Satellite Receiver Node Design for Scintillation Measurements

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Background

Ionospheric Scintillation of Satellite Signals

Satellite signal scintillations result from reflection, refraction, and scattering of signals by the plasma within the ionosphere[1]. Research on scintillation is relevant to real world applications because scintillation can cause significant attenuation, making satellite links unstable and decreasing the accuracy of satellite radio position data.

Solar Eclipse

In 2017, there will be a total solar eclipse across the United States for which the totality region will traverse from Oregon to South Carolina. During the eclipse, the sun will be covered by the moon's shadow. Since the ionosphere is generated and stabilized by solar radiation, its electron density will change, which may in turn trigger instabilities that could cause scintillation.

Design Approach

Targeting Signal Determination

To measure scintillation accurately the satellite signals must be strong enough to be detected by our low gain antenna. The signal must have a stable waveform as well because scintillation is measured in terms of its SNR (signal to noise ratio).

The two graphs in Figure 1 are satellite signals that meet these conditions: 1) the Inmarsat satellite downlink near 1540 MHz, and 2) the SARSAT (search and rescue satellite aided tracking) downlink near 1544 MHz.

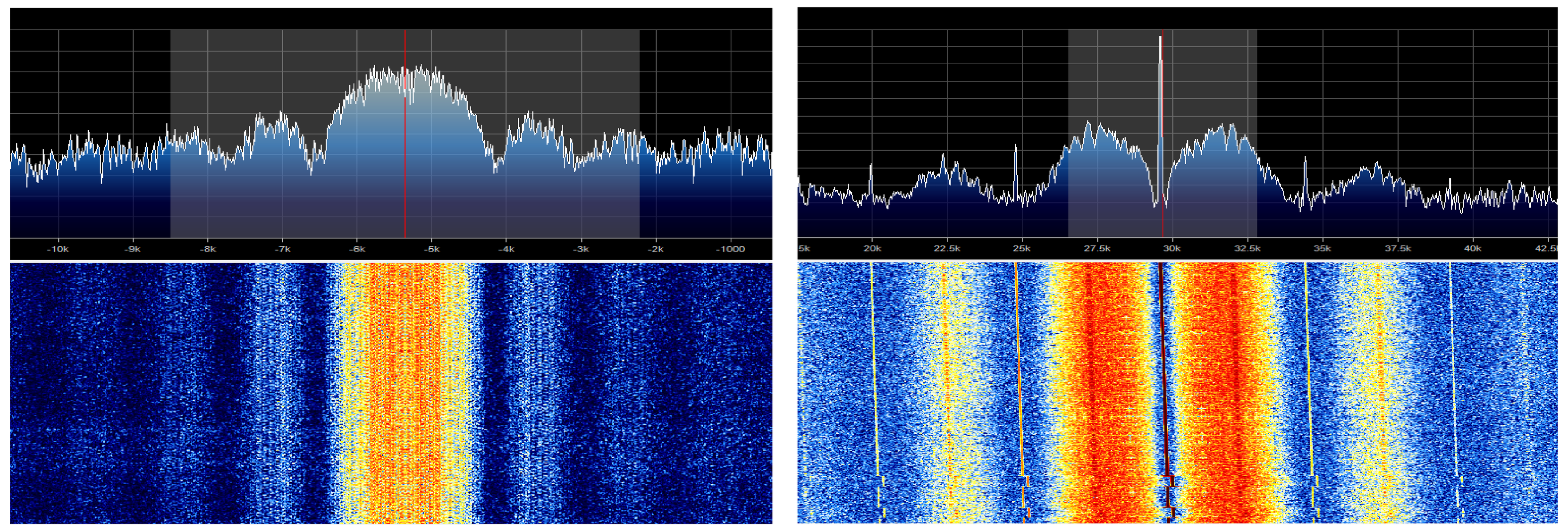

Figure 1. Inmarsat downlink signal (left) and SARSAT downlink signal (right)

The signal pattern shows the Inmarsat BPSK (binary phase-shift keying) signal modulation with a constant peak. The SARSAT signal has a constant tone in the center.

The Inmarsat satellites are in the Geo-synchronous orbit. Therefore, the antenna used to detect its signals always faces a fixed direction. We have identified several specific locations in which to deploy receivers so that their look angle to Inmarsat passes through the eclipsed F region of the ionosphere.

