

# **A Radio Frequency Interference Mitigation Strategy for the Allen Telescope Array**

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## **ABSTRACT**

We describe a multi-layered strategy for the mitigation of radio frequency interference (RFI) at the Allen Telescope Array (ATA). Because of the unique broadband nature of the ATA, RFI is a greater problem than for existing arrays. However, the large number of antennas in the ATA and new flexibility in the digital architecture provide unprecedented opportunities for RFI mitigation. We describe measurements of RFI at Hat Creek with a dedicated RFI monitor. We have also tested a variety of algorithms including adaptive cancelling, interferometric nulling and time blanking. These place requirements on the array design.

## **THE ALLEN TELESCOPE ARRAY AND RADIO FREQUENCY INTERFERENCE**

The Allen Telescope Array is a 350-element centimeter-wavelength interferometer under design by the UC Berkeley Radio Astronomy Laboratory and the SETI Institute [1]. The 6.1-m dishes will give the array approximately the sensitivity of the Very Large Array. The ATA faces unique problems and opportunities with respect to radio frequency interference (RFI).

The array will have full frequency coverage from 0.5 to 11.2 GHz. This will provide access to spectral lines and bandwidths currently inaccessible to other interferometers. However, observations outside of the protected radio astronomy bands must deal with RFI. In addition, the entire frequency range is transported from the front end to the digital, which makes the array sensitive to saturation and non-linear effects outside of the observing bandwidth.

The large- $N$  capability of the array, however, makes the ATA a very flexible instrument for RFI mitigation. A number of algorithms for RFI mitigation become increasingly effective as the number of elements increases. Growing awareness of the problem of RFI and potential solutions for it have influenced the design of the digital architecture, allowing implementation of algorithms not previously tested in radio astronomy.

No single algorithm will be effective against all types of interference. We describe below several techniques that we have tested and are planning to implement with the ATA. We also describe observations of RFI made with the RFI monitor at Hat Creek Radio Observatory, the future site of the ATA.

## **RFI MONITOR AT HAT CREEK RADIO OBSERVATORY**

We have installed a RFI monitor at Hat Creek for the purpose of studying RFI from 100 MHz to 11 GHz. The monitor consists of two discone antennas covering 100 MHz - 3 GHz and 3 GHz - 11 GHz, respectively. The antennas are installed only one at a time atop a 10 m tower. Both antennas have relatively flat frequency response over the given ranges and isotropic sensitivity at the horizon. A broadband amplifier gives 40 dB of gain. The signal is transmitted over coax into the laboratory. A 20 GHz spectrum analyzer under computer control is used to read back the signal. The system permits a variety of observations including sweep over a wide frequency range, fast retrieval of maxima and a peak hold mode. The PC runs linux and communicates with the spectrum analyzer through GPIB.

The monitor has detected a wide variety of interferers at Hat Creek Radio Observatory, the future site of the ATA. Interference generated by the BIMA millimeter interferometer contributes substantially (Figure 1). Although the mm array will be removed before construction of the ATA, this emphasizes the need for self-shielding of the ATA.

Other, non-self-generated interferers detected at Hat Creek include radar at 1250 and 1340 MHz, distance measuring equipment (DME) from aircraft at 960-1200 MHz, pager and cellular phone signals below 1000 MHz, television and FM radio transmitters, microwave ovens, and a variety of satellite transmitters including Iridium, Glonass, GPS and digital audio radio service (DARS) at 2.3 GHz. These represent a wide variety of signal types that must be dealt with through different techniques.

