Integrated Sunlight Spectrometer

1. System Block Diagram

(do we have a better drawing with higher resolution? Most signs are illegible.)



2. Optical

The optical system that comprises the ISS is composed of six major sections.

- Fiber-optic feed
- Fiber-optic, six position spectrograph input selector
- Prism type predisperser

- Czerny-Turner two-meter focal length, f/14 grating spectrograph operating in a double-pass configuration
- Two axis, XY CCD camera scanning stage at spectrograph exit
- 1024 X256 SITe CCD

2.1 Optical Layout

2.1.1 Fiber Optic Feed

The fiber optic feed consists of a Polymicro FV series, UV enhanced stepped index fiber of 710 μ m overall diameter. The 660 μ m cladding is protected with a Polyimide buffer. The inner core OD is 600 μ m. The entire length of the fiber is further protected by a PVC, and Stainless Strip wound jacket.



Figure 2: Plot of the transmission characteristics of the FV series fiber

2.1.2 Four Position Fiber Selector

Four fibers are available as inputs to the ISS. Fibers 1 and 2 are the primary solar light feeds. The solar fibers are fed by means of an 8-mm aperture lens with a focal length of 40 mm. This produces a f/5 beam, which is a good match to the numerical aperture of the input fiber. The first of these projects a 400 μ m image of the Sun directly on the end of one fiber. The second solar fiber feed is identical except that the imaging lens looks through an iodine vapor cell to provide a well known absorption spectra superimposed on the solar spectra for calibration.

Fibers 3 and 4 are available as calibration sources for the ISS. Fiber 3 is a quartz lamp

illuminator, for quick flat fielding of the CCD and Fiber 4 was reserved for use with an Uranium hollow cathode emission lamp (currently, not in use). Positional accuracy and repeatability of the fiber translation is better than $10 \,\mu$ m.

2.1.3 Prism Type Predisperser

The grating used in the spectrograph is an eschelle working at up to 15th order. A prism predisperser, mounted between the fiber positioner and the main spectrograph slit, is used for the order isolation prefilter. Tunable range is 350 nm - 1100 nm. The predisperser allows for the passage of non-dispersed light, for use in zero order spectrograph alignment.

Predisperser position is software locked to the grating angle and order. Both the predisperser and the grating position are controlled by the Stepper drive system.

2.1.4 Spectrograph



Figure 3. Major assembly drawing of the ISS spectrograph (do we have a better drawing showing more details?).

<u>F ratio:</u>	F/14
Entrance slit:	Adjustable 5-500 μ m spectral, 20 mm spatial, 30 μ m X 1 mm nominal A30 μ m slit using a 600 μ m fiber, the image will smear to a width of 50 μ m at the blaze angle. This is a good match to the 24 μ m pixel size in terms of the sampling theorem.
Shutters:	Entrance shutter, Intermediate shutter in double path
Optics:	Spherical collimator and camera mirror Al-MgF2. Focal length 2m.
Grating:	316 G/mm Blaze 7500 at 6.8°. Wavelength range 3800 to 10840Å

Table 3 The spectrograph performance calculations. The 316 G/mm grating provides the following two pix resolutions in the McPherson 2062 spectrograph in double-pass mode.

Wavelength	Order	2 pixel resolution	plate scale	Free Spectral Range	Spectral window
390.0 nm	14	341,149	0.029 nm/mm	27.9 nm	0.58 nm
390.0 nm	3	37,620	0.036 nm/mm	130.0 nm	5.31 nm
650.0 nm	8	288,248	0.056 nm/mm	81.2 nm	1.15 nm
650.0 nm	2	41,975	0.038 nm/mm	325.0 nm	7.9 nm
1083.0 nm	5	330,536	0.082 nm/mm	216.6 nm	1.68 nm
1083.0 nm	1	34,734	0.078 nm/mm	1083.0 nm	15.96 nm

2.1.5 XY CCD Camera Scanning Stage

The CCD camera head is mounted on a precision XY translation stage that moves the CCD along the dispersion and spatial direction in a precisely controlled and repeatable way. The range of motion available is +/- 5.0 mm in the spatial direction +/- 15.0 mm in the spectral direction. The step resolution of the platform is 2 μ m. The purpose of this is to permit calibration of the response of all of the pixels relative to each other to produce a high precision flat field.

