DDF annual report

Title of Investigation:

A Variable-delay Polarization Modulator

Principal Investigator:

Dr. Gary F. Hinshaw (Code 665)

Other In-house Members of Team (include Code):

Dr. David T. Chuss (Code 665), Dr. Edward J. Wollack (Code 665), Dr. S. Harvey Moseley (Code 665), George M. Voellmer (Code 543), and Mike Jackson (Code 552)

Other External Collaborators:

Dr. Giles Novak and M. Krejny (NASA Graduate Student Researchers Program Fellow), Northwestern University

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$0

Funding Authorized for FY 2005:

$45,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $45,000

Status of Investigation at End of FY 2005:

Transitioned to a NASA ROSES (Research Opportunities in Earth and Space Sciences) APRA (Astronomy and Physics Research and Analysis) Award

Expected Completion Date:

January 2008

Purpose of Investigation:

In astronomy, sources (such as dust clouds, the Cosmic Microwave Background, and hot plasma in magnetic fields) are often slightly polarized. That is, they have different properties in different directions perpendicular to the direction of the radiation. To measure this polarization and extract the wealth of scientific information that it provides, special measurement techniques must be used to separate the polarized part from the much larger unpolarized part of the signal. It is for this reason that polarization modulation is essential for astronomical polarimetry. Well-designed polarization modulators allow the polarization of the incoming light to be changed in a known way without affecting the unpolarized part of the signal. Once the detector measures the output polarization signal, the polarization can be identified with the signal that changes as the modulator state is changed. The unpolarized part should be constant over the modulation cycle. The goal of this investigation is to develop a novel polarization-modulation technology, which could be used in astronomical polarization systems that operate in the far infrared through microwave parts of the electromagnetic spectrum.

This novel polarization modulator, which we have called a "Variable-delay Polarization Modulator" (VPM) in our published work, splits the incoming signal into horizontally and vertically polarized parts. It then introduces a path difference between the two and recombines them. This path difference translates into a difference between the phases of the electric fields in the two polarizations. The output signal measured by a detector that is sensitive to linear polarization is dependent upon: 1) the input polarization; 2) the phase introduced; and 3) the relative angle between the polarization-sensitive detector and the beam-splitting polarizer in the transformer. We considered the two distinct architectures for the modulator as shown in Figure 1. Highly sensitive astronomical-polarimetric measurements in this part of the spectrum are applicable to problems in the areas of both star formation and fundamental physics of the early universe.

Accomplishments to Date:

We have constructed a device based on the sketch in Figure 1A. This architecture is basically the internal part of a Martin-Puplett interferometer. We built the test setup shown in Figure 2 and tested the response from 75 to 115 GHz using a vector network analyzer (VNA), with an input signal that was vertically polarized. The transmission in terms of the scattering parameter S21 (transmission) is shown for four different delays is shown in Figure 3. The results (solid lines) for the two orthogonal polarizations at the output port are compared with the expected curves (dashed lines).

Polarization can be described in terms of the Stokes parameters: Q, U, and V. Collectively, Q and U describe the linear polarization, while V describes the circular polarization. The measured spectra of Stokes Q and V are shown in Figure 4. For a vertically polarized input signal, we expect Q=–1, U=0, and V=0. Note that a device with this particular setup is insensitive to Stokes U. The band-averaged results for Q and V are –1.002+/-0.003 and 0.001+/-0.013, respectively.

The alternative architecture shown in Figure 1B has the advantage of being compact in optical systems that have limited space. Such a modulator was constructed and tested using the same technique as the first architecture. Results for the Stokes parameters, Q (linear polarization)

