HINDS INSTRUMENTS, INC.

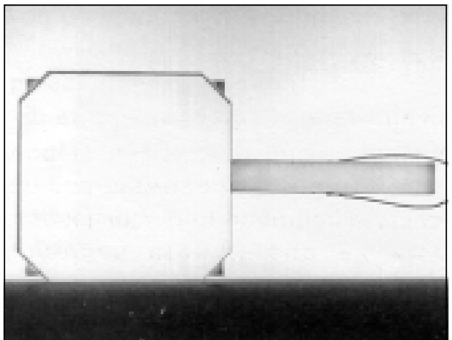
PEM™

APPLICATIONS NEWS FOR USERS OF PHOTOELASTIC MODULATORS

WINTER 1995

Featured Application

Solar Polarimetry: Zurich Imaging Stokes Polarimeters



PEM SERIES II/FS42 & 47

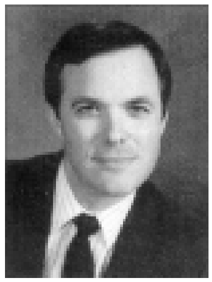
Most real-time measurement of the complete Stokes parameters using PEM technology requires the use of two PEMs operating at different frequencies with their modulator axes oriented at 45 degrees with respect to each other. Hinds PEM models II/FS42 and II/FS47 are well-suited for this purpose.

These PEMs use UV grade fused silica with spectral transmission from 170 to 2500 nm. The operating frequencies are 42 and 47 kHz, respectively. (For operation at wavelengths between 210 and 3500 nm, models II/IS42 and II/IS47 provide optical elements of IR grade fused silica.)

The symmetrical design of series II modulators provides several benefits important to Stokes polarimetry and certain other measurements: greater retardation for a given PEM thickness, radially symmetrical apertures, and large apertures for maximum light throughput.

Fused silica is a rugged material with excellent modulation characteristics. The II/FS42 and II/FS47 are two of Hinds' most popular PEM models. This translates into shorter lead times and quantity-based pricing for our users.

Welcome to PEM News



Paul Hinds, president of Hinds Instruments

Welcome to the PEM newsletter, an applications bulletin for current and potential users of photoelastic modulators. Our plan is to publish two or three times a year.

Each issue will feature a specific user's application, related product information, and technical support news.

Our goals are to educate the PEM user community about applications and products, to stimulate new applications, and to encourage communication between PEM users. We hope also to provide a forum for you to share ideas.

In this first issue we are pleased to share the work of Drs. Hanspeter Povel and Christoph Keller from the Swiss Federal Institute of Technology in Zurich. They have developed a novel approach to imaging polarimetry which we believe will be of interest to many, even those outside their particular field. We are working closely with them to provide the special modulators needed for their unique application.

If you wish to contribute an article regarding a noteworthy application, or have a suggestion regarding newsletter content, please contact us.

About the Scientists

Dr. Hanspeter Povel (left)
Dr. Christoph Keller

Drs. Hanspeter Povel and Christoph Keller were instrumental in developing the Zurich Imaging Stokes Polarimeter (described in our feature application article inside) at *Eidgenössische Technische Hochschule Zürich* (ETH). ETH is the Swiss Federal Institute of Technology.

Hanspeter Povel

Povel studied physics in Germany and went to CERN, the high energy physics laboratory in Geneva, to get his Ph.D. with work on experimental nuclear and particle physics. In addition, he has worked on the reliability of industrial electronic devices and systems. Since 1981 Povel has been employed by professor Dr. J.O. Stenflo at the Institute of Astronomy at ETH, where his work with optics and instrumentation has carried over to astrophysics.

"A lot of experience I gained in particle physics, I could use in this application," he says. "I am actually working not as an astronomer, but as a physicist developing instruments."

Povel's interest in astronomy is "more of a private interest. When I

(Continued on page 4)

Solar Polarimetry: The Zurich Imaging Stokes Polarimeters

One of the first uses of the photoelastic modulator (PEM) was astronomical polarimetry. Dr. James Kemp, late professor of physics at the University of Oregon, used PEMs to study the polarization of light from nearby stars and features on the sun, such as sunspots.

Dr. Hanspeter Povel, Dr. Christoph Keller, and a group of astronomers centered at the Swiss Federal Institute of Technology in Zurich, Switzerland have taken Dr. Kemp's work a giant step forward by developing imaging polarimeters which produce a two-dimensional image of a region of the sun. Each pixel in the image contains complete polarization information, four numbers called the "Stokes Parameters." This is much more efficient than doing point-by-point scans, as was required by previous polarimetry techniques based on PEMs.