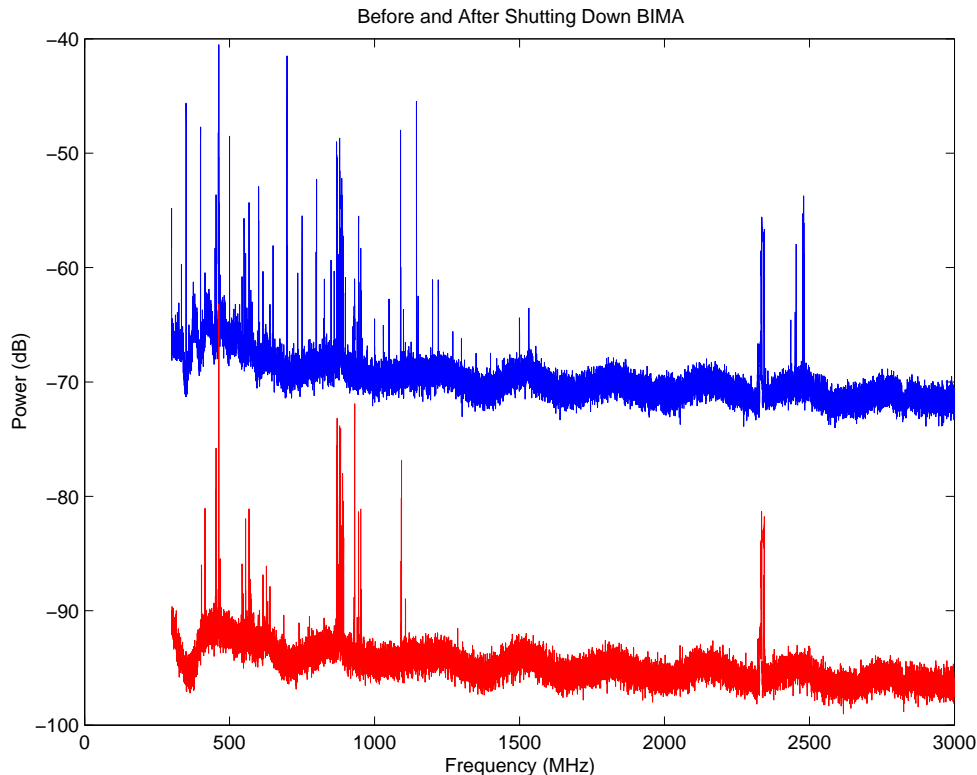


Figure 1: Spectrum obtained with the RFI monitor at Hat Creek before (top) and after (bottom) turning off all electrical and mechanical systems associated with the BIMA millimeter array. The absolute power levels are uncalibrated. The noise floors are the same but have been offset by 20 dB for clarity.

## ADAPTIVE CANCELLING

The ATA will implement an adaptive canceller to eliminate RFI from phased array signals. The canceller will employ a Wiener filter or other adaptive method to subtract interference obtained from reference antennas. Up to 10 of the antennas will be available as independently steerable reference antennas. In the time-dependent Wiener filter approach, the cross-correlations of these reference signals with the astronomy signal in the single phased array beam will be used to generate an optimal filter for subtracting the interferer or interferers.

We have tested the effectiveness of this technique with data obtained from the Rapid Prototyping Array, a 7-element L-band interferometer. We have achieved over 30 dB of attenuation of GPS and Glonass signals [2]. See Figure 2 for an example. Similar results have also been obtained through a post-correlation analysis [3].

## INTERFEROMETRIC NULLING

The ATA has a substantial number of degrees of freedom for beam forming. These allow the formation of a large number of nulls in angular and/or frequency space without substantial loss of sensitivity in the beam direction [4,5]. For example, the array maintains 80% sensitivity with the placement of 100 widely separated nulls on the sky (Figure 3). Nulls can be closely packed in angular space allowing for uncertainties in source positions (Figure 4). Nulls can also be closely packed in frequency space, allowing for nulls that are much broader than the characteristic 100 kHz width of a narrow band signal. A wide variety of patterns can be achieved.

These nulls will be formed through phase and amplitude gains implemented in the digital IF system. These complex gains must be updated every 10 msec to achieve maximum rejection. This system is not adaptive. It requires *a priori* knowledge of the interferer location, trajectory and spectrum to be effective. Antenna gain properties far outside of the primary beam must also be identical or very well known, as well.

