DESIGN OF A TRANSVERSE MAGNETO-OPTICAL FILTER

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ABSTRACT

The Sun is an active star that produces solar flares, highly energetic outbursts that are usually associated with Sunspots and magnetic activity. Flares can release up to $6 \times 10^{25}$ Joules of energy and are associated with coronal mass ejections (CME’s). Both these phenomena can impact the Earth’s magnetosphere and ionosphere, producing severe radiation hazards to astronauts, satellites, and potentially entire power grids. One of the methods used to study the Sun is helioseismology. Helioseismology uses Doppler shifts in the Sun’s spectrum to study its internal structure, in much the same way mechanical waves from earthquakes are used to study the internal structure of Earth. The instrument that we use for these observations is a Compact Doppler/Magnetograph (CDM), a remote solar sensing instrument that observes line-of-sight velocities and magnetic fields within the Sun’s photosphere. Among our main research goals was to modify the CDM to improve its sensitivity by redesigning one of its main components, then building and testing the improved design. We will discuss the modified CDM design, the test equipment used and a comparison between the sensitivity of our new design with that of the previous CDM.

INTRODUCTION

Studying the Sun, our nearest star, can provide us with insight into how other stars function. In addition to this, the Sun is a source of solar wind, a massive outflow of gases that stream past the Earth at great speeds and interacts with our planet's magnetic field. These gasses inject energy into the radiation belts and can cause surges in power lines resulting in power outages. Active regions on the Sun's surface can, and often do, flare up and eject ultraviolet light, X-ray, and other radiation that heat up Earth's upper atmosphere, damage satellites and cause harm to astronauts. Disruption in satellite operations can affect flight instrumentation and communications on Earth, causing severe problems. Learning more about the Sun can help us predict solar activity and give us time to react.

PROJECT GOAL

The Compact Doppler/Magnetograph is used to study the Sun – sounding its interior to determine its structure. Magnetic Field measurements show us how active magnetic regions and sunspots evolve. Current Doppler and Magnetograph instruments used in space are large and heavy which limits their value on payload-constrained missions but the CDM provides the same capability in a much smaller and lighter package. As the main component of the CDM's filter section, the Magneto-Optical Filter (MOF) is can be tweaked to increase the instrument's sensitivity by changing the magnetic field imposed on the MOF from longitudinal to transverse, which will narrow the pass-bands resulting from the Zeeman effect and provide a sharper image.
In order to be able to collect data with the CDM throughout the day we use a Heliostat to track the Sun. The Heliostat accomplishes this by reflecting light off its primary mirror to a secondary mirror, which in turn reflects it down a tube leading to the lab where the CDM is located. As another mirror reflects the incoming light from the tube it sends it into a beam splitter that sections off a small amount of light and directs it onto a Quad Diode. The Quad Diode has four quadrants tuned to the same sensitivity relative to each other and if a quadrant is receiving more photons than the others it sends a message to the controls to adjust the primary mirror for Right Ascension and Declination, as appropriate, which helps us track the sun throughout the day.
The light that wasn't diverged by the beam splitter is sent to the CDM which is comprised of three main parts – a polarization analyzer, a filter section, and a wing selector. As a beam of light enters the polarization analyzer it first goes through a quarter-wave plate. Light incident on the quarter-wave plate is randomly polarized, however, we are only interested in the left and right circularly polarized light because it provides sensitivity to the line-of-sight magnetic field through the Zeeman effect.

![Pass-bands after Filter Section](image)

![Pass-bands after Wing Selector](image)

**Fig.2** Illustrates the pass-bands due to the Zeeman effect. The transverse field results in narrower pass-bands, which increases sensitivity.

As it emerges from the quarter-wave plate, the circularly polarized light is transformed to linearly polarized light. Light then passes through the polarization rotator which oscillates between 0°
and 45° with respect to its optic axis and rotates the incoming light by two times its angle. Therefore, linearly polarized light coming in at 0° is rotated by 0° and is then sent down through the crossed entrance polarizer in the filter section which only permits light that was initially right circularly polarized to make it through as it's polarization matches the linearly polarized light. Light going through the polarization rotator at 45° degree is rotated by 90° so that when it hits the crossed entrance polarizer of the filter section only light that was initially left circularly polarized is allowed to pass. This allows the observation of two polarization states which provides us with sensitivity into the magnetic field of the Sun.

