

A NEW SYSTEM FOR OBSERVING SOLAR OSCILLATIONS AT THE MOUNT WILSON OBSERVATORY*

I. System Design and Installation

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Abstract. In this paper we describe a new observing system which is currently nearing completion at the Mount Wilson Observatory. This system has been designed to obtain daily measurements of solar photospheric and subphotospheric rotational velocities from the frequency splitting of non-radial solar p -mode oscillations of moderate to high degree (i.e. $l > 150$). The completed system will combine a 244×248 pixel CID camera with a high-speed floating point array processor, a 32-bit minicomputer, and a large-capacity disc storage system. We are integrating these components into the spectrograph of the 60-foot solar tower telescope at Mount Wilson in order to provide a facility which will be dedicated to the acquisition of oscillation data.

1. Introduction

The observations described in the previous paper (Rhodes *et al.*, 1983) were obtained as a portion of the on-going program of visitor research conducted at the Kitt Peak National Observatory. As such these observations could only be obtained when the

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McMath telescope was available for this particular project. In order to provide similar observations with enough frequency to study temporal fluctuations in the solar rotation rate and in the excitation and decay of the p -mode oscillations, an observing system must be provided which is nearly dedicated to the acquisition of solar oscillation observations. Such a system is now nearing completion at the Mount Wilson Observatory. In this paper we will give a brief description of this system and outline its current state of development.

2. Scientific Goals

As described in the preceding paper (Rhodes *et al.*, 1983), the solar non-radial p -mode oscillations can be utilized to measure the rate of rotation of the Sun both within the photosphere and over a range of distances below it. A technique for doing so with moderate and high-degree modes was described by Rhodes (1977), by Rhodes *et al.* (1979), and by Deubner *et al.* (1979). By repeatedly observing a rectangular area at the center of the solar disk for intervals of up to 12 hr in duration, we can separate out those oscillations traveling eastward around the Sun from those traveling westward.

When the Sun is accurately kept centered in the telescope's field of view for such long durations, the p -mode ridges are shifted by an amount, $\Delta\omega$, which depends directly upon both the rotational velocity, V_{drift} , and the horizontal wavenumber, k_h , as follows:

$$\Delta\omega = V_{\text{drift}} k_h.$$

Thus, by measuring $\Delta\omega$ as a function of k_h , one can measure the rotational velocity of the wave pattern across the telescope's field of view.

The first such observations were obtained by Franz Deubner during 1977 at the Sacramento Peak Observatory with the diode array on the tower telescope there. These results were published by Deubner *et al.* (1979). In that paper rotational velocities, V_H , normalized to the surface ($Z_{\text{eff}} = 0$) velocity were shown as functions of depth, Z_{eff} , for three different days. Near the surface the three days gave essentially the surface rotation rate, while below a depth of 8000 km there was some suggestion of an increase in rotational velocity with depth. However, the observational scatter became larger below 8000 km and the three days' measurements were insufficient to conclusively demonstrate the existence of more rapid rotation below the photosphere. Furthermore, earlier at this colloquium both Deubner (1983) and Rhodes *et al.* (1983) presented more recent observations of p -mode frequency splitting which did not show any evidence for such a rotational velocity increase. On the other hand, Claverie *et al.* (1981) recently presented evidence of rapid interior rotation based on the frequency splitting of dipolar and quadrupolar p -modes in the five-minute band. If the interpretation suggested by Claverie *et al.* (1981) is correct, then the solar angular velocity must increase at some depth below the photosphere.

Apart from such questions of the reality of a radial gradient in the angular velocity, the technique described above is also useful for obtaining absolute rotational velocities in a manner that is completely independent of existing Dopplershift techniques.

Preliminary absolute rotation rates were discussed by Rhodes *et al.* (1983) and additional analysis of the data they presented is currently in progress.

