

Coupling of an Absorber to a
Polarization-Sensitive Antenna

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Abstract

The polarization-sensitive cross slot antenna recently constructed by Papathanakos [1] was used to investigate the possibility of designing a polarization-sensitive bolometric detector. A bolometer or other absorber located near a polarization-sensitive antenna may couple to the antenna, preferentially absorbing electromagnetic waves of the polarization radiated by the antenna. Lock-in amplification techniques were used to compare the response of the cross-slot antenna to a microwave source, with and without a nearby absorber. A difference between the antenna responses with and without absorber was not detected. An upper bound on the power absorbed by the absorber is 11% of the total power in the antenna.

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Chapter 1

Introduction and Background

The recently-detected [2] polarization of the Cosmic Microwave Background (CMB) is a new frontier in CMB research¹. The CMB is light left over from the time in the universe’s evolution know as recombination, when previously free protons and electrons began binding together as the universe cooled. One cause of this CMB polarization is found in the Thompson scattering of light waves by charged particles such as electrons (see figure 1.1). Unpolarized waves incident on the electron along the positive or negative y axis will cause waves polarized parallel to the z direction to reach an absorber on the x axis. Similarly, unpolarized waves incident from the $\pm z$ direction will result in observed waves polarized in the $\pm y$ direction. Therefore, a difference in the observed intensities of light polarized in the y and z directions implies the presence of a quadrupole moment in the intensity distribution of unpolarized light incident on the electron. An electron moving with respect to a given laboratory frame “sees” a

¹In fact, this discovery was announced just weeks before the completion of this project, and the findings are soon to appear in a publication.

different intensity distribution than an observer at rest in the laboratory frame. This means that measuring the polarization of the CMB can give clues about the velocity distribution of the fluid present at the time of recombination.

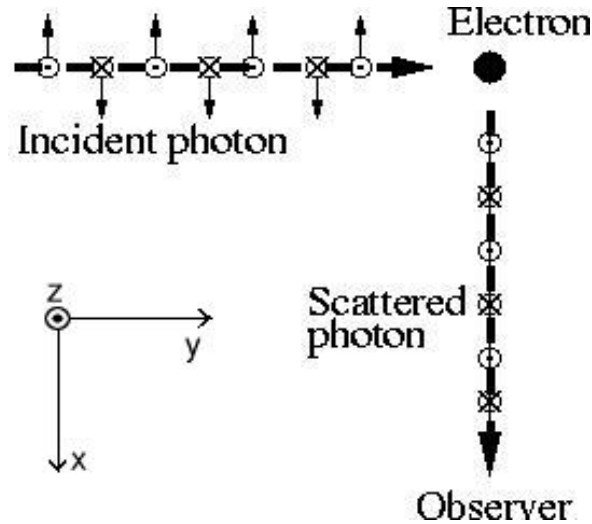


Figure 1.1: The scattering of incident electromagnetic waves by an electron. Circles with dots or crosses denote arrows into the page or out of the page, respectively. The arrows perpendicular to the direction of each wave show the polarization modes present in that wave.

The bolometer, a detector which measures the intensity of all incident light in a given band of frequencies, is not itself sensitive to polarization. One possible way to make a polarization-sensitive bolometric detector is to couple the bolometer to a polarization-sensitive antenna. Incident radiation will generate currents in an antenna, causing the antenna itself to radiate. An absorbing object, such as a bolometer, located near to the antenna can absorb this radiation from the antenna. If the antenna is sensitive to one specific polarization, then the radiation that it emits will be polarized. Thus the radiation absorbed will be preferentially polarized. An attempt was made at measuring this effect

and the feasibility of using it to construct a polarization-sensitive bolometric detector. A polarization-sensitive antenna was made the target of polarized incident microwave radiation. Using lock-in techniques, the signal in the antenna was measured with the presence of an absorber at various distances from the antenna. Comparisons were also made between the signal detected by the antenna with and without an absorber present. It was expected that the absorber would absorb energy from the electromagnetic field around the antenna, causing the signal detected by the antenna to decrease.

