An RFI Mitigation Strategy for the Allen Telescope Array

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Abstract

The Allen Telescope Array faces unprecedented challenges and opportunities with respect to radio frequency interference. Its broadband frontend gives the ATA unique observing flexibility but makes it vulnerable to interference outside of the protected radio astronomy bands. This vulnerability occurs through direct conflict at the observing frequency between radio astronomy sources and interferers and through frontend saturation in the case of strong interferers regardless of the observing frequency.

For these reasons, the ATA is the first radio telescope designed with RFI mitigation as an integral element. The large-N nature of the ATA, the reliance on programmable digital electronics and an awareness of new algorithms and techniques will make the ATA particularly effective at RFI mitigation. Mitigation is integrated into the design from the antenna to the IF processor to the correlator. Our observing strategy employs a range of techniques and new hardware elements to address specific interference problems and specific science goals. Without these tools, many of the science goals of the ATA cannot be achieved.

1. The Allen Telescope Array

The Allen Telescope Array (ATA) is a new centimeter wavelength interferometer currently being designed and prototyped by UC Berkeley and the SETI Institute. The array will be the first of the next generation of large radio telescopes including the EVLA, LOFAR, and SKA. The design exploits new technologies that allow for a large number of elements supported by flexible digital electronics.

The ATA will consist of 350 6.1-m offset-Gregorian parabolas equipped with log-periodic feeds sensitive in two linear polarizations from 500 MHz to 11.2 GHz. The entire radio frequency signal will be transported by fiber optic cables to the lab, where four individual frequency bands of 100 MHz each can be selected. Two generic types of backend will be possible: phased array processors and a correlator. Up to four phased array beams can be formed within the primary beam of the antenna for each frequency. The array is both multiple single dish antennas and an interferometer simultaneously. See the ATA website and memo series for further instrument details (`http://www.seti.org/science/ata.html`).

We discuss the unique radio frequency interference (RFI) problems and solutions available to the ATA. There are no "magic bullets" to the problem of RFI. Our philosophy emphasizes a tool box approach with different tools for different interferers and different science goals. The more we know about a particular interferer, the more we can mitigate its effects.

2. The Interference Environment

Site selection is the most important RFI mitigation technique available. The Hat Creek Radio Observatory is remote and isolated from population centers by several mountain ranges. Modeling indicates that the terrain suppresses interference from outside the Hat Creek valley by ~ 100 dB. Nevertheless, interference from a variety of sources is still present at the site.

We have been able to identify, characterize and quantify many of these sources through two instruments: the Rapid Prototyping Array, a 7-element L-band interferometer dedicated to RFI studies and located in Lafayette, CA; and, the RFI Monitor, an isotropic antenna with frequency coverage from 100 MHz to 11 GHz located at HCRO. The RPA gives us detailed and high SNR knowledge of the characteristics of interfering signals. The RFIM gives us knowledge of the interferers present at HCRO.

