Description of SIRVLAS RF Mission

Andrew Healey, Santiago Lisa, Vijay Shanmugam, Aaron Chyatte, Gautom Das

October 2019

1 Introduction

SIRVLAS (Space-based Ionosonde Receiver and Visible Limb-viewing Airglow Sensor) introduces a novel method of analyzing, predicting and calculating electron densities in the ionosphere by intercepting oblique incidence linear frequency modulated ionosonde soundings in the F layer of the ionosphere. It also introduces a method of improved estimation of 3-dimensional electron density profiles based on correlation of intercepted ionosonde soundings and 1-dimensional electron density profiles collected from the optical instrument onboard. Methods used in the Visible Limb-viewing Airglow Sensor are not novel and exist solely for measurements used in correlation.

2 Background

The ionosphere is a region of the Earth's atmosphere stretching from 50 km to 1,000 km above the Earth's surface which contains electrons and ions excited and regulated by various physical and photochemical interactions involving UV and X-ray solar radiation. The density of charged particles is non-uniform and fluctuates rapidly, with electron density often greatest at higher altitudes due to increased exposure to solar radiation. High frequency (HF) radio waves travelling through the ionosphere are refracted by an index of refraction determined by the frequency of the radio wave and the plasma frequency along its path (Figure 1). Likewise, the frequency at which a radio wave is completely reflected off of the ionosphere is based solely upon electron density.

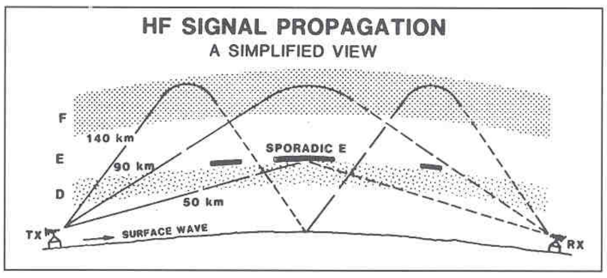

Figure 1. Radio wave propagation using the ionosphere. Courtesy Gerald Oicles/BR Communications, Sunnyvale, CA

Figure 1: The propagation of shortwave radio waves through the ionosphere.

The refraction and reflection of HF radio waves in the ionosphere is typically utilized in military applications such as over-the-horizon radar and in amateur radio communications. However, in order to correctly employ this behavior, one must have accurate estimations of topical electron densities in the ionosphere. Since electron density everywhere is constantly fluctuating, frequently updated measurements of it are required.

Currently, there are several imperfect methods to measure electron densities in the ionosphere. Among them is the use of ionosondes.

An ionosonde is a ground-based high-powered radio transceiver designed to estimate ionospheric conditions near it by transmitting and receiving high-powered radio waves. An ionosonde transmits radio waves over a wide frequency in a certain band (often the HF band) and receives them after they reflect downwards from the ionosphere. It then uses the time-of-flight data of every wave to generate an ionogram, a plot of estimated peak height of each wave versus its frequency. There are two

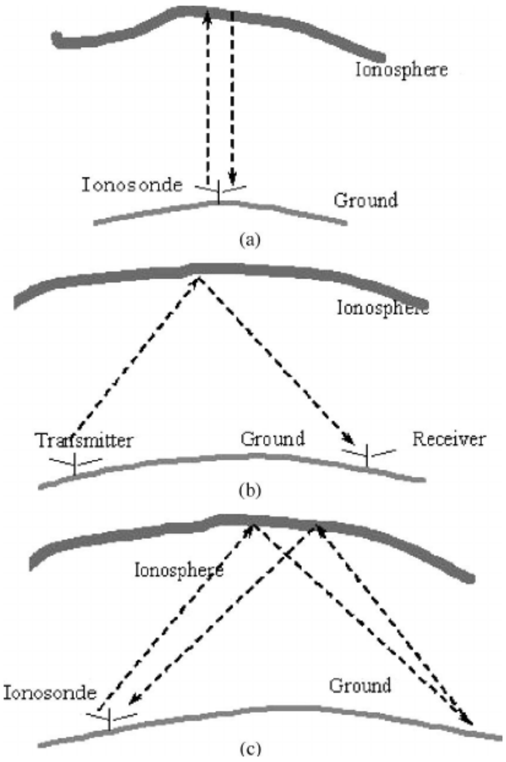

Figure 2: Ionosonde Type diagram, where (a) corresponds to vertical incidence, (b) to oblique backscatter, and (c) to oblique bistatic.

common types of ionosondes and two common types of transmission (Figure 2).

The radio signals which an ionosonde sends are transmitted into the ionosphere and are then typically refracted back to the ionosonde. Whenever an ionosonde transmits or receives a radio wave, it records the time of transmission/receipt t_0 or t_1 and the frequency of the signal, f.

