Radio Transmitter and Receiver with Software-Defined Radio to Model Location and Intensity of Forest Fires

ECE/BME 499

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Group ID: 2

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Table of Contents

Executive Summary

Wildfires are increasingly severe threats to natural ecosystems and human settlements. Traditional detection methods, such as satellite imaging, suffer from delays and resolution limitations. This project proposes an alternative technique that leverages Software Defined Radio (SDR) to monitor ionospheric disturbances triggered by forest fires. Using Ettus USRP devices, we successfully transmitted and received a 5 MHz signal embedded with Barker's code, and verified its behaviour through direct line transmission. Phase differences and timing of signal reception form the basis of future work, including ionospheric reflection and triangulation. Our prototype offers a low-cost and responsive path to augment wildfire monitoring systems.

I Introduction

Forest fires are a growing environmental threat. Early detection is crucial for minimizing damage and enabling timely response. This project addresses this need by proposing the earth's ionosphere as a medium to detect electromagnetic disturbances caused by forest fires. Using Software Defined Radio (SDR), our system detects phase shifts in radio waves. The social impact is that this project contributes to environmental safety and disaster prevention, aligning with EGBC's Code of Ethics, acting in the public interest, promoting sustainability, and enhancing quality of life. The main use base of this technique would be forest management agencies, emergency responders, and environmental organizations.

II Objectives

- Design and build a system to detect forest fires by measuring ionospheric disturbances using Software Defined Radio (SDR).
- Use SDR to record the phase and timing of reflected radio waves from the ionosphere.
- Triangulate data from multiple receiver stations to estimate the position and intensity of the disturbances.
- Goal to achieve:
  - Prototype setup at a single receiver location
  - Successful detection of a 5 MHz wave.
  - Preliminary analysis of ionospheric wave patterns.

III Design Specifications

Ettus USRP N210
Dipole antenna for transmission
Loop antenna for reception
MIMO cable

IV Literature Survey

This project has minimal market research due to being a topic created by Rodney Herring.

This project involves RF and analog/digital signal processing.

Rodney Herring project presentation [x]

Nicholas Bruce Masters Thesis: Development of a phased-array ionospheric imaging system [x]

As mentioned in our literature survey, traditional methods for

V Team Duties & Project Planning

Name	**Duties**
Ayman Al Rubaey	**Lead Research:** Completed reading Nicholas Bruce's master thesis [1] and ECE 350 Lab 2 [2] to understand USRPS. Started doing research to find the best way to use analog for the receiver. Completed reading "LimeSDR USB Channel Alignment" [4] on github to find out a different digital method than USRPS. Did research on Buoyancy frequencies to figure out how to calculate frequency changes of forest fires. Setup the two USRP hardware and was able to send and receive a 5MHz signal through a function generator. Designed a website and poster with

	a summary of the project.
Ian Sefton	**Team Lead:** Coordinate with supervisors and student team on time and place to meet, send weekly report to TA, deal with other administrative duties, and editing midterm and final reports. **Research:** Spent time looking at Nicholas Bruce's Master's Thesis [1] and understanding ECE 350 Lab 2 (which is strong component of this project) [2]. **Part sourcing:** Involved with finding military grade tubing that will support our two radial receiver antenna, assisted with gathering two USRP's on loan from UVic Engineering Labs, and involved with trying to find a MIMO cable which is yet to be obtained
Alexander Gowans	**Research:** Reviewed Bruce's thesis [1], for information on the use of dual USRPs, as well Lab 2 from ECE 350 [2]. **Part sourcing:** Searching for dipole antennas and the elusive MIMO cable. Reviewed pricing and lead times of various components [5] for the event some needed to be acquired. **GNU Radio:** Creating and testing GNU radio block diagrams for creating, transmitting, and handling the bpsk waveform.
Oluwateniola Fasanmi	**Research:** Searched for ways to use two LFRX daughterboards in one USRP. Looked into ways of synchronizing two USRPs without a MIMO cable and/or having two LFRX daughterboards in one USRP. [8][9] **Part sourcing:** Looked into various types of USRP boards, specifically their MIMO compatibility/ dual LFRX daughterboard compatibility.
Eric Le	**Research:** Basic radio wave theory. [1] Master student thesis on transmitting radio carrier waves and receiving data from that wave from the ionosphere and antenna setup. [1] Overview of ECE 350 labs for GNU software. [2]

	Part sourcing: Searching for antennas and MIMO cable.