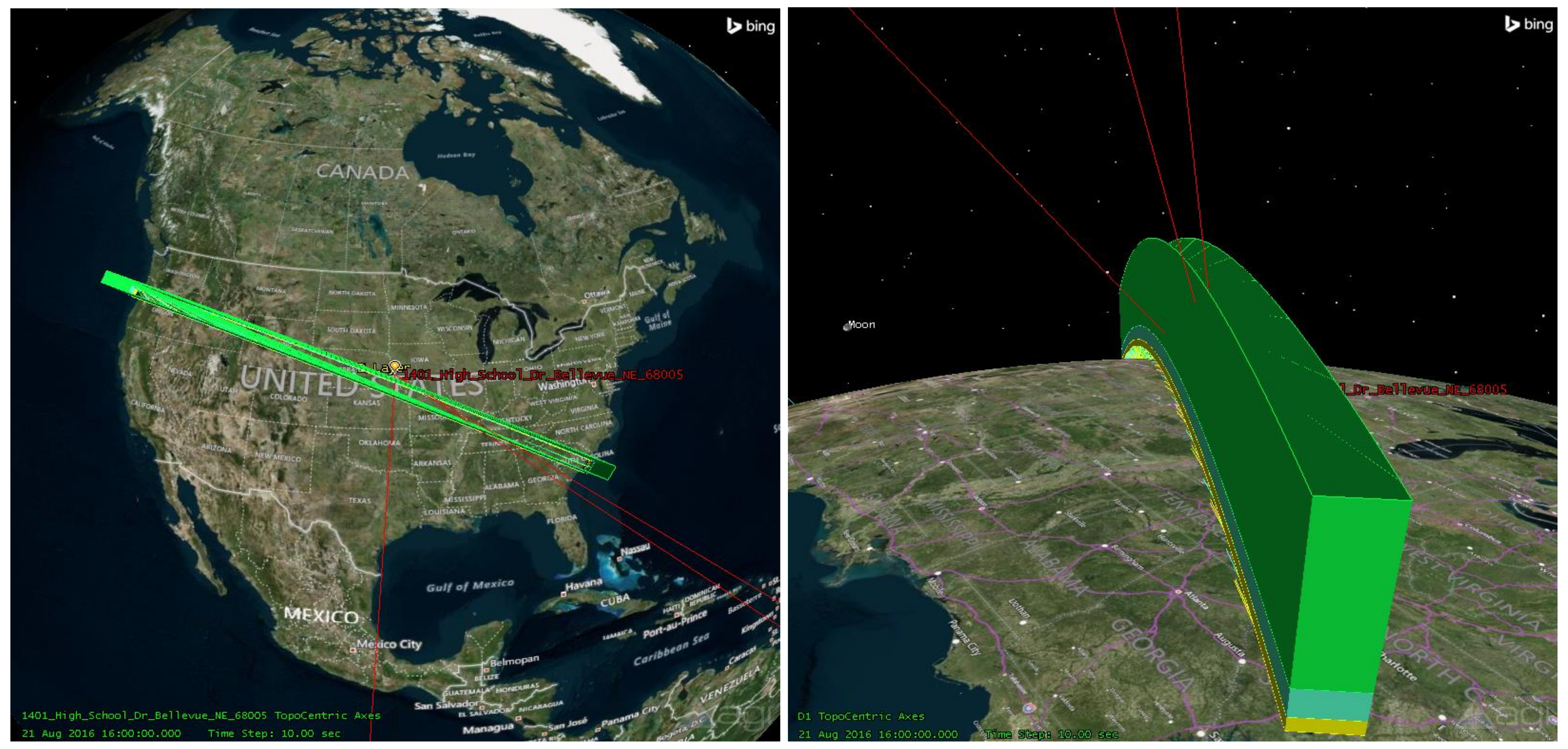

Figure 2. STK Plots of Receiver deployment location at Bellevue East High School, NE

Deploying Location Determination

The plots in Figure 2 show the propagation paths to the satellite through the various ionospheric regions of the totality path. The yellow, blue, and green regions represent the D, E, and F-layers respectively. From the figure, it can be seen that the general location for our receivers is about 100 miles north of the totality region. The location shown in the plots above will be one of our field sites at Bellevue East High School in Nebraska. Two additional field sites have been approved using this model and have been confirmed for use during the experiment.

Receiver Prototyping

The Inmarsat and SARSAT signals are all in the L-band near 1540 MHz, but the Inmarsat downlink is RHCP (right hand circular polarization) and the SARSAT downlink is LHCP (left hand circular polarization).

The L-band receivers are two RTL-SDRs (inexpensive commercial software defined radio receivers). We use SDRs because the flexibility to design one hardware architecture capable performing multiple tasks. Each RTL-SDR connects to a patch antenna and low-noise amplifier (LNA). The LNA is designed for the L-band Inmarsat and SARSAT signals. The patch antenna is manufactured as RHCP, but it can easily be modified to LHCP for our stations.