With records of the time and frequency of all transmitted and received frequencies, an ionosonde can calculate the time-of-flight (time elapsed between transmission and receipt of a wave) of any transmitted radio wave by calculating the $t_1 - t_0$ of the wave. Using the speed of light, the ionosonde can then estimate the peak height that the wave reaches (this estimate is called "virtual height") in the atmosphere. The estimation for a vertical incidence ionosonde is the following:

$$h \approx \frac{c\Delta t}{2}$$

The ionosphere is comprised of multiple layers, for example, D, E, F1 and F2, which correspond respectively to increasing heights, each with a distinct chemistry of ions. In each layer of the ionosphere, the lowest radio frequency which can penetrate the layer is called the critical frequency of the layer and is denoted on ionograms in the format fo followed by the layer name (Figure 3). The virtual height of this peak in each layer is denoted as hmD, hmE, hmEs, hmF1 and hmF2[1].

Electron density in the ionosphere is not always increasing. There are peaks at which the electron density is greater than the altitudes above or below; because of this, radio waves which have sufficiently high frequencies to penetrate these peak densities are almost guaranteed to pass through the lower-electron-density regions directly above the peaks. This results in radio waves never being reflected down at the lower-electron-density regions; therefore, the methods that ionosondes use cannot determine any information about electron densities in these regions besides that they are less than the electron density of the peak.

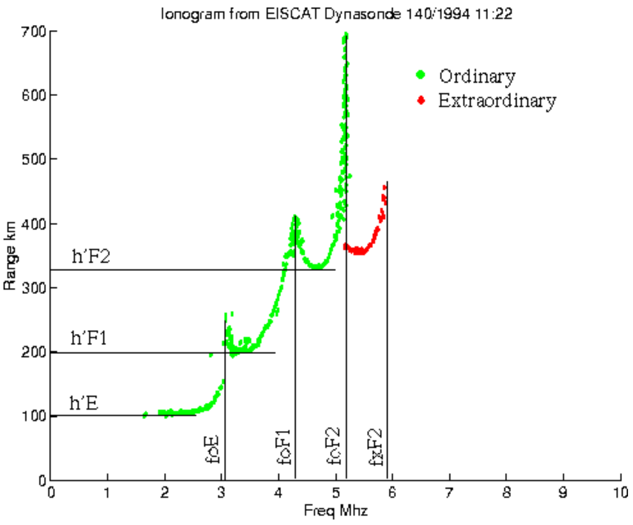

Figure 3: The virtual height (or range) of emitted radio waves (km) vs. their frequency (MHz).

Using the vertical height approximation for vertical incidence ionosonde sounding, this approximation assumes that the radio waves travel in the exact direction in which they were originally pointed, reflect directly downwards at a single point in the ionosphere, then return directly towards the ground at the speed of light in a vacuum. Most importantly, it assumes that the radio wave experiences no refraction, but rather only reflection. This assumption can lead to large margins of error; for example, near critical frequencies (for example, foF2), a radio wave near the critical frequency will be slowed as it passes through locations where the plasma frequency is very close to but not exactly the required frequency to fully reflect the transmitted wave downwards (Figure 3). For this reason, asymptotes often appear at critical frequencies on ionograms[2]. Pre-existing methods such as ionogram autoscaling attempt to account for this; however, they are not perfect.

Oblique ionosondes, which are another type of ionosonde, exist to do something that vertical incidence ionosondes cannot: measure the ionosphere between two locations which may be over an ocean, mountains or other inaccessible geographical locations. Vertical incidence ionosondes function by transmitting their radio waves directly upwards; hence, their measurements are specific to the region directly above them. This limits vertical incidence ionosondes to measuring the ionosphere above locations which have solid ground and generally favorable measurement conditions,

---

[1] https://ftp.unpad.ac.id/orari/library/library-sw-hw/amateur-radio/propagation/Radio%20Wave%20Propagation%20part%206%20-%20Critical%20Frequency.pdf

[2] https://www.ukssdc.ac.uk/ionosondes/ionogram_interpretation.html

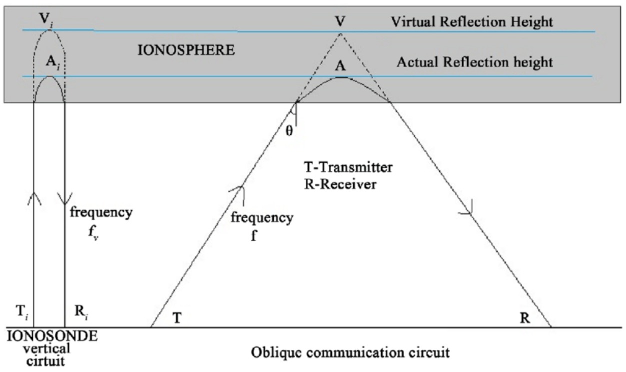

Figure 4: The predicted peak height of an ionosonde sounding overlaid on its real peak height, exhibiting one source of inaccuracy in standard ionosonde calculations.

thereby eliminating the possibility of measuring over the ocean or other places.

