinket board is used to generate the required duty cycle, i.e. how frequent and long the “beeps” coming from the transmitter are. It also requests a particular signal frequency of 457 KHz from the frequency generator. Lastly, it operates the LEDs that indicate the battery charge and the optional switch to establish power supply to the rest of the circuit.

The pin that generates the duty cycle is Pin 12. This pin is connected to the AND gate, which performs a logical AND function on the duty cycle signal and the 457 KHz frequency signal, so that the 457 KHz frequency is toggled on and off.

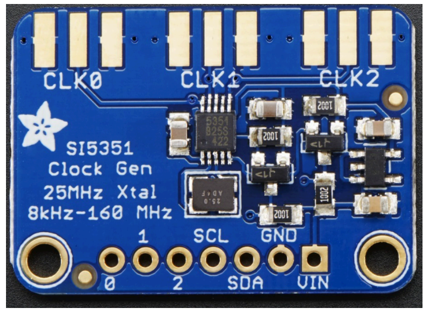
The SDA and SCL pins are connected to the SDA and SCL pins of the frequency generator. Pins 3, 4, 5, 6, 8 and 13 are connected to the battery indicator LEDs and the button that toggles the 3V supply to the rest of the circuit.Pin 20 reads the analog value from the batteries to determine the battery charge.



Adafruit Si5351A Clock Generator

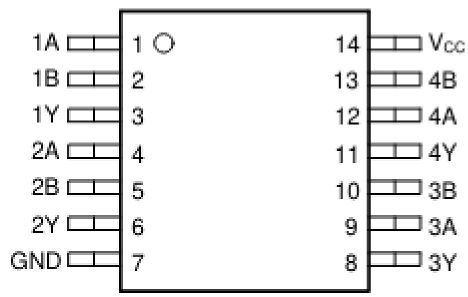
The clock generator outputs a consistent signal of 457 KHz. The programmed pin that outputs the signal is Pin 0. It is denoted as “1” on the schematic. This pin is connected to the AND gate, where it’s AND’ed with the duty cycle from the Trinket board.

The SCL and SDA pins are connected to the SCL and SDA pins of the Trinket.



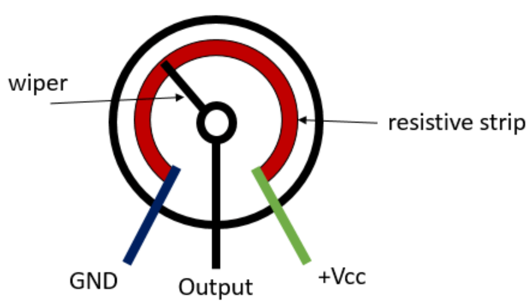
AND Gate

The AND gate used in this design is SN74HC08AN, but any other component that implements the AND function can be used. This component has 4 AND gates, so it can be swapped for a more compact component. The input pins of an AND gate are generally denoted as “A” and “B”, e.g. 1A and 1B for the design described in this manual. And output pins are denoted as “Y”. Reference the datasheet for the selected component to identify which pins of the physical package correspond to the inputs and output. For this design, the two input pins are 1 and 2, and the output pin is 3.



Potentiometer

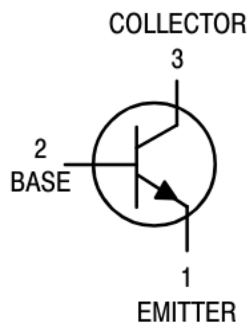
Potentiometers come in different packages. The potentiometer used for this design is 3296W-1-103, which can go up to 10 KOhm. It has a layout of three pins that go in the same row and fits well on a breadboard. When using a potentiometer, connect either of the outer pins to the input and the middle pin to the output. Make sure to ground the other outer pin.



Transistor

The transistor used in this design is 2N3904 - K51. This is a three pin NPN transistor. The pins are 1 - emitter, 2 - base, 3 - collector. When current is applied to the transistor base, it enables current from the collector to the emitter.

The collector pin (3) needs to be connected to the power supply through the antenna part of the circuit. The emitter pin (1) needs to be grounded. The base pin (2) need to be connected to the output from the potentiometer.



As the potentiometer is adjusted, it would range output resistance from 0 to 10 KOhm, which in turn would range the current to the transistor base.

The relationship between the base current and the collector-emitter current is defined by the formula below:

$$I_{C\rightarrow E} = \beta \times I_B$$

β is the scaling factor. For example, if current to base is 1 A and β is 10, the current through the transistor is going to be 10 A, actual possible values are provided in the transistor datasheet.

For the transistor used in this design, the scaling factor varies from 30 to 60. The design includes the potentiometer to adjust the base current which in turn changes the collector current and, consequently, the strength of the magnetic field the antenna generates.

Refer to Appendix IV: Schematic and layouts for exact connections between pins of different components.

Appendix II: Tooling

Team and Development Tools

The collaboration tools Team Avalanche will be using:
Github Version 3.12.4
Link: https://github.com/PNevins971/ECE585Project
How to install: Create an account on Github and log in then click on the link above to our repository.
Discord Version 229.20
Link: https://discord.com/
How to install: Click on the link to the Discord site, download and install the software or just use the web version. Make an account and log into the specified server.
Zoom Version 6.0.10
Link: https://zoom.us/
How to install:Go to Zoom link above. Download and install the software or use a web based version. Create an account and log in. Connect to the call you would like to be a part of.
Google Drive Version 89.0
Link: https://drive.google.com/drive/u/1/folders/0AGYZY_v6RHRRUk9PVA
How to install: Follow the link above and use the web based platform for storage.
Google Meet Version 23.0
Link: https://meet.google.com/
How to install: Follow the link above and use the web based platform for meetings.
Google Calendar Version 24.20.0
Link: https://calendar.google.com/calendar/u/0/r
How to install: Follow the link above and use the web based platform for scheduling.

Technical tools and Languages to be used by Team Avalanche:
KiCad 8.0.2 Version
Link: https://www.kicad.org/
How to install: Follow the link above download and install the software
LTSpice Version 24.0.9
Link: www.analog.com/en/resources/design-tools-and-calculators/ltspice-simulator.html
How to install: Follow the link above download and install the software
C language Version C17

How to install: No installation needed just start writing code in an IDE or on a notepad.

Appendix III: Team Avalanche Test Plan

Authored by: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin
04/07/24

Overview

This document is to serve as the test plan for Team Avalanches capstone project for electrical and computer engineering program. In this document we will cover top down testing and well and bottom up unit tests for our avalanche transmitter.

Top Down Testing

In this section of the test plan we will cover the top down testing method for the system. We will analyze the system as a whole and test based on the assumption the system is working. There will be subtests to test the system in various places to ensure proper signal tracing through the system.

