Microwave Frequency Polarizers

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I. ABSTRACT

This article describes the fabrication and analysis of microwave frequency polarizing grids. The grids are designed to measure polarization from the cosmic microwave background. It is effective in the range of 500 to 1500 µm wavelength. It is cryogenic compatible and highly robust to high load impacts. Each grid is fabricated using an array of different assembly processes which vary in the types of tension mechanisms to the shape and size of the grids. We provide a comprehensive study on the analysis of the grids' wire heights, diameters, and spacing.

II. INTRODUCTION

To begin to understand the early universe, we must examine the remains of an event that happened nearly 13.8 billion years ago. We constructed microwave frequency polarizers to measure the polarization of the cosmic microwave background (CMB) in search of gravitational waves produced during an inflationary epoch in the early universe. A variable-delay polarization modulator on each telescope chops between linear and circular polarization to isolate the polarized signal and filter brighter unpolarized emission. It is effective in the range of 500 to 1500 µm wavelength. The polarizers operate in a cryogenic environment to minimize the thermal emission from the instruments. The design must also be resilient in high load impacts upon landing a projected eight times. Many other design criteria such as CTE match, payload weight, and functionality are also considered in the construction of the microwave frequency polarizer grids.

The microwave frequency polarizers will be onboard the Primordial Inflation Polarization Explorer (PIPER) proposed to launch in 2014. PIPER is a predecessor to COBE-FIRAS that is used to measure the CMB and observe dust and line emission from the Galaxy. As a comparison, the wires used on the COBE-FIRAS grids are 20 µm at 32 +/- 15 µm spacing. The wires on PIPER's grids are 35 µm at 117 +/- 5 µm spacing. The greater uniformity improves frequency response and minimizes systematic error.

III. INSTRUMENT CONSTRUCTION

There polarizers are constructed in many different sizes each with the aim to suppress unpolarized emission. All polarizers share similar construction procedure. A well calibrated Tormach CNC 770 mill is used to cut the teeth spaced at 117 µm into a secured copper piece. The same machine is then used to wind 35 µm tungsten, nickel adhered wire into the teeth of the copper. The wires are tensioned at 75% of yield stress and then soldered onto the copper. The tension

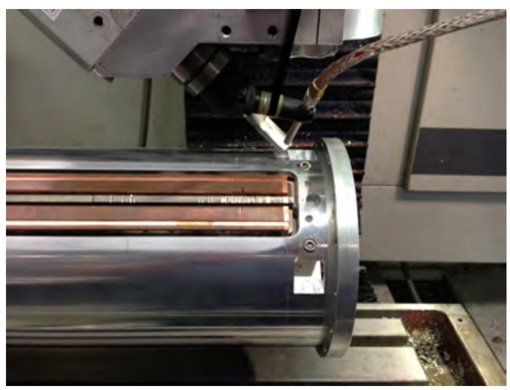

Figure 1. Teeth cutting using Tormach CNC 770 mill.

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helps avoid wire slacking and evens the distribution by reducing the number of displaced wires.

A. Large Grid

In the production of a large grid, the teeth are cut while a copper piece attached to a specially made mandrel is rotated at a set pitch below the drill. After the cuts are made, a wire feeder assembly is attached with the function of evenly tensioning the wire onto the teeth. The rotation process is repeated, except with the drill removed and the wire feeder assembly in position. The unique mandrel includes a series of hot plates which heat the copper to a set temperature for soldering. This innovative design avoids the unnecessary movement of wires which inherently causes uneven distribution of wires. After the wires are soldered, the copper pieces are carefully removed and tensioned into a wire grid frame.

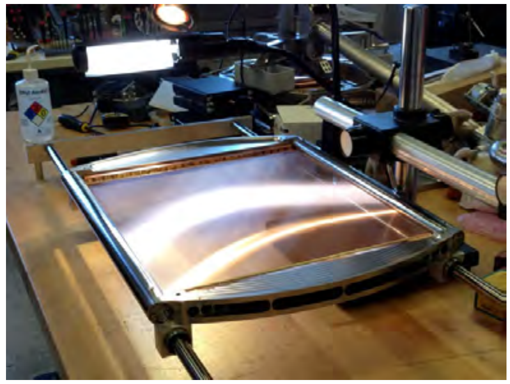

Figure 2. Complete large wire grid.

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B. Single Ring and Double Ring

The construction of the single and double ring grids are exactly the same as the large grid with a few extra steps. Once a portion of the large grid is made and properly tensioned, a stainless steel compression preloaded ring or double ring is glued onto the wires with stycast. After the glue has dried, the wires are cut and the rings' compression preloads are released. The process of using preloaded ring removes any displacement that may happen from straining the material under tensile force. This removes any potential for the wire to go slack and increases uniformity.