VI Design Methodology & Analysis

The core design method took an iterative approach. Several options and paths were laid out such as 2x2 MIMO, single, and analog. The choice between these and some of the individual parts such as the antenna were restricted based on availability, as such some concessions in performance were made. Once the core hardware was decided on, work began on ensuring basic functionality, by transmitting a simple unmodulated carrier wave, first on the software, then through the RX/TX devices via direct wiring, and finally through air transmission. Once the hardware was confirmed to be working with a simple waveform, we could begin now modulating the wave form and repeating the process of software, hardware wired, hardware air to ensure correct behaviour before increasing complexity. Analysis was performed via both software scopes and physical oscilloscopes to confirm that the waveforms being sent and received were as expected.

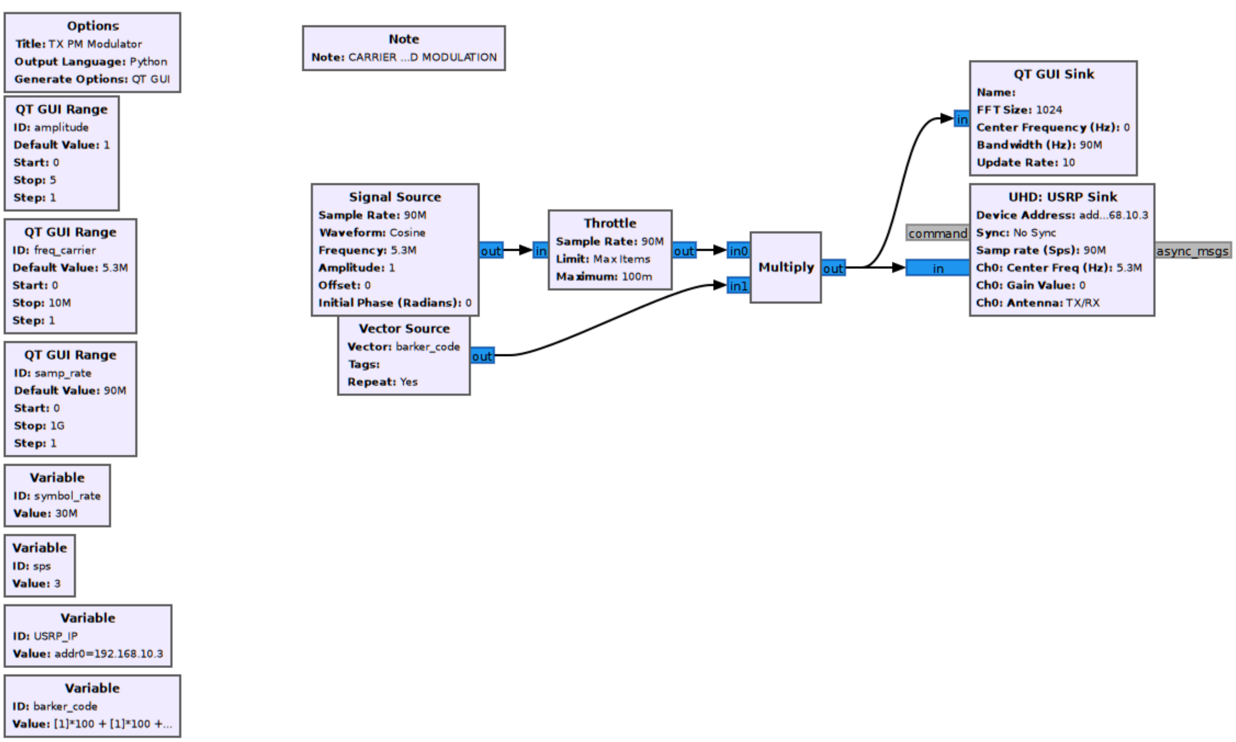


Figure x. GNU Radio TX Block

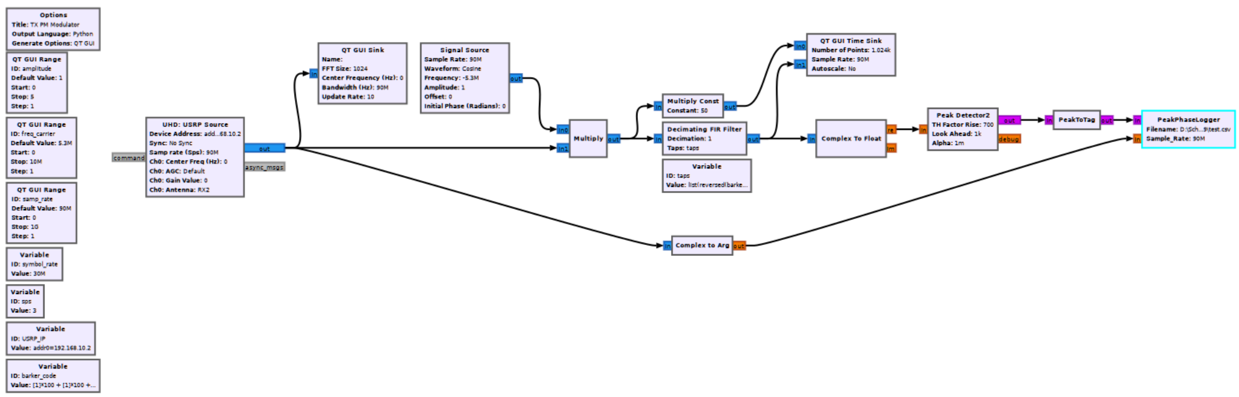


Figure x. GNU Radio RX Block

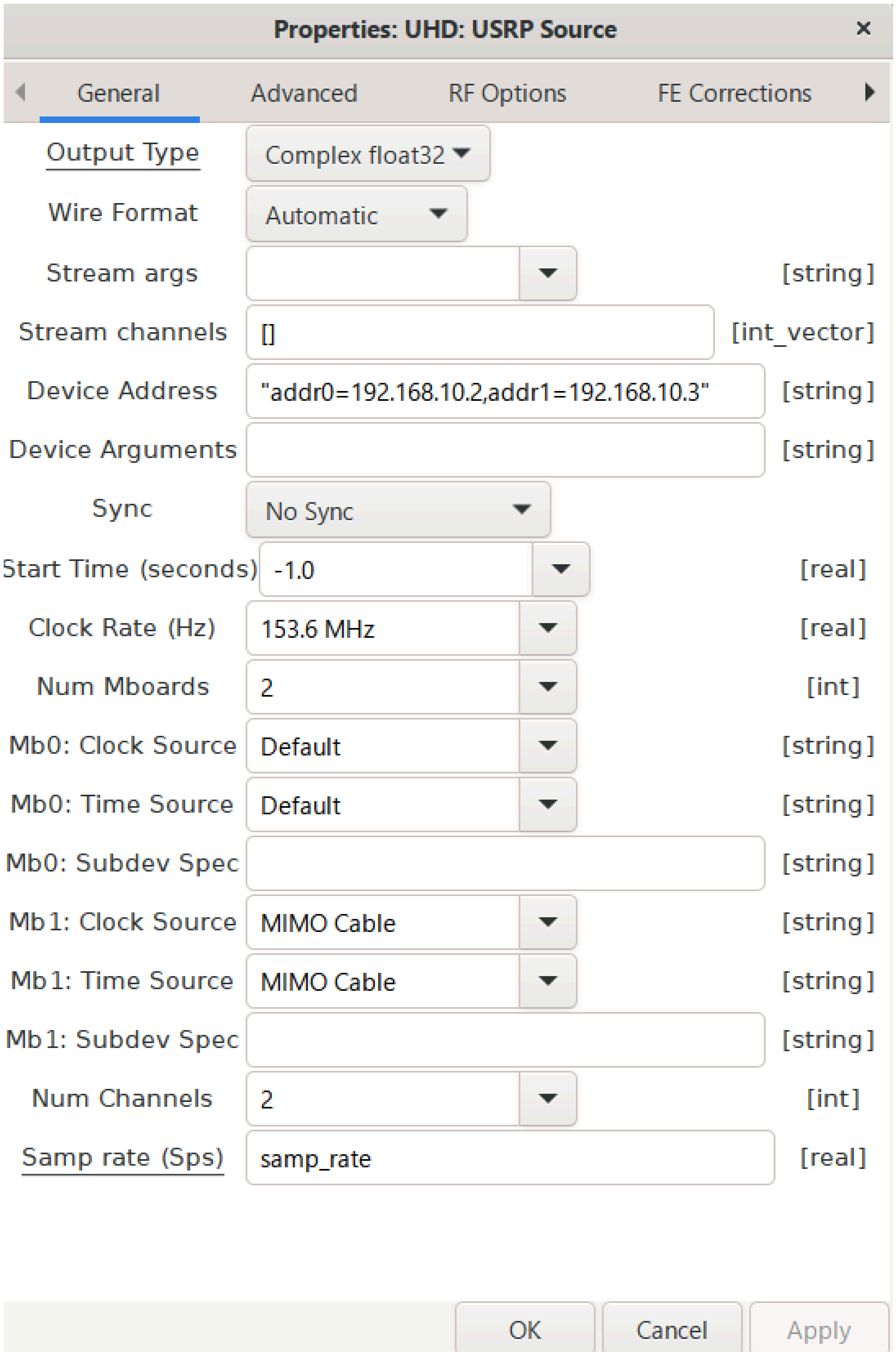
VII Design & Prototype

The final prototype consists of two USRP devices, one using the LFRX board variant and the other using the LFTX board. These devices are then connected to individual PCs via ethernet cable to receive instructions via GNU radio. The device works by creating a 5.3MHz carrier signal via software, modulating the phase with a Barker's code and then transmitting the signal via the USRP. This signal is then sent via direct connection to the receiving USRP. The received signal is then demodulated to get the Barker Code signal passed through a decimating FIR filter in order to receive peaks from the correlation of the code. These peaks are then used to tag a given sample which is then compared to the same sample on the originally received wave where the time of arrival and phase is then saved. Future considerations include transmitting this signal over the air as well as operating on the saved data. The time difference between each received peak will be treated as an amplitude and plotted vs time to give the 'captured' wave from the ionosphere. The major limitations going forward are related to the method of phase modulating the carrier, which will require some form of syncing the two USRPs. One way to do this would be by using the MIMO cable to phase lock the two devices, however this requires them to be in the same location, which makes capturing only the airwave and not the ground wave tricker. Alternatively a manual adjustment of the demodulating carrier frequency on the receiver side could be used in liu of more advanced syncing methods.

