CBASS: Digital Backend and RF Interference

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ABSTRACT

The C-Band All Sky Survey (CBASS) is an experiment to map the entire sky at 5 GHz in total intensity and linear polarization. CBASS is expected to make a significant contribution to future CMB missions as well as providing an opportunity to study the Galactic environment. In this report, I describe the CBASS experiment and my work towards it. This includes the digital backend, designed for component testing but potentially suitable for use in the science run, and the measurement of radio frequency interference in Owens Valley.

Subject headings: radio continuum: ISM – instrumentation: polarimeters – site testing

1. Introduction

Caltech is leading two experiments currently ramping up at the Owens Valley Radio Observatory (OVRO). The C-Band All Sky Survey (CBASS)[1] is an experiment to map the sky in total intensity and dual polarization (Stokes parameters I, Q, and U) at 5 GHz with $\sim 50'$ resolution, while the 40 m telescope is being used to observe 1200 blazars every two days at 14 GHz in support of the Gamma Ray Large Area Space Telescope (GLAST)[2] mission.

I worked on both projects this past summer. For CBASS, I designed a digital backend for testing the receiver prior to delivery, which may also be adequate for the science run. I also began work to characterize the radio frequency interference (RFI) in Owens Valley, as we hope to choose a bandpass free of RFI. For the 40 m, I worked on characterization of the telescope (including gain curves, focus curves, and beam shapes), calibrations, and on taking observations.

In the interest of keeping this report to a reasonable length, I will only discuss the CBASS work. This report will discuss the motivation for, the design of, and the work completed by myself on CBASS.

2. Motivation

The Cosmic Microwave Background (CMB) provides a means of studying the physics of the early Universe through its temperature, anisotropy, and polarization. In particular, the B-mode polarization is due mainly to gravitational waves originating in the inflationary period. Measurement of the B-mode thus represents our first opportunity to directly study inflationary physics (Dodelson, 2003).

The measurement of the B-mode is limited by polarized emission in the foreground (Bock et al, 2006). A successful measurement will require these foreground effects to be characterized and accounted for. CBASS will map the synchrotron emission and the anomalous dust emission (Draine & Lazarian 1998) for this purpose. In gathering these data, CBASS will also allow for the study of Galactic magnetic field within 1 kpc.

3. Design

The CBASS instrumentation consists of a broad-band analog polarimeter measureing Stokes parameters I, Q, and U.(see Fig. 1) which will be mounted on a 6.1 m telescope at OVRO. Af-

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[1] `http://www.astro.caltech.edu/cbass/`

