Using Allen Telescope Array Data on GNU Radio

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History of HCRO & ATA

1958: Hat Creek Radio Observatory was founded

~1962-2004: Multiple different radio telescopes pass through site

~2002 - 2007: Construction of ATA

2019: Beginning of the 3-year feed refurbishment program
Use Cases

• Pulsars
• Fast Radio Bursts
• SETI Research
The Allen Telescope Array

- **Antennas**: 42x 6.1m offset Gregorian 1 - 11.2GHz bandwidth
- **ATA Signal Path**: Analog RF over fiber link into the central signal processing room
- **Signal Processing Room**: 4 independent tunings with 700MHz each
- **Digital Signal Processing**: Currently three DSP systems deployed. SNAPs, GNU Radio USRPs, and RFSoCs
GNU Radio at the ATA today

- **GR-ATA**: Control the antennas in GNU Radio Companion
- **2x USRP N320/N321**: 200 MHz of bandwidth with two antennas
- **gnuradio1 server**: Processing of collected data
Summary of Refurbishments

- 21 existing feeds refurbished and operational (cryogenically cooled)
- 4 original feeds in operation (non-cryogenically cooled)
- 30 feeds by the end of this year are planned
Signal Processing Room

Before

After
The Telescope’s New Backend

- RFSoC Multi Mode Digital Backend
- Supported operations:
  - Correlation
  - Baseband capture
  - Beamforming
  - ...

![Diagram of real-time pipeline with ADC/FPGA/NIC stack, Blade GPU beamforming, Blade GPU Hi-Res channelization, and NVMe storage.]
Correlator

- **N_ants**: 20 antennas (210 baselines)
- **Integration lengths**: 8ms - X mins
- **Backend**: xGPU-based pipeline.
- **Visibilities**: uvh5 output file format
- **Calibration**: Current use of correlator is phase/bandpass calibrating of beamformer + tests of delay engine.
Correlator + beamformer calibration

Before delay/phase cal

After delay/phase cal
Beamformer - beam pattern simulation

Zenith angle offset from ZA=30.00 [deg]

Azimuth offset from Az=150.00 [deg]
Beamformer

• First light December 2021

• Beamforming library: BLADE; developer: Luigi Cruz (research intern)

• Capabilities constantly improving

• Real-time synthesis of up to 8 beams, if outputting complex voltages (io-bound)

• Output format: “modified” GUPPI format + sigproc filterbank (under development)
Mars observation

- 60 seconds observation with 20 antenna beamformer, centered at 8500 MHz (where most orbiter downlink frequencies are)
- Beamformer calibrated using the typical correlator observation
- Orbiters were detected (Mars express was detected in an earlier recording)
Voyager observation

• Voyager 1, furthest human-made object, detected by the ATA

• July 9th, 2022, 900 second recording with the beamformer was performed.

• Measured C/N0 ratio is as expected from link budget calculations

• Read more: https://wfarah.github.io/blog/voyager1/
Joint Polar Satellite System (JPSS)

- 30 MHz bandwidth
- X – Band (7812 MHz)
LTE Downlink

- 20 MHz bandwidth
- LTE Band 2 (1960 MHz)
GUPPI Files

- Streaming data is stored in blocks.
- Each block is composed of an ASCII metadata header followed by binary data.
- Binary data is laid out as a matrix of mixed-domain data (frequency, time, polarization).
- Multiple beams or antennas can be added as an optional dimension.
- Sample type can be integers or floats
gr-teleskop

- Provides reader block for ATA-generated GUPPI files.
- Internally converts mixed-domain data into a time-domain stream.
- Fast enough to decode 96 MHz of 16-bits floating-point data in 0.5x real-time.
- Planning to capabilities to other observatories in the future.
gr-teleskop

- Type selection (32-bits floating-point output).
- Repeat toggle (just like native file reader).
- Number of Aspects (antennas, beams, or none).
- Channel Binning (lower/upper channel).
- Polarizations (X, Y, XY).
Circular Polarization

- Circular polarization synthetization by summing (RHCP) or subtracting (LHCP).
- Calibrations for polarizations X and Y are necessary.
- Available soon for the Allen Telescope Array!
Channel Binning

- Channel binning discards frequency channels that aren’t necessary.
- Set by the “Lower Channel” and “Upper Channel” parameters.
Channel Binning

Channel 0 to 192 (96 MHz)
Full Frequency Range

Channel 48 to 144 (48 MHz)
Binned Range
Aspects

Optional: Antenna or Beam can be chosen with the “Aspect” parameter.
Thank you for your attention!

https://github.com/luigifcruz/gr-teleskop