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# GNU Radio at the Allen Telescope Array

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## Abstract

The Allen Telescope Array (ATA) located in Hat Creek, CA, comprises 42 antennas and was built with the primary goal of conducting SETI (Search for Extraterrestrial Intelligence) observations. Like other SETI programs such as Breakthrough Listen (BL), the SETI program at the ATA generates large amounts of data in specialized formats which have traditionally had a high barrier to entry, requiring an understanding of radio astronomy and digital signal processing. These projects are now seeking to engage members of the public – including the GNU Radio community as well as students and educators at a wide range of age levels – to become actively involved in the search alongside professionals in the field. As well as helping to develop novel algorithms and processing techniques, interested individuals will be able to take advantage of the flexible capabilities of the ATA, interfaced with GNU Radio, to capture data from a wide variety of objects of interest and for a wide range of applications. A major benefit of GNU Radio is its visual, user-friendly interface, and this makes it an ideal tool to bring radio astronomy techniques to members of the public and the GNU Radio community. As part of our goal to utilize GNU Radio to make radio astronomy and SETI more accessible, we have installed two USRPs (an N320 and N321) onsite for data collection and have implemented a GNU Radio interface for the ATA which includes a control system and data acquisition capabilities.

## 1. Introduction

### 1.1. SETI and the ATA

The Search for Extraterrestrial Intelligence (SETI) is a field with a rich and unique history. The question “is there intelligent life beyond Earth” is age-old, but the radio astronomy approach to SETI was established in 1960 by astronomer Frank Drake at the Green Bank Observatory in West Virginia, following the publication of a theoretical study by (Cocconi & Morrison, 1959), who proposed that a search for radio signals would be an effective scientific method of searching for ETI (Drake, 1961). For much of SETI’s history since its beginnings in 1960, it has struggled to maintain steady funding and telescope time, but that has changed in recent decades, with the construction and commissioning of the ATA as well as the inauguration, in 2015, of the \$100 M SETI project Breakthrough Listen, the largest SETI program to date, which utilizes telescopes across the world including the 100m Green Bank Telescope in WV, the 64m Parkes Telescope in Australia, and the optical Automated Planet Finder at Lick Observatory (Welch et al., 2009; Worden et al., 2017).

The ATA, which is run by SETI Institute and became operational in 2007, comprises 42 antenna elements with offset feeds. The offset feed design offers improved aperture efficiency and beam quality, and minimizes the introduction of out-of-beam radio frequency interference (RFI). The array operates between 1 and 11.2 GHz, and is currently undergoing an upgrade that will increase this range to 1-15 GHz (ata). The ATA’s primary focus is SETI research, but it has also been used for a variety of research projects in other areas of astronomy as well, including neutral hydrogen (HI) surveys, radio transient searches, etc. (Bauermeister et al., 2009; Croft et al., 2009; 2012; Siemion et al., 2011; Williams et al., 2012).



Figure 1. The Allen Telescope Array in Hat Creek, CA (Image credit Seth Shostak / SETI Institute)

### 1.2. GNU Radio, SETI, and Outreach at the ATA

GNU Radio has found application in many (formal and informal) radio astronomy outreach efforts, including Open Source Radio Telescopes (OSRT), Digital Signal Processing in Radio Astronomy (DSPIRA) with its associated Research Experience for Teachers program, along with many others (White et al., 2018; Bandura et al., 2018). It lends itself well as a teaching tool because running a GNU Radio flowgraph does not require any prior knowledge of a programming language, and at the same time allows the user to see what is going on “under the hood.” In addition, GNU Radio’s user-friendly nature and customizability has allowed it to begin to find its way into professional radio astronomy applications as well, including at Dwingeloo Radio Observatory in the Netherlands.

Members of the SETI community intend to utilize GNU Radio to introduce students to radio astronomy, digital signal processing, and the detection of natural and artificial radio signals. Our goals are to promote a broader understanding among students, educators, and members of the public about the mission of SETI and the processes involved in the search. Using the “hook” of SETI, we aim to inspire students and others to learn more about various STEM fields, which could help them (a) identify possible career paths of interest, and (b) become more scientifically and technically literate citizens. We aim to, ultimately, develop curricula and examples to provide background on radio astronomy, SETI, GNU Radio, and DSP, with the additional goal that time on the ATA be allocated to the GNU Radio community, students, and educators. In order for outside communities to observe with the ATA, we have installed two USRPs onsite to gather data from two ATA antennas, and have developed an out-of-tree module called gr-ata which contains several blocks that can be used to point and control the ATA.