An oblique incidence ionosonde, which can be either bistatic or reliant upon backscatter, works somewhat similarly to the vertical incidence ionosondes defined above (Figure 2): it transmits and receives HF radio waves into and from the ionosphere, uses time-of-flight measurements to calculate peak height estimates and creates an ionogram. However, oblique ionosondes do not transmit radio waves directly upwards, but rather at an angle, such that the radio waves are refracted down from the ionosphere onto other oblique ionosondes (bistatic) or large portions of land and then back to the transmitter (backscatter).
In a bistatic setup, or circuit, the transmitting and receiving ionosondes share the transmission and receipt data with each other. With this shared data, the time-of-flight for each wave, and therefore a full ionogram (with similar assumptions as vertical incidence ionograms depend upon), can be measured. Oblique backscatter ionosondes transmit in the same way but use only one transceiver location, relying on the fact that some radio waves colliding with the Earth's surface will be reflected directly backwards off of it (and therefore, backwards along the original path that the radio wave took). Oblique backscatter ionosondes convert time-of-flight data into virtual height estimates with the following equation:

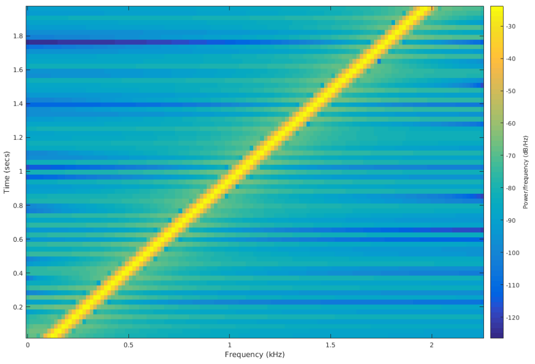

Figure 5: A spectrogram depicting a chirp transmitted by a linear frequency modulated ionosonde.

$$h \approx \frac{c\Delta t}{4}$$

The additional scale of $\frac{1}{2}$ is caused by the increase in the vertical distance travelled by the radio wave as it travels upwards, reflects downwards, hits a large portion of land, then reflects off of the ground, re-tracing the same path in reverse.

Linear frequency modulated ionosondes transmit in ”chirps”, or soundings whose frequency increases linearly with respect to time; i.e. the frequency of transmission increases linearly with respect to time at x $\mathrm{kHz\,s^{-1}}$. The rate at which an LFM sounding increases in frequency is called the chirp rate and the lowest frequency of a chirp is called the start frequency.

SIRVLAS is designed to passively receive Linear Frequency Modulated (LFM) oblique ionosonde soundings (chirps emitted from one ionosonde and received by another, on another place on Earth). One important benefit of passive reception from a satellite is the ability to sample the propagation path at many bistatic locations in the ionosphere as it travels around the earth, to gain information about the ionosphere from multiple ionosonde transmitters which already exist around the globe. The cost-effectiveness of the technique that SIRVLAS employs (which is that it does not transmit actively) could allow for the deployment of constellations of many CubeSats for improved models of electron densities.

3 Receiving Ionosonde Soundings

Ionosonde soundings are sufficiently powerful to be received by SIRVLAS; for example, the Relocatable Over-The-Horizon Radar transmit site in Virginia performs ionospheric measurements using a Lowell sounder, which sounds chirps frequently from 0.5 MHz to 30 MHz at a transmit power of 100 W[3]. In order to calculate the estimated power at the antenna of SIRVLAS, one must first calculate the Free Space Path Loss (FSPL) of the signal.

$$FSPL = 20log_{10}(d \cdot f \cdot \frac{4\pi}{c}) - G_{Tx} - G_{Rx}$$

In this case, we will calculate the worst-case scenario, in which the signal is the highest in frequency. We do overestimate distance from the ionosonde in order to prove the possibility of receiving second or third skips.

$$d = 600\,\mathrm{km}$$

$$f = 28\,\mathrm{MHz}$$

$$G_{Tx} = G_{Rx} = 0$$

$$FSPL = 136.946\,\mathrm{dB}$$

$P_{ionosonde} = 100\,\mathrm{W}$

The power captured by the antenna is equal to the transmit power of the ionosonde antenna, attenuated by the FSPL (including the transmit antenna gain and receive capture area).

$$P_{antenna} = \frac{P_{ionosonde}}{10^{\frac{FSPL}{10}}}$$

$$P_{antenna} = \frac{200 * 10^3}{10^{\frac{\mathrm{A}}{10}}}\,\mathrm{kW}$$

$P_{antenna} = 4.04 \cdot 10^{-7}\,\mathrm{W}$

The power received now depends upon a few properties of the characteristic (antenna port) and load (receiver) impedance; this will be used to calculate the Vertical Standing Wave Ratio (VSWR). VSWR can be calculated as follows:

The input impedance of the antenna is:

$$Z = R_{rad} + R_{loss} + jX$$

Radiation resistance is given by:

$$R_{rad} = 20\pi^2 \left(\frac{L}{\lambda}\right)^2$$

And radiation loss is given by:

$$R_{loss} = \frac{L}{6\pi\alpha}\sqrt{\frac{\pi f \mu}{2\sigma}}$$

where σ is the conductivity of the dipole.

The imaginary part of the dipole is given by:

$$X = \frac{-120\lambda}{\pi L}\left(\ln\frac{L}{2\alpha} - 1\right)$$

---

[3] https://apps.dtic.mil/dtic/tr/fulltext/u2/a474069.pdf

Thus, for an antenna that we consider to have a radius of 5mm and a length of 1m, where the antenna operates at a frequency of 15 MHz and uses nitinol (which has very similar properties to titanium) as the metal, with a conductivity of $2.38 \cdot 10^6\,\mathrm{S\,m^{-1}}$. The radiation resistance is calculated to be $0.39\,\Omega$. The loss resistance is $5.51\,\mathrm{m}\Omega$, and the imaginary part is approximately $1500\,\Omega$. Calculated VSWR is 1.28.

