RFI shielding and mitigation techniques for a sensitive search for the 327 MHz line of Deuterium

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Abstract

An array of 24 stations, each with 24 crossed-dipoles, has been built at the Haystack Observatory in Westford MA. This array has been designed to make a sensitive search for the 327 MHz spectral line of Deuterium. Since the deuterium line is expected to be about 50 dB weaker than the 1420 MHz hydrogen line the amelioration of RFI is the major challenge for the "Deuterium array". Locally generated RFI both from the array and from nearby sites has been reduced by extensive shielding and in some cases the removal of consumer electronics, like certain digital answering machines, which emit strong signals in the 327.3 to 327.5 MHz band of prime importance for the search. Since almost all the RFI comes from the horizon the station array has parasitic directors added to the dipoles to reduce the response at the horizon. A RFI monitor with 12 active Yagi antennas pointed every 30 degrees in azimuth provides a means of determining the direction of the RFI and information of frequencies and time spans with need to be excised from the array data. We present details of the array design, the RFI excision algorithms, levels of spectral and continuum RFI measured at the observatory and the performance of the array from initial long integrations from a subset of the full array.

1. Introduction

Starting in the late 1950s and early 1960s the detection of deuterium in the interstellar gas has been considered one of the most important efforts in radio astronomy. Its measurement constrains the photon to baryon ratio, and hence the cosmological baryon density. This measurement, combined with dynamical measurements in clusters and other estimates of the overall mass density, provide a gauge of the amount of non-baryonic dark matter in the universe. Furthermore, the degree to which deuterium is depleted in the interstellar medium of our Galaxy and other galaxies provide a tracer of stellar activity. The small isotope shift in the optical lines makes the deuterium measurement extremely difficult and subject to systematic error at optical wavelengths. In contrast, at radio wavelengths the hyperfine lines of deuterium and hydrogen are separated by more than a factor of three in wavelength. Detection of the deuterium line at radio wavelengths would introduce a new tool, for studying deuterium abundances.

Several groups have tried to detect the deuterium hyperfine line including Sander Weinreb whose thesis experiments (Weinreb, 1962) set an upper limit for $N_D/N_H = 8 \times 10^{-5}$. More recent limits by Anantharamaiah and Radhakrishnan (1979), Chengalur et al (1997), Heiles et al (1993) and Blitz and Heiles (1987) are comparable or slightly better. UV/Optical measurements give $N_D/N_H \approx 1.5 \times 10^{-5}$ toward several lines of sight in the interstellar medium (Wood et al. 2004). To reliably detect the 327 MHz line for this D/H ratio we need to improve the sensitivity, over that achieved by Weinreb, by a substantial factor. The noise contribution from RFI plays an important role in achieving the required sensitivity.

MIT Haystack Observatory has built an electronically steerable, multi-beam array optimized for the 327 MHz line of deuterium. The array is located in a soccer-field size area on the Haystack Observatory ground (Figure 1). Since radio frequency interference (RFI) is a major issue at these frequencies, a dedicated RFI monitor has been added and has been in operation since the start of the project.

Figure 1: View of Deuterium Array site at MIT Haystack Observatory

2. Controlling internal sources of RFI

The RFI environment at Haystack Observatory is extensive. RFI from the internal electronics of the receiver and the antenna had to be dealt with hardware adjustments in the receiver and active antenna design. The low noise active antennas include coaxial stub filters that minimize the RFI coming into input of the low noise amplifier (Figure 2). The receiver has been placed in an enclosed box with the analog electronics being placed in internal boxes. The USB and Ethernet cables have ferrite filters on them, while the AC power has double filtering. The control and data paths are through fiber optic cables to avoid conduction of RFI out of the receiver box.