## 2. GR-ATA - An Overview

To create a user-friendly control interface for the ATA, we developed gr-ata. This module consists of four blocks: the Control Block, the Track Scan Block, the On-Off Block, and the IF Switch Block. These blocks are written in Python and serve as wrappers for functions in the internal ata\_control Python library that directly interfaces with the array.

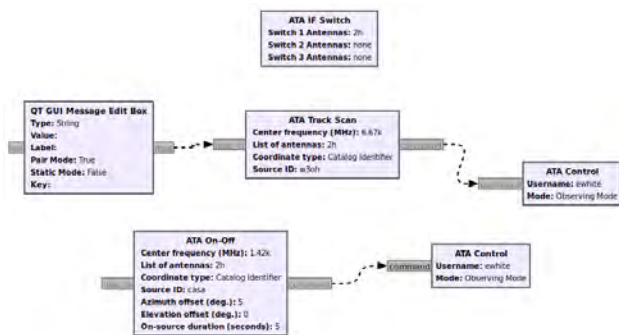


Figure 2. Example flowgraphs utilizing gr-ata blocks

### 2.1. Control Block

The Control Block performs necessary initialization steps for the observation, executes commands to point the antenna(s) (which it receives from the ATA observation blocks, more on this in the next subsection), and does any cleanup tasks necessary to wrap up the observation.

Initializing the observation involves a number of steps, the first of which is to check that the user can, in fact, connect to the ATA machine which is capable of controlling the array; an error is returned if not. If the user wishes to test out gr-ata without actually moving the array or connecting to the ATA server, they can select “Offline Mode” and perform a dummy observation. If, however, the user selects “Online Mode” and carries out an observation, additional setup steps are performed, including reserving the antennas the user has requested (if they are available), setting the array’s Local Oscillator (LO) frequency (which cannot be changed in the flowgraph if the user is not the primary observer), turning on the low noise amplifiers (LNAs), and running Autotune to set the correct power level of the analog signal path (which sets the gain on the LNAs).

When the Track Scan Block or the On-Off block sends a pointing command, the Control Block first checks if the commanded target source is above the horizon, and if so, it slews the antennas to their destination. Finally, when the user stops the flowgraph – or if it crashes due to some error – there is a deconstruction function which cleanly exits the observing session by stowing and releasing the antennas

that the user has reserved.

## 2.2. Observation blocks

The Track Scan Block and the On-Off Block accept input from the user about what source to observe; the target source can be indicated either by inputting a string identifier for a source that corresponds to an ID within the ATA source catalog, or by inputting the Right Ascension / Declination or Azimuth / Elevation that they wish to point at. In addition to being able to indicate a target source by filling out the fields in the blocks before running the program, the blocks are configured such that the user can connect a QT GUI Message Edit Box to the input port of the Track Scan or On-Off block, then input new sources to slew to during an observation.

The Track Scan block sends a message that causes the Control Block to point the antennas to whatever source you have indicated and tracks on it until you either input a new source location or end the session. The On-Off block is slightly different; it first sends a message to the Control Block telling the antennas to point on the indicated source, then after a user-provided duration of time has passed, it sends another message telling the antennas to slew to a location slightly offset from the main source (the offset amount is also provided by the user); this is useful if the user wishes to compare the on-source scan with the off-source scan.

The key thing to note here is that, while the Control Block executes the commands, the Track Scan and On-Off blocks control the observing pattern of the array. So if a user wishes to observe in some more elaborate pattern – for example a daisy map or some other unusual observing sequence – they could easily write their own observation block to send messages to the Control Block, telling it to execute pointing commands in a given sequence. Thus, while this control system works well without modification, it is also extremely customizable to the observer’s unique needs.

## 2.3. IF Switch Block

Unlike the other three blocks, the IF Switch Block does not affect the control of the array. At the ATA, the signal from each antenna is processed through an RF Conversion Board (RFCB) which downconverts the signal to an intermediate frequency (IF). There are 42 RFCBs onsite, one for each antenna, and since there are four possible local oscillator (LO) tunings available, each of the RFCBs has 8 outputs: 2 polarizations per antenna times 4 tunings. The output from multiple RFCBs is connected to a unit called an IF switch (see Figure 3), which allows the user to select one of the connected antennas to be routed to the output and therefore to the USRP. The IF Switch Block in GR-ATA lets the user

select which antenna(s) they would like to receive output from via the USRP(s).