In view of the somewhat contradictory nature of observations of both the absolute photospheric rotation rate and of the sub-photospheric rotation rate, we believe that it is important to obtain additional observations of the type presented by Deubner *et al.* (1979) and by Rhodes *et al.* (1983). Specifically, we hope to study the following problems: (1) What is the absolute, non-normalized rotational velocity determined for each day in the photosphere? (2) Are there daily variations in this rate? (3) Is there a true radial gradient in rotational velocity? (4) If so, does it extend as deep as 20 000 km? (5) Are there temporal fluctuations in the deepest observable rotational rates? (6) Can we see any evidence for the rapid interior rotation observed by Claverie *et al.* (1981)?

With the system we are describing here, we plan to obtain rotational velocity vs. depth maps similar to those shown by Deubner *et al.* (1979), on a daily basis for large fractions of each year. We are aware that Gough (1978) has criticized the technique employed by Ulrich *et al.* (1979) in the computation of the effective depths at which various p -modes are sensitive to the rotational velocity. Specifically, Gough (1978) criticized the assumption of a monotonic increase in angular velocity with sub-photospheric depth which Ulrich *et al.* employed. Gough further argued that when he employed a theoretical angular velocity profile which was not monotonic with depth, he found the effective depths calculated with the Ulrich *et al.* technique to be multi-valued.

In answer to this criticism we note the following points: (1) The method used by Ulrich *et al.* employed a Taylor series expansion of the solar angular velocity profile. While they truncated this expansion to include only the constant and linear terms in the numerical computations they presented, they pointed out that effective depths corresponding to the higher-order terms could also be calculated after which a least-squares analysis could be carried out to determine the magnitudes of these terms should future observational data suggest a need to do so. (2) The more recent observational data of Deubner (1983) and Rhodes *et al.* (1983) do not support the existence of any radial gradient in the angular velocity and instead suggest that the alternative inversion techniques described by Gough (1978) are not necessary. (3) The inversion technique described by Gough (1978) employs a linear combination of eigenfunctions to obtain a contribution function which is sharply localized. As Gough (1983) has himself pointed out at this colloquium, this linear combination includes both positive and negative coefficients and hence can be quite sensitive to observational errors in the frequency shifts. Gough (1983) has gone on to outline a modification of his 1978 technique which is designed to allow for such observational uncertainties; however, this revised method has not yet been employed with actual data.

By obtaining a $k_h - \omega$ diagram each day, we will be able to search for evidence of the temperature and horizontal flow perturbations described at this colloquium by Hill *et al.* (1983). For those intervals of time when day-to-day fluctuations are small we should be able to improve upon the error brackets presented by Deubner *et al.* (1979) by combining the results of successive days.

Furthermore, with this system we will be able to study the statistical properties of the

p-mode oscillations themselves. In particular, we plan to compare the oscillation amplitudes and the observed frequencies on different days in order to search for possible changes with time. Beating between unresolved eigenmodes can certainly produce amplitude variations; however, it should be possible to test this hypothesis by studying a long sequence of observations and then combining data from several sequential days of observation.

3. The 60-Foot Telescope

The new system is currently being installed at the 60-foot solar tower telescope at Mount Wilson. This telescope is the instrument with which magnetic fields were discovered on the Sun (Hale, 1908) and with which the solar '5-minute' oscillations were discovered (Leighton *et al.*, 1962). The Sun is acquired with two movable flat mirrors which are located in the dome at the top of the tower. With this coelostat arrangement the solar image does not rotate during the course of a day. The light from these two mirrors is aimed down the tower to either of two alternative sets of optics. In the first optical arrangement a 12-inch doublet lens is located just below the two flat mirrors. This lens has a 60-foot focal length and forms a 6.8-inch diameter solar image at the entrance slit of the spectrograph which is located at the bottom of the tower.

In the second optical arrangement the light follows an off-axis folded path. A 10-inch diameter off-axis paraboloid mirror is located just to the side of the optical axis of the tower at the level of the spectrograph entrance slit. The light from the flat mirrors at the top of the tower is reflected upward by this off-axis mirror to a third flat mirror which is located 15 feet above it. The converging beam is reflected back downward by the flat mirror and finally forms a 3.4-inch diameter image at the spectrograph entrance slit. The three aperture masks which are used with the paraboloid mirror have diameters of 5, 7, and 10 inches, resulting in $f/72$, $f/48$, and $f/36$ beams, respectively.

