Developing New Techniques for Characterizing Optical Properties of Millimeter Wavelength Detectors

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Abstract

Characterization of the Cosmic Microwave Background (CMB) is a major research focus in cosmology because the CMB contains information about the origin and content of our universe. Millimeter wavelength detectors used to monitor the CMB must be extensively characterized, but current testing methods are slow and costly. A solution to this problem is using a Neutral Density Filter (NDF) to transmit light of limited intensity onto the detector arrays. However, NDFs have a polarization that impacts the transmitted light and must be characterized before the NDF can be properly used to test detectors. The focus of my senior project was to determine the NDF polarization using computational and experimental methods.

Motivation

The test beds located at CWRU are used to characterize detector arrays before they are implemented in CMB experiments. The problem is that different detector arrays have different frequency bandwidths. Current testing methods use an absorbing filter that attenuates light as a function of frequency, as shown in Fig. 1.

A reflective NDF transmits the same amount of light at all frequencies, which would allow us to test many detectors in one run. An NDF is made by depositing ~5nm layers of nickel and gold on a plastic sheet, which causes the filter to have polarization properties. The NDF polarization is a function of angle and surface conductivity and must be characterized so that we can adjust for its effects after testing.

Computational Method

Simple (Fig. 3): Since the skin depth of the materials are much larger than the thickness of the film, the NDF can be modeled as an infinitely thin film with a surface current. I applied Maxwell’s equations and boundary conditions to calculate the intensity of transmitted light for perpendicular and parallel polarizations in Fig. 5, 6.

Robust (Fig. 4): The NDF with a finite thickness and apply boundary conditions to determine the intensity of transmission. This method involves accounting for reflections off of the back surface as well as the decreasing amplitude of an electromagnetic wave through a conducting material.

Experimental Method

The setup, shown in Fig. 2, involves a Gunn Oscillator firing a beam of light (oriented vertically) through the NDF. At the end of the stream, a diode collects the transmitted light, and a lock-in amplifier displays its intensity. The filter was rotated around the vertical axis to angles of 20, 30, 40 and 45 degrees and then rotated around the horizontal axis. The diode was then rotated 90 degrees to obtain data for parallel and perpendicular components.

Experimental results are shown in Fig. 5, 6.

Discussion

The discrepancy between the experimental data and the computational model needs to be resolved. One possible solution is to develop the robust computational model, which accounts for the reflections and the decreasing amplitude within the NDF. Once the model and the experimental data match, the NDF polarization can be determined as a function of angle and surface conductivity. This information can be used to accurately correct for the polarizing effects that NDF has on test results.

Future Work

The setup in Fig. 2 involves a Gunn Oscillator firing a beam of light (oriented vertically) through the NDF. At the end of the stream, a diode collects the transmitted light, and a lock-in amplifier displays its intensity. The filter was rotated around the vertical axis to angles of 20, 30, 40 and 45 degrees and then rotated around the horizontal axis. The diode was then rotated 90 degrees to obtain data for parallel and perpendicular components. The setup, shown in Fig. 2, involves a Gunn Oscillator firing a beam of light (oriented vertically) through the NDF. At the end of the stream, a diode collects the transmitted light, and a lock-in amplifier displays its intensity. The filter was rotated around the vertical axis to angles of 20, 30, 40 and 45 degrees and then rotated around the horizontal axis. The diode was then rotated 90 degrees to obtain data for parallel and perpendicular components. The setup, shown in Fig. 2, involves a Gunn Oscillator firing a beam of light (oriented vertically) through the NDF. At the end of the stream, a diode collects the transmitted light, and a lock-in amplifier displays its intensity. The filter was rotated around the vertical axis to angles of 20, 30, 40 and 45 degrees and then rotated around the horizontal axis. The diode was then rotated 90 degrees to obtain data for parallel and perpendicular components.

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References


Fig. 2: SolidWorks sketch of the experimental setup. The Gunn Oscillator and diode can be oriented vertically or horizontally

Fig. 3: Simple theoretical model

Fig. 4: Robust theoretical model

Fig. 5: Predicted (top) and experimental (bottom) results of the fractional transmission intensity for the parallel component of polarization. Fractional transmission was determined experimentally and theoretical conductivity was adjusted to 0.00415 (S/m) to match this result.

Fig. 6: Predicted results (solid curves) match the experimental results (dashed curves) closely for the parallel component of polarization. Theoretical NDF conductivity was matched from parallel component (0.00415 (S/m)).

Fig. 7: Predicted (solid curves) and experimental (dashed curves) polarization angle of transmitted light of an NDF with conductivity 0.00415 (S/m). This is the angle of the output polarization relative to the input, which is vertical at theta = 0.

Acknowledgements