This work, together with the work of Papathanakos[1], represents a preliminary effort toward the prototyping of an antenna-coupled bolometric detector. Further study, possibly using the apparatus constructed for this project, will be necessary in order to reach this goal. Other researchers have conducted more advanced investigations of antenna-coupled bolometry and have succeeded in building such detectors for a range of frequencies. For reference, see the paper by Jones, *et. al* [3], as well as the Berkeley Bolometers Group at <http://bolo.berkeley.edu>[4].

Chapter 2

Apparatus

2.1 Microwave Signal

A Hewlett-Packard (HP) 8620C Sweep Oscillator with an HP 86290B RF Plug-in was used to generate a polarized microwave signal at a frequency of 6.8 GHz and a wavelength of 4.4 cm. The microwaves were emitted through a horn (see figure 2.1). At the distance scale dealt with in this experiment, the waves emitted by the horn were nearly spherical waves [1]. The microwave radiation then passed through a plastic disk that was transparent in the microwave region of the electromagnetic spectrum. Along the edge of half of this disk was a 0.5 cm wide strip of microwave-absorbing cloth. The cloth was measured to absorb $(33 \pm 15)\%$ of incident microwave radiation at 6.8 GHz. Through the center of the disk was an axle, which allowed an attached motor to spin the disk. The disk was spun at frequencies up to about 3.5 Hz. During half of the rotation period of the disk the absorbing cloth was brought into the center of a cross-slot antenna (see figure 2.3).

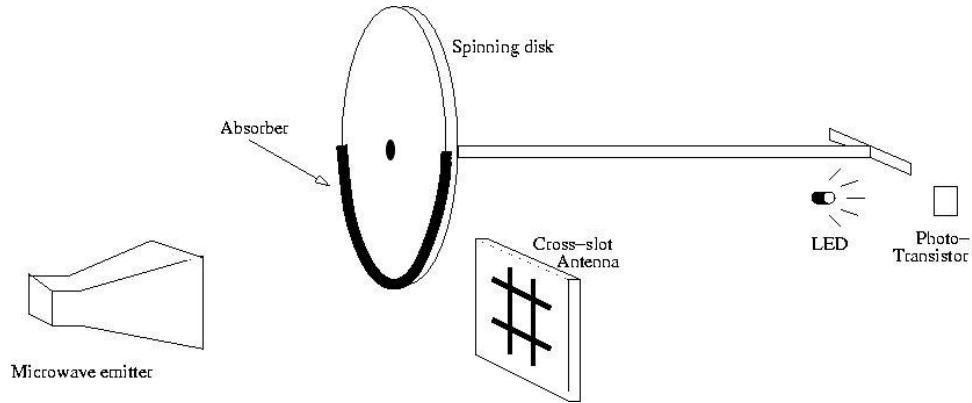


Figure 2.1: The experimental apparatus.

2.2 Antenna

The cross-slot antenna is described in an article by Chattopadhyay and Zmuidzinas [5], and in the thesis of Chattopadhyay [6]. It consists of a pair of vertical strips and a pair of horizontal strips. Each pair of strips responds to polarizations perpendicular to its length. The antenna is designed in such a way that the pair of horizontal slits and the pair of vertical slits function independently of each other.

The actual antenna used was constructed by Papathanakos [1]. See figure 2.2 for details on the antenna used. For the purposes of this experiment, only the pair of horizontal slots was used, and the incident microwave radiation was polarized in the vertical direction. The incident power absorbed by the antenna, in the absence of any external absorbers, was $32\mu W$.

The signal received at one of the horizontal strips of the antenna was rectified using an Agilent 8473C Crystal Detector. The diode response curve is shown in figure 2.4. The actual signal power per millivolt output by the diode was found to be $(54.4 \pm 0.6)\mu W/mV$. From the detector diode, the rectified signal was sent to a Stanford Research SR-560 Preamplifier, where it was amplified by a factor of 200. Finally, the signal went to an Ithaco model 3961B Lock-in Amplifier.