2.2 Expected Optical Performance

The ISS is designed to be a low cost instrument that gives high spectral resolution and purity with light that has been carefully integrated across the solar disk. The fiber feed to the spectrograph produces sunlight scrambled in both angle and position so that any output angle from any position on the exit face is well integrated. The double-pass configuration allows scattered light to be detected and also provides high spectral resolution. The selection of an eschelle grating allows the selection of both a low resolution mode for a wide spectral window, and higher order high resolution modes for comparisons to similar measurements of solar-like stars.

The spot diagram of the ISS illustrates four point sources at the entrance to the spectrograph spread over a 600 μ m diameter fiber. Two of the spots are at the center of the field, separated by 10 μ m. The bar length is 480 μ m, and two 24 μ m pixels are shown for comparison. The line widths are a good match for the pixel sampling.

(Add figure from proposal? showing the spot diagram)

Figure 4. The spot diagram of the ISS.

2.3 1024 X 256 SITe CCD

The camera used at the spectrograph exit is a modified Model 500 manufactured by Spectral Instruments. The detector is a SITe 1024 X 1024 back illuminated CCD. We readout a subarray in an unbinned 1024 X 128 format. The pixel size is 24 μ m with an unbinned well depth of 250K e⁻. Read noise is on the order of 5 e⁻/pix/sec. The CCD is TE cooled to -10°C. Camera readout rate is 10 Hz.

Since the camera has a rather long operational life of 25 years, a special effort has been made to minimize maintenance. The vendor has paid special attention to the camera head to minimize the need for periodic vacuum pumping. The camera head is filled with dry nitrogen and 14g of dehydrated molecular sieve. The computed length of time the getter will be able to absorb water vapor for the dew point to rise above -28°C based on measured o-ring gas permeation rates in a 30°C ambient environment, is 300 years. In addition, the camera has been modified to use air cooling to avoid coolant leaks.

3. Mechanical

The spectrograph is mounted on an vibration isolated, optical bench located in a heavily insolated room that is temperature controlled to $25^{\circ}C \pm 0.5^{\circ}C$ by means of an integrated HVAC system (see Figure 5). The environment is controlled and monitored by a Johnson system intelligent controller. Use of Johnson controllers have the advantage of being available for monitoring over net connection.



Figure 5: ISS in a temperature controlled room at Kitt Peak.

4. Electrical

4.1 Servo Control

4.1.1 Servo System Is Vendor Supplied

The ISS was contracted as a complete instrument. The ISS control system was the first control system to be specified and as such, it was specified by the supplying vendor.

4.1.2 Control System Modifications

Currently, the ISS servo control system is a #DMC1380 VME bus based controller (probably need a little more 'meat' regarding the control system).

4.1.3 Software Controls Ported - (do we need this, and if so how should it now read?)

A benefit of using the Galil controllers is that the VME and ISA version controllers are functionally identical. Use of the controller parameters supplied with the ISA controller will allow the software to be ported to the VME controller with minimal effort and then function identically to the ISA controller.

4.3 Data Acquisition System (DAS)

The primary function of the ISS DAS is to receive the pixel data from the camera system and simply present the image array to the ISS Data Handling System (DHS) for further processing.

The baseline DAS for the ISS is a direct connection from the camera system to a General Standards PMC-HPDI32 high speed parallel data I/O board connected directly to the ISS Data Handling Computer board. See Appendix 1 for the PMC-HPDI32 specification sheet. The HPDI32 board can acquire parallel data up to 100 Mbytes/sec and should easily keep up with the ISS camera data rates.

4.3.1 Input Operation Is Programmable

The input to the HPDI32 board is controlled by a FPGA. It is anticipated that one of the standard format interfaces will fit the ISS camera interface. If not, General Standards will provide custom programming for the FPGA. (needs clarification as to what we use)

4.3.2 DMA Capable

The HPDI32 board includes a DMA engine capable of transfers at 166Mbytes/sec directly into computer memory. Once the data is in computer memory, it is in the final location for the DHS.