Figure 3. The ATA IF-Switch

## 3. Data Acquisition with USRPs: Summary and First Results

Two USRPs – an Ettus N320 and an N321 – were installed at the ATA in August 2020 to enable data acquisition capabilities with GNU Radio. USRPs do not currently make up the primary backend for the ATA, but they form a development system that could be expanded with the addition of more USRPs.

The USRPs have two ports each, so the system in sum has four ports – allowing an observer to collect data with two antennas with both polarizations or four antennas with one polarization each. The first light with the N321 USRP connected to a single antenna yielded a promising detection of neutral hydrogen (HI) in the plane of the Milky Way toward a right ascension (RA) of 23.8 hours, and a declination (Dec) of 64.7°, as seen in Figure 4. This plot shows the power spectrum plotted on a logarithmic scale against the velocity corrected with respect to the local standard of rest ( $v_{lsr}$ ). Note that this data has not been bandpass corrected or flux calibrated. Figure 5 shows a plot from the LAB survey conducted in part by the Dwingeloo Radio Telescope in the Netherlands; this plot shows HI at the same coordinates on the sky as the ATA’s HI observation (Hartmann & Burton, 1997). The quality of this data and the observed agreement between the position of the HI line on the  $v_{lsr}$  axes of the ATA plot versus the LAB plot provides an encouraging initial confirmation of the ATA system.

The combination of GNU Radio’s flexibility in data acquisition and data processing methods, along with the high quality of the N320 and N321 USRPs installed at the ATA make it an excellent testing ground for members of the GNU Radio community, education community, and scientific community to explore various digital signal processing capabilities and methods, as well as pursue investigative projects ranging from radio astronomy observations to SETI projects to satellite captures. We look forward to col-

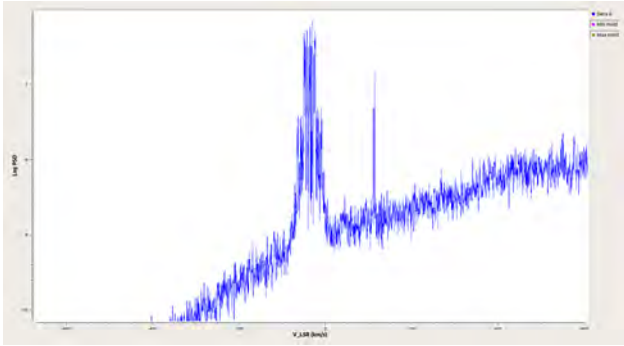


Figure 4. Neutral hydrogen (HI) line data recorded at the ATA using an Ettus N321 USRP and a single 6 meter antenna.

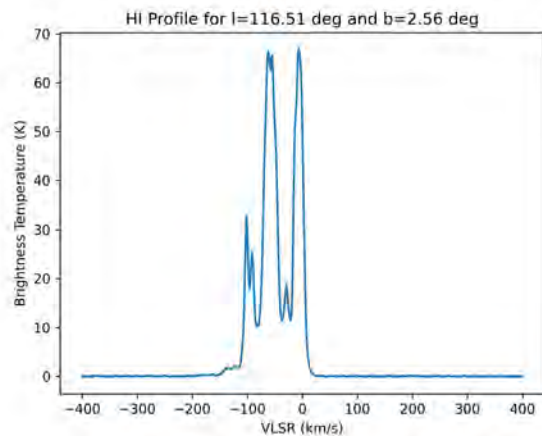


Figure 5. HI line data from the LAB survey toward RA = 23.8 hours, Dec = 64.7°.

laborating with GNU Radio users to further explore the vast and exciting possibilities this new infrastructure has to offer.

#### 4. Conclusions and next steps

We have demonstrated that GNU Radio can be utilized to create an effective and intuitive control interface for a major radio telescope array, which will make the array more accessible to a broader user community. In addition, we have done initial testing that shows the effectiveness of USRPs coupled with GNU Radio as a means of data acquisition and signal processing at the ATA. In the future, we hope to continue to improve the existing gr-ata blocks, and add further functionality with input from the broader GNU Radio and radio astronomy communities. In general, we look forward to continuing to foster collaboration between SETI and GNU Radio to bring radio astronomy to a broader com-

munity.

#### 5. Acknowledgements

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#### 6. Software and Documentation

The `gr-ata` out-of-tree module can be cloned from this repository: [github.com/SETIatHCRO/gr-ata](https://github.com/SETIatHCRO/gr-ata). The README file within that repository contains instructions on how to install the prerequisite Python libraries from ATA-Utils. For additional documentation and tutorials, please visit our page on the GNU Radio wiki: <https://wiki.gnuradio.org/index.php/GNURadio@theATA>.

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