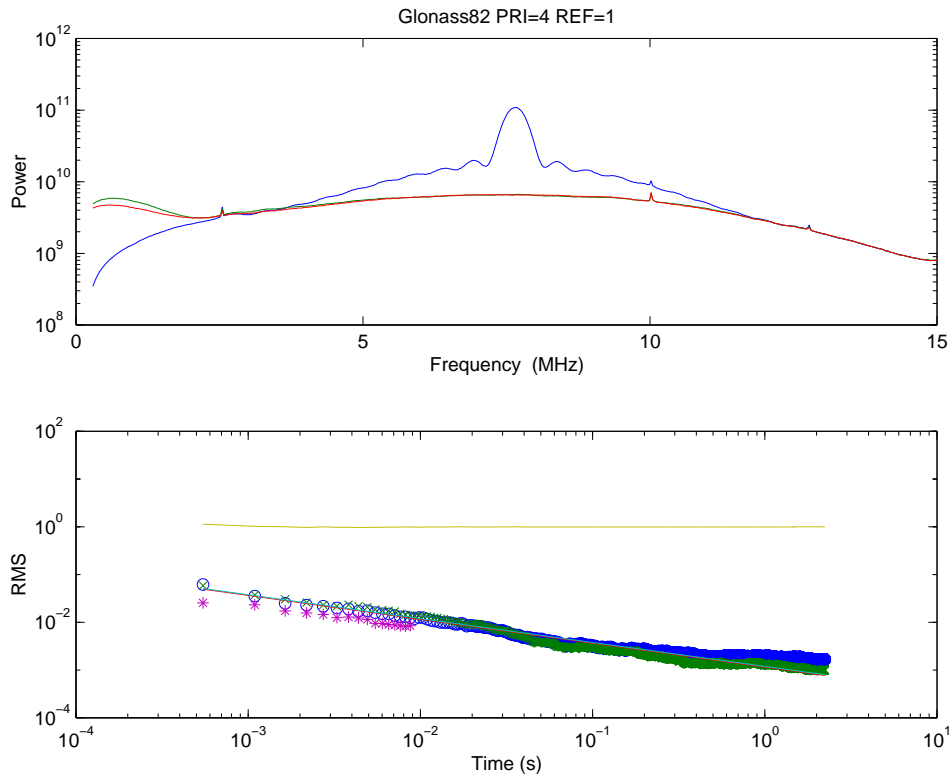


Figure 2: The effect of a Wiener canceller on a Glonass signal. In the top panel, the original spectrum in the astronomy channel shows the Glonass signal (blue). The red and green spectra show the result after cancellation using a reference antenna pointed at the Glonass satellite with single and dual polarization, respectively. In the bottom panel, we show the rms of the original spectrum (gold), the result after cancellation with the single polarization Wiener solution (blue) and the dual polarization Wiener solution (green), and the measured response of a short off-spectrum (purple). We achieve 30 dB of attenuation, the maximum obtainable in this 2 second interval.

## TIME BLANKING

Time blanking will be implemented in individual backends separately. In the correlator, time blanking will have a characteristic time scale of  $\sim 100\mu\text{sec}$ . This duration is due to the effects of the poly-phase filter bank on the time response of a delta function. Blanking will be integral for dealing with observations of red-shifted HI that face radar or DME interference.

## POST-CORRELATION ANALYSIS

The correlator will have a maximum dump rate of 10 msec. Visibility data will be fed to a large cluster of general purpose computers, which will perform RFI mitigation, calibration, self-calibration and imaging. A variety of RFI mitigation algorithms can be employed at this point. The limitation will be principally driven by computing power.