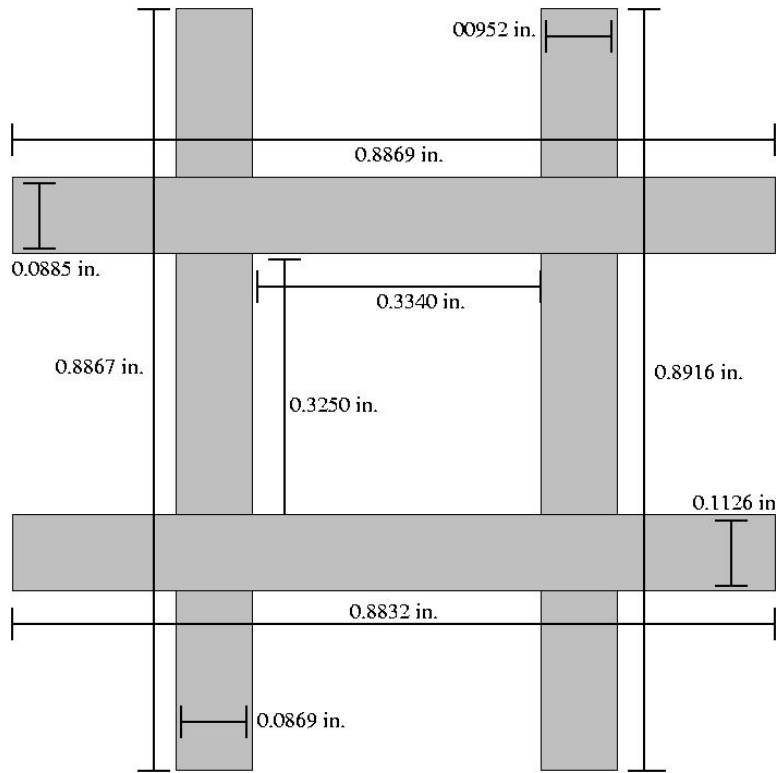


Figure 2.2: Cross-slot antenna constructed by Papathanakos (drawn approximately to scale).

2.3 Reference Signal

A reference signal was generated when a copper rod attached to the spinning axle of the disk blocked a beam of light emitted by an LED (see figure 2.1). When the beam was blocked, the phototransistor's output signal changed from high to low. This signal was sent to a circuit (see figure 2.5) that cleaned and digitized the signal. A flip-flop changed the resulting signal into a square wave whose period was equal to the period of rotation of the disk. Thus, the final signal was, up to a phase shift, high when the absorber on the disk was at the center of the antenna, and low when the absorber was not there.

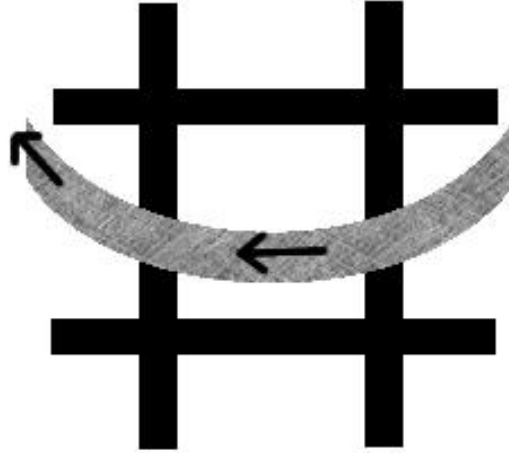


Figure 2.3: Cloth strip moving through antenna.