The four Stokes parameters (I, Q, U, V) give a complete description of the polarization state of a light source. These parameters include the total intensity (I), two linear polarization components separated by 45 degrees (Q and U) and a circular component (V).

PEM-based polarimeters typically use two PEMs with different frequencies, f1 and f2, with their modulator axes oriented at 45 degrees to each other. Detection of the two linear components is made at 2f1 and 2f2 while the circular component is detected at f1 or f2.

The key to the Zurich Imaging Stokes Polarimeters is an ingenious use of charge coupled devices (CCD), "slow" optical detector arrays (e.g., 50 Hz frame rate).

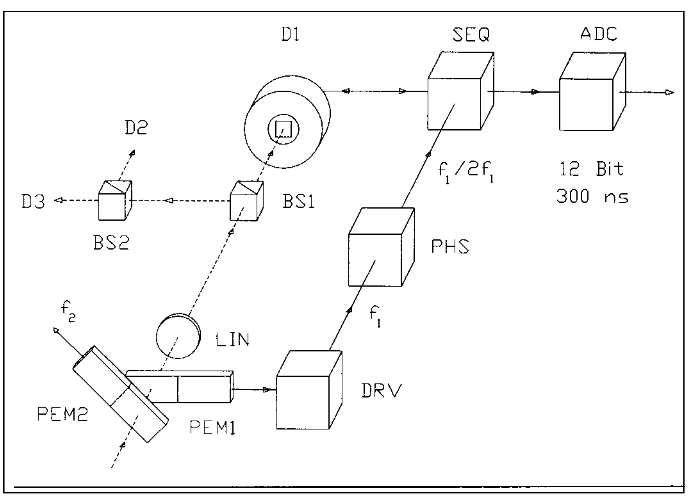


Figure 1. Setup for recording all four stokes parameters. The orientation of the components is given with respect to Stokes Q. PEM1 (0 degrees), PEM2 (45 degrees): piezo-elastic modulators, LIN (22.5 degrees): linear polarizer (Glan Thomson), BS1, BS2: beamsplitter cubes which direct the modulated light to detectors D1, D2, D3.

They are used both as detectors and demodulators for the fast (e.g., 42 kHz) PEM modulation signals.

ZIMPOL I

The optical setup for the first of these imaging polarimeters, ZIMPOL I, is shown in Figure 1. The two PEMs are followed by a linear polarizer whose passing axis bisects the modulator axes. Two beamsplitters divide the light to three detectors which detect f1, 2f1, and 2f2.

Each CCD detector has a mask which covers every other row of pixels. Each covered pixel is paired with an open pixel. Charge accumulates in the open pixel proportional to the number of photons which strike it. The charge on the pixels is switched between the open and covered pixels by the appropriate square-wave reference signal. The two charge images accumulate for a period of time, typically less than one second, before the CCD array is "read out." The operation is similar to a boxcar integrator.

In measurements at the Swedish Vacuum Solar Telescope in May 1993, a single ZIMPOL I camera proved to be able to record simultaneously the intensity (I) and one of the polarization parameters (Q, U, or V) with high accuracy and sensitivity. The recorded data include a variety of different solar observations such as vector polarimetry with a spectrograph of sunspots and highly sensitive magnetograms of active regions and the quiet sun. Figure 2 shows an example.

Measurements performed in 1994 at the Kitt Peak and Sacramento Peak solar observatories prove that this new type of imaging polarimeter can achieve the increased levels of polarization sensitivity required by modern magnetic field research.

ZIMPOL II

ZIMPOL II, the second generation imaging polarimeter, is being developed now. It will offer a six-fold increase in efficiency by using a single CCD and by using a micro-lens array which ensures that all the light incident on the CCD array is collected.

ZIMPOL II will use two PEMs synchronized at the same frequency with a 90-degree phase difference and modulator axes 45 degrees apart (Figure 3).

The light is focused on the CCD with a micro-lens array such that out of four pixels in one column, only one is used for light detection while the remaining three pixels are used for temporary charge storage (Figure 4). The four charge packets correspond to four independent linear combinations of the four Stokes parameters. These will be sequentially shifted between

Figure 2. Broad-band circular polarization near the solar limb around 4500Å. The left panel shows the white-light image where the dark patch is a sunspot and the brighter areas are faculae (large patches of bright material forming a veined network in the vicinity of sunspots). Both are magnetic structures. The right panel shows the circular polarization signal resulting from the net asymmetry of Stokes V signals in magnetic areas. Solid black and white correspond to ±0.15% circular polarization.