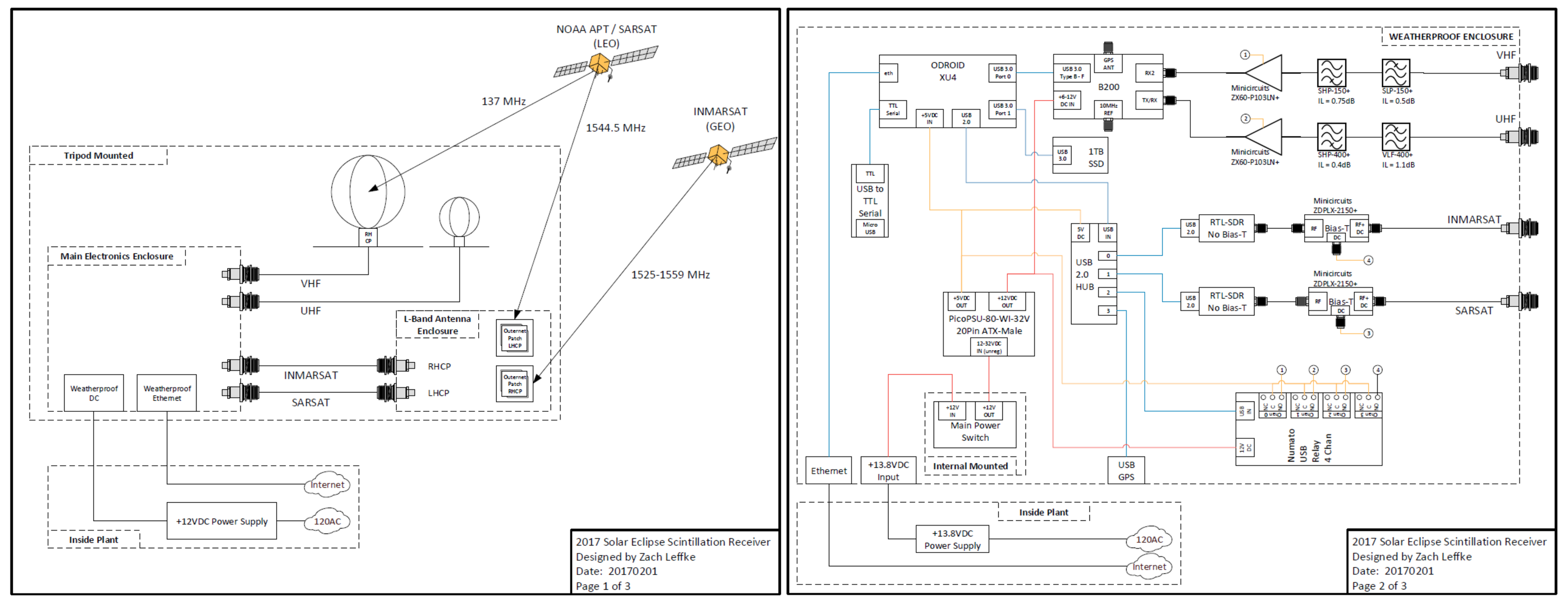

Figure 3. Block diagrams of the prototype

The photo in Figure 4 shows one of three receiver nodes at Virginia Tech. A microprocessor is used to control the system. Based on previous experience we have chosen the Odroid XU4. It has sufficient speed and memory to perform the required scintillation calculations while maintaining a fast data transfer rate. The receiver prototype has UHF and VHF abilities to receive the VHF downlink from SARSAT. Two signals received on different frequencies from the same satellite will enable calculation of TEC (total electron content) over the region, providing additional scientific data for comparison with other sources such as the SuperDARN radars, the CORS TEC network, reverse beacon network data from the amateur radio community, and a set of HF transceivers fielded by Virginia Tech at various locations across the country.

Figure 4. Photo of the receiver prototype

Future Work

- Record data before and after the eclipse to provide a baseline for comparison with eclipsed conditions.
- Configure the network setting so that our field receivers can be remotely controlled from Virginia Tech.
- Write a Python code to initiate recording target of opportunity LEO satellite passes, so that more satellite signals can be ingested and analyzed.
- Validate the performance of the radio software and processing algorithms.
- Contact the deploying location owner to purchase a suitable mounting for the equipment.
- Pack and ship the receivers to the selected field locations one month prior to the eclipse.
- Set up the receivers at each field site and ensure network connectivity to Virginia Tech.
- Relocate the receivers to local high schools for educational use and public outreach after the eclipse.

Reference

[1] Groves, K. M., et al. "Equatorial scintillation and systems support." Radio Science 32.5 (1997): 2047-2064.