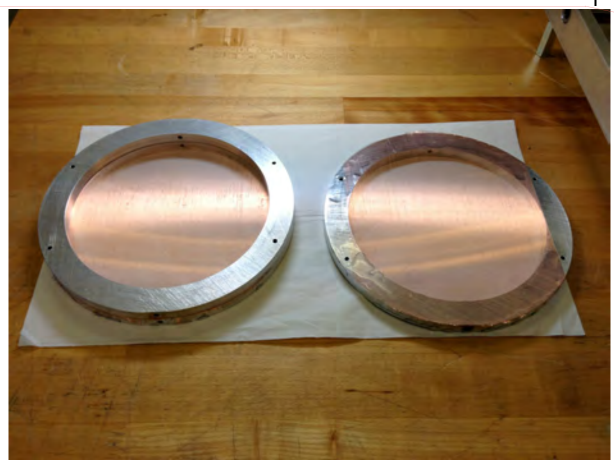


Figure 3. Completed Rings (Left) Double ring. (Right) Single Ring

C. Small Grid

The assembly procedure of a small grid is different from the previously mentioned grids. The formation of the teeth and setting of the wires is a combination of rotation, linear, and arc movements. Unlike the other grids, the copper piece is preloaded using flexures before any cutting or wire feeding is done. After the wires are placed into the teeth, they are soldered and the preloaded flexures are released. This type of tensioning mechanism allows for even distribution of tension on a small grid.

V. DATA GATHERING

The data collection process of the grids was done on the Tormach CNC 770 mill, the same machine used to create the grids. A confocal spectrometer is attached to the spindle of the mill. The spectrometer is set to measure the distance from the beam tip to the reflective surface at 300 Hz. The grid is attach beneath the spectrometer and is translated across its length at a feed rate between 0.5 to 1.0 in/min.

Each grid is scanned in a rectangular pattern which comprises of several scans. After the confocal spectrometer outputs height information across the length of the grid, the grid is shifted in a perpendicular direction to continue a scan on a different region. In this process, the spectrometer is set to read zero during the perpendicular shift to separate the scans in the data file. The information is processed through a CHR150 chromatic confocal spectrometer and stored into text document for data analysis.

V. DATA ANALYSIS

A.

A. Processing

The data gathered from the grids were analyzed using Python. The processing begins by reading the data file and storing height values into an array. The raw data is filtered using convolution methods to find the edges of wires. Every scan is separated and assigned their position, which is calculated using the feed rate and sampling rate. The data goes through a cycle of filtering processes to eliminate any inconsistency from the readings that are believed to be caused by unreflective dust particles on the wires during the scanning process.

'igure 4. Confocal Spectrometer Scan

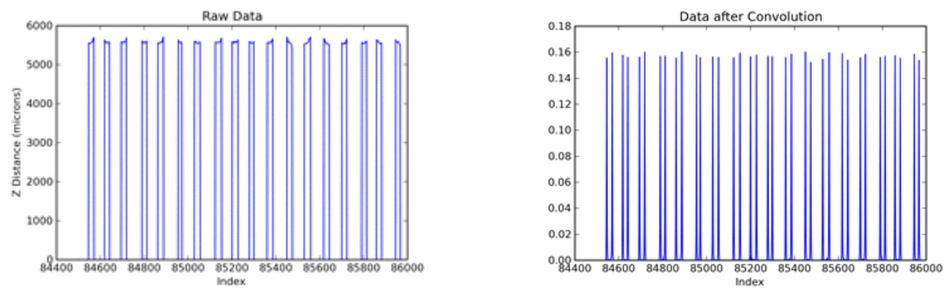
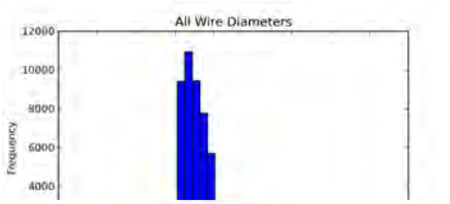


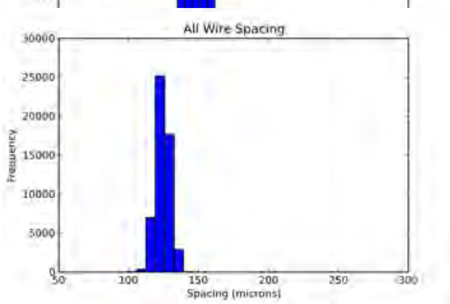
Figure 5. Height Data. (Left) Raw data. (Right) Data after convolution to find edges of the wires.

B. Wire Data

The wire diameter was calculated by measuring the number of indexes between the lead and trail edges of the wire. This was then applied to a calculation using feed and sampling rate. The data concluded that the wire diameter is 35 µm with a standard deviation of $\sigma = 5$.

$$Diameter = Number\ of\ Indexes\ \mathbf{x}\ \ Sampling\ Rate Feed\ Rate$$





C. Spacing Data

The wire spacing is the distance between two centers of wires. It is calculated by adding the radius of two wires that are beside each other in addition to the distance between the two edges of the same wires. We find that the spacing is 117 µm with a standard deviation of $\sigma = 5$. This is very uniform in comparison

D. Height Data

The height data is extensively covered in our analysis. It is calculated by finding the middle index between the lead and trailing edges of wires and searching for the nearest minimum within that region. Essentially, it is finding the highest point on the wire, which is the shortest height in our data.