[2] `http://glast.gsfc.nasa.gov/`

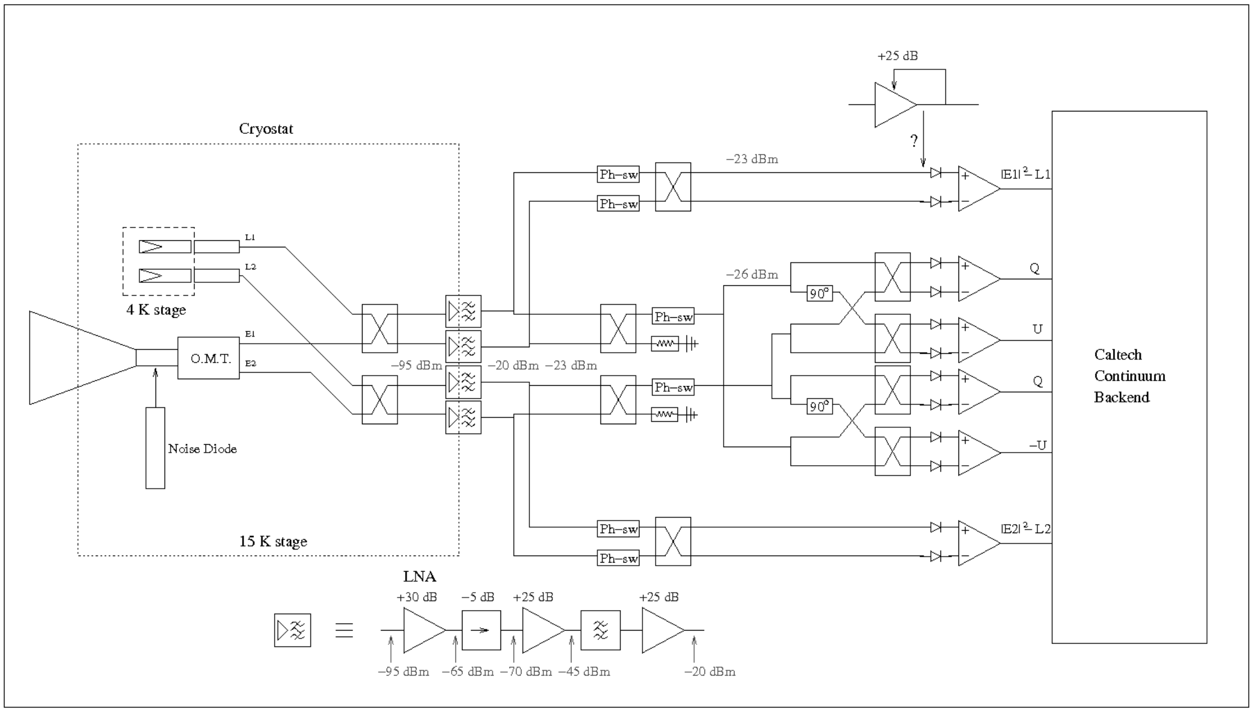

Fig. 1.— Schematic of the CBASS receiver. All components are to be fabricated by Oxford except the LNAs and the CCB which are the responsibilities of Manchester and Caltech, respectively.

ter mapping the Northern sky at OVRO, the polarimeter will be sent to South Africa, mounted on a 7.6 m telescope, and used to map the Southern sky.

The fabrication of the CBASS receiver is mainly the responsibility of the Oxford collaborators (see, for example, Grimes et al. 2007). The components excepted from this are the Low Noise Amplifiers (LNAs) and the backend, to be built by Manchester and Caltech, respectively. The purpose of the backend is to demodulate, integrate, and digitize the incoming data. The original plan called for a clone of the Caltech Continuum Backend (CCB) built for the Green Bank Telescope.

4. Digital Backend

Oxford will need to test the receiver components prior to shipment. An inexpensive solution is to use a digital backend. I visited Oxford for four weeks to design and implement this backend.

The digital backend was envisioned as follows: following the detector diode and high-pass filter (> 30 Hz), the voltages in the channels are read and digitized by an off-the-shelf data aquisition (DAQ) card. Demodulation and arithmetic are then performed in software. Parallel to this, the software also generates the modulation signals and which are sent to the DAQ output. The software was written using LabView.

5. Backend Demonstration

Two tests were performed to demonstration of the software's functionality. Both tests used the same experimental set-up (see Figure 2). A Continuous Wave (CW) signal is generated and split through the first 180° hybrid; one branch traversed a phase switch while the other passed through a semi-rigid cable of approximately the same path length. The signals were re-combined using a second 180° hybrid. The output was put through a detector diode, high-pass filtered, and read-in through the DAQ. It should be noted that, due to unmatched dispersion between the two paths, there was a frequency-dependent phase difference between them.

The first demonstration sent through CW signals from 4 GHz to 6.4 GHz, incremented by 100 MHz. This was compared to the same measurement made with a Vector Network Analyzer (VNA). See Figure 3. The excellent agreement demonstrates that the data acquisition set-up is reading data as expected. This plot should ideally show a constant voltage over the frequency range. The reason it doesn't is due to unmatched dispersion between the phase switch and the semi-rigid cable.

The second demonstration made a continuous, 3 hr measurement using phase switching on a 5 GHz CW signal. This was compared to a continuous measurement without phase switching. As a Fourier spectrum was desired, both data series were cropped to 1 h 50 m (2^{16} samples). See Figure 4 for the time series and Figure 5 for the Fourier spectra. These results nicely demonstrate the dramatic increase in stability offered when phase switching is used. They also demonstrate the usefulness of the digital backend.

6. Radio Frequency Interference

Interference, particularly if it is directional and time-variant, can lead to spurious signals in the data. We hope to avoid this problem by choosing a bandpass with as little RFI as possible.

To avoid RFI, we must first identify it. Using the Frequency-Agile Solar Radiotelescope (FASR) Subsystem Testbed (FST, see Liu et al. 2007), a subset of the Owens Valley Solar Observatory (OVSO), we have begun to do so. The FST consists of three 1.8m telescopes which allow total power measurements in 500 MHz bandpasses spanning 1-9 GHz.

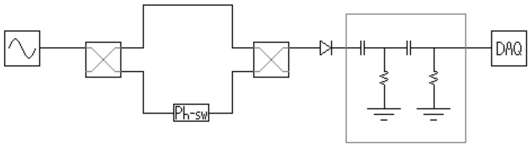

Fig. 2.— Layout of the experiment. The two highpass filters within the grey box were only included while phase-switching was enabled.