5. Data

A single CCD frame is recorded for each spectral line observed. Many more calibration frames are obtained in order to meet the scientific specification for a photometric precision of 0.1%. The processed data is stored and remain accessible at high speed for the length of a solar cycle since the variation of line parameters with the cycle is the most interesting scientific question for ISS. Current core ISS program includes 10 spectral ranges observed twice a day (weather permitting) with a storage requirement of 1024 X 256 X 2 = 524 kB per frame. Additional lines can be added upon sufficient scientific justification.

5.1 Calibration

The ISS records spectra of calibration sources for flatfielding and for wavelength calibration. Currently, the calibration source for flatfielding is the solar image itself, but it may include a quartz lamp if needed. The wavelength calibration is based on either a gas absorption cell or a comparison lamp, depending on the application of the given spectrum. In addition, spectra can be obtained in a low resolution mode (R = 30,000). The main purpose of the low resolution spectra is to provide sufficient spectral range in a single spectrum so that the entire bandpass which is used in stellar flux calibrations is included in a single observation.

5.1.1 Flat Field

For each spectral band, observations are taken in four different positions by moving the CCD in respect to the spectra in the spectrograph focal plane: the first image (image 1, 512 x 1024 pixels in size) is taken with the CCD centered at a corresponding wavelength (for a given spectral band), image 2 is shifted by 1 pixel in the direction of dispersion, image 3 is shifted by 11 pixels, and image 4 by 129 pixels. It takes about 5 minutes to complete the full cycle of observations for most spectral bands; for Ca ii K observations it takes about 12 minutes, and for He I 1083.0 nm about 15 minutes. Four images are used both for the purpose of flat fielding and to create the final spectrum for a given spectral band. Because in four images the CCD is shifted in respect to fixed spectral features, the same pixels are exposed to a different level of light. Assuming that the solar source remains constant during the observing cycle (3 - 15 minutes), the images can be used to derive flatfield and CCD gain based on an algorithm described in Toussaint, Harvey, and Toussaint (2003). A dark field is taken for each observed spectral range at the beginning of four-image cycle by closing the intermediate shutter of the double pass system. The same dark field is used for all four images taken in each spectral band.

A quartz lamp is also available as a black body source for flatfielding.

5.1.2 Wavelength Calibration

The wavelength calibration sources include a iodide absorption cell.. Sunlight passing through the cell produces an iodide absorption spectrum superimposed on the solar spectrum. By recording both the integrated solar spectrum and the iodide absorption spectrum simultaneously as they traverse the same optical path, ultra-high precision measurements of Doppler shifts in the solar spectrum seen as a star can be performed.

5.2 Normal Observing

The ISS observing program consists of a core observing program and a PI program. The core program is comprised of daily ISS observations of specific spectral regions. The first priority observation is that of the Ca II K and H lines. This is in view of (1) their strong response to the solar magnetic cycle, (2) the significant data-base of K-line observations for the past 30+ years that already exists, (3) the strong correlation between K-line variations and solar luminosity variations, and (4) the availability of a large data-base of K-line observations of solar-type stars from the Mt. Wilson program.

Following the first-priority Ca II H and K observations, the remaining chromospheric/solarcycle and photospheric diagnostics is recorded. Nominally, the core program is run twice a day: in the morning and at noon.

6. Extinction Monitor

A solar extinction monitor is included in the ISS head mounted on the Full Disk Patrol (FDP) instrument. It is important to monitor extinction gradients across the solar disk, since unexpected gradients can lead to artificial weighting that can influence the interpretation of spectral features. This can occur in both observed shape and line strength. In addition, the relative signal levels of each solar image are used as a guide to integration times during ISS observations. See Figure 6 for an illustration of the block diagram for the extinction monitor.



6.1 Optical System

The monitor consists of a monochromatic CCD camera, with a 640 x 480 array with 9 micron pixels. The optical system has been designed to project three full disk images of the Sun onto the CCD array. The effective focal length of the camera is 90 mm, giving images approximately 95 pixels in diameter. Each image would be in