This finally gives us a final power of 98% of the received power, or $3.9592 * 10^{-7}$ W. This power is reasonable for the instrument; in other words, it is possible for SIRVLAS to receive ionosonde soundings.

4 Requirements for Success

A successful RF mission is determined by the criteria below:

- Full RF mission success requires the detection of multiple ionosondes at or below 300 km and creation of at least one accurate ionogram.
- Partial RF mission success requires the detection of a single ionosonde sounding below 300 km.
- Minimum RF mission success requires the deployment of the HF instrument and confirmation of the operation of ionosondes below 300km. Additionally, SIRVLAS must remain fully operational for the entire orbital lifespan.

5 Signal Processing Chain

There are a few different possible signal processing pipeline variations which might be used, all of which produce slightly different data to downlink:

1. A ”zoomed-in” spectrogram containing the ionosonde sounding. This format contains the maximum amount possible of information about ionosonde soundings which can be derived from any of these methods; it allows for creation of an ionogram and is the largest of the options in data transmission size. This is due to the fact that, in order to gain a high range resolution (see Range Resolution), the FFT must have enough bins to reach the desired frequency resolution. This puts a strain not only on the downlink size, but also on the possibility of running an FFT with the number of bins calculated in the Range Resolution section; however, this problem can fundamentally only limit the range resolution which SIRVLAS maintains and is not likely to, given the processing power of the AstroSDR. In order for SIRVLAS to create a very accurate ionogram, the range resolution should be 1 km. However, for partial mission success, the range resolution is permitted to be a much lower value. Ultimately, the viability of a high range resolution in comparison with ground-based ionosondes depends almost entirely upon the capabilities and processing power requirements of the AstroSDR in tandem with limitations to the data rate. Despite the fact that we have not finished calculating these things, we do have a solid mission plan which fulfills the criteria for partial to complete mission success for all possible outcomes of FPGA power requirement testing and data rate calculation upon further correspondence with AWS Ground Stations.
2. A compressed form of the spectrogram with a significantly reduced amount of data points. This method is an optional improvement upon the original spectrogram method. It allows for compression of the spectrogram, removing parts which are distant from the line representing the chirp (and therefore irrelevant). This method might be used in order to allow for downlinking of higher-resolution spectrograms for improved range resolution (over method 1). This method primarily exists to handle the possibility of a bottleneck in data rate. Feasibility of this method is determined by processing power on the AstroSDR.
3. An array of estimated times-of-flight and frequencies. This data structure maps every received frequency to a time of flight. It also requires very little bandwidth, as it is based not on an FFT, but rather on peaks of a matched filter, and outputs one dimension of data for downlinking. This form of data to downlink would lose some information which can only be retained in a full spectrogram; however, it would still allow for reasonable range resolution.