Currently, the 60-foot telescope and its spectrograph are being used to continue two daily sequences of calcium k-line and H α spectroheliograms which were begun in 1915. The acquisition of these spectroheliograms requires only an average of 30 min per day. Consequently, the telescope and spectrograph can be dedicated to the acquisition of oscillation observations for the remainder of every clear day.

4. Guider Assembly

One of the critical requirements of the rotation-measurement techniques we are using is that of very accurate guiding of the solar image. Specifically, the limbs of the solar image must be kept fixed with respect to the spectrograph entrance slit to within a tolerance of less than one or two arcseconds for durations of up to 12 hr at a time. To obtain such stability we have installed a new guider assembly at the 60-foot telescope. The new guider is a smaller copy of the four-limb guider currently in operation at the 150-foot telescope, which is a well-tested design. Each of the two axes of the guider functions in the following way: The light from opposite ends of a diameter of the solar

image strikes the cathode of a single photomultiplier tube alternately as a chopper admits each beam. A servo amplifier nulls the a.c. signal which results from an offset of the image by tilting one of the flat mirrors at the top of the tower. The d.c. component of the photomultiplier signal is kept constant by varying the high voltage to the tube so that the characteristics of the servo do not vary with sky transparency. This type of guider has advantages over the multiple-detector variety where the image may drift as the characteristics of the individual detectors vary with time.

In operation a beam splitter sends a part of the main telescope beam to the guider assembly. The light from four limb positions is measured and kept balanced by the guider electronics. Additionally, the guider head now has stepper motors and encoders on each of the two orthogonal axes. These items were added to the guider assembly to provide the necessary scanning capability for this project. Under the control of an LSI-11 the guider head will move across the large plate on which it is mounted. The signal generated by the guider will then move one of the mirrors at the top of the telescope by just the correct amount to move the solar image across the spectrograph entrance slit. A 256-pixel Reticon linear array will be interfaced to the LSI-11 to serve as a limb-position sensor on the spectrograph to keep a record of any drifts of the solar image during each day. These limb positions will then be used to register successive scans during the post-observing data reduction process.

5. The Spectrograph

The spectrograph to be used is a vertical pit spectrograph having a 13-foot focal length. It is located within a 25-foot deep concrete pit which is located within the earth at the bottom of the tower. The bottom of this pit is colder than the ambient room temperature at the top. The collimating and camera lenses and the grating are suspended from the top of the spectrograph itself in a girder-enclosed cage. This cage has been baffled and enclosed in order to interfere with the formation of air currents within the pit.

The spectrograph assembly is motorized and is used daily as a spectroheliograph, however, in our studies we will not move the spectrograph during the acquisition of the observations. Instead, we will use the instrument solely as a spectrograph. In addition, the cage assembly containing the spectrograph optics can be firmly attached to the side of the spectrograph pit during each day's oscillation observations in order to eliminate any vibrations which might be present in the spectrograph itself.

The spectrograph grating is a 5×6 inch Babcock grating having a groove spacing of 600 per millimeter. The grating is blazed for the second order yellow ($\lambda 5800$). The dispersion is 1.54 \AA mm^{-1} in the second order at $\lambda 5576$.

6. The Oscillation Observing System

A. SCANNING GEOMETRY AND FRAME RATES

One of the design goals of this system is the ability of obtaining three-dimensional (x, y, time) radial velocity maps during each day for later spatial compression and

analysis. For each position of the entrance slit on the Sun, the spectrograph will disperse a small portion of the solar spectrum onto a CID array camera which will be part of this system. In this way we will be able to record spectral intensities at 244 different wave-lengths for each of 248 one-arc sec-wide positions along the spectrograph entrance slit. By recording this spectrum and then using the guider to rapidly step the solar range across the entrance slit, we will be able to obtain an $I(\lambda, x, \text{ and } y)$ map once every scan, where I is the intensity at wavelength λ at location x, y on the solar disk.