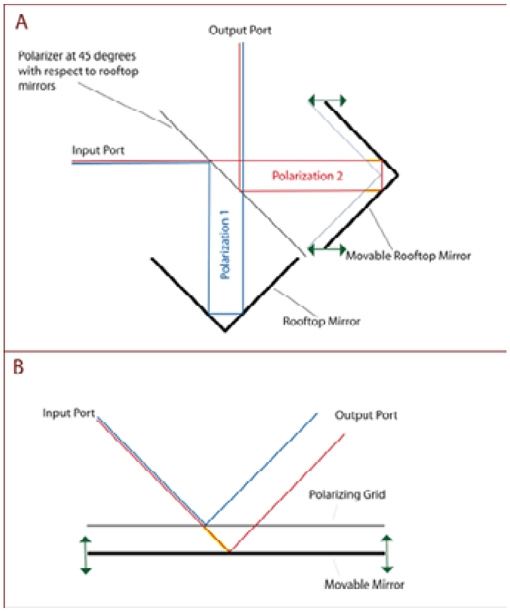

Figure 1. Two architectures for a variable-delay polarization transformer are shown. The two orthogonal polarizations are shown as red and blue lines. The relative delays between the red and the blue polarizations are shown highlighted in gold.

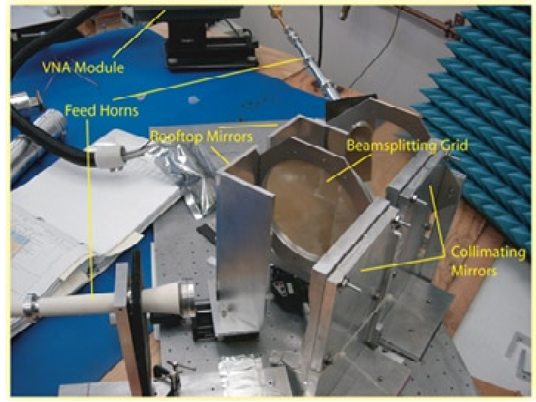

Figure 2. The setup for the measurement of the polarization modulation of the architecture in Figure 1A using the VNA is shown.

and V (circular polarization), were similar to the case of Figure 1A. This modulator is shown in Figure 5. A drive mechanism for automation also was included in this effort. We used a piezoelectric-based drive flexure that was placed in a feedback loop with a capacitive sensor.

A novel flexure was developed for use in the submillimeter (350 microns). It holds the required parallelism over its motion using a single actuator. This bearing (see Figure 6) was machined out of a single piece of titanium. A special annealing step was included in the fabrication of this bearing to make it amenable to cryogenic operation. We measured the parallelism over a 300-micron translation to be 1.5 microns. The target parallelism was 3 microns.

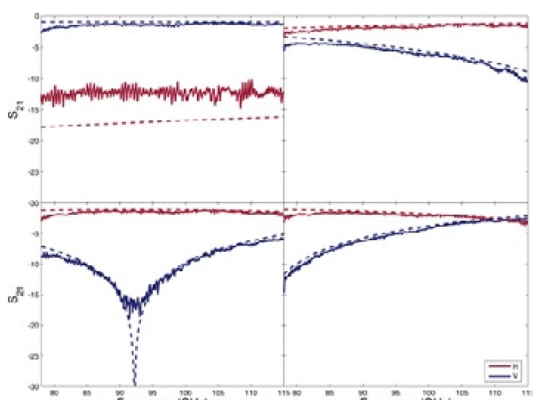

Figure 3. The output spectra for the two polarizations are shown (solid lines). Each panel represents the data from each of four different mirror positions. The expected curves are shown as dashed lines. Imperfections in the system components limit the agreement in the two left panels.

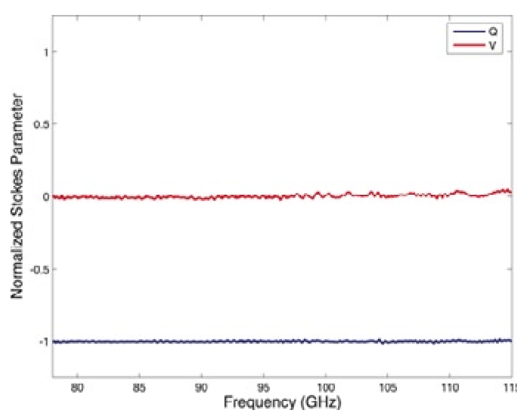

Figure 4. The Stokes parameters Q and V as measured by the modulation of the device in Figure 1A for a vertically polarized signal.