## REFERENCES

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- [4] G.C. Bower, "Simulations of Narrow-Band Phased-Array Null Formation for the ATA," *ATA Memo Series*, #37, 2001.
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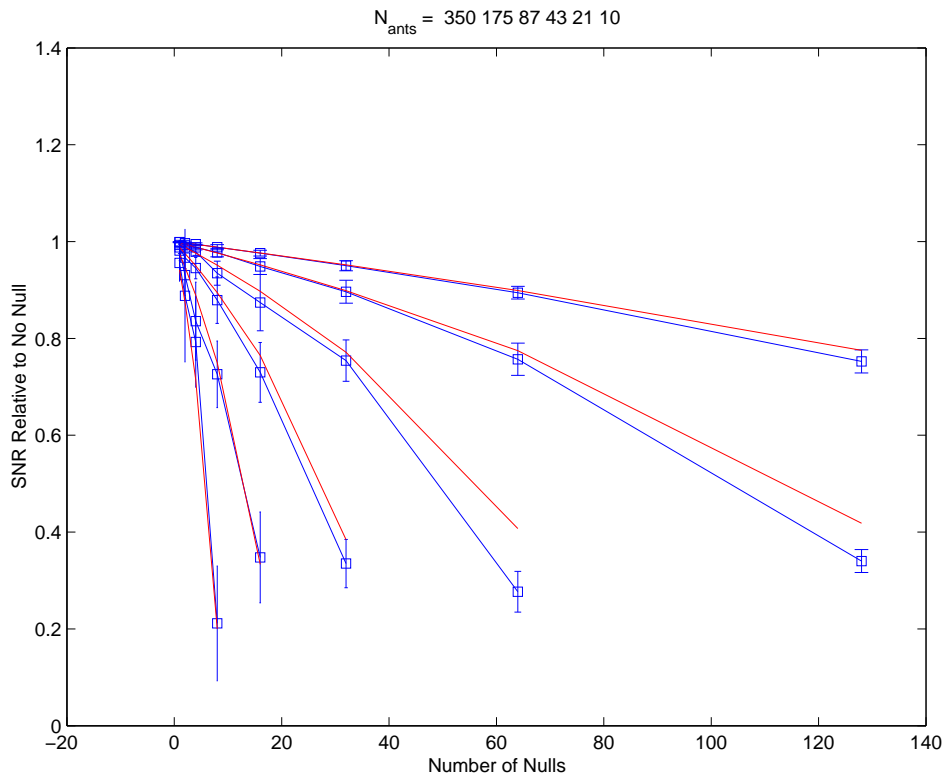


Figure 3: The SNR obtained in the astronomy direction for arrays of 350, 175, 87, 43, 21 and 10 antennas as a function of number of nulls located randomly on the sky. Blue points are measured with simulations. Red curves are the theoretically expected SNR. The SNR remains above 80% for the 350-antenna array and over 100 nulls.

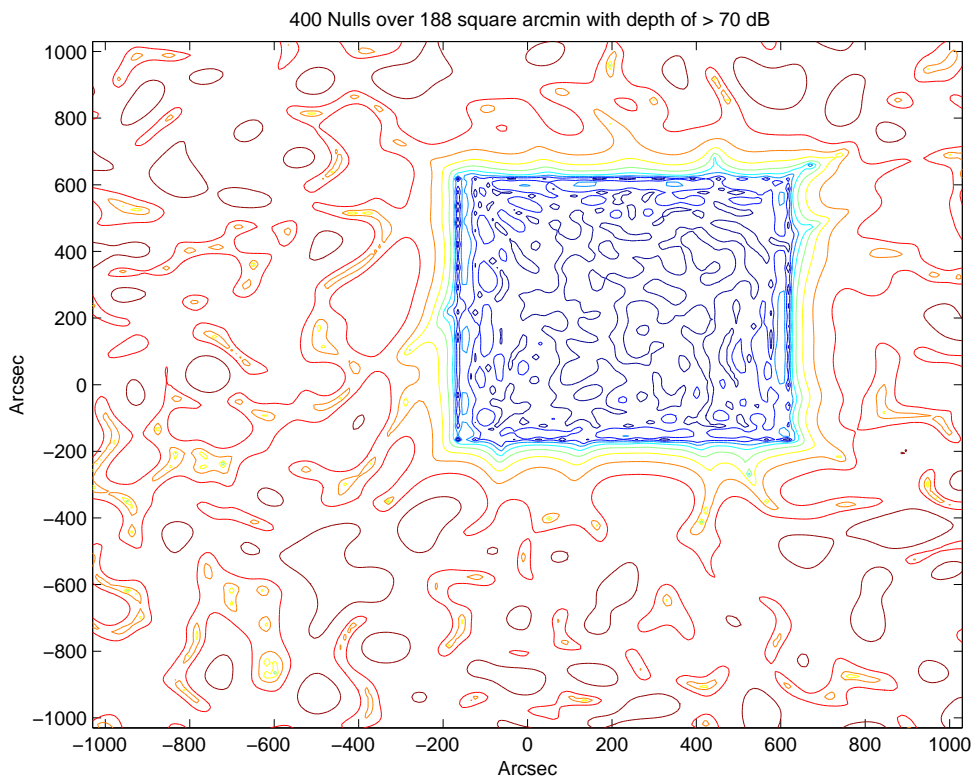


Figure 4: ATA sensitivity in the direction of a large area null. Contours are 10 dB relative to a beam peak of 1.