The geometry of the area which will be scanned in this fashion will be that of a large rectangle. The 248 one-arc sec-wide pixels which will be aligned parallel to the spectrograph's entrance slit on the CID array will be oriented in a north–south direction. The guider will be used to scan the image in the east–west direction. Hence, for a slit width of four arc sec, a 1000 arc sec distance along the solar equator will be obtained in 256 readouts of the CID array camera.

Preliminary light-level tests we have carried out at Mount Wilson with the CID camera suggest that we should be able to reach 50% of the chip's saturation level in 50 to 100 ms, depending upon time of day, time of year, magnification of the spectrum on the CID chip, and cleanliness of the optics in the telescope and spectrograph. Adding in the 50 ms readout time to read 7440 pixels (i.e. 30 rows of 248 pixels each), we should get a combined exposure and readout time of 100 to 150 ms. Allowing a few seconds for backward scanning between successive frames, we should be able to scan across the rectangle on the disk in 30 to 45 s. These frame rates are faster than the 60 s rate used at Kitt Peak by Rhodes *et al.* (1981). The frame time may be cut further by 15 s by modifying the camera circuitry so that a portion of the array can be readout simultaneously with the exposure of the remainder of the array. This modification would also eliminate the need for the cylindrical shutter.

B. ABSOLUTE VELOCITY REFERENCE PROVISION

By observing two telluric lines located on either side of the reference solar line, it is in principle possible to remove spectrograph drifts down to 10 to 20 m s^{-1} .

Two such solar lines are the Fe I line $\lambda 6302$ and the Ni I line $\lambda 6213$. Both of these lines have been employed at Kitt Peak by Rhodes, Harvey, and Duvall. The first, $\lambda 6302$, is partially blended with one of the reference lines and is not too useful. The second, $\lambda 6213$, a clean line which is free of blends. This line was used in May, 1980, to obtain the p -mode power spectra presented by Rhodes *et al.* (1981). In these observations the telluric lines were also recorded but for the spectra which were published in Rhodes *et al.* the telluric lines were not actually used to calculate absolute wavelengths. Rather, the mean of each velocity scan was subtracted before the power spectrum was computed. Other, unpublished power spectra have been generated by Rhodes *et al.* in lines such as the Na D lines, $\lambda 8542$, Mg B $\lambda 5173$, $\lambda 6314$, and H α without absolute velocity reference information. Thus, it is our belief that, for studies of the frequencies of p -modes in the 5-min band, an absolute velocity reference is not essential. On the other hand, for studies of the excitation and decay of these modes and for the low-frequency portion of the $k_h - \omega$ plane such a reference system may be essential. If we find that the telluric

lines are not adequate for this purpose, then we will work to incorporate a laboratory reference line into our system.

C. OPTICAL PATH

In order to allow for both the continuation of the existing series of spectroheliograms and the oscillation observations, the schematic design shown in Figure 1 was selected. In this design the CID camera assembly is mounted in an enclosure which is attached to the side of the main spectrograph. Through the use of a narrow-periscope assembly, light can be deflected to the CID detector array which will in turn be located within a liquid-nitrogen-cooled dewar. By allowing the whole dewar-periscope assembly to move on rails in the direction of dispersion of the spectrograph (into and out of the plane of Figure 1), we can position it so that it is completely out of the path of the light which is used to expose the photographic plates placed above the spectrograph's exit slit each morning.

