RFI Survey Design

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Abstract

We aim to gain an understanding of the radio frequency interference environment at the Hat Creek Radio Observatory (HCRO) using the Allen Telescope Array. These results, recorded in this memo, can inform future observing campaigns, and will be easily accessible via an interactive visualization tool on the HCRO GitHub page

1 Campaign Design

For this survey, we were attempting to gain a thorough understanding the radio frequency interference (RFI) environment through a campaign that could be completed in 2–4 weeks. Informed by this goal and the time constraints, we made the following survey design decisions.

1.1 Frequency

The new Antonio feeds on the Allen Telescope Array (ATA) are sensitive to frequencies between ∼1–11.2 GHz. We would like to cover this entire region, while also evaluating the lower-frequency environment between 400–1000 MHz; while the ATA Antonio feeds will likely not be used for astronomy at these lower frequencies, other stakeholders on the site, e.g., CHIME and the NRDZ collaboration, would be interested in these regions of the spectrum, motivating a survey that covers those frequencies as well. Therefore, the 400–1000 MHz region will be surveyed by the "old" ATA feeds. 1 GHz of overlap will be built-in between the regions of frequency space that the two feed designs will cover, allowing a direct comparison of the RFI response of the two different feed designs between 500-1500 MHz.

The instantaneous bandwidth that can be covered by a single ATA "tuning" in the flat response area of the bandpass is 672 MHz. Therefore, to cover the entire bandwidth (with some overlap), we would need 17 different tunings for the new feeds, with an additional 2 tunings on the old feeds.

1.2 Duty Cycle

We would like our survey to be sensitive to changes in the RFI environment over a) the course of a day and b) the course of a week. To ensure daily sensitivity, we will repeat the observing plan at four times of day: midnight, 6am local time, noon, and 6pm local time. This should capture changes due to transmitters on day/night cycles, and temporal interference associated with e.g., commuter traffic. To ensure weekly sensitivity, and evaluate the temporal occupancy of particular transmitters (e.g., what % of the time a certain interferer is present), we will repeat the observations on each day of the week, in a consecutive 7 day span, if possible. This should capture changes due to transmitters which are more active during e.g., weekdays or weekends.

1.3 Sky Position

For this survey, designed in January 2022, we can employ up to 20 6-meter ATA antennas. Regardless of whether we use a Fly's Eye widefield observational mode (W1v1; 20 antennas) or a "Gorgon's Eye" wide-field observational mode (W2v1; 5 antennas/subarray, 4 subarrays), we cannot tile the sky with individual pointings at the highest frequencies: the beamsize is just too small. Therefore, we will either have to select particular pointings-of-interest with which to use either of the aforementioned observational modes, or we will have to use a continuous raster scan (W3v1, up to 20 antennas).

RFI is not isotropically-distributed on the sky — it tends to be concentrated near the horizon and near the geo-stationary satellite arc. For the first part of the RFI survey, we will focus on the horizon. However, even when limiting to the horizon, it is still impossible to tile the region in a reasonable amount of time. To ensure that we get full azimuthal coverage, therefore, we have selected the W3v1 continuous raster scan mode.

To survey the horizon, we must operate near the ATA antennas' minimum pointing elevation. For the purposes of this survey, we are using a pointing elevation of 20°, the lowest elevation at which astronomical observations are recommended with the instrument.

1.4 Antennas and Feeds

If we would like to be able to directly compare the RFI environment seen by the old vs. the new feeds at the same sensitivity, we are limited to the number of old feeds, currently 4, that are active on the antennas. Therefore, 4 antennas will participate, incoherently summed, in the raster scan.

The four antennas with old feeds and SNAP boards are 1a, 1f, 4g, and 5c. 1a and 1f are located on one side of the site, and 4g and 5c are located on the other side of the site, with the signal processing room falling between them. This will allow us to potentially localize observatory site RFI originating from the signal processing room.