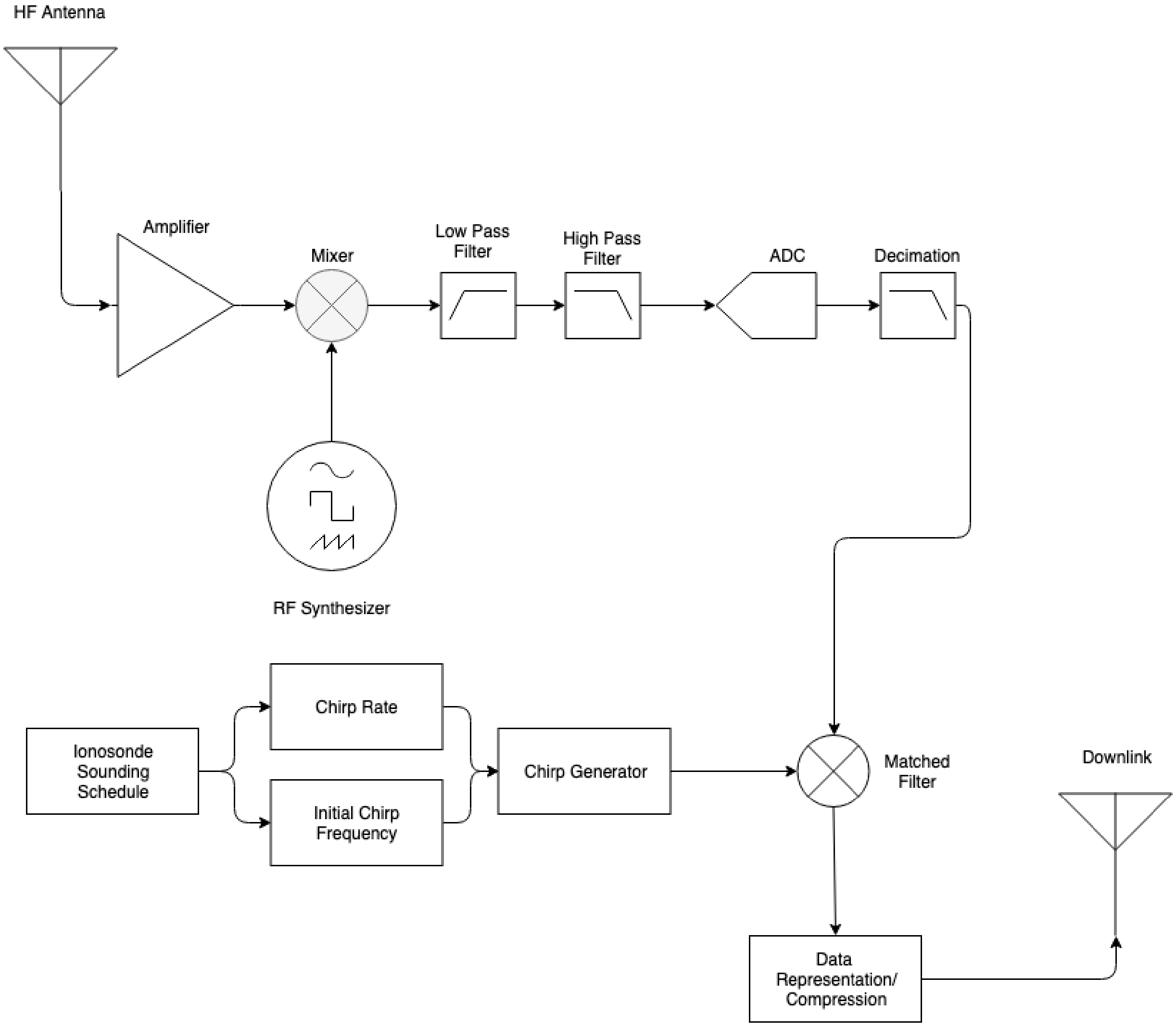

Figure 6: The general signal processing pipeline which SIRVLAS will utilize, agnostic of one of the four possible downlinking options.

4. A start frequency, end frequency and timestamp of a received ionosonde sounding, representing the lowest and highest frequency received by SIRVLAS. This mode essentially provides a general lower frequency bound for what can reach the altitude of SIRVLAS, allowing for confirmation of virtual heights of lower-frequency radio waves in LFM soundings. Although the likelihood of SIRVLAS being required to use this method because of data rate or power budget is absolutely miniscule, it is important to note that SIRVLAS collects valuable data which can be used to validate ionospheric charge density estimations; for example, even this very small amount of simple data allows for measurement of critical frequencies in the ionosphere (with an error of $< 1\,\text{kHz}$ due to Doppler shift). The reason that Doppler shift is inconsequential in this case is because even if Doppler shift cannot be corrected for, it will really affect the frequency of received radio waves by a maximum of 756 Hz. The stringent requirements that calculation of time-of-flight places upon the instrument are no longer relevant because calculation of virtual height requires multiplication by c, whereas calculation of critical frequency does not. kHz frequency resolution is still valuable, meaning that this mode fulfills the minimum requirement for success.

All of these methods are built on one basic signal processing pipeline, which is pictured in Figure 6. Although the cost in data rate and in processing power will contribute to which choices are feasible and best, there is a plan for every scenario which leads to some degree of mission success.

Although blair3sat plans additionally to intercept soundings of non-cooperative ionosondes, that method must be confirmed to be feasible on an FPGA with the processing power which is available on SIRVLAS. The possible limit in processing power required for this method is the use of the Hough transform, which requires iteration through all ”pixels” of a spectrogram and updating b_{cr} variables for each pixel (where b_{cr} is the bins used for determination of the chirp rate). This makes the Hough transform an $O(m * n * b_{cr})$ operation, which may be prohibitively expensive. Implementation testing is required to determine feasibility.