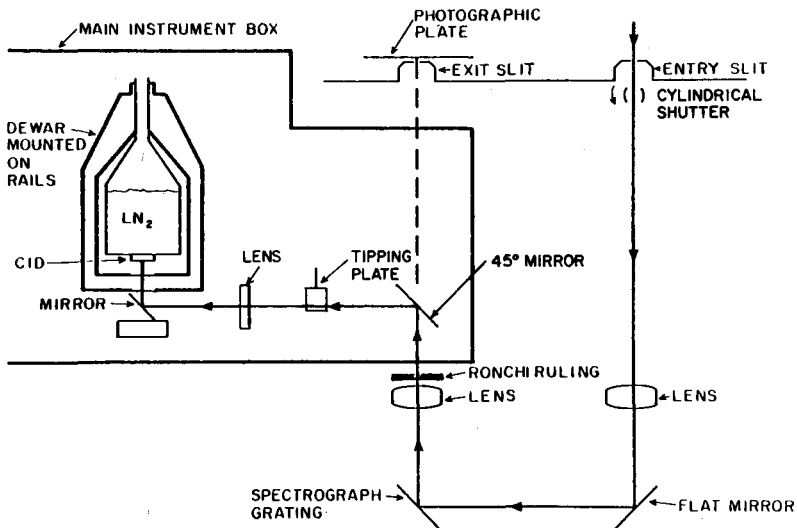


Fig. 1. Schematic design of the new system. The CID camera is mounted inside of an enclosure which is mounted in the side of the existing spectrograph. The light from the spectrograph can be directed toward either the CID camera for oscillation studies or the exit slit for photographic spectroheliograms. The various optical components are described in the text.

Other components of the system included in Figure 1 are: (1) a high-speed rotating cylindrical shutter which provides the short (~ 50 – 100 ms) exposure times needed for this project; (2) an anamorphic lens which magnifies the spectrum along the dispersion direction while leaving the spatial dimension unchanged; (3) a tipping plate which can be used to keep the spectrum centered on the CID detector array during each run; and (4) a small glass Ronchi ruling which can be swung into the light beam just above the exit lens of the Littrow spectrograph in order to provide flat-field illumination of the CID array when needed. The Ronchi rulings are parallel to those of the grating so that

at the focus of the spectrograph many overlapping orders effectively smear out the spectrum lines. Also, since the CID chip is only 1 cm on each side and is located at a distance of roughly 13 feet from the location of the Ronchi ruling, it subtends an angle of only 0.2 degrees which is small enough that the light is uniform over the area of the chip.

D. CURRENT INSTALLATION STATUS

The instrument enclosure and moveable stage described above was machined at U.C.L.A. and at the Jet Propulsion Laboratory, was assembled at the Jet Propulsion Laboratory and is now permanently mounted on the side of the spectrograph. It covers a hole which was cut into the side of the spectrograph to allow for the movement of the mechanical stage and the periscope assembly inside of it. The stage assembly was designed to provide rotational symmetry about the centerline of the downward-looking CID chip itself for ease in lining up the solar spectrum on the chip, while also providing for focus travel and motion along the dispersion of the spectrograph. When the stage and periscope are located within the spectrograph, the light arrives at the periscope from the spectrograph collimating lens which is located at the bottom of the cage assembly which supports the grating. The light is then reflected to a second 45° flat mirror which is located within the stage assembly. This second mirror reflects the light upward where it is imaged upon the downward-looking CID chip in the dewar. In normal operation, curtains are attached to the sides of a large plate which separates the enclosure from the spectrograph. These curtains serve to prevent air currents which might build up within the enclosure from disturbing the optical path of the spectrograph.

7. The CID Camera

A. DESIGN

The CID camera system was built by Photometrics, Ltd. of Tucson, Arizona. The CID chip itself is a General Electric Model D 244 × 248 pixel charge-injection device. As previously described this chip is located in a dewar which is cooled to the temperature of liquid nitrogen to minimize thermal noise. Also part of the camera head is a small electronics box which is mounted on the dewar. This box includes the 12-bit high speed analog-to-digital converter, the analog circuits, the clock drivers, and the line drivers and receivers for the cables connecting the camera to the controller and to the array processor.

This camera is similar in overall design to the 244 × 248 pixel camera currently in operation at Kitt Peak, since it was designed by the same man, Richard Aikens of Photometrics, who designed and built the Kitt Peak system (Aikens, 1980). However, this camera has been improved over the Kitt Peak camera in several respects: (1) it is faster than the Kitt Peak system, with a per-pixel read time of only seven microseconds; (2) it provides in-camera row-crosstalk correction; (3) it contains enough memory to store a single bias frame (i.e. a low-intensity, artificially-exposed frame) within the

camera; and (4) it subtracts the bias frame pixel-by-pixel from each data frame before outputting the digitized pixels. Thus, this system provides high-speed cleaned-up 12-bit digital data at a video rate. Only a flat-field frame need be stored outside the camera for use in subsequent photometric corrections.