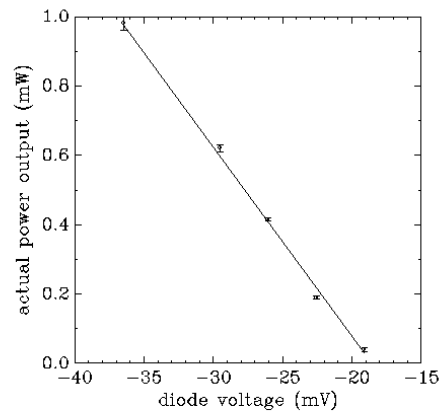


Figure 2.4: Signal power vs. diode output voltage.

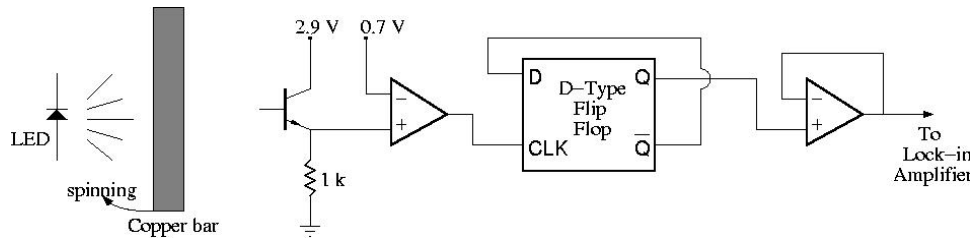


Figure 2.5: Circuit used to produce a reference square wave signal with a period equal to the period of rotation of the disk.

When this square wave reference signal, along with the antenna signal, was sent to the lock-in amplifier, the lock-in looked for a component of the antenna signal with the frequency of the reference. Such a component would measure the diode voltage difference as the absorber is brought into and out of the center of the antenna. If the absorber were truly coupling to the antenna and absorbing microwave radiation, the diode voltage would be low when the absorber was inside the antenna and high when the absorber was outside the antenna. The amplitude detected by the lock-in amplifier should be half of the difference between the high and low voltages of the input antenna signal.

Chapter 3

Results and Conclusions

3.1 Errors in Measurements

Even when the distance from the antenna to the absorber and the frequency of rotation of the disk were held constant, the amplitude reported by the lock-in amplifier varied slightly with time. In order to estimate the actual amplitude and the associated error, at least five measurements were made in each case. The amplitude was taken to be the mean value of these, and the error in amplitude was taken to be their standard deviation.

Another source of error was the uncertainty in the measurement of distance between the absorber and the antenna. Because of a slight wobble of the spinning disk, and the difficulty in making precise distance measurements without a ruler attached to the apparatus, each distance measurement is uncertain to about ± 0.1 *cm*.

3.2 Amplitude vs. Frequency

The lock-in amplifier detects a component of the antenna signal whose period matches that of the reference signal. If this component resulted from the motion

of the spinning disk and the absorbing strip, as expected, then the period of this component would change in response to a change in the period of rotation of the disk. Meanwhile, the amplitude would remain constant. In order to test this prediction, the rotation frequency was varied while the antenna-absorber distance was maintained constant at 1.3 cm . See figure 3.1 for a plot of observed amplitude vs. rotation frequency. The data are consistent with the prediction that the amplitude should not change with changing frequency.

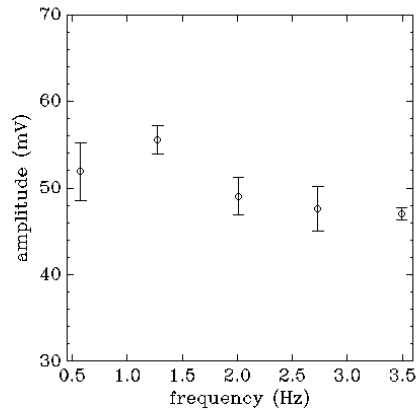


Figure 3.1: Amplitude vs. rotation frequency.