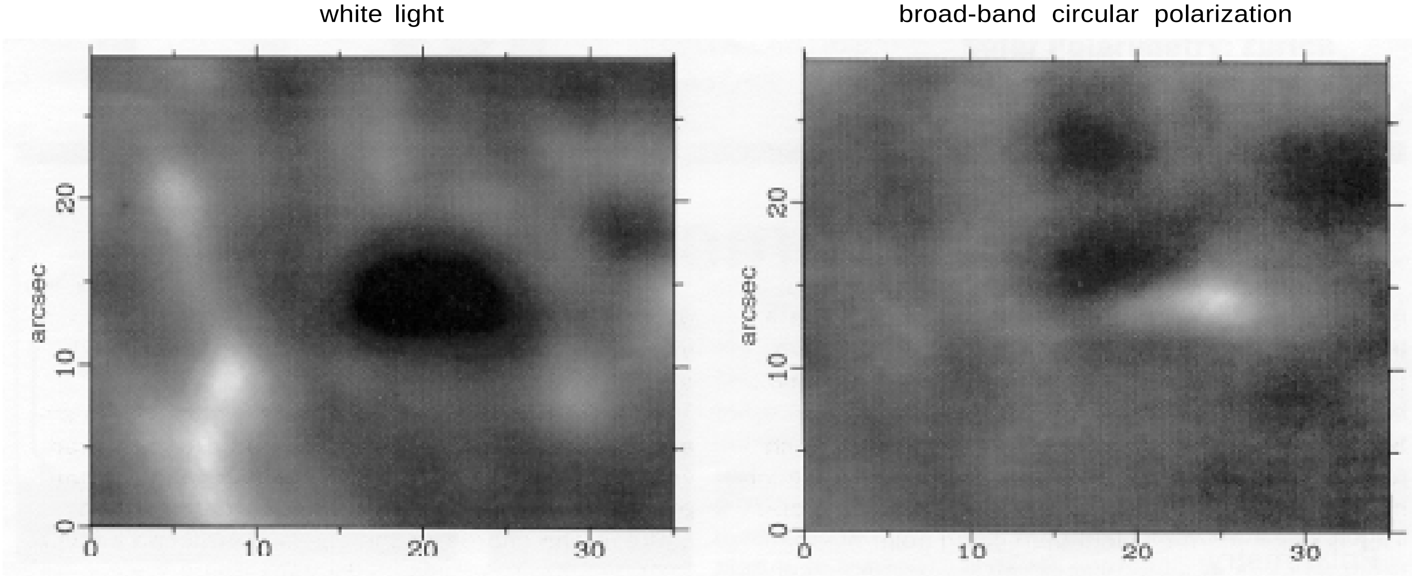
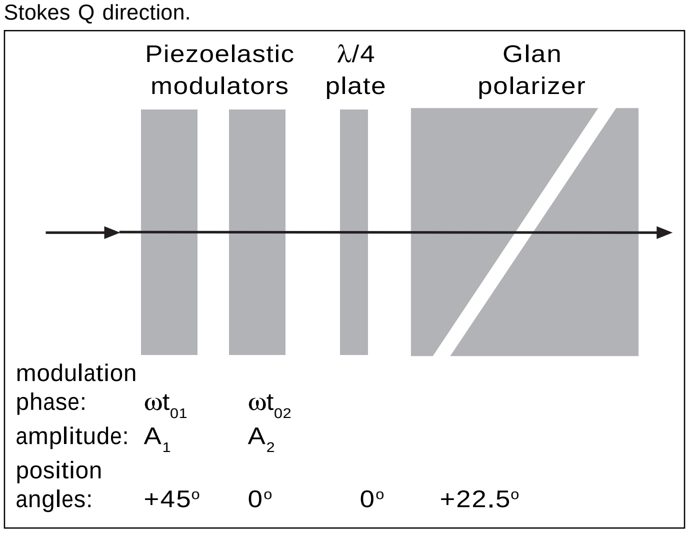


Figure 3. Optical scheme of the phase-locked modulator package of ZIMPOL II. The position angles are given relative to the positive Stokes Q direction.



the pixel rows in phase with the modulator reference signal. After the CCD is read out, the four Stokes parameters will be calculated from the digitized pixel charges. In this way, a precision imaging polarimeter recording simultaneously all four Stokes parameters will be realized with a single CCD sensor.

