Polarimeter Receiver Prototyping and Testing for the South Pole Telescope Upgrade

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Abstract

Experimental evidence has so far been supportive for the inflationary Big Bang model of cosmology, while imposing other mysteries, such as the fact that dark matter and dark energy actually consist of 95% of the observable universe. The forthcoming upgrade of the South Pole Telescope, planned for 2010, will include a polarimeter with increased sensitivity. Measurements of the CMB polarization anisotropy to a high accuracy will describe the angular power spectrum of the B-mode polarization, which will help unravel some of the mysteries. We prototype and test a digital frequency multiplexed readout system for the SPT upgrade. The digital system has the advantage of being able to reconstruct the phase of the signals. We characterize the performance of the readout and we compare it to the theoretical expectations. The noise is found to be statistically insignificant (insert quantitative proof), and the system performs as expected, significantly better than the previous implementation. We conclude that the digital fMux readout system should be sent to the South Pole Telescope.

1 Introduction

In this section, I will briefly explain current experimental efforts in cosmology, and their significance for the scientific community. Theoretical topics will include the Cosmic Microwave Background and dark matter. For the experimental efforts I will focus on astrophysics and telescopes.

The South Pole Telescope, located in Antarctica, is a significant detector that aims to investigate the mysteries of dark energy and inflation. The 10 meter diameter telescope has been operating since 2007 and observes microwaves and millimeter waves, in frequencies between 70 and 300 GHz. Bolometers are used to detect the distortions of the cosmic microwave background (CMB), due to interactions between CMB photons and ionized gas in galaxy clusters, an effect first discovered by Sunyaev and Zel'dovich [**?**]. Using a subset of the data, four previously unobserved galaxy clusters were discovered in October 2008.

Increasing the sensitivity of the telescope's polarimeter will enable the characterization of the angular power spectrum of the B-mode polarization to an unprecedented accuracy. Current sky maps with temperature anisotropies produced by WMAP can describe the angular power spectrum up to multipoles of l 600. After the upgrade, the

South Pole Telescope will be able to probe the spectrum to multipoles exceeding l 2000. This will allow scientists to put tighter constraints on the cosmological parameters Ω_m and Ω_b.

The B-mode polarization spectrum is also sensitive to gravitational waves predicted by certain inflationary models. Even though the instrument's systematics and the foregrounds will most likely shadow the small gravitational signal, the search may prove fruitful. At the same time, the foregrounds make possible putting more stringent limits on neutrino mass.

State-of-the-art technology is being used in the South Pole Telescope and is being developed in the collaboration between the University of Chicago, UC Berkeley and McGill, among others. Radiative power incident upon bolometers is transformed to a change in the current required to voltage bias them. Since bolometers operate at the temperature of superconductive transition, even a minuscule change in current, of the order of a few picoAmps, is detected. Superconducting quantum interference devices (SQUIDs) are used in readout circuits, as well as in multiplexing the detector readouts.

We will describe our prototyping and testing of a new fully digital polarimeter receiver, as opposed to the current semi-digital receiver. The full digitization of the readout multiplexing will enable the reconstruction of the phase of the signals, which will greatly increase the sensitivity of the polarimeter.

2 Principles of operation of fMux readout

In this section, I will describe how the MHz frequency domain multiplexed (fMUX) readout system works theoretically. To put this into context, I will explain briefly the operation of bolometers (with figure) and how they measure the incident radiation. Then I will state the need for a multiplexed readout system and how it should work and what the benefits are. A figure will show the circuit of the readout system. Special mention should be made to the SQUIDs, and the advantages/need for very low temperatures (near the absolute 0).

3 Upgrade from analog to digital fMux readout

Explain shortcomings of current (analog) hardware implementation; it does not reconstruct the phase of signals. The digital upgrade we are prototyping and testing will have the advantage of reconstructing the phase. Digitizing will occur at 10MHz. Describe the need for the upgrade, and what it will achieve in more detail. Advantages and challenges of digital system.

4 Hardware implementation of digital fMux readout

In this section, I will briefly describe what we actually are going to do, what materials we ordered, how we will assemble the electronics together, and how this is supposed to work (ie. what parts will be at room temperature, what parts in cryogenic temperatures).

5 Testing the digital fMux readout

In this section I will describe and show the measurements we are going to make to verify that the digital fMux readout system we are going to assemble works as expected.

5.1 Configuring SQUID array readout

Here we want to measure the voltage-magnetic flux (V-Φ) response of the SQUID array, and compare it to the analog system and the theoretical expectations. Figures on each response should be included.

5.2 Validating feedback operation with bolometers

Our goal is to validate the operation of the feedback loop with bolometers. In particular, we'll assess the V-Φ response with the feedback loop. First we are going to test this with resistors, and then we will test it with bolometers and SQUIDs.

5.3 Measuring noise of digital fMux readout system

This is particularly important. We need to make sure the noise is at an acceptable (low) level, and quantify this with respect to the expected signal.

6 Conclusions - Next steps

After prototyping and testing the digital fMux readout system, we will describe whether it is ready to be built and sent to the South Pole Telescope. We should report on its performance compared to the current implementation, and the theoretical predictions. If any discrepancies are found, we should suggest ways to remove these discrepancies before the build and test these ways on the prototype.

This SPT upgrade will make possible a more precise measurement of the CMB polarization anisotropies, which will describe the angular power spectrum of the B-mode polarization. This will make it possible to put constraints on the neutrino mass and improve the measurements of Ω_m and Ω_b cosmological constants. Gravitational wave B-mode detection is also possible for a specific gravitational wave model, but is difficult because of the small signal and foregrounds and systematic uncertainties.

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