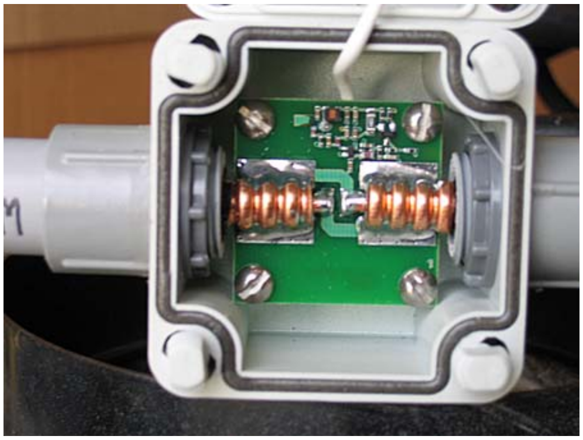

Figure 2: View of the circuit associated with the active dipoles which includes coaxial stub filters to reduce the susceptibility to the generation of intermodulation products in the low noise amplifiers.

While most of the RFI features were identifiable and associated with particular devices, several features were identified as inter-modulation products. As mentioned above, stub filters are used on active antennas in order to reject low frequency interference features and the pre-amp contains a 327 MHz output filter on the preamp which provides over 50 dB out of band rejection. A 327 MHz input filter in the receiver and a 50 MHz I.F. filter provide another 50 dB out of band rejection and following an analog to digital conversion, a digital down converter filter gives over 100 dB out of band rejection. The receiver noise, typically about 40 K is estimated using a sky brightness model (Rogers et al. 2004).

3. Characterization of external sources of RFI

Most of the external sources of RFI have been identified as coming from on-site equipment (such as personal computers) and instrumentation which are located within 500 m of the array. Digital answering machines and other home electronics within 5 km also introduce strong sources of RFI. Occasional continuum transients mostly of unknown origin have also been detected and these have spectral features due to multipath. Figure 3 shows a sample of the complex spectrum produced by a digital modem at the nearby Westford radio telescope site. This modem has been replaced by another which generated little or no RFI in the 327 MHz band. It is obvious that unless some of these sources are controlled or eliminated any excision technique would result in the loss of a large amount of data.

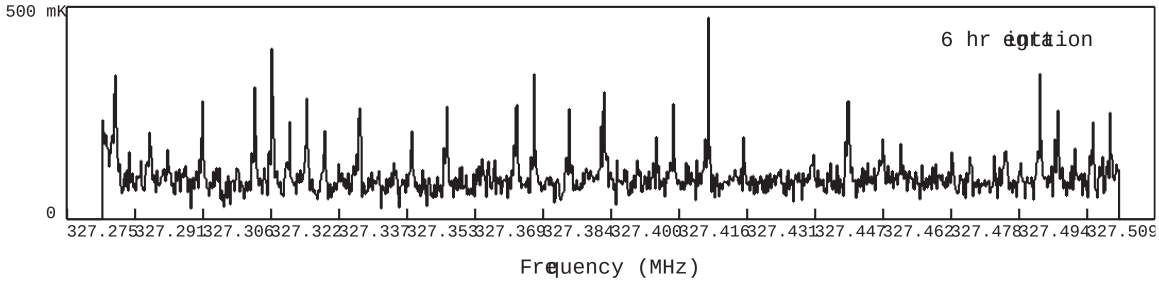

Figure 3: Plot from one channel of the RFI monitor showing the interference from a digital modem at the Westford radio telescope site which is about 180m away. Any RFI source whose effective isotropic radiated power is greater than about -97 dBm at 100 m will be stronger than the deuterium line.

Many of the RFI sources were identified as coming from nearby homes and offices. Several measures have been taken to control the RFI at the source including negotiating with neighbors to replace certain consumer products which have clock harmonics close to 327 MHz. In addition we have shielded buildings within 500m of array including shielding some of the windows.

In addition, an effort was made to minimize the horizon response of the array by placing the dipoles over a horizontal ground plane and adding parasitic directors (Figure 4) to reduce gain at horizon by about 10 dB. Placing a clutter fence around each station was considered but they needed to be large and were very expensive.

Figure 4: Close up view of the Deuterium Array dipoles showing the directors that have been added to control the horizon response. The trailer in the background has the 12 Yagis of the RFI monitor mounted on it as well as one set of active antennas pointed at zenith.