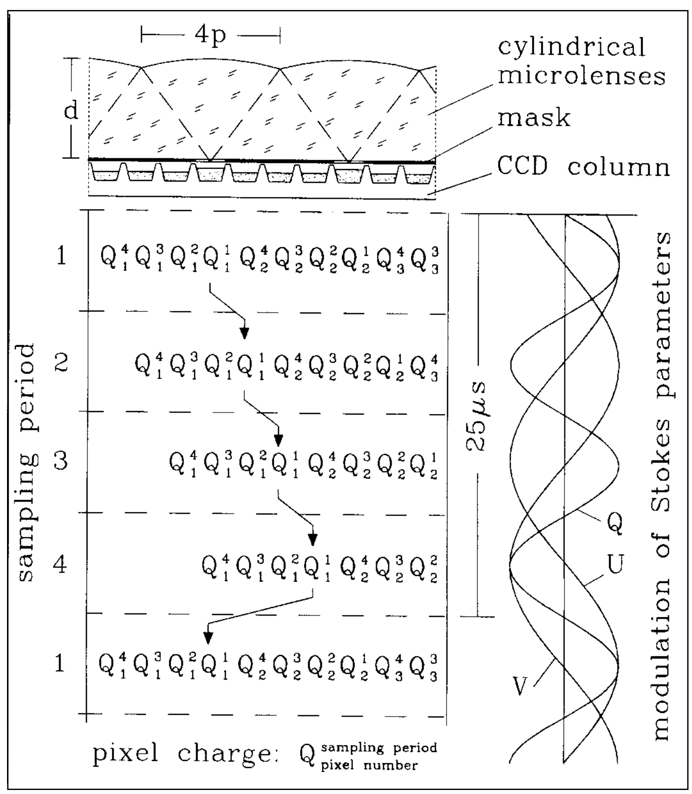
Partial List of References

Keller, C.U., et al. "On the strength of solar intra-network fields," *Astronomy and Astrophysics* 286, p. 626, 1994.

----------. "Zurich Imaging Stokes Polarimeters I and II," SPIE Proceedings 2265, p. 222, 1994.

Povel, H., et al. "Two Dimensional Polarimeter with a Charge-Coupled Image Sensor and a Piezo-elastic Modulator," *Applied Optics* 33, p. 4254, 1994.

Figure 4. Principle of the ZIMPOL II demodulation scheme. The upper part shows a cross-section of the micro-lens array in a plane perpendicular to the pixel rows. "p" is the pixel size (about 80 μm). "d" is on the order of 1 mm. The right part shows the modulation of the Stokes parameters Q, U, and V. The left part shows the charge shifting scheme with respect to modulation.



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INSIDE PEM

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- PEM Models II/FS42 & 47

NOTES OF INTEREST

Trade Shows

The PEM system will be on display at two upcoming conferences:

- PITTCON '95 in New Orleans, March 5-10, Booth Number 5723
- CLEO '95 in Baltimore, May 21-26

Our technical staff will be on hand to answer your questions and hear your suggestions. Several new products will be on display. Please stop by.

New Technical Note

If you use a photoelastic modulator with laser light, a new PEM technical note may interest you. Ted Oakberg has written a detailed analysis about modulated interference effects and ways to reduce or eliminate them. The article is scheduled for publication in the June 1995 issue of *Optical Engineering*. We would be glad to send you a pre-publication copy.

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Scientists . . .

was young I had an amateur telescope. Today I prefer reading books and journals on astronomy."

A number of years ago Povel met Dr. James Kemp, inventor of the PEM system, when Kemp visited Zurich. "I had some discussions with him. He told us about his ideas," Povel says. "It gave me a deeper understanding of the construction of PEMs." Povel used his understanding to develop the demodulation scheme for ZIMPOL that enables the CCD arrays to detect the fast oscillations of the PEM.

Christoph Keller

Since January 1994, Keller has been working at the U.S. National Optical Astronomy Observatories (NOAO) in Tucson, Ariz.

Besides using the ZIMPOL I instrument, current projects include: 1) a high-resolution, balloon-borne telescope which will circle around the South Pole, 2) interferometric techniques that eliminate image distortion resulting from the earth's atmosphere, and 3) a new array detector that is highly wavelength sensitive.

This last project is in conjunction with ETH's physical chemistry lab. "This project is a lot of fun," Keller says. "It will detect the wavelength of every photon that falls on the detector. It might take another 10 years until we have something that will work in astronomical applications, but it might be a real breakthrough."

Keller received his M.S. degree in physics and a Ph.D. degree in natural sciences from ETH where his studies included optics, astrophysics, and particle physics. "I prefer astrophysics because you can work in smaller groups," he says. "In particle physics you need 100 people to get good experimental results."