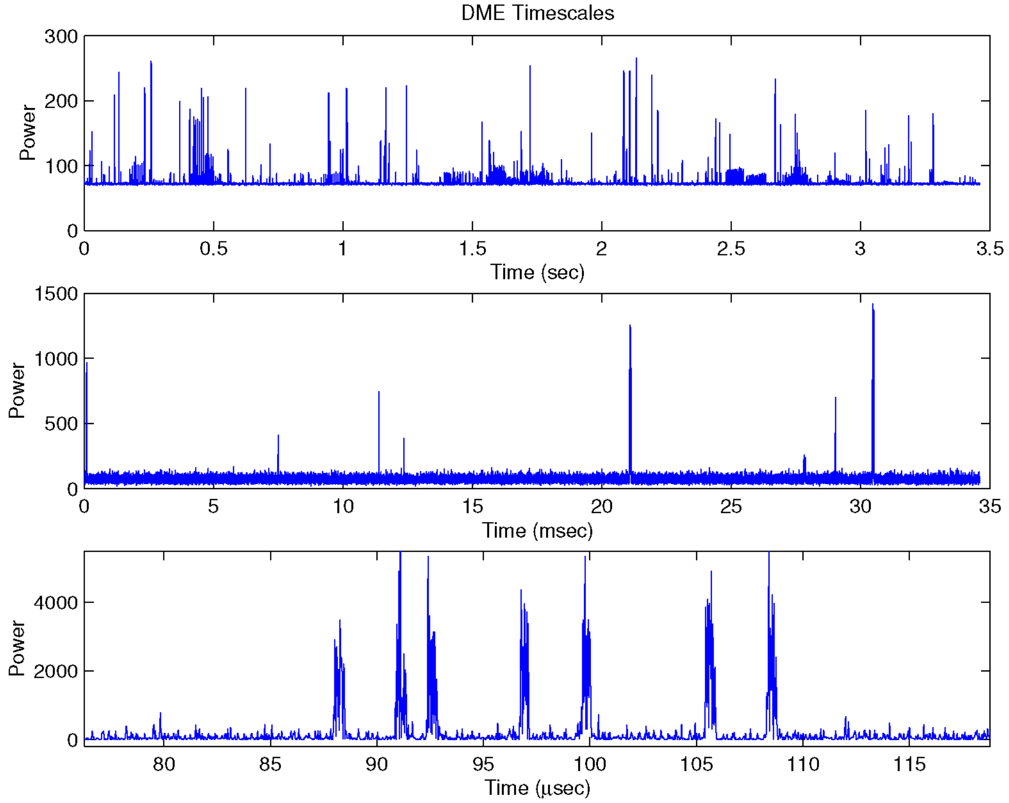
Among the interferers detected and studied are radar, aircraft distance measurement (DME), cellular phone and pager signals, microwave ovens, orbiting satellites such as GPS, Glonass, DARS and Iridium, geostationary satellites and local interference from computers, oscillators and digital electronics associated with the BIMA millimeter array. Combining the results for radar and DME from RFIM and RPA, for example, allows us to measure the spectrum and the time occupancy from microsecond to day timescales (Figure 1). This detailed knowledge allows us to tailor mitigation strategies to the specific problem.

3. Engineered RFI Mitigation

The low sidelobes of the ATA offset Gregorian antenna are an important mitigator of RFI. These provide ~ 40 dB rejection of interference signals which are outside of the primary beam.

The front end simultaneously receives signals over its entire frequency range. Thus, a strong interferer such as Iridium at 1625 MHz can saturate the front end even if the observations are tuned to a different frequency.

Figure 1. Plot of the time averaged power in one channel of the DME band on second, millisecond and microsecond timescales.



To compensate for this, 20 dB of headroom above the system temperature noise is available in both the broadband front end amplifier and in the optical fiber link between the antenna and the RF/IF downconverter.