In order to characterize the external RFI environment and develop techniques to identify and mitigate the interference from the data, a monitor has been installed and operational since the beginning of the project. The monitor consists of 12 directional Yagi antennas pointing every 30 degrees around the horizon. This provides not only a detection capability but also the ability to identify the direction of the RFI. In addition, there are two active dipole antennas (replicas of the deuterium array antennas) pointing in the zenith direction (see Figure 4). Further localization of the RFI source is done with a handheld receiver and a variety of antennas, including an active Yagi. Figure 5 shows some sample spectra from the Yagis of the RFI monitor showing that the relative strength of the RFI features provides a measure of the direction of arrival.

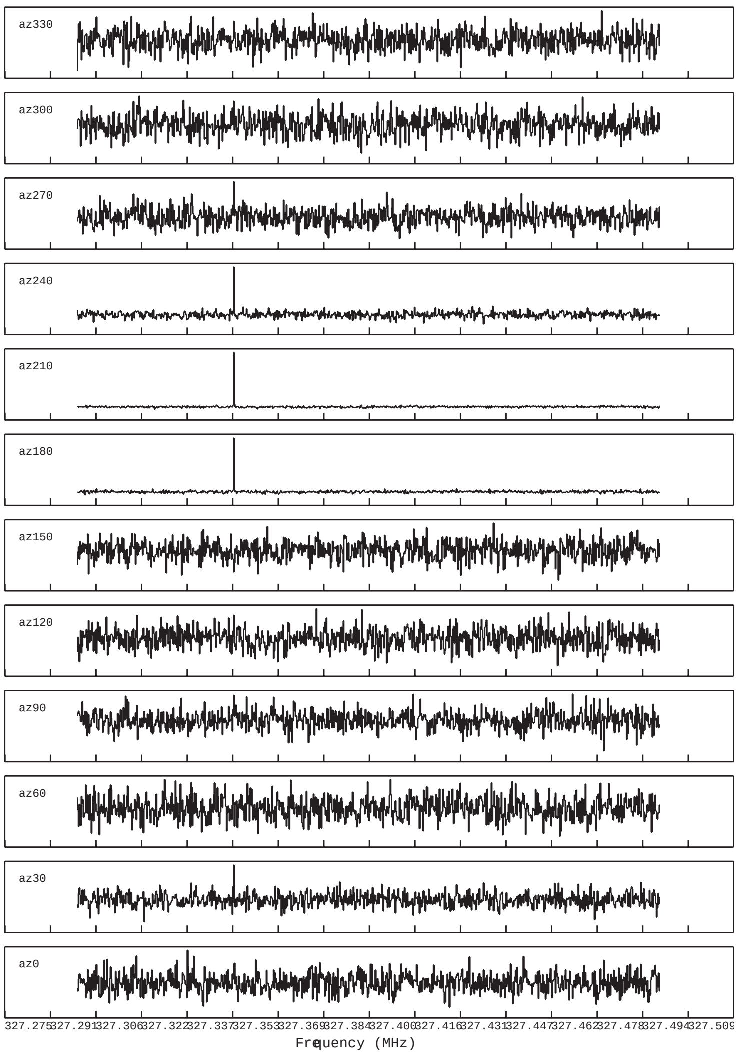

Figure 5: Sample plot from the RFI monitor showing a strong interference spike in some channels – such information is used in determining the originating direction of the interference.

4. Mitigating RFI in the deuterium array data

Once most of the major sources of RFI were identified and controlled at the source, residual RFI features are excised through data processing techniques. For transient sources the software excises data from the deuterium array channels for any spectral or continuum signal exceeds the 8 sigma level in the RFI monitor. For features that are seen in frequency space, spectral exclusion is performed of any 244 Hz frequency channels in the array data for which RFI is detected above the 8 sigma level in 24 hours of integration. A weighted least squares smoothing to 2 kHz resolution is used to “interpolate” over the excluded frequency channels for each day’s integration. A sample result of this excision technique is shown in Figure 6 for the case of the average spectra from all the individual elements of the array. Averaging all 1152 elements gives an equivalent integration of over 30 years and is a good test of the RFI mitigation given the few weeks the array has been in operation.