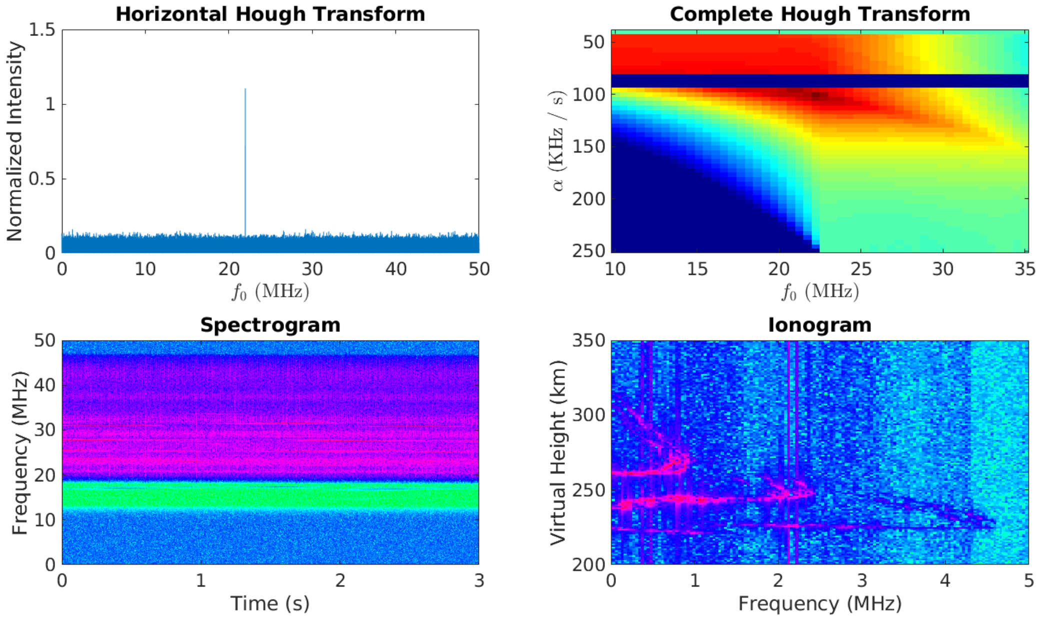

Figure 7: The outputs of the tested algorithms required for generation of a spectrogram, compression of the spectrogram, the reception of non-cooperative ionosonde soundings, and the creation of an ionogram. Given that the test was run on a non-cooperative ionosonde sounding, it is impossible to explicitly verify the results; however, the ionogram output from the test is as expected.

6 Hardware Requirements

SIRVLAS will receive analog signals through a 1 m short-wave nitinol antenna, which will initially be spooled up inside SIRVLAS's tuna can. The properties of nitinol cause it to tend towards a straight and rigid state but become malleable in low temperatures. These thermal behaviors will allow blair3sat to cool the antenna before placing it spooled up inside the tuna can with a burner switch. As the antenna returns to a normal temperature, it will strain against the burner switch, and passing current through the switch during operation will break the burner switch, allowing the antenna to return unconstrained to its natural straight and rigid state.

Each received signal will be upconverted (with a NuWaves Multi-Octave RF Upconverter, 2-70 MHz IF, 2-3000 MHz FF) to provide a usable frequency for the rest of our signal-processing chain operations. SIRVLAS passes this modified signal through high- and low-pass filters to remove AM transmissions and aliasing, respectively. All further signal-processing operations will be handled by an on-board AstroSDR.

Algorithms have been tested on the ground in MATLAB. Passive reception of ionosondes has been implemented in juha's gr-chirphunter and zooming of the spectrogram to focus solely on the ionogram has been successfully used and tested. This ground test was based upon receipt of a non-cooperative ionosonde, meaning that chirp parameters had to be calculated. The zoomed spectrogram was Hough transformed to extract the chirp rate and starting frequency. Based upon these parameters, an ionogram was generated from the zoomed spectrogram.

7 Power Usage

A GOMSpace 3U Powerpack will power all SIRVLAS onboard operations. 4 solar panels, part of the Powerpack, will provide approximately 8.4 W of power: although the Powerpack's datasheet specifies a maximum 60 W output, the approximately 2-hour orbital period and the angle of the panels means that only a small portion of the solar panels will be exposed to light at a time.

When active, the AstroSDR will consume a maximum of 30 W of power, depending on the data it is processing. However, we estimate that the RF payload will be active for only 5% of SIRVLAS's orbital average duty cycle, during which time it will cause the AstroSDR to consume 5.5 mW to 30 mW, depending upon the FPGA implementation of the signal processing chain. The remainder of the onboard signal processing hardware will consume, in total, only 6.65 W under complete systems load: The NuWaves upconverter will consume 3.6 W of power for 5% of the duty cycle. This high-power, low-use method can be powered by battery power of the Powerpack, which provides a maximum of 30 W. Due to this, the RF payload (which does not include downlinking) is expected to have low power usage and a sustainable power budget.

8 Doppler Shift

SIRVLAS will receive ionosonde soundings from an unknown direction at an unknown velocity while the instrument is moving at a calculated maximum of 8 $\mathrm{km\,s^{-1}}$ in any direction (limited only by that the y-component of the velocity of SIRVLAS is 0).

8.1 Worst-Case Scenario

One can calculate the maximum expected Doppler shift affecting receipt of soundings with a simple equation:

$$\lambda_{observed} = \lambda_{source}\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}$$

As the range error of a calculated ionogram is determined by frequency, it is helpful to represent the above equation in terms of frequency.

Given that

$$c = f * \lambda$$

We can calculate the following:

$$f_{observed} = \frac{f_{source}}{\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}}$$

Next, we use reasonable upper bound parameters for SIRVLAS:

$$f_{source} = 1,28\mathrm{km\,s^{-1}}$$

$$v = \pm 8\,\mathrm{km\,s^{-1}}$$

$$c = 299,792\,\mathrm{km\,s^{-1}}$$

Where f represents the frequency of light, with a minimum at 1 MHz and a maximum at 28 MHz; v represents the absolute velocity of SIRVLAS, with a calculated maximum speed of less than 8 $\mathrm{km\,s^{-1}}$; and, c represents the speed of light in a vacuum. SIRVLAS has both angular and radial velocity in relation to the ionosonde and bounce points; however, we assume that the total velocity is also the radial velocity. This assumption increases the magnitude of the Doppler shift past the amounts that SIRVLAS would observe, expressing an upper bound on the effect. Applying the known variables to the proportion of frequency, we find:

$$\sqrt{\frac{1+\frac{\pm 8}{c}}{1-\frac{\pm 8}{c}}} = 1.000026, 0.999973$$

Applying this value in the original equation, we find the following shifted frequencies in all extreme cases:

2.000054 MHz, 1.999948 MHz, 28.000756 MHz, and 27.999272 MHz.

These values differ from f_s by at most 756 Hz, giving us an upper bound on the magnitude of the frequency shift.