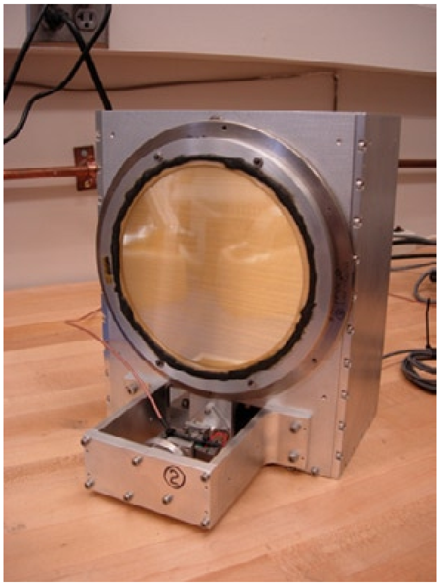

Figure 5. A submillimeter polarization modulator that utilizes the architecture in Figure 1B is shown. In this device, a mirror is moved behind a grid to modulate the path difference between two orthogonal linear polarizations.

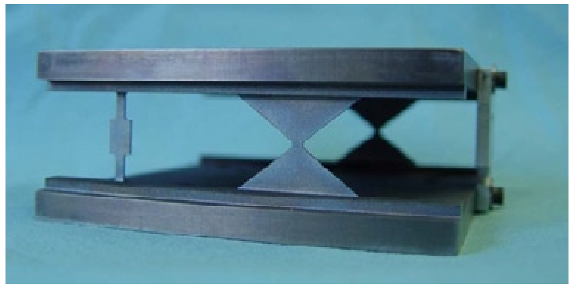

Figure 6. The flexure for the flat-plate modulator is machined out of a single piece of titanium. This flexure is designed to maintain the required parallelism with a single actuator. Its single-material construction, combined with an annealing procedure in its fabrication will allow for cryogenic operation.

Publications:

Chuss, D.T., E.J. Wollack, S.H. Moseley, & G. Novak, "Interferometric Polarimetric Control," *Applied Optics*, accepted.

Papers for Presentation at Professional Society Meetings, Seminars, Symposia, and Other Important Forums:

Chuss, D.T., D.J. Benford, S.H. Moseley, J.G. Staguhn, G.M. Voellmer, E.J. Wollack, M. Krejny, G. Novak, C.Y. Drouet d'Aubigny, D. Golish, A. Hedden, C. Kulesa, C. Walker, "Submillimeter Polarimetry Using Variable-delay Polarization Modulators," 207th AAS Meeting, 2006, Accepted.

Krejny, M., et al., 2006 SPIE Astronomical Telescopes and Instrumentation, submitted.

Voellmer, G. et al., 2006 SPIE Astronomical Telescopes and Instrumentation, submitted.

Awards:

We have received funding to incorporate this technology into a submillimeter polarimeter at the Submillimeter Telescope Observatory in Arizona. This funding was obtained in response to NASA's Research Opportunities in Earth and Space Science (ROSES) proposal call. The specific area of funding is the Astronomy and Physics Research and Analysis (APRA) program.

Planned Future Work:

We will test a two-stage submillimeter polarization modulator on an astronomical system. In addition, we will investigate the capability of this device to modulate polarization over a broad band. Finally, we will model a concept for Inflation Probe that will utilize such devices as primary modulators.

Key Points Summary:

Project's innovative features: These devices have several potential advantages over current state-of-the-art modulators (e.g. wave plates). First, these devices have the potential to operate over large parts of the electromagnetic spectrum. Second, it is possible to chain two devices together. This arrangement can be used to completely characterize the polarization of a light source (measure Stokes U in addition to only Q and V). Third, the small linear motions require no frictional bearings that can wear out with repeated use. This property makes this device a promising technology for space-polarimetry missions because these applications require years of operation.

Potential payoff to Goddard/NASA: Astronomical polarimetry is at the forefront of the Einstein Inflation Probe mission. Sensitive polarization measurements of the Cosmic Microwave Background will give a direct measurement of the physics of the universe's earliest epoch. Such measurements are extremely difficult and require special techniques to extract the small signal of interest from the background radiation. Polarization modulation will be a key feature of any system trying to accomplish this.

The criteria for success: The two important milestones for this work were the ability to use a polarization modulator to extract Stokes parameters from a source and the construction of a viable automation mechanism for operation in an astronomical instrument. Both were achieved.

Technical risk factors: It was unclear that the cryogenic flexure design would be able to meet the target parallelism.