Top Down Test Plan

Date test is completed	5/1/24
Tester name	Ken Sutter, Phil Nevins, Allen Bakira, Roberto Torres, Dmitrii Fotin

Purpose

The purpose of this test is to test that the system for the avalanche transmitter is working properly. It is also to test the robustness of the system. The test will walk you through a full system test including testing the system as a whole but also various subsystems through test points included in the test plan.

Equipment Needed

- System Equipment
    - Most recent updated software from Team Avalanche Github repository
    - Power supply/Battery circuit
    - Microcontroller/Clock generator circuit (with below items connected)
        - Battery indicator circuit
        - Transistor circuit
        - Amplifier circuit
        - Filter circuit
        - Antenna circuit
- Test Equipment

    - This is the test infrastructure needed operate your system, possibly in “test mode”
    - Screwdriver with phillips head small to medium sized
    - Multimeter
    - Oscilloscope
    - Digital DC power supply
    - Function generator
    - Receiver/Transceiver that detects 457 kHz range
    - Spectrum Analyzer
    - Vector Network Analyzer (VNA)
- Other Equipment
    - Static free area
    - Basic safety equipment
    - Device to record test outcomes
    - Laptop

Pre-Test Setup

1. Prepare work space for testing
    a. Clean area
    b. Layout circuit
2. Collect all materials needed and begin testing in a lab
    a. Including all test equipment listed above
    b. Including all other equipment listed above
3. Power on all test equipment

Top Down Test Steps

1. Open IP65 case
2. Ensure the batteries are properly seated in the battery pack
3. Test the battery power
    Press the battery indicator button
        i. Green light should show for full charge
        ii. Yellow light will show for medium charge
        iii. Red light will show for low charge
4. Turn the power to the system on.
    a. Move the power switch to the on position
5. (If needed) Flash the latest software to the microcontroller.
    a. Get the latest software from the Team Avalanche repository
    b. Plug the microcontroller into laptop using usb
    c. Use IDE to upload latest software version to the microcontroller
6. Once the circuit is functioning check the output frequency and range. This can be tested by using an oscilloscope or transceiver that can detect 457 kHz frequency.
    a. Ensure the frequency being emitted is 457 kHz and the range is under 30 m.
7. Use an oscilloscope to test the voltage and signal going into the antenna.
    a. Ensure it matches the desired value of 3 V.
8. Test the output of the filter to ensure no extra harmonics or frequencies are being

output into the world.
    a. We are looking for a 457 kHz signal with 1000 ms duty cycle total + or - 100 ms and on time is greater than 70 ms and off time is 400 ms or greater..
9. Test the input and output of the amplifier with an oscilloscope.
    a. Ensure proper gain value is observed.
10. Use an oscilloscope to test the output of the transistor.
    a. signal frequency should be observed at 457 kHz
    b. duty cycle should be observed at 1000 ms duty cycle total + or - 100 ms and on time is greater than 70 ms and off time is 400 ms or greater..
11. Test the output of the signal generation chip and the microcontroller.
    a. Ensure frequency is 457kHz
12. Test the antenna tuning by connecting the tank circuit to S1 and the other end to ground
    a. Set the VNA to S11 and measure the reflection frequency of the antenna. Make sure the reflection is at 457kHz
13. Test the trigger signal on the output of the microcontroller
    a. Ensure the signal is 2 V to 3.5 V to trigger the transistor
    b. Duty cycle should be 1000 ms duty cycle total +/ - 100 ms and on time is greater than 70 ms and off time is 400 ms or greater.
14. Test the output of the power supply.
    a. Voltage is between 3 V and 6 V.
15. Test the battery system
    a. Ensure the battery is seated properly and does not fall out or become dislodged.
16. Test the battery indicator circuit.
    a. Ensure it properly reads the voltage of 5 volts or higher. For full battery charge.
    b. Ensure it properly reads the voltage of 3 volts to 5 volts. For medium battery charge.
    c. Ensure it properly reads the voltage of 0 volts to 2 volts. For low battery charge.
17. Finally let the system run and transmit for 200 hrs.
    a. Record voltage of the power supply and the output of the battery indicator every 12 hours.

Post-Test Teardown

1. Power down the system
2. Close IP65 case
3. Pack in a safe place and avoid dropping the unit.

Top-down Test Plan Conclusions / Discussion

Overall the test was a success we did not pass every specification but this is a great starting point for tuning the circuit and getting it to meet the stated requirements,

Bottom Up Test Plan

This section of the test plan will cover the bottom up testing method for the system. We will analyze each subsystem individually. We will also analyze each subsystem's corresponding inputs and outputs to ensure proper functionality and reliability of each subsystem.

Subsystem tests to perform

- Power supply subsystem test
- Microcontroller and clock generator circuit subsystem test
- Transistor circuit subsystem test
- Amplifier circuit subsystem test
- Filter circuit subsystem test
- Antenna circuit subsystem test

Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin							
	Test Case Name:	Power supply subsystem test		**Test ID #:**			#1
	Description:	This test is designed to ensure its working at proper operating voltage for the circuit. The test will also test the battery indicator by testing the power supply at various levels of charge and seeing if the indicator is accurate or not. Finally a robustness test to ensure the power supply will power the circuit for 200 hours.		**Type:**			☐ white box ☐ black box ☐ ______________
Tester Information							
	Name of Tester:	Ken Sutter		**Date:**			4/21/24
	HW/SW Version:	1.2		**Time:**			9:27 AM
	Setup:	Use a multimeter or oscilloscope to take measurements. Use a timer to measure time.					
TEST	**INPUTS**		**EXPECTED OUTPUTS**	**PASS**	**FAIL**	**N/A**	**Comments**
1	4 AA batteries in battery holder		3 volts to 6 volts output	X			
2	Batteries input 5 volts or higher		Battery indicator reads full	X			
3	Batteries input 3 volts to 5 volts		Battery indicator reads medium	X			

4	Batteries input 0 volts to 2 volts	Battery indicator reads medium	X			
5	Connect the power supply to full circuit and let it run for 200 hrs.	Runs for 180+ hours.		X		
	Overall test result:		X			

Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin				
	Test Case Name:	Microcontroller and clock generator circuit subsystem test	**Test ID #:**	#2
	Description:	This test is designed to test the output of the microcontroller and clock generator circuit. The goal of this test is to ensure proper output signal of this subsystem.	**Type:**	☐ white box ☐ black box ☐ ______________
Tester Information				
	Name of Tester:	Ken Sutter	**Date:**	4/18/24
	HW/SW Version:	1.2	**Time:**	4:53 PM
	Setup:	Use power supply to apply power to the microcontroller and clock generator circuit. Use an oscilloscope to take output measurements.		