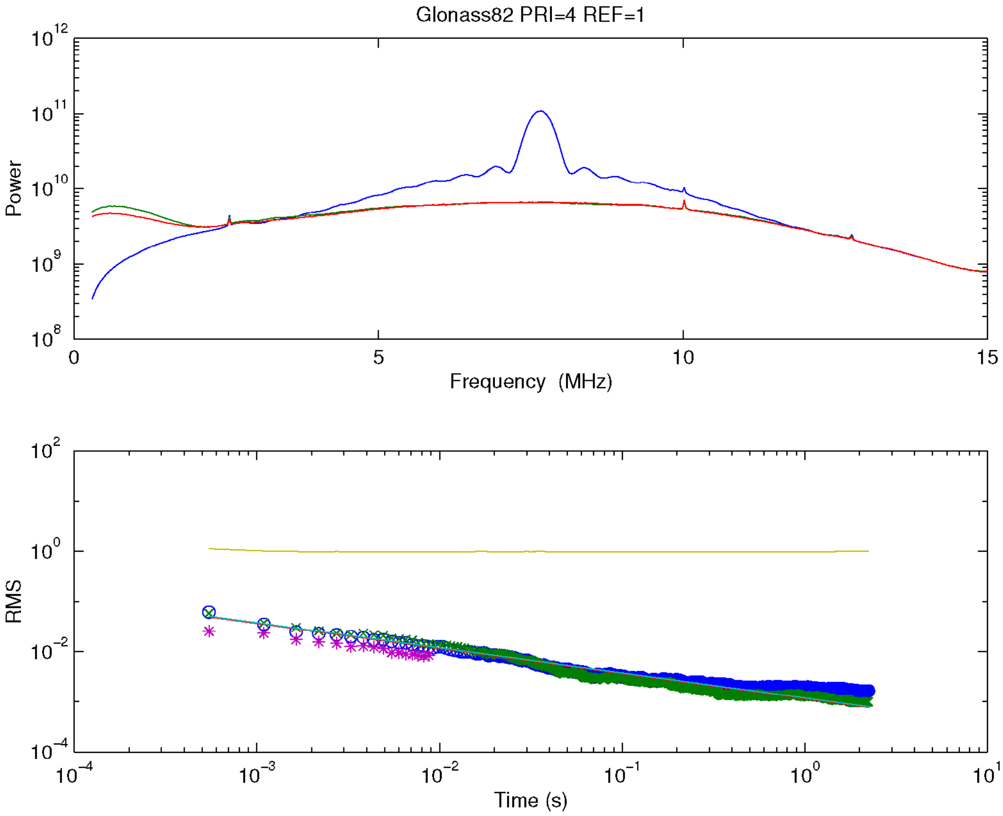
Similar techniques to prevent saturation and nonlinear effects of strong interfering signals are present throughout the system including the use of 8-bit ADCs in the IF processor. A polyphase filterbank in the correlator will prevent bleed-through of interference from one channel to the next.

4. Real Time RFI Mitigation

Scheduling is the first layer of defense against interferers in the real time system. To prevent saturation of the front end, artificial horizons will be placed around the most powerful interferers in the sky. The array will never point within 15 degrees of an Iridium satellite, for example. Additionally, the use of the RFIM will permit us to schedule experiments when particular interferers are quiet. Our monitoring has shown that aircraft DME is typically quiet in the early morning hours.

We expect to use at least four active techniques: time blanking, adaptive canceling, interferometric nulling, and post-correlation analysis. These techniques exploit the large-N nature of the ATA and are integrated into the digital design in some cases.

Figure 2. In the top panel, spectrum before (blue line) and after cancellation of a Glonass signal with a Wiener filter method. We show the residual power spectrum for single (green) and dual (red) polarization cancellation methods. In the bottom panel, blue circles and green crosses indicate the rms residual in the power spectrum from the single and dual polarization modes, respectively. These follow $t^{-1/2}$ laws (red and aqua lines). Purple stars indicate the rms residual for a measured noise spectrum. The gold line is the residual in the uncorrected power spectrum.



4.1. Time Blanking

Radar and aircraft DME occur in the frequency range from 960 - 1400 MHz. Without mitigation, it will be very difficult to observe extragalactic HI at redshifts between 0 and 0.5. While these signals overlap in frequency space with desired astronomy signals, they actually have a very small time occupancy (Figure 1). This is because they are pulsed rather than continuous. Research by Fisher (these proceedings) at the GBT has demonstrated that a predictive time blanker can achieve 90% observing efficiency. In the ATA, the time blanker will be a stand alone device that will provide blanking signals to the individual backends. Each backend can then blank or zero the signal in a way that best fits the scientific need. The time blanker will take input from the RFIM, a phased array signal, or one or more reference antennas taken from the array. Blanking can be on timescales as small as a microsecond and in individual frequency channels.