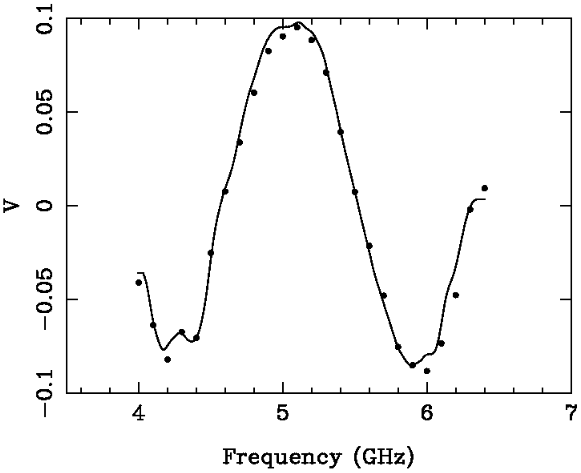

Fig. 3.— Voltages measured as a function of frequency. Points were measured using the data acquisition card and software developed; solid line was measured using the VNA.

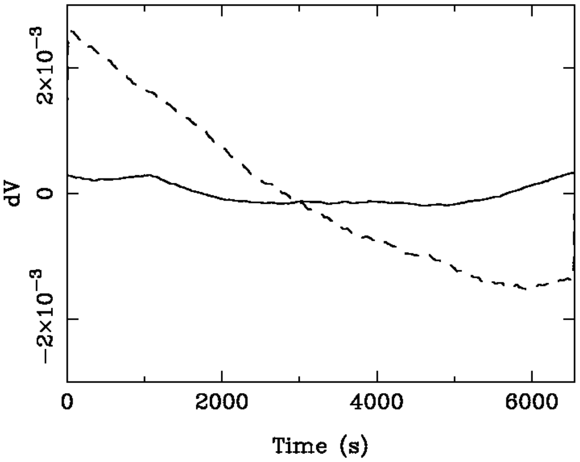

Fig. 4.— Voltages measured as a function of time, with 100 ms integration intervals. Solid line is with phase-switching; dashed is without. Both curves have been convolved by a $\sigma = 10$ s Gaussian in this plot to improve readability. DC offset has been removed.

The first data were collected on the night of 31Aug07, with the antennas pointing at zenith. Right circular polarization was used. A one minute integration was used for each bandpass from 4 GHz up to 7.5 GHz. The FST software was used to calculate the spectra. See Figure 6. Many features are visible in the three spectra, however only those coincident to all three are likely to be RFI. Features seen in only one spectrum are likely due to interference local to the receiver (Dale Gary, private communication).

We observe little interference in this frequency range. The most obvious features are at 6 GHz. Avoiding these, we are free to choose a 1 GHz bandpass such as 4.5-5.5 GHz. We plan further observations to confirm this preliminary result.

7. Continuing Work

The experiments in Section 5 showed that the digital backend performs as expected and is useful for measurements. It has been suggested that the digital backend be used in lieu of the CCB during the science run. Further testing is planned here at Robinson to determine if this is practical. If it is, the savings in cost and man-hours will be significant.

The RFI measurements in Section 6 are promising, but need to be followed up with observations at different times-of-day, pointings, and polarizations. It will also be enlightening to track down the sources of the RFI. Doing so will allow us to better avoid them.

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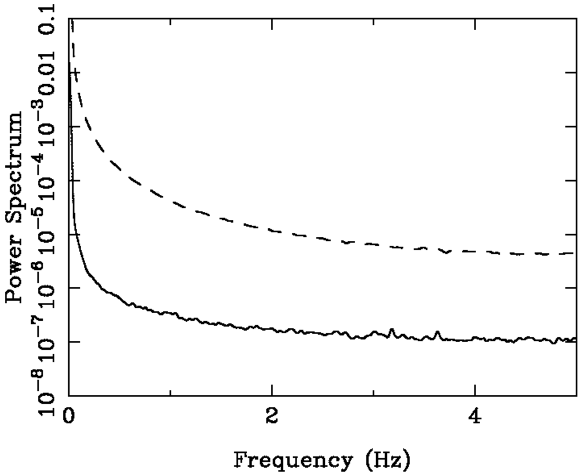

Fig. 5.— Power spectra of the data series. Solid line is with phase-switching; dashed is without. Both curves have been convolved by a $\sigma = 15\,\mathrm{mHz}$ Gaussian in this plot to improve readability.

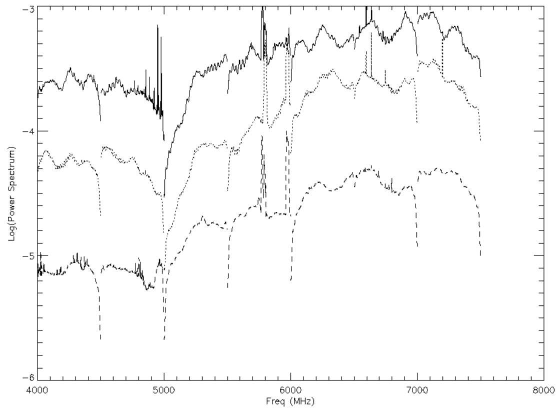

Fig. 6.— FST spectra showing RFI. Dips in the spectra every 500 MHz are due to the bandpass filter.

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