TEST	INPUTS	EXPECTED OUTPUTS	PASS	FAIL	N/A	Comments
1	3.3 volts to power the microcontroller and clock generator circuit.	Signal of 2 V to 3.5 V to trigger the transistor	X			
2	3.3 volts to power the microcontroller and clock generator circuit.	Duty cycle of 1000 ms +/ - 100 ms. On time is greater than 70 ms. Off time is 400 ms or greater.	X			
3	3.3 volts to power the microcontroller and clock generator circuit.	Clock generator frequency is 457 kHz.	X			
4						

	Overall test result:	X			

Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin				
	Test Case Name:	Transistor circuit subsystem test	**Test ID #:**	#3
	Description:	This test is designed to test the transistor circuit. We will be testing the output of the transistor as well as the trigger input to ensure proper switching and output signal.	**Type:**	◻ white box ◻ black box ◻ ______________
Tester Information				
	Name of Tester:	Ken Sutter	**Date:**	4/18/24
	HW/SW Version:	1.2	**Time:**	4:18 PM
	Setup:	Use an oscilloscope to take output measurements.Use frequency generator or microcontroller for input signals.		

TEST	**INPUTS**	**EXPECTED OUTPUTS**	**PASS**	**FAIL**	**N/A**	**Comments**
1	Signal of 2 V to 3.5 V to trigger the transistor	Frequency of 457 kHz.	X			
2	Clock generator frequency is 457 kHz.	Frequency of 457 kHz. Duty cycle of 1000 ms +/ - 100 ms. On time is greater than 70 ms. Off time is 400 ms or greater.	X			
3						

4						
	Overall test result:		X			

Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin				
	Test Case Name:	Amplifier circuit subsystem test	**Test ID #:**	#4
	Description:	This test is designed to test the output of the amplifier circuit. This test will also test the gain of the circuit to ensure its in proper range for signal amplification.	**Type:**	☐ white box ☐ black box ☐ _______________
Tester Information				
	Name of Tester:	Ken Sutter	**Date:**	4/18/24
	HW/SW Version:	1.2	**Time:**	3:04 PM
	Setup:			

TEST	INPUTS	EXPECTED OUTPUTS	PASS	FAIL	N/A	Comments
1	Input 457 kHz signal	457 kHz signal output 3 V output Gain of 2.0	X			
2						
3						
4						
	Overall test result:		X			

Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin				
	Test Case Name:	Filter circuit subsystem test	**Test ID #:**	#5
	Description:	This test is designed to test the various frequencies emitted by the circuit. This test will also test the filter circuit to ensure it is properly filtering out the harmonics not necessary for our signal.	**Type:**	☐ white box ☐ black box ☐ ______________
Tester Information				
	Name of Tester:	Ken Sutter	**Date:**	4/20/24
	HW/SW Version:	1.2	**Time:**	9:46 AM
	Setup:	Use an oscilloscope and spectrum analyzer to take output measurements. Use a function generator or micro controller for input signals.		

TEST	INPUTS	EXPECTED OUTPUTS	PASS	FAIL	N/A	Comments
1	Input 457 kHz signal	457 kHz signal with no harmonic frequencies.	X			
2						
3						
4						

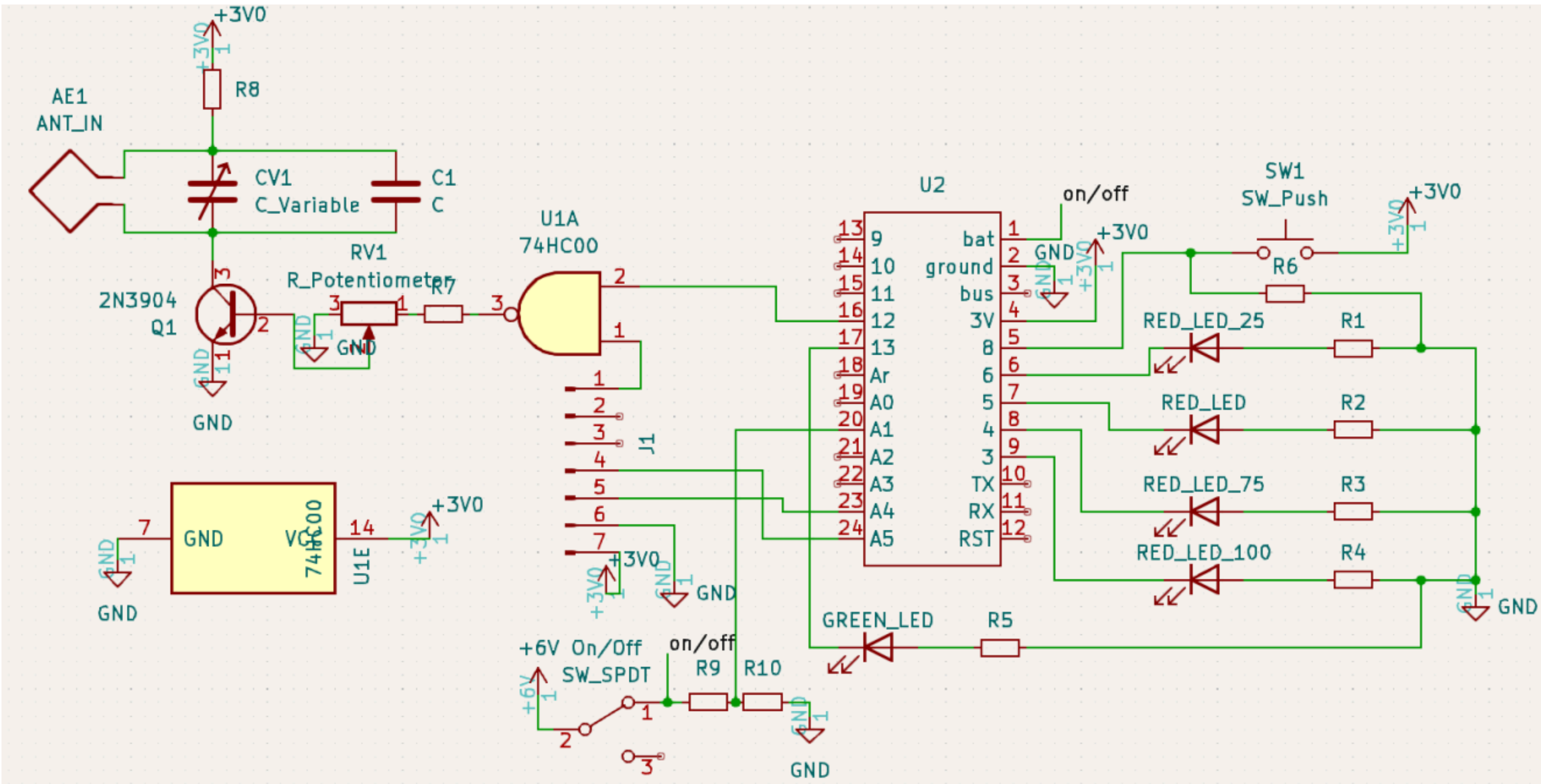
	Overall test result:		X			
Test Author: Ken Sutter, Phil Nevins, Allen Bakira, Rob Torres, Dmitrii Fotin						
	Test Case Name:	Antenna circuit subsystem test	**Test ID #:**			#6
	Description:	This test is designed to test the antenna circuits operation. This test will also test the range of the signal transmission as well and signal accuracy and strength.	**Type:**			☐ white box ☐ black box ☐ _______________
Tester Information						
	Name of Tester:	Ken Sutter	**Date:**			4/20/24
	HW/SW Version:	1.2	**Time:**			10:12 AM
	Setup:	Use a VNA and spectrum analyzer to take tuning measurements of the subsystem. Use a function generator or micro controller for input signals. For the final test use a production avalanche transceiver to detect the signal.				