The linearity of both General Electric model B and D CID chips has been measured accurately. Aikens (1980) has presented a plot showing that a model B CID in use at Kitt Peak was linear to better than 0.05% for light levels ranging between 10 and 95% of that chip's saturation level. It is the non-linear behavior below the 10% threshold which makes it necessary to acquire and subtract a bias frame as discussed above. More recently, Aikens (1982) has measured the linearity of model D chips identical to the one installed in the Mount Wilson camera and has likewise found no deviations larger than 0.05% for light levels ranging between 10 and 95% of the saturation of this chip.

The G.E. model D chip in use at Mount Wilson is a slightly re-designed version of the model B chip in use at Kitt Peak. The design of the earlier chip was altered to eliminate a small odd-even pixel difference which was present in the model B chips when they were illuminated with a sharp intensity gradient. The model D chip employs a strictly periodic electrode spacing between all pixels in a given row to eliminate this problem.

On both types of CID chips a small amount of signal leakage exists among adjacent pixels in a given row. This so-called row-crosstalk is removed from the Mount Wilson camera's video data by custom-designed signal-processing circuitry which is built into the electronics of this camera as mentioned above.

The random noise generated within the camera itself has been measured both in Tucson and at Mount Wilson by recording a low-level bias frame on the chip and then subtracting this bias frame from itself with the camera's non-destructive readout mode. By doing this over many successive frames, an rms noise of only one least-significant-bit of the A/D converter was measured in Tucson. Since the saturation signal level is close to 4096, an rms signal-to-noise ratio of about 4000 to 1, is possible with this type of detector. (The peak-to-peak noise was measured in the same tests to be about four or five times larger.) Since most measurements will be made at less than the saturation signal level, the signal-to-noise ratio will generally be less than the above upper limit. The model B CID chip in use at Kitt Peak has obtained a signal-to-noise ratio of 1500 to one (Aikens, 1982) in actual operation.

Because of the relatively noisy electromagnetic environment at Mount Wilson (due to the close proximity of numerous radio and television transmitters to the Observatory), we have retested the CID chip at the telescope. Our preliminary test results show an rms noise of two to three A/D converter units with a corresponding decrease in signal-to-noise ratio. However, these preliminary tests were carried out prior to any extensive efforts at shielding the camera. Since merely placing the camera inside the enclosure on the side of the spectrograph reduced the noise level by a factor of three, we are confident that additional shielding efforts will further reduce the measured noise so that it will approach the levels measured in Tucson. In any event, when we average the 248 pixels along the spectrograph slit in order to convert the three-dimensional

(x, y, time) data arrays into two-dimensional (x, time) array, we will realize an approximate 16-fold increase in the signal-to-noise ratio.

All of the optical components have been installed in the system and the Na D1 line has been focused on the CID chip. An analog display of this portion of the solar spectrum is displayed in Figure 2. This figure shows the spectrum as it is displayed on