There are eight antennas attached to new feeds and SNAP boards (see Section 1.6): 1c, 2a, 4j, 2h, 3d, 1k, 1h, and 2b.

Because we are performing a scan that is very close to the horizon, some antennas will be subject to "shadowing" from the other antennas; their beam will be partially or entirely blocked by antennas that are nearby. We performed shadowing calculations between each pair of antennas at the site, with a pointing elevation of 20°. The results of that exercise are showing in Figure 1.

Given the shadowing calculations, the antennas used for this survey will be 1h, 1k, 3d, 4j (new feeds) and 1f, 1a, 4g, 5c (old feeds). The old-feed antennas and azimuths subject to shadowing are contained in Table 1.

Observing Antenna	Antenna Causing Shadowing	Azimuth With Expected Shadowing
1f	1g	91.6°
4g	4h	166.5°
5c	5b	110.5°
5c	5h	182.6°
5c	5g	220.1°
5c	5e	322.1°

Table 1: Antennas in the RFI Survey (all with old feeds) subject to shadowing from other antennas at a pointing elevation of 20°. 5c is the most severely affected, with 4 shadowings.

1.5 Scan Speed

We wish to set a survey raster-scanning rate that will allow for completion of the survey within the designated timeframe, but will also ensure at least one spectrum per "beamwidth" on the sky, even at the highest frequencies. A rate that satisfies these requirements, and allows for ease of calculation, is a slew rate of 1 degree/second, allowing for a complete azimuthal scan in 6 minutes. With a SNAP readout time of 10ms (see Section 1.6), this allows for 3 spectra / beamwidth even for the highest frequencies.

1.6 Data Products

For the first-pass of the RFI survey of the horizon, we are interested in obtaining data products which will be informative and not unwieldy. Therefore, we will use antennas that have SNAP boards, instead of those with RFSoC boards. The SNAP boards have a custom spectrometer mode which allows for coarse-resolution spectra to be quickly and easily written to disk. For this broad look across the bandpass, we have chosen an output spectral resolution of 1 MHz, with the intention of high-resolution spectroscopy at frequencies/times/positions with high levels of interference. These spectra, read out every 10 ms, can be easily mapped onto azimuth, and used to create an interactive, RFI map of the horizon, incorporating spectral and temporal occupancy to help visualize the RFI environment

2 Observing Scripts

[SOF: Details of how the observing scripts were written, e.g., central tuning frequencies, raster scan function, etc. will be contained here]

3 Observation Scheduling and Completion

Currently, the RFI survey is scheduled to begin on February 6th, 2022. It should take a minimum of a week (4 2-hour sessions / day for 7 days) to complete these observations.

[SOF: Details of observing calendar will be contained here]

4 Interactive Visualizer

[SOF: Details of writing the interactive visualizer, as well as a GitHub link to a Jupyter notebook, and probably a few screenshots will be contained here]

The data gathered from this survey are multidimensional, and would best be explored and parsed with an interactive software tool. Python provides nice options for interactive graphics, for example `ipywidgets` (for interactive sliders) within `Jupyter` notebooks.

5 Results

[SOF: The things that we learn from exploring the data in the visualizer will go here, e.g., patterns we notice in frequency/time/position, parts of parameter space we would like to examine in higher resolution for future surveys, etc.]