TEST	INPUTS	EXPECTED OUTPUTS	PASS	FAIL	N/A	Comments
1	Connect antenna tank circuit to port 1 and ground on a VNA	A reflected signal with a significant dip 457kHz	X			
2	Input 457 kHz signal (Function Generator) to transmitter and set transceiver to search mode	Able to receive 457 kHz signal and hear beeping from the transceiver	X			
3	Input 457 kHz signal (Battery Pack) and set transceiver to search mode	Able to receive 457 kHz signal and hear beeping from the transceiver 0 m to 30m away	X			
4						

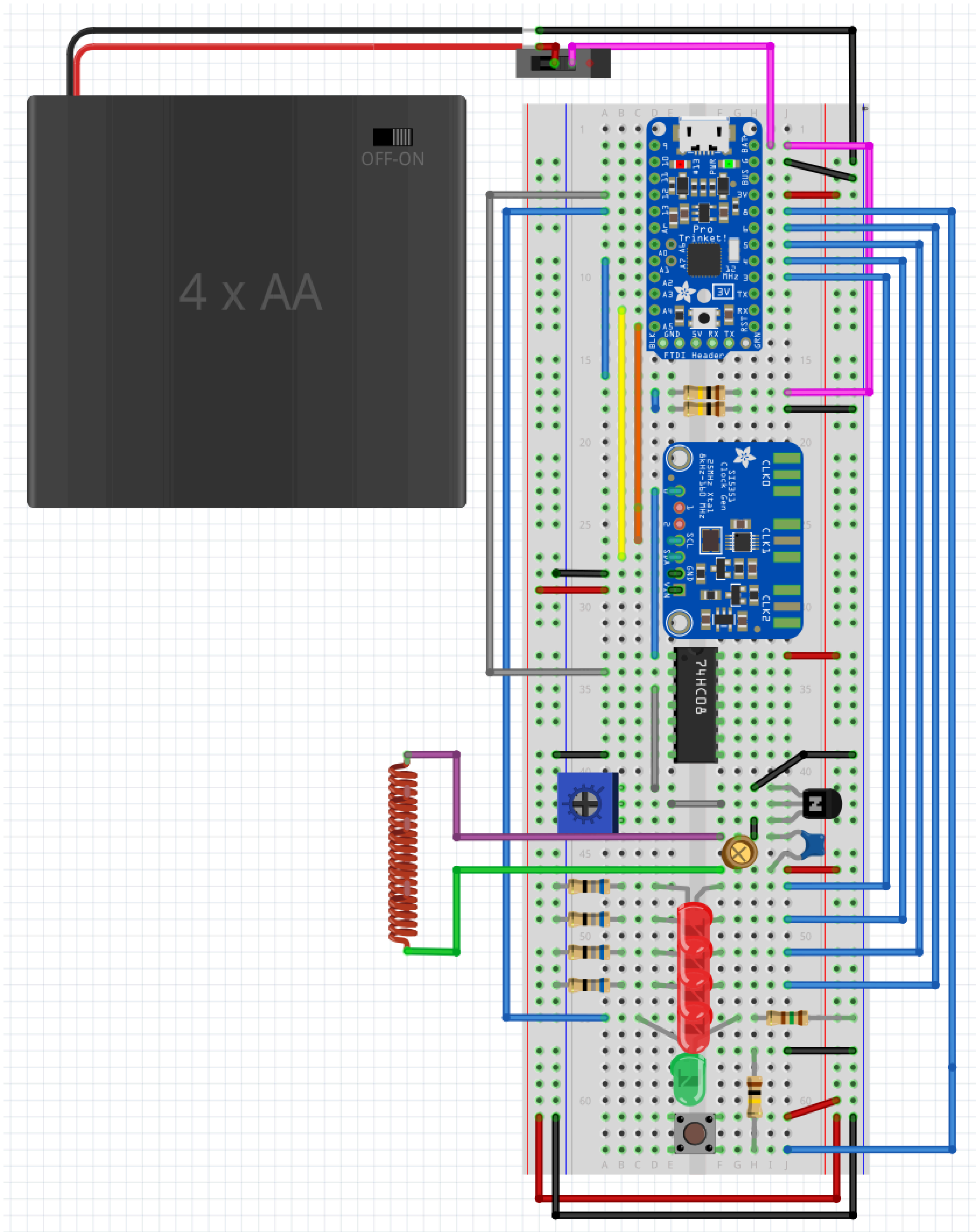
	Overall test result:	X			

Appendix IV: Schematic and layouts

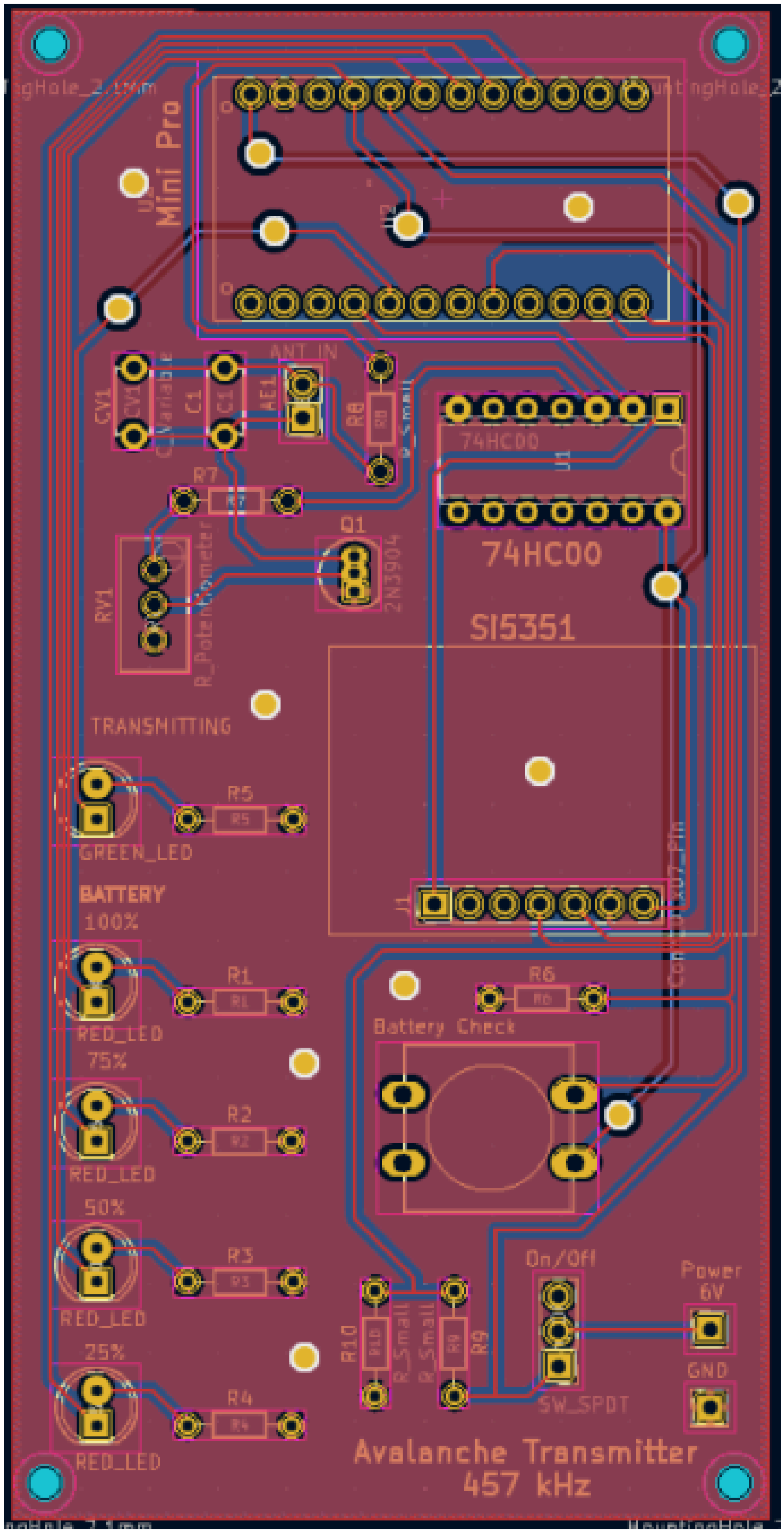
Final circuit schematic for avalanche transmitter.



Breadboard Layout and Wiring Diagram. (Fritzing Diagram)

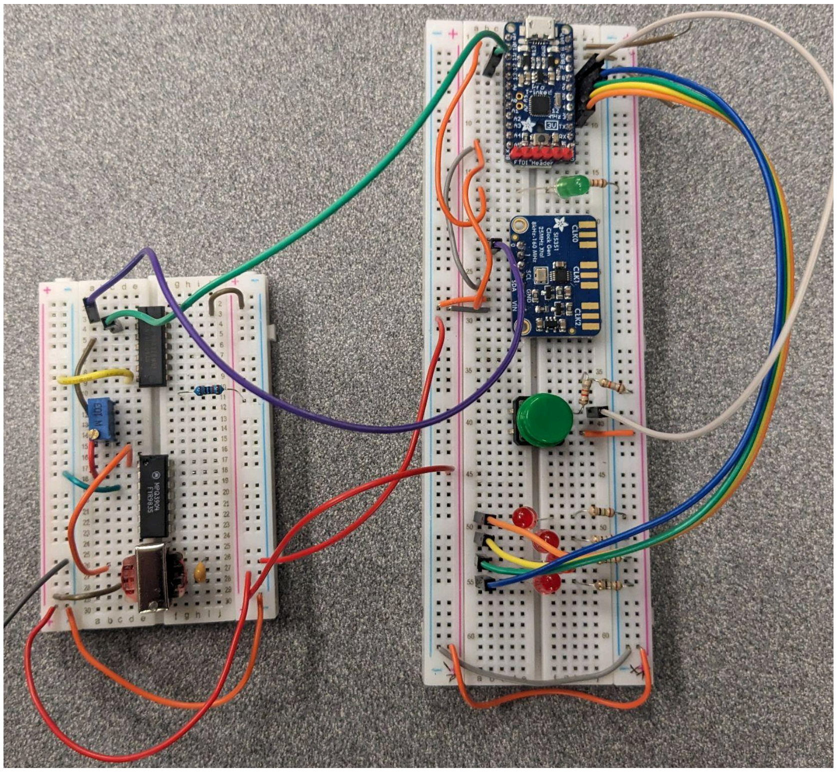


Final PCB layout and design for avalanche transmitter circuit.