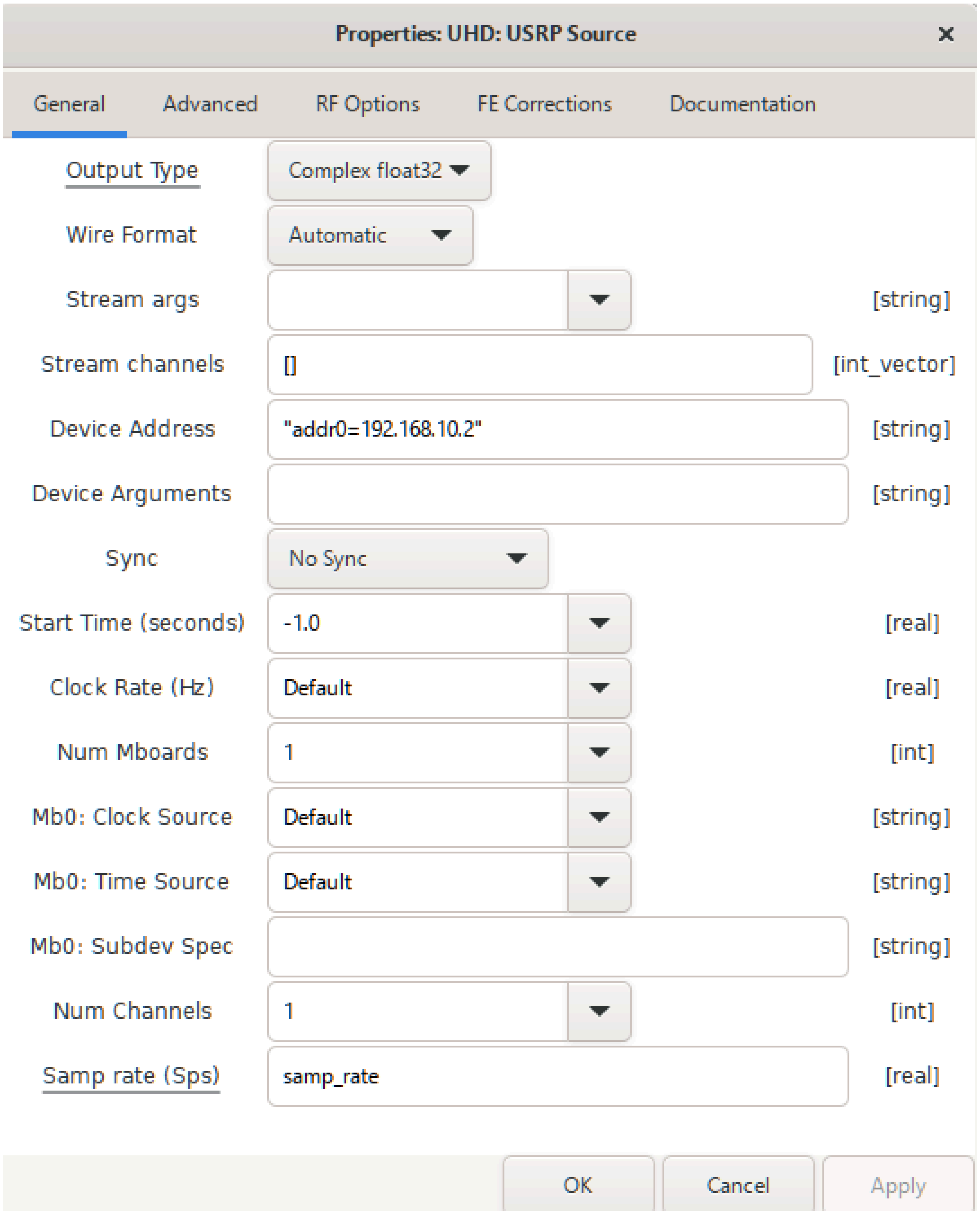
The steps for initializing the USRP setup is as follows.

- Install GNUradio, radioconda, and the uhd packages.
- In Windows' network settings, change the Ethernet IPV4 to 192.168.10.1
- With the USRP connected to the PC via ethernet and turned on, run the `uhd_find_devices` command in radioconda. By default the USRP has an IP of 192.168.10.2.
- If using a MIMO 2x2 setup the two USRPs may have an IP conflict.
- Connect a single USRP without the MIMO connected.

- In radioconda navigate to the folder your uhd packages are installed. (`cd <install-path>/lib/uhd/utils`)
- Change the IP of the device and then power cycle it. `./usrp_burn_mb_eeprom --args=<optional device args> --values="ip-addr=192.168.10.3"`
- Reconnect as 2x2 and rerun `uhd_find_devices`
- Both devices should now be recognised and the 2x2 MIMO setup documentation will work correctly.
- Within GNUradio the following settings will apply a 2x2 MIMO setup.



- For a single USRP as used in the final prototype, use the following.



- Ensure the correct channel is selected in the RF options tab. Listed as RX/TX A/B on the daughterboard and corresponding to RX/TX 1/2 in the options.
- Test by sending/receiving a simple single frequency signal and check on an oscilloscope.