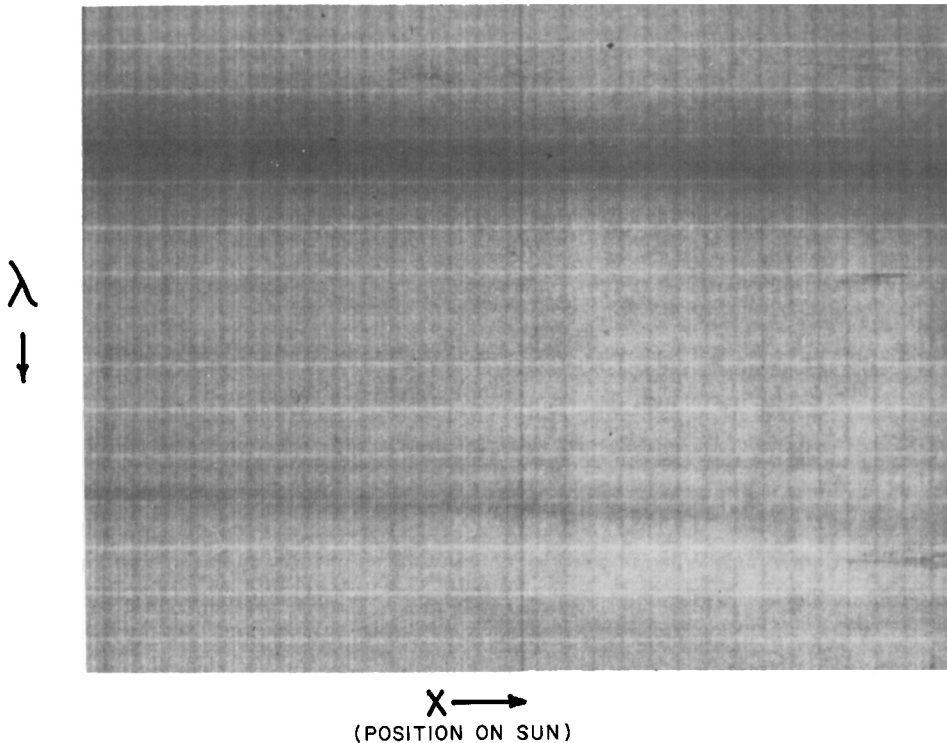


Fig. 2. A monitor display of a portion of the solar spectrum near the Na I D1 line is shown. The spectral intensities are shown as various grey levels. The directions of increasing wavelength and position on the Sun are shown at the edges of the display. The bright lines are the reseau pattern on the monitor and are not defects in the camera.

the Tektronix 604 persistence monitor located beside the spectrograph. The spectral lines are shown as a grey-level display. The original digital data generated by the CID camera has been re-converted into an analog signal display on the monitor. The evenly-spaced bright and dark lines in the picture are not defects generated by the CID but are simply a grid located on the monitor faceplate. Furthermore, this display was not corrected for diode sensitivity changes since the flat field corrections are made later in the array processor. The uncorrected display will be used mainly for focusing and alignment purposes during actual observations.

8. The Data Processing System

A. DATA PATH

The data path of this system is shown schematically in Figure 3. The CID camera system is controlled by an LSI-11 microcomputer which functions solely as a control microprocessor. The LSI-11 obtains interrupt pulses from the rotating cylindrical shutter and commands the camera to alternately build up exposures or read them out. It also commands the bias-frame exposures and flatfield exposures. The LSI-11 also controls the guider as it scans the solar image and controls the tipping plate and Ronchi grating motors.

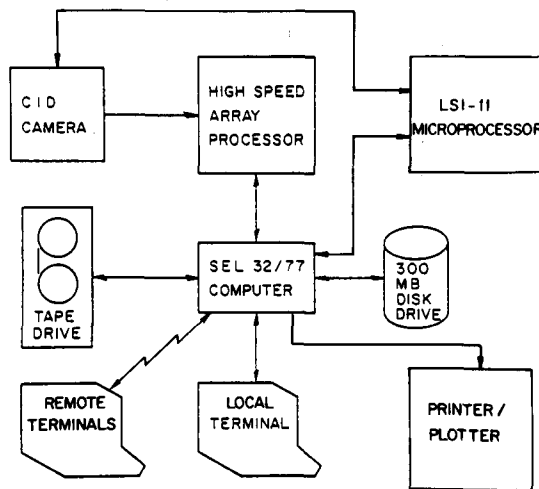


Fig. 3. The data path for the system is shown schematically. The camera spectral data is passed into the array processor for real-time conversion into line-of-sight Doppler velocities. The velocities are then passed to the SEL 32/77 computer for collection into two-dimensional images before being stored on the disc storage system. The LSI-11 serves as the control processor for synchronizing the camera, shutter and array processor. The entire system also can be monitored and operated remotely via dial-up telephone line connections.

From the CID camera the data passes through an auxiliary I/O port into a high-speed CSPI MAP 300 array processor. The camera is designed to signal the I/O device upon the completion of each exposure and to signal it as each pixel within a single frame is ready to be output to the array processor. The CSPI MAP 300 processor is designed for high-speed asynchronous applications and is configured with memory on two different internal buses. Thus, the CID camera system can send one picture of data of the MAP 300, while the processor is computing with the previously-transmitted picture's data. This double-buffered approach allows for a very high speed, yet it is completely synchronized to the operation of the camera on a frame-by-frame basis.