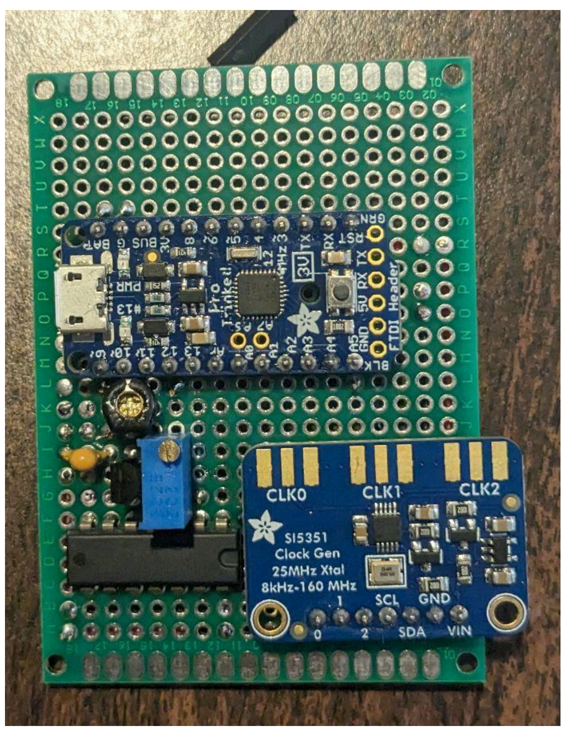


Appendix V: Images of Project

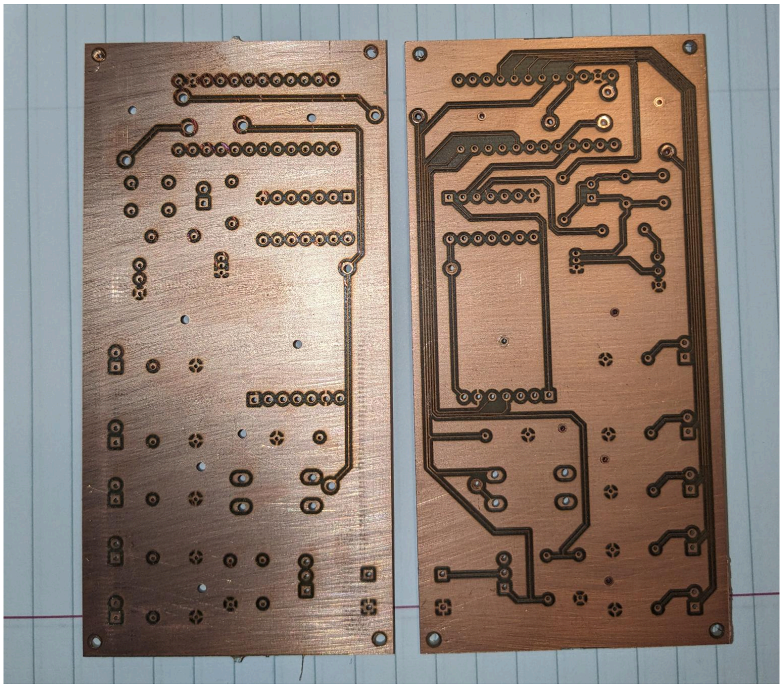
Breadboard Prototype

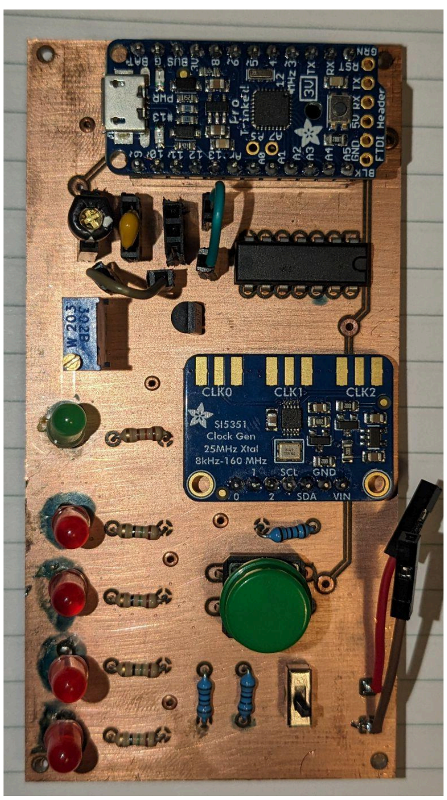


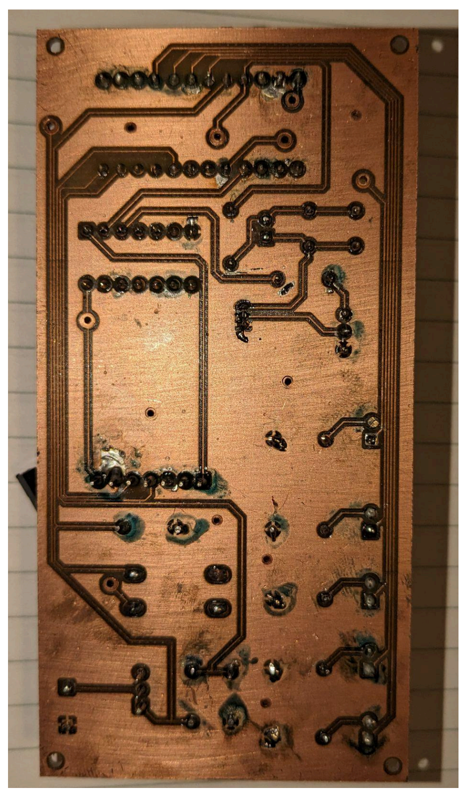
Protoboard Prototype



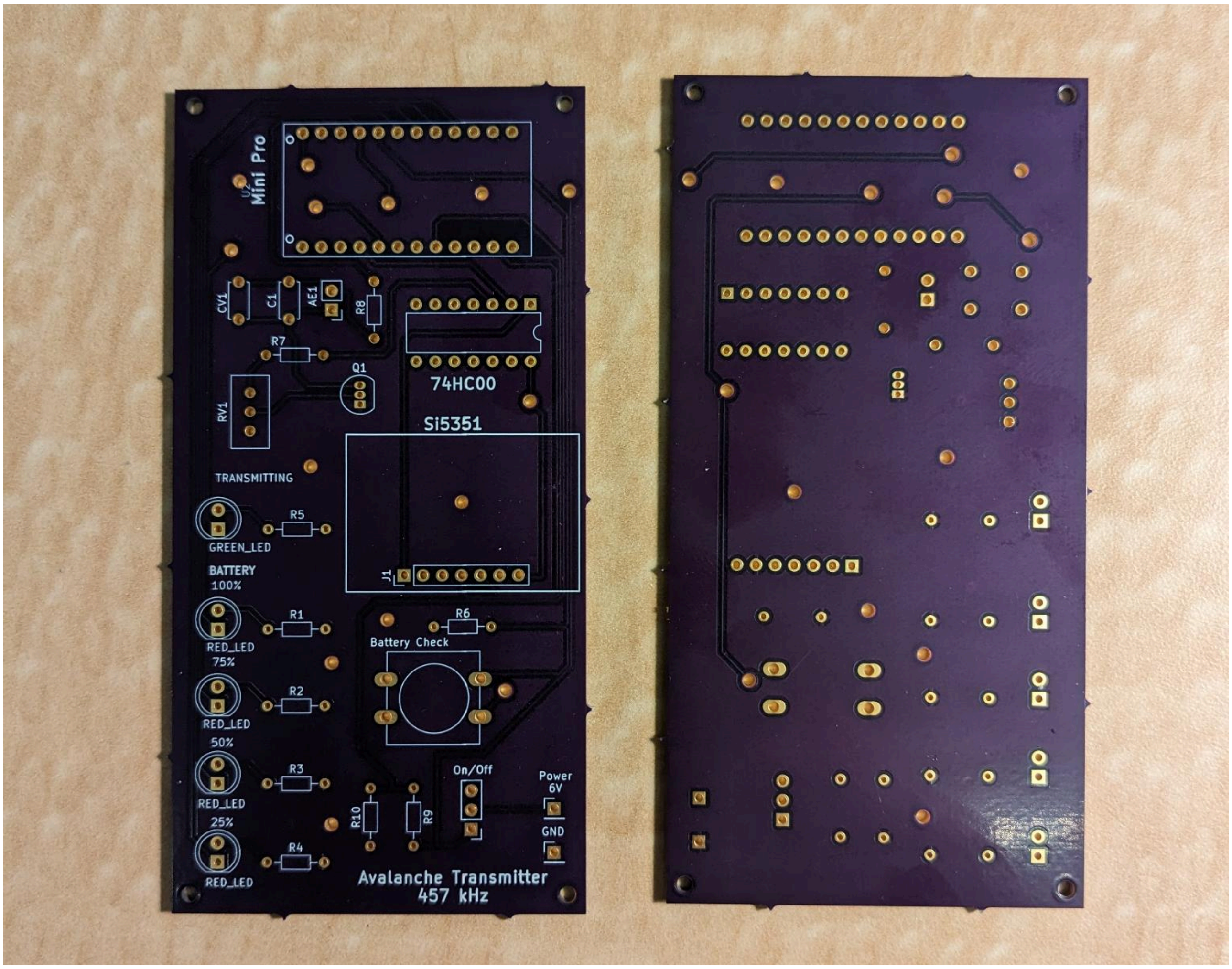
PCB Printed at PSU Electronics Prototyping Lab