VIII Testing & Validation

Initial testing was performed using direct wired connections between transmitter and receiver USRPs. The modulated Barker-coded signal was successfully transmitted, received, and demodulated. Scope plots verified peak detection and correct sample tagging. Validation of functionality under controlled conditions provides a solid baseline for extending to air-based transmission. Additional validation will be required for ionospheric reflection scenarios.

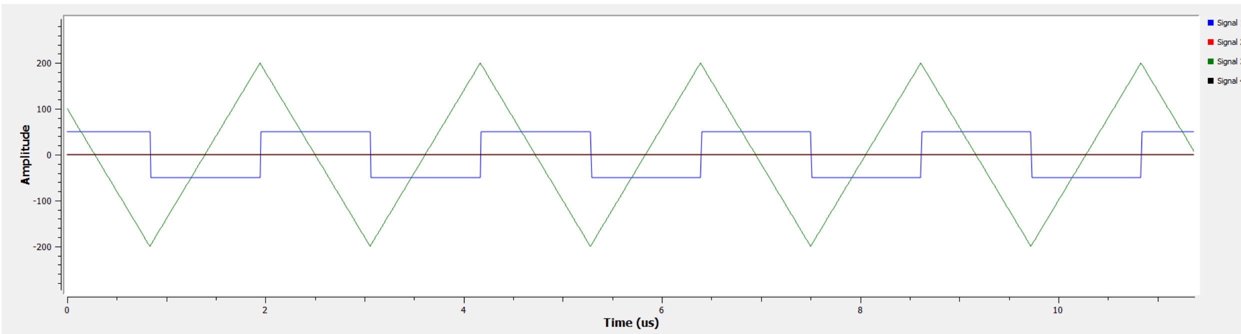


Figure x. 2 Bit Barker’s Code

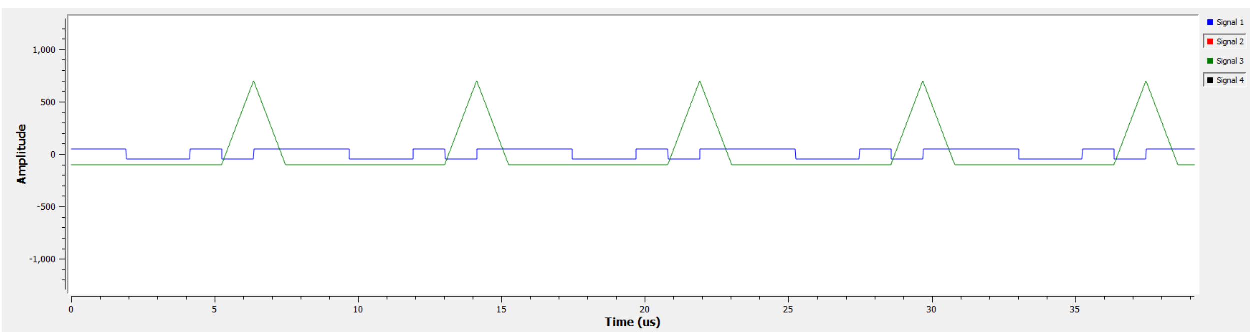


Figure x. 7 Bit Barker’s Code

XI Cost Analysis

Ettus USRP N210
Dipole antenna for transmission
Loop antenna for reception
MIMO cable

X Conclusion & Recommendation

In conclusion, we developed a working prototype capable of transmitting and receiving a 5 MHz wave embedded with Barker code through a wired connection. The next major step involves transitioning to wireless antenna-based communication and validating against ionospheric

signals. Incorporating buoyancy frequency analysis will allow mapping the intensity and timing of forest fire-related disturbances. With further development, this system has the potential to be scaled into a real-time forest fire detection and alerting tool.
A recommendation would be to use a different modulation technique called LFM (linear frequency modulation). Using Barker code will give frequency timing problems and requires the use of a MIMO cable to avoid that. This is an issue because in a real case scenario the USRP's will be in two different locations and connecting a MIMO cable would be difficult. While LFM can solve this issue by modulating frequency, thus both USRP's don't need to be synced with a MIMO cable.

References