4.2. Adaptive Canceling

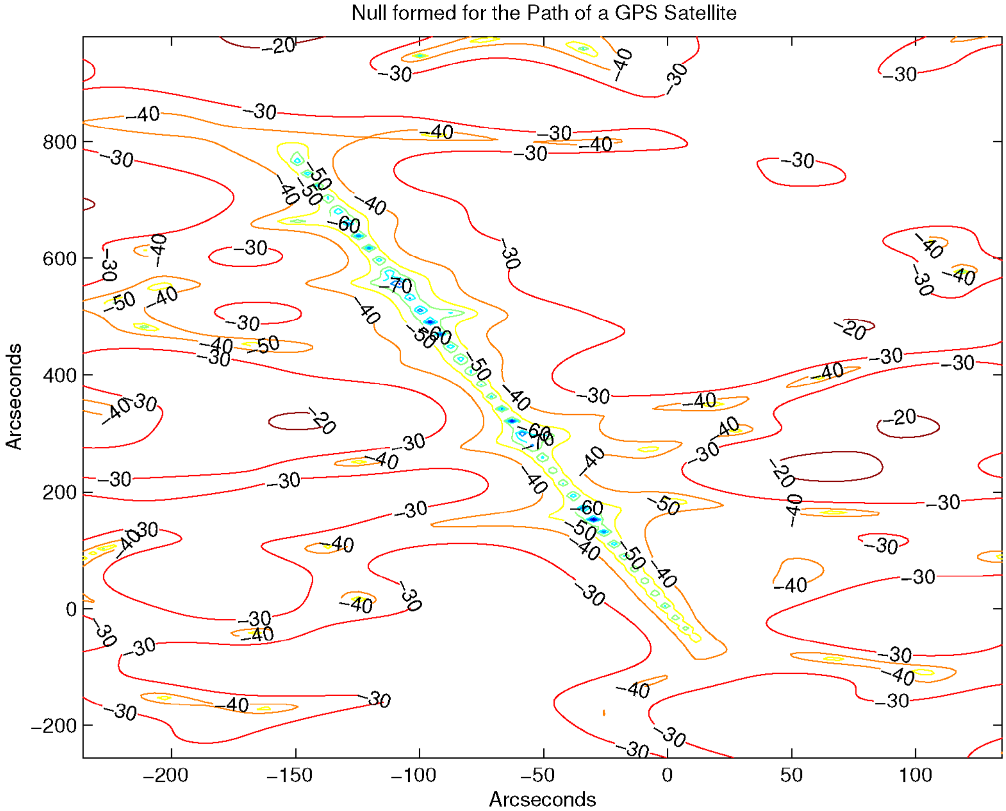
Reference antennas can also be used to implement adaptive canceling (Barnbaum & Bradley 1998, Ellingson et al. 2001). In this technique, a reference signal with a high interference-to-noise ratio is obtained and used to estimate the weaker interference present in the astronomy signal. The estimate is subtracted from the astronomy signal leaving the signal interference free. The estimate can be determined through a Wiener solution, an adaptive LMS method, or parametric estimation as in the case of GPS or Glonass where the interference signal is well-known. These techniques are inherently wideband and are insensitive to multi-path problems. They are ideal for interferers that can be tracked with an antenna: fixed transmitters and satellites with known trajectories. For the ATA, an adaptive canceler will be implemented as a stand-alone device which receives as input the signals from multiple reference antennas. The canceler will provide an interference free copy of the phased-array output of the ATA.

We have tested both the time and frequency-domain Wiener solutions and LMS methods with data obtained at the RPA (Bower 2001a, Mitchell & Bower 2001). We can achieve > 30 dB suppression of GPS and Glonass signals (Figure 2), where the limiting factor in these result is the amount of data that we have obtained, not the algorithm.

4.3. Interferometric Nulling

We can exploit the full power of the array through the use of interferometric nulling. For interfering sources in known positions, we can manipulate the complex gains of the array to place a null in the location of the interferer while maintaining most of the gain of the array in the direction of the astronomical source (Bower 2001b, Harp 2002). Since these gains must be updated rapidly for fast moving interferers, we have designed into the IF processor the capability to update the gains every 10 msec. In cases of multiple interferers or in cases of interferers with poorly determined positions, it will be desirable to place a large number of nulls on the sky (Figure 3). The ATA is well-adapted for this technique since the number of nulls which can be placed on the sky is limited by the number of antennas in the array (Figure 4). Finally, while this technique is intrinsically narrowband, we have shown that just as one can place multiple nulls in the spatial domain, one can place multiple nulls in frequence space. So, 100 nulls can be placed

Figure 3. Null formed for the path of a GPS satellite. Fifty individual nulls were placed along the 1.5 second path of the GPS satellite.