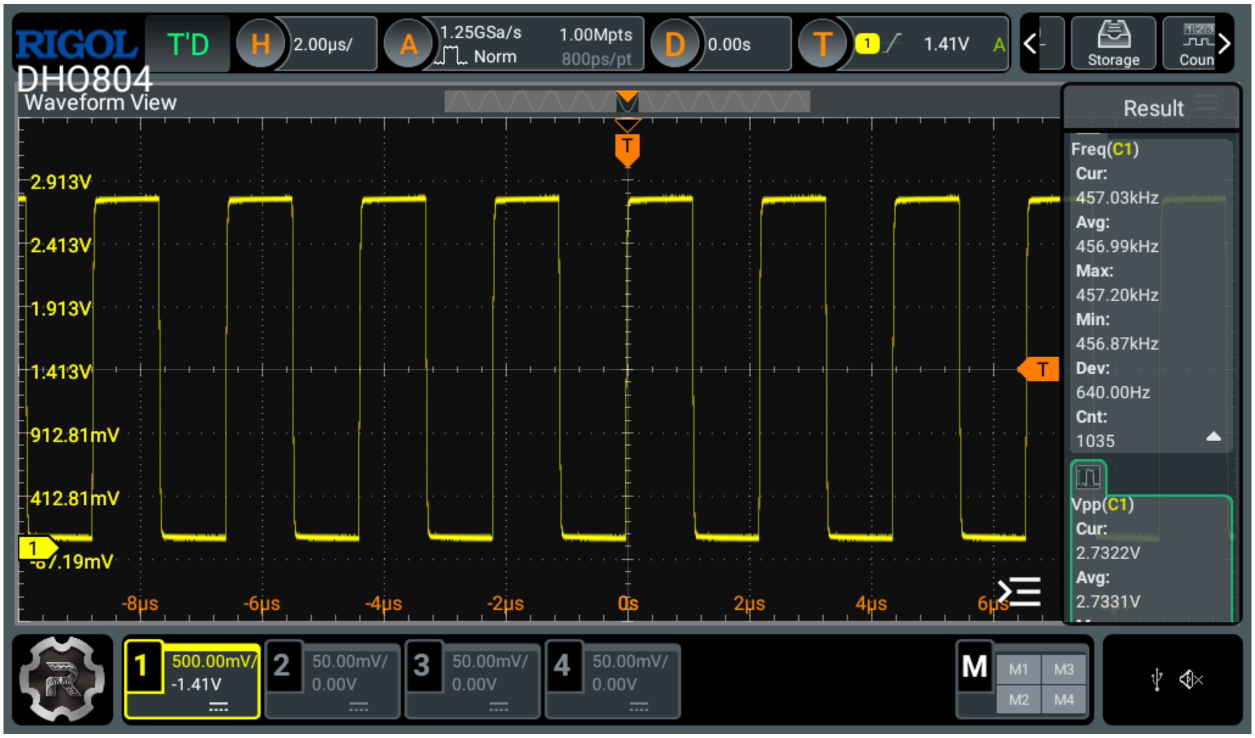




PCBs Manufactured by OSHPark

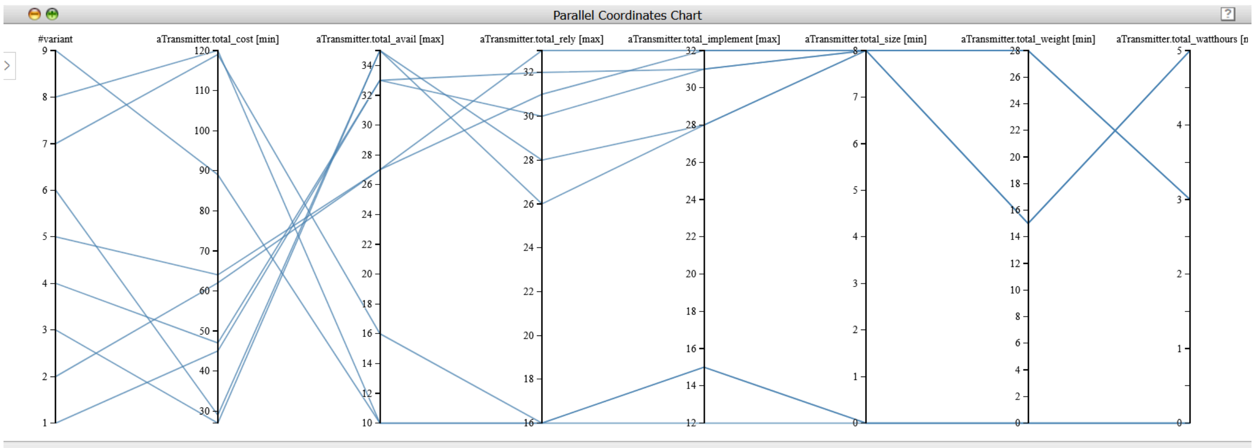


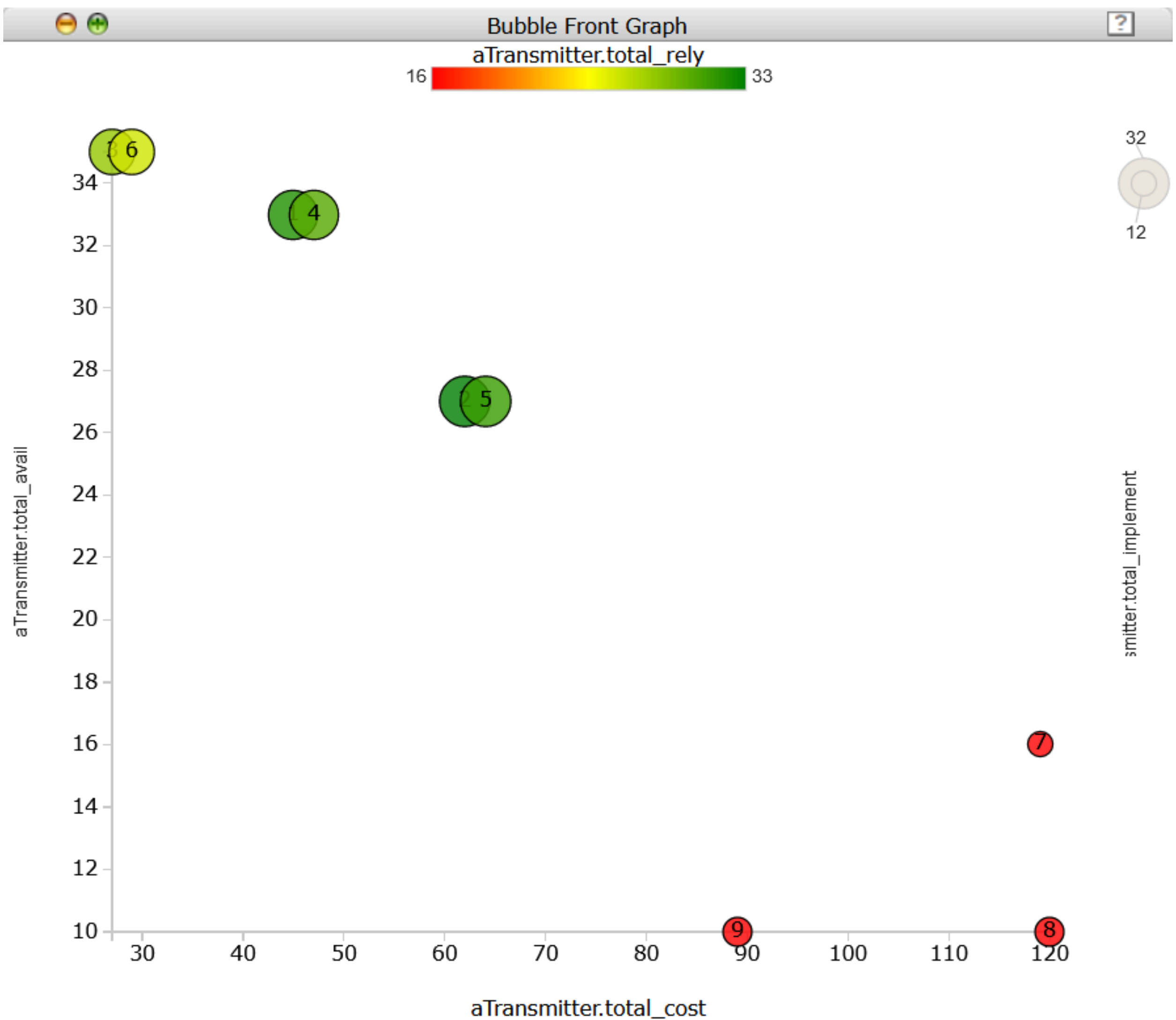
Oscilloscope outputs



Appendix VI: Clafer Feature Modeling

Clafer Feature Modeling - Deciding between feature options in design phase.
Visualizations created by Clafer MOO Visualizer





Clafer Program. Also available on Github.

```
//Avalanche Transmitter Clafer MOO
//Team Avalanche PSU Capstone 2024
// by: Roberto Torres
//Many component values below placeholders to be updated

abstract Component
    cost -> integer //dollar * 10
    avail -> integer     //1-10 higher more available
    rely -> integer      //1-10 higher more reliable
    implement ->integer //1-10 higher easier to implement

abstract BatteryComponent : Component
    size -> integer
    weight -> integer
    watthours ->integer

//abstract Enclosure : Component

abstract Transmitter
    hardware
        xor DesignType
                Team_Designed_PCB
                        xor Freq_Gen
                                LC : Component
                                        [cost = 5 ]     //0.50
                                        [avail = 10 ]
                                        [rely = 4 ]
                                        [implement = 4 ]
                                XO : Component
                                        [cost = 40 ]    //4.0
                                        [avail = 2 ]
                                        [rely = 9 ]
                                        [implement = 8 ]
                                VCXO : Component
                                        [cost = 23 ]    //2.32
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 7 ]

                        xor LED Driver
                                MCU : Component
                                        [cost = 15]      //1.50
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 6 ]
                                DotDisplayDriver : Component
                                        [cost = 5]       //temp needs to be updated
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 8 ]

                        xor Batteries
                                StandardCell : BatteryComponent
                                        [size = 8 ]
                                        [weight = 15 ]
                                        [cost = 2 ]
                                        [watthours = 5 ]
                                        [avail = 9 ]
                                        [rely = 8 ]
                                        [implement = 10]
                                RechargeStandardCell : BatteryComponent
                                        [size = 8 ]
                                        [weight = 28 ]
                                        [cost = 4 ]