The two linearly polarized beams then go through the filter section, which consists of two crossed polarizers placed at 90° from each other so as to filter all light and cell filled with potassium vapor. Until now a longitudinal magnetic field was imposed on the cell but this was changed to a transverse magnetic field which narrows the pass-bands to increase the instrument's sensitivity. In the absence of the vapor cell, the crossed polarizers would block all transmission of light through the filter section but the magneto-optical effect, more specifically circular birefringence, within the vapor changes the polarization state in a narrow pass-band on either side of the potassium resonance line at 770nm which allows the beams to pass through the second polarizer.

As light exits the second polarizer of the filter section it goes through the wing selector, the first component of which is another vapor cell, this one with longitudinal magnetic field imposed on it. Photons passing through the cell are partially absorbed via the inverse Zeeman effect which circularly polarizes the two pass-bands with opposite polarization. Light then passes through another quarter-wave plate which linearly polarizes the circularly polarized pass-bands. It then hits the narrow-band filter which rejects out-of-band light passing through the filter section. Finally, the light enters the last component of the wing selector, which is a Wollaston prism that separates the two linearly polarized pass bands into two separate beams, red and blue, which are then imaged onto the CCD.

**METHODS**

Our research this summer was aimed at designing a transverse field magnet assembly to replace the existing longitudinal field assembly and test the Compact Doppler/Magnetograph with the new Magneto-Optical Filter to determine if sensitivity is increased as predicted by theory. The design of the magnet assembly required some imagination and creativity as we were not aware of any previous designs using a transverse field in a MOF. There were space constraints that had to be observed because the new assembly was meant to be used as a drop-in replacement of the old assembly as opposed to redesigning the whole optical bench.

Certain issues arose with the parts available for the new magnetic assembly, most of which were from different kits used in previous projects so they had some minor differences which required repeatedly tweaking the design to ensure they fit together properly. Several different designs were made, as well as several different ways to mount them onto the optical bench, each with its own pros and cons but the hardest part was making sure the magnet itself wasn't making contact with any of the assembly bolts.
When we were finally able to design a magnet assembly which addressed all the constraints we had to work around we noticed that the cell didn't fit through the magnet itself which required adjustments to be made to the magnet to accommodate the reservoir of the cell.

It then turned out that the magnetic flux in the center of the magnet was higher than it was in the longitudinal magnetic assembly which is problematic because too strong a field can affect the polarization in such a way that not enough light may pass through the crossed polarizers of the filter section. To resolve this issue we replaced a magnet from both sides with a piece of metal which we filed down to the right size. The new transverse field MOF was placed on the optical bench and adjusted for height and tilt to make sure it was centered right in between the crossed polarizers.

RESULTS

With the MOF in place we turned on the instrument and were happy to see that everything was working properly so we began testing to determine the new MOF's temperature sensitivity. After collecting data for different operation temperatures over several days and analyzing it we were encouraged by the new instrument's temperature sensitivity. We did however notice a significant decrease in the photon count, as compared to the longitudinal field MOF, which we suspect may be due to a light leak caused by contamination of the cell windows. The results so far have been encouraging
although further testing directly comparing the longitudinal and transverse field MOFs' sensitivity will be required. In the future, certain changes may have to be implemented to address shortcomings of the magnet assembly's design, weight being one of the more significant issues, and also further testing of temperature sensitivity is necessary to determine the optimal operating temperature of the instrument.

![Image](image_url)

Pic. 4 (left) shows the raw image taken with the new transverse field MOF. Pic. 5 (right) shows a magnetogram taken on the same day with the transverse field MOF.

**CONCLUSION**

While the new magnet assembly we designed has several limitations, it is nevertheless a successful proof of concept for a transverse field MOF-based CDM which can be a low-cost flight instrument replacement for the much heavier instruments currently being used in space (such as on SOHO, MIDI, and Solar Dynamics Observatory), which would reduce costs and allow the addition of more instruments to spacecraft. The sensitivity improvement that can be achieved with the transverse field MOF will also allow for more detailed imaging of the sun which will help in observations of sunspots and other solar activity.

**ACKNOWLEDGEMENTS**

This research was supported by the National Science Foundation under grant 0852088 to Cal State LA, it was carried out at NASA’s Jet Propulsion Laboratory with the help and support of our mentor Dr. Neil Murphy, CURE program director Paul McCudden, as well as David Falk, Rich Alvidrez, Marshal Fong, Dr. Milan Mijic and last but not least our fellow interns Tzitlaly Barajas and Karen Garcia, Duy Vo, and Bradley Cannon.
REFERENCES


