RFI Mitigation with the Rapid Prototype Array

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The Rapid Prototype Array (RPA) is a 7-element L-band interferometer designed for RFI mitigation studies. We give an overview of the system design and data path. We also describe some of the early work that has been done with the RPA in RFI measurement and mitigation.

The Rapid Prototype Array

The 7-elements of the RPA are arranged in an elongated hexagon with a central element. The minimum and maximum baselines in the array are 7 m and 18 m, respectively. Each element is a 3.6-m Orbitron antenna with a modified X-Y mount and drive system. Antenna tracking rates are sufficient to follow LEOs, including Iridium. The antennas are each controlled with a micro-controller located on the antenna. The micro-controller communicates through a fiber-optic connection to a Sun Ultra 60. Control of the array is through GUI frontends constructed with the Labview package.

The dual-linear-polarization prime-focus feeds are sensitive to sky signals at L band. Front end filters limit the passband to 1400 - 1630 MHz. These signals are mixed to baseband in a two-step process. The first LO mixes RF frequencies to 200 MHz, where a 10 MHz filter is applied. The second LO mixes these IF signals to baseband. Variable attenuation is possible for the RF and IF signals. Gains were set such that the strongest interference signals can be observed in the main beam without saturation. The system temperature is 260 K and the efficiency is ~50%. A noise calibration signal can be injected into in each polarization.

The data stream from each antenna is sampled with an A/D card connected to one of seven Sun Ultra 60s. Each card accepts inputs from the two polarizations, as well as an external clock and a trigger signal. The maximum data rate is 50 Msamples/second in each channel. Typically, we set the sample rate to 30 Msamples/second, providing 15 MHz of bandwidth per channel. The data are sampled with 8 bits. Data-taking may be synchronized with the use of the trigger signal. The trigger signal is a fast-rising step function that is synchronized to the external clock and controllable manually or through
software. Up to 255*256*1024 samples can be taken contiguously in each polarization. The data is stored in memory and then written to disk in each data-taking operation. All further analysis including delay control, correlation and formation of spectra is performed with MATLAB or with custom software.

**RFI Studies with the RPA**

The RPA is a prototype array for the Allen Telescope Array (ATA), a 350 element interferometer currently under design. It serves as a testbed of RFI mitigation techniques and RFI measurements that will influence the design of the ATA. The software backend provides the opportunity to test a number of RFI techniques without construction of digital hardware. The RPA is also used as a testbed for ATA software and as a tool for student instruction.

A number of satellites and interferers have been detected and studied with the RPA. In Figure 1, we show a calibrated map of the integrated emission made in the geostationary arc as a function of frequency. The isolated feature at 1575 MHz is a GPS satellite that passed through the arc during observations. Data were calibrated with the noise calibration source. Each scan involves 9 msec of data in one polarization. We see no evidence for emission in the protected radio astronomy band.

We have tracked Iridium and GPS satellites among others. The tracking rate required for Iridium satellites is greater than 10 times sidereal. Array control permits sidereal tracking as well. We have tracked and detected a handful of celestial sources including the Sun, Cas A, and HI in the Galactic Center.

We are currently testing the suitability of various algorithms for the ATA with the RPA. Recently, we have pursued application of adaptive filtering techniques (e.g., Barnbaum \\& Bradley 1998) for removal of satellite signals with the RPA. We collected 2.2 seconds of simultaneous data on 6 antennas of a single GPS satellite. The satellite was in the main beam of one antenna and the beam sidelobes of the other antennas. This data is available in the form of a CD-ROM for users interested in applying their own techniques. (See [http://astro.berkeley.edu/~gbower/rfi](http://astro.berkeley.edu/~gbower/rfi) for details). We used the main beam signal as the reference signal input into a Wiener filter algorithm. The algorithm uses a cross-correlation technique to find the FIR filter that minimizes the difference between the primary and filtered reference voltages. The filtered version of the reference signal was then subtracted from the primary signal. We achieved a maximum attenuation of 16 dB (Figure 2). The algorithm was equally successful when an LMS approximation was used following an initial Wiener solution. We are currently investigating other approaches to the GPS data, as well as change to our algorithm to increase attenuation.

By replacing the frontend filter in one antenna with a broader filter that covers 1300 to 1780 MHz, we have also been able to collect radar data with RPA at 1338 MHz. Although the array is located in a valley without a direct line of sight to the radar (which
is at a distance of 38 km), the signal is quite strong. These data will be useful for comparison with the Green Bank Telescope radar data presented by Fisher at this meeting. A CD-ROM of this data will also be soon available.

*Figure 1* Power observed along the geostationary arc with the RPA as a function of frequency. The power is integrated over 10 MHz strips. The isolated feature is a GPS satellite at 1575 MHz.
Figure 2: An example of elimination of GPS data with a Wiener filter. The top spectrum is the initial primary signal. The bottom spectrum is the same data after filtering.