For a frequency shifted by x Hz, the matched filter predicts the chirp start time as $\frac{x}{chirp\_rate}$ seconds earlier. Therefore, Doppler shift by x hertz to one wave causes the estimated time-of-flight of that radio wave to have an error of $\frac{x}{chirp\_rate}$. The relationship between error in time-of-flight and calculated virtual height is as follows:

$$h \approx \frac{c\Delta t}{2}$$

$$\Delta h = \frac{cx}{2(chirp\_rate)}$$

Therefore, the maximum error in virtual height for the maximum Doppler shift, assuming a chirp rate of $100\,\mathrm{kHz\,s^{-1}}$, is calculated to be 1133 km.

8.2 Solving for Doppler Shift

Clearly, accurate ionograms cannot be generated with unsolved Doppler shift. Thus, we propose a method to solve for Doppler shift in postprocessing:

SIRVLAS will hear two chirps for every sounding transmitted by an ionosonde (once on the ascent of the radio wave, and once on the descent), and both represented chirps represent the same data. With the assumption that the chirp will be essentially not refracted at all during its ascent (because the chirp has not yet reached the altitude of sufficiently high electron densities to be reflected and refracted), one can calculate the absolute velocity of the wave as it was first received by the instrument. We also assume that the angle of reflection of a oblique incidence ionosonde sounding during its descent is equal to the angle of incidence during the ascent of the wave at the same altitude; this assumption is shown in Figure 1, in which an oblique ionosonde sounding has an axis of symmetry at the peak of the sounding. The conclusion that we reach is that the direction of the descending radio wave at altitude h is equal to the y-inverted direction of the ascending radio wave at altitude h.

Doppler shift is calculated as follows:

$$\frac{f_o}{f_s} = \frac{1}{\gamma(1+\beta\cos\theta_r)}$$

f_s is the absolute frequency of the radio wave and f_o is the observed frequency of the radio wave (aka Doppler-shifted). β is the fraction of the speed of light at which the receiver is travelling and θ_r is the relative velocity of the radio wave. γ is the Lorentz factor, a value determined by β.

This value is also known as the Doppler factor, or the ratio between the absolute and the observed frequency of a radio wave.

The difference between the Doppler factor when SIRVLAS receives a radio wave while it is ascending and when SIRVLAS receives that same radio wave while it is descending can be calculated as follows:

First, we take β to be unchanged; SIRVLAS is essentially moving in a straight line. Given this, we can assume that γ is unchanged as well.

Second, we calculate θ_r during ascent and descent. θ_r is equal to the angle between the direction vector of SIRVLAS, v_s, and the direction vector of the radio wave, v_w. Both v_s and v_w are 3-dimensional vectors with an x, y and z component.

Since SIRVLAS is not falling rapidly through the ionosphere during measurement, we can assume that if SIRVLAS receives an ionosonde sounding during ascent and later during descent, its altitude has not changed. This means that the absolute velocity of the radio wave during second (descending) receipt is equal to the y-inverted velocity of the radio wave during first (ascending) receipt. In mathematical notation,

$$v_{w_2} = < x_{w_2}, y_{w_2}, z_{w_2} > = < x_{w_1}, -y_{w_1}, z_{w_1} >$$

The relative velocity of the wave, which is calculated by $v_w - v_s =< x_w - x_s, y_w - y_s, z_w - z_s >$, is changed only in the y component because the absolute velocity of the radio wave has only changed in the y component and the absolute velocity of SIRVLAS has not changed at all. Since $y_s = 0$, the relative velocity of the descending radio wave received by SIRVLAS has been proven to be equal to the y-inverted relative velocity of the radio wave during its ascent.

As the y component of the relative velocity of the radio wave has been inverted and not changed in any other manner, θ_r is unchanged (in magnitude, at least).

Since the only use of θ_r in the equation for the Doppler factor is $\cos\theta_r$, and $\cos(x)$ is an even function, if the magnitude of θ_r is unchanged, there is no change in the Doppler factor due to θ_r. Since the magnitude of θ_r is unchanged, there is no change in Doppler factor if a radio wave is ascending or descending.

It has been demonstrated that there is no difference present in β, $\cos\theta_r$ and γ in the case of an ascending radio wave versus the descent of the same radio wave. Thus, we can draw the following conclusion:

The Doppler effect on any oblique incidence radio wave is the same for reception of ascent and descent of that wave if a common altitude is used.

Assuming that the radio wave received by SIRVLAS is not yet refracted by the ionosphere when it reaches SIRVLAS and that the originally transmitted sounding is perfectly LFM, we can assume that the radio wave when it reaches SIRVLAS is also perfectly LFM. Given this, we can assume that the observed frequency differs from a perfectly LFM sounding only because of Doppler shift.