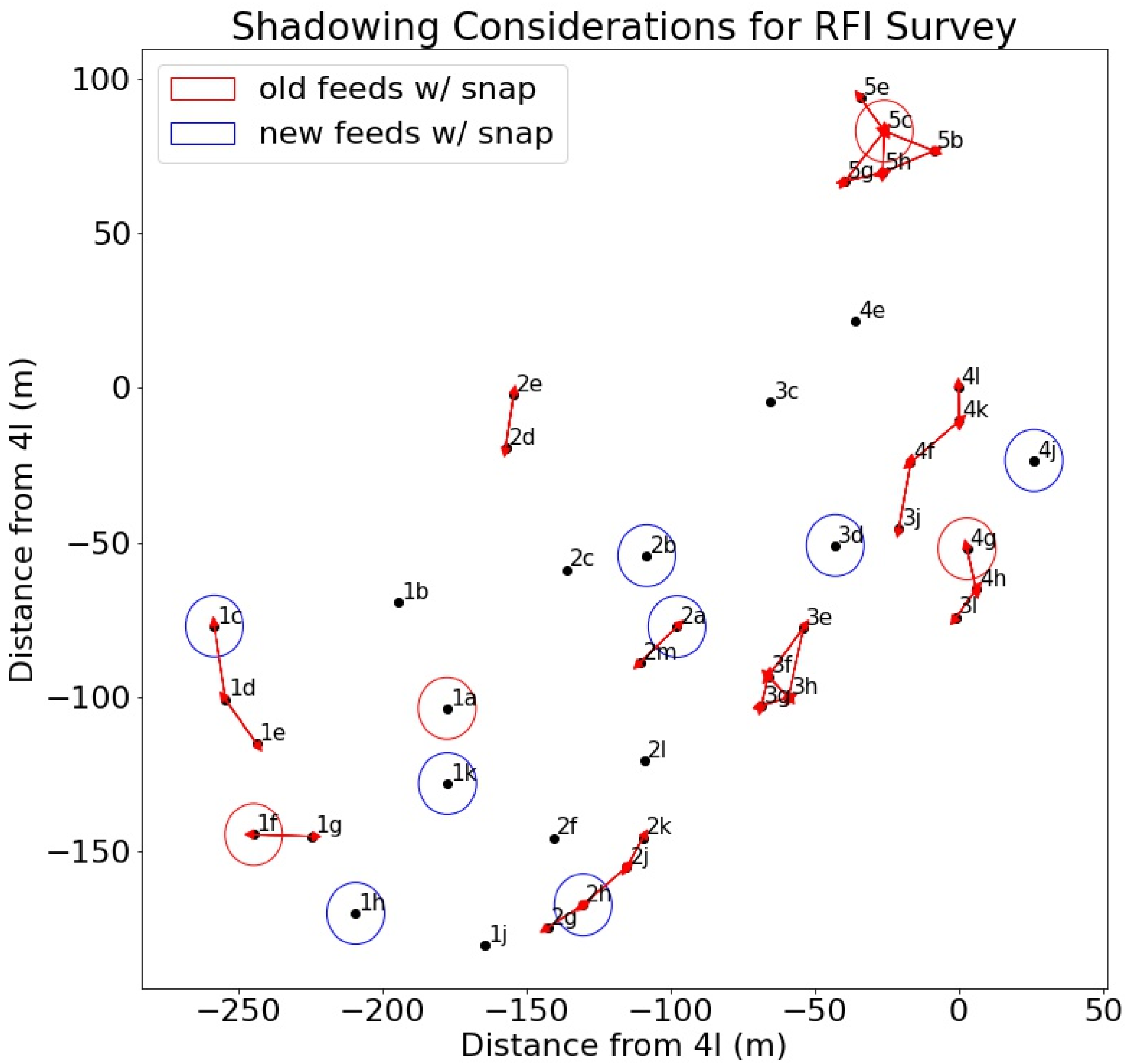

Figure 1: A top-down map of the ATA antennas, showing shadowing between antennas at a pointing elevation of 20°. An arrow pointing from Antenna A to Antenna B illustrates that A is blocked by B. As the site is relatively flat, most, but not all, shadowings are bi-directional. All antennas currently connected to SNAP boards are circled, with antennas outfitted with old feeds shown in red and antennas outfitted with new feeds in blue. In summary, it is trivial to select a set of 4 new antennas with SNAP boards that are immune to shadowing, but 3 of the 4 the old feeds will be subject to some shadowing, especially 5c.