                                        [watthours = 3 ]
                                        [avail = 9 ]
```

```
                                        [rely = 6 ]
                                        [implement = 10 ]
                                BatteryPack : BatteryComponent
                                        [size = 108 ]
                                        [weight = 120 ]  //172
                                        [cost = 93 ]
                                        [watthours = 30 ]
                                        [avail = 7 ]
                                        [rely = 6 ]
                                        [implement = 4 ]

                COTS_PCBs_Breakouts
                        xor Freq_Gen
                                Si5351_Adafruit : Component
                                        [cost = 80]
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 8 ]
                                AD9833DDS: Component
                                        [cost = 49]
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 8 ]

                        xor SBMCU       //Single Board MCU
                                AdafruitProTrinket : Component
                                        [cost = 100]
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 9 ]
                                AdafruitTrinket : Component
                                        [cost = 70]
                                        [avail = 8 ]
                                        [rely = 8 ]
                                        [implement = 4 ]
                                RaspPiPico : Component
                                        [cost = 40]
                                        [avail = 2]
                                        [rely = 8 ]
                                        [implement = 7 ]
                //xor Batteries // Can we just call the same component, or declare elsewhere?

    //enclosure
         //COTS IP65 enclosure
                 // xor types of COTS enclosures here
                         //component attributes here
                 //types of COTS
         //3d printed
                 //3d printed enclosure
                         //components attributes here

    total_cost -> integer = sum Component.cost
    total_avail -> integer = sum Component.avail
    total_rely -> integer = sum Component.rely
    total_implement -> integer = sum Component.implement
    total_size -> integer = sum BatteryComponent.size
    total_weight -> integer = sum BatteryComponent.weight
    total_watthours -> integer = sum BatteryComponent.watthours

aTransmitter : Transmitter
<< min aTransmitter.total_cost >>
<< max aTransmitter.total_avail >>
<< max aTransmitter.total_rely >>
<< max aTransmitter.total_implement>>
<< min aTransmitter.total_size >>
<< min aTransmitter.total_weight >>
<< min aTransmitter.total_watthours >>
```