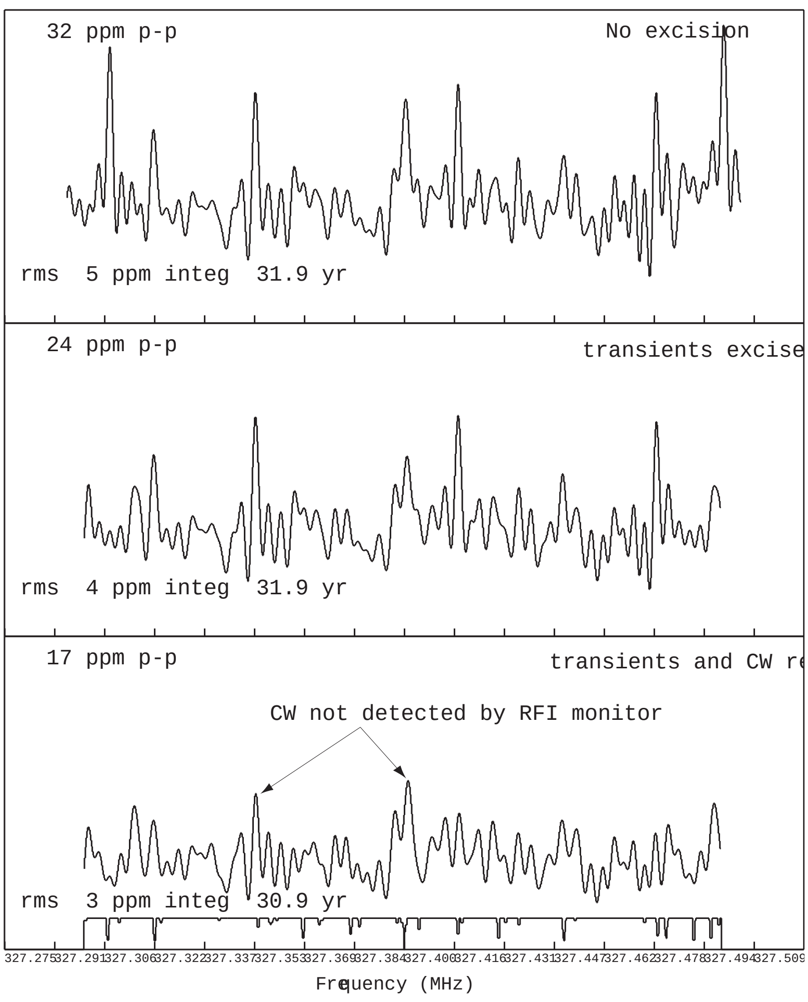

Figure 6: An example of the RFI excision technique. The resolution has been smoothed from 244 Hz to 2 kHz. The amplitude scales are in units of parts per million (ppm) of the system noise. The deuterium line is expected to be about 3 ppm.

In the actual operation mode of the array, each station is combined with its individual beam. At any instant the software running at each station processes simultaneous beams in four different directions. This allows the simultaneous observation of regions like the Galactic anti-center, where we expect to detect the deuterium line, along with other regions which can be used for reference or comparison. Each station has two beams, corresponding to two polarizations and formed in a given direction. Hence, with a few weeks of operation we have only an equivalent of a few months of integration time in the data from the 48 beams. However, because of the added rejection of signals from the horizon by the beams, there is no evidence of RFI contamination once the transient events have been excised. The caveat to this conclusion is that the array is currently surrounded by heavy foliage so that the general RFI environment is about 6-10 dB quieter than is expected in the winter months when the trees are bare. In that situation, it is expected that more RFI signals, both transient and continuous wave (CW) will be detected.

5. Conclusions

MIT Haystack Observatory has recently completed the construction of a dedicated array to detect the 327 MHz line of deuterium. Detecting, characterizing and excising RFI has been the challenge of the early part of this project. Currently, the combination of removing strong and persistent sources of RFI at the source and excising transients in the data has resulted in the successful elimination of most of the RFI in the deuterium array data.

The Deuterium Array project at MIT Haystack Observatory has been funded by grants from the National Science Foundation and MIT.

7. References

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