Doppler shift affects only the observed frequency of a wave and not the observed time. In other words, we know that every radio wave in the observed chirp observed by SIRVLAS is received x units of time after the radio wave was transmitted. Since the value x is constant throughout all radio waves making up the chirp, we can use one calculation to generate x, the time shift of all waves in the chirp:

$$t_{shift} = t_{end_{observed}} - t_{end_{transmitted}}$$

$t_{end_{observed}}$ is the time that SIRVLAS received the end of the chirp and $t_{end_{transmitted}}$ is the time that the ionosonde transmitted the end of the chirp. This allows us to align the frequency-time graph of the received chirp and the transmitted chirp by shifting all times of the transmitted chirp back by t_{shift} units of time.

At this point, since we assume that there is no ionospheric refraction affecting the transmitted wave and that the time-aligned transmitted chirp is essentially equal to the chirp being received at SIRVLAS before Doppler shift.

We can iterate through radio signals in the chirp transmitted by an ionosonde in order to create a mapping of observed radio frequency to transmitted radio frequency.

In the downlinked data representation of the received chirp during its descent, the ground station or other postprocessor can use the mapping generated above (generated specifically based on the received chirp during its ascent) in order to reverse the Doppler effect on observed radio waves of the descending chirp, thereby allowing for accurate creation of ionograms.

blair3sat is using an ionospheric ray-tracing program which consumes electron density profiles and initial radio wave parameters and outputs parameters of the wave at many points upon the traced line[4]. The team is currently using this program to create a simulation of the reception of LFM soundings at SIRVLAS; once complete, this simulation will provide blair3sat with estimations of the accuracy of the Doppler correction method.

It is expected that the assumptions used for this method of Doppler correction are not always valid; however, we expect that they are effectively true in many conditions of SIRVLAS and the ionosphere. Based on our simulations and pre-existing models of ionospheric charge density, it is possible to generate error bars in ionograms calculated by SIRVLAS. These error bars will likely be determined by the accuracy of assumptions about Doppler shift and simplifications of ionospheric propagation used in the method.

---

[4] https://arxiv.org/abs/1202.2079

9 Duty Cycle

As the RF instrument is designed to receive soundings of ionosondes, its use will be limited to time periods during which soundings are of sufficient frequency to reach the satellite. Although the success of the instrument does not depend upon this, it is important to note that there will be no data collection above 300 km, as this is the nominal height of the electron density peak in the F2 layer[5]. SIRVLAS's RF instrument (excluding command and downlink components) will be active according to a predetermined schedule. Additionally, the instrument will only be activated when SIRVLAS passes within a certain distance of sounding ionosondes, which depends on its position over the Earth and the power of transmission of the ionosonde by which SIRVLAS is passing. Because of the 300 km upper limit to SIRVLAS' operation, blair3sat plans to request for SIRVLAS to be launched at or near 350 km.

10 Uses of Collected Data

The RF instrument on SIRVLAS is designed to receive soundings of ionosondes on the ground and downlink them for creation of ionograms and/or other methods of evaluation or creation of electron density profiles.

10.1 Estimation of Electron Density Profiles from Oblique Ionograms

An expected scenario for SIRVLAS is the downlinking of spectrograms which can be used to generate ionograms. These ionograms can be used to generate electron density profiles at the midpoint of the line between the transmitting and receiving antennas. The method is complex but is used on many Lowell Digisondes for autoscaling and electron density profile generation[6].

Since the means of calculating electron density profiles is based upon a few things, fulfilling those will allow SIRVLAS to use the same algorithm. The algorithm takes in an ionogram and outputs electron density profiles for the area between the transmit and receive antenna; however, it is possible to replace the location of the transmit and receive antenna with the the location of SIRLVLAS during its receipt of the ascending wave and the descending wave, respectively, because SIRVLAS is at the same altitude during each receipt. The basic assumptions that the Lowell method requires are still fulfilled, with only a small change required to be applied to SIRVLAS' generated ionograms: since SIRVLAS' generated ionograms measure time-of-flight between the transmission of the chirp and the receipt of the same chirp when it is descending, we can subtract the time between transmission and receipt of the ascending chirp, which gives us the time-of-flight between receipt of the ascending chirp and receipt of the descending chirp. This is the format necessary for us to calculate electron density profiles using the Lowell method.

11 Cooperative and Non-Cooperative Ionosondes

SIRVLAS introduces a method of intercepting oblique ionosonde soundings from ionosondes which publish their sounding schedules. SIRVLAS is planned with the expectation of pre-determined information in this regard; in fact, blair3sat already has confirmed support from Astra Space, which operates an oblique incidence ionosonde in the western United States, for the schedule and all other pertinent information regarding the sounder. SIRVLAS will also use information from other sources, such as the Digisonde Ionogram Database (DIDBase), for scheduling and parameters of publicly available ionosondes.

Non-cooperative ionosondes are a possibility for SIRVLAS and are currently being planned for. However, only receipt of cooperative ionosonde soundings has been extensively planned and proven to work. Creation of programs and algorithms to calculate electron density profiles given soundings, if executed, will only ever affect postprocessing or insubstantial onboard processes such as small changes in programs running on the SDR. In other words, any method of non-cooperative ionosonde soundings which may be created in the future will not substantially affect the feasibility of the design of SIRVLAS or disturb success of the mission.

---

[5] http://www.astrosurf.com/luxorion/qsl-propa2.htm

[6] https://www.researchgate.net/publication/50300861_Mid-point_electron_density_profiles_from_oblique_ionograms