3.3 Amplitude With and Without Absorber

If the absorber were coupling to the antenna and absorbing some radiation, then the amplitude observed (that is, the difference between the high and low voltages of the signal from the antenna) should have been higher with the absorber on the disk than without. In order to test this, measurements were made of the

amplitude at several different antenna-absorber distances. Afterwards, the strip of absorbing cloth was removed from the disk, and amplitude measurements were again made at various distances (here, distance refers to the distance between the antenna and the face of the disk where the absorber had been). See figure 3.2 for a plot of amplitude vs. distance, with and without the absorber, and see figure 3.3 for a plot of the fractional difference in recorded amplitudes. The data show virtually no difference between the observed amplitudes with and without the absorber on the spinning disk.

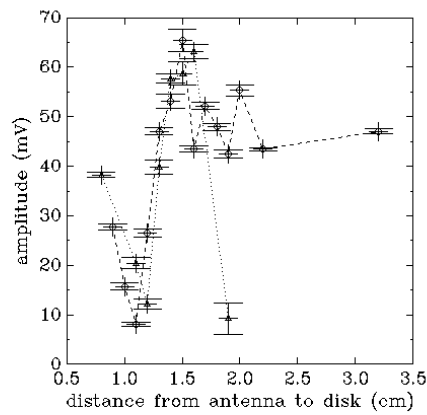


Figure 3.2: Amplitude vs. distance. The circles connected by a dashed line are the data taken with the absorber on the disk, and the triangles connected by a dotted line are the data taken without the absorber.

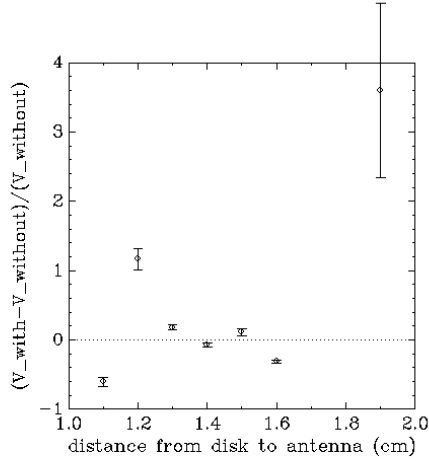


Figure 3.3: Fractional difference in amplitudes with and without absorber,

$$\frac{V_{with} - V_{without}}{V_{without}}$$

3.4 Upper Bound on Power Absorbed

If the contribution to the amplitude due to the presence of the absorber had been larger than the error in the difference of amplitudes, then some statistically significant difference would have been seen between the two amplitudes. Thus, an estimated upper bound on the contribution of the absorber to the observed amplitude is the error in the amplitude difference at any given distance. An upper bound at the 2σ level is twice this error.

Since the signal output by the detector diode was amplified by a factor of 200 before being fed to the lock-in, and the amplitude is half of the difference between the voltages with and without the absorber at the center of the antenna, the actual voltage difference is $0.01 * A$, where A is the amplitude. The power may be obtained by multiplying by $54.4 \mu W/mV$, the slope of the diode response curve (see figure 2.4). The resulting upper bounds on the power absorbed by

the absorber are plotted in figure 3.4. These upper bounds are at the 2σ level, implying a 95% confidence that the actual absorption is below the bounds shown. The overall upper bound on the power absorbed, for all distances measured, is $3.6 \mu W$, which represents 11% of the total power incident on the antenna..

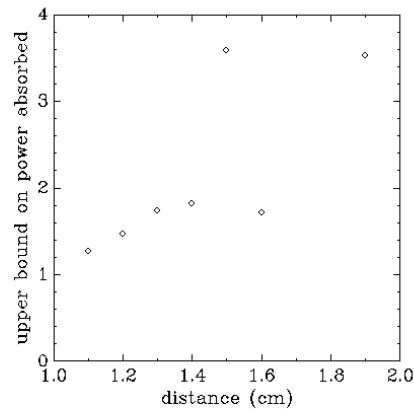


Figure 3.4: Upper bounds on the power absorbed by the absorber at various distances, at the 2σ level.

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