The array processor will take as input from the CID camera a set of thirty or forty different spectral intensities at each of the 248 spatial locations along the entrance slit. The processor will next correct the raw data for the previously-stored flat-field irregularities and then convert the line profiles into Doppler velocities. Several different methods of line center determination can be used with the floating point array functions provided in the MAP 300. We will empirically determine which profile-fitting technique is most useful for our purposes.

Following the conversion of the spectral intensities into 248 Doppler velocities for each CID frame, the velocities will then be sent to the Systems Engineering Laboratories (SEL) 32/77 computer before ultimately being stored on an Ampex 300 megabyte disk storage system. The SEL 32/77 is a 32-bit minicomputer capable of providing up to 16 separate users one-megabyte partitions. The SEL 32/77 we have currently has 1.25 megabytes of 600-nanosecond MOS memory. The SEL 32/77 will store each set of velocities on the disk system and then at the conclusion of each day's observing, it will read the data back from the disk, convert three-dimensional (x , y , time) arrays into two-dimensional (x , time; or y , time) arrays and then compute the two- or three-dimensional power spectra which will result from each day's worth of data.

The 300 megabyte capacity of the disk system was selected to provide sufficient storage for a complete 12-hour observing sequence. In one 248×256 element frame there will be nearly 64 000 pixels. By storing the velocities as 16-bit halfword integers we will require roughly 128 kilobytes to store a frame. At a frame rate of 2 frames per minute, as discussed earlier, we will require 256 kilobytes per minute. Since there are 720 min in 12 hr, we should be able to store one full run in roughly 180 megabytes. Furthermore, the velocity measurements themselves will not require 16 bits of storage and so it should be possible to store an 8-bit intensity pixel and an 8-bit velocity pixel in each 16-bit halfword. In this way we could obtain power spectra of both velocity and intensity images each day. Alternatively, we could combine two 8-bit velocity pixels in each halfword and obtain power spectra in two separate spectral lines each day. Upon computation of the power spectra, the SEL 32/77 will then calculate the solar rotational velocities for different locations on the $k_r - \omega$ plane. Finally, the power spectrum and rotational velocities from each day's run will be stored on magnetic tape with two Kennedy model 9100, 75 inch-per-second, 9-track tape drives. The complete system will be under the local terminal control of the observer at the telescope and under remote control from one of several remote terminal stations. A Printronix P300 printer/plotter is also available for generating simple contour and gray-level displays of the power spectra as well as computational printouts. A Tektronix 4006 graphics terminal is also available for higher-resolution plotting in real time. A Tektronix 4014 graphics terminal, hard copy unit, flat-bed plotter, and line printer are also available at a remote workstation on the U.S.C. campus. All plots generated at Mount Wilson can be sent to U.S.C. for inspection there. Other terminals which provide text-editing capability alone are located at the Mount Wilson offices in Pasadena, at the Jet Propulsion Laboratory, and at U.C.L.A.

B. CURRENT INSTALLATION STATUS

The computing hardware has all been installed in a new data room which was added to the 60-foot telescope for this project.

The I/O port connecting the CID camera to the array processor has been successfully operated under program control. Digitized video data has been transferred from the camera into the array processor before being transferred into the SEL 32/77 computer. A tape containing the digital data was subsequently generated and taken to the Mount Wilson offices in Pasadena, California and displayed there with other equipment.

The LSI-11 has been successfully linked to the SEL computer and programs and data have been transferred between the two. The new guider and its scanning hardware and control circuitry have all been installed. The cylindrical shutter has been built and mounted on the spectrograph.

9. Tasks Remaining

The remaining tasks are the completion of control circuitry to interface the guider, shutter, and camera to the LSI-11 which will provide the real time control signals; the completion of the real-time operating software, the array processor software, and the final data reduction software which will convert the time series of velocity measurements into $k_{\text{h}} - \omega$ power spectra.

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