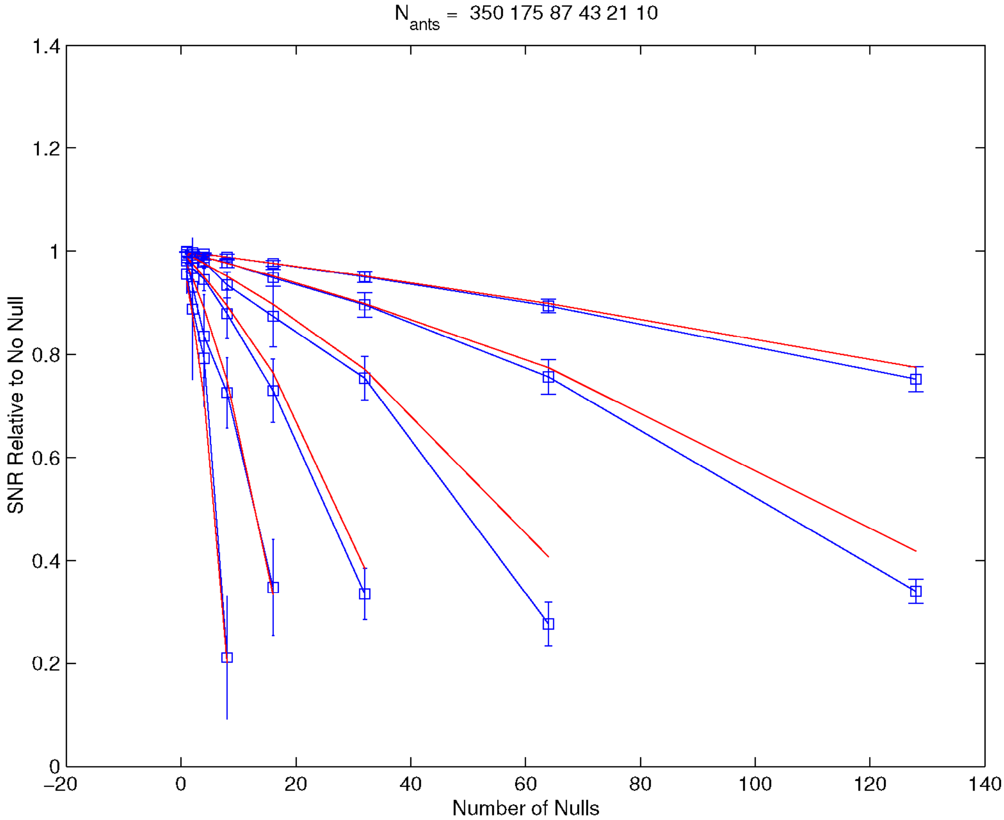


to null out a region that is 45 arcmin^2 in solid angle or 10 MHz in frequency space, while maintaining greater than 80% efficiency.

4.4. Post-Correlation Analysis

A number of mitigation techniques exist which require a measured correlation matrix (Leshem et al. 2000, Briggs et al. 2000). Some of these are essentially adaptive counterparts to the a priori technique of interferometric nulling described above. We are designing the correlator and its backend so that it is capable to implement these techniques. The correlator will be able to dump the correlation data at a maximum rate of 100 Hz, which is necessary for fast moving interferers. A multi-processor backend such as a Beowulf cluster will handle both general calibration and imaging tasks as well as implement post-correlation techniques. These techniques are very general in their application. The software implementation allows for a variety of techniques as algorithm development.

Figure 4. SNR at the phase center as a function of number of nulls and number of antennas. The blue curves indicate the results of simulations for arrays of 350, 175, 87, 43, 21 and 10 antennas. The red curves are the theoretical values expected. As an example, the ATA with 350 antennas can place more than 100 nulls while maintaining > 80% sensitivity.



5. Summary

We have described a variety of techniques for RFI mitigation with the ATA. These techniques exploit the unique capabilities of the ATA, especially the large number of antennas and the flexible digital electronics. The ATA will be the first array built with active mitigation strategies designed into the system.

We emphasize that these are experimental techniques. The flexibility of the system will allow us to develop and test these and other new techniques. Future generations of hardware will include substantially more sophisticated implementations.

6. References

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