After the heights for each wire are collected, the best planar fit in XY and YZ are removed and their values are recorded. These values will be used in the flattening process on the VPM. As you can see in *Figure 7*, the result is a very flat grid, with the exception of bending in the center of the grid. We believe that this is caused by the heat cycle during the soldering process which may cause the copper bars to deform. Nevertheless, this problem is addressed using a flattener, which removes the bending in the center almost entirely.

igure 6. Histogram of wire diameter and pacing. Both data sets have normal distribution.

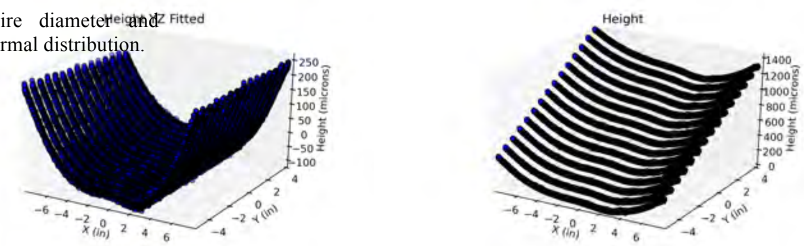


Figure 7. To the left is the raw height data with the minimum height beginning at 0 µm. On the right, the XZ and YZ planes have been removed. The result is a fairly flat grid.

The correlation between the fitted heights and the number of wires away is an important statistic to analyze. To accomplish this, we have completed scans on identical flattened and unflatten grids. The flattener proves to function as it should. *Figure 8* displays our results. When the flattener is applied, the correlation decreases and the amount of noise in the power spectral density increases. This result establishes that there is very little correlation of a bin that one away versus a hundred away. If there was, it would indicate that there is a mechanical error within the fabrication process of the grids likely from the CNC mill. Fortunately, there was no strong correlation that would signify that type of problem.

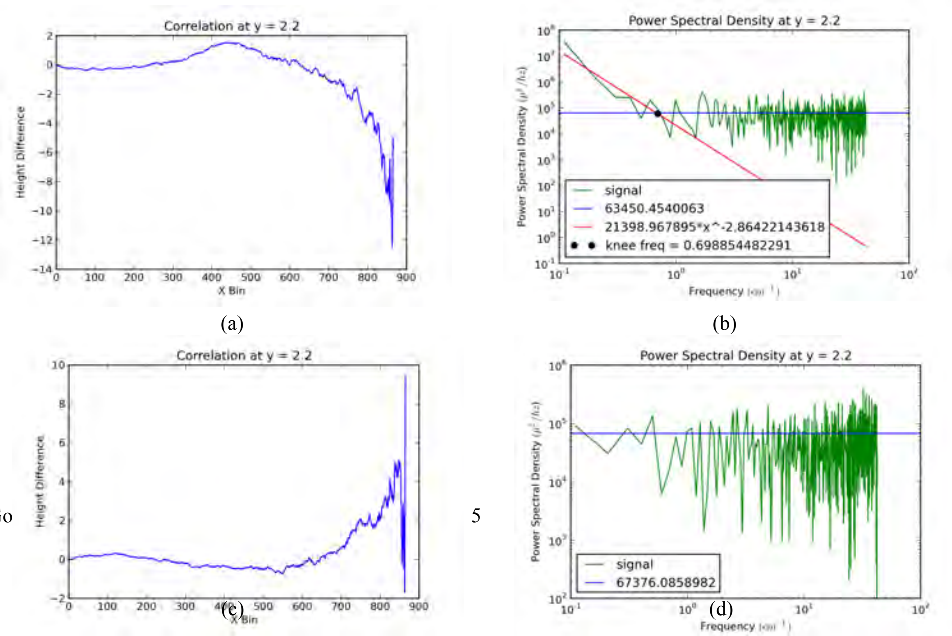


Figure 8. (a) Correlation of unflatten grid. (b) Power spectral density plot of unflatten grid. The red line is the power curve. The blue line is the level of white noise component. (c) Correlation of the same grid as (a) with grid flattener applied. (d) Power spectral density plot of flatten grid. There is no longer a power curve because white noise dominates.

VI. CONCLUSION

We fabricated microwave frequency polarizers effective in the range of 500 to 1500 µm. The grids offer great spatial uniformity and high frequency response. Experimentation shows different effective fabrication processes. Analysis proves the effectiveness of a grid flattener by reducing deformity in height distribution. The grids will be flying onboard PIPER in 2014, where we hope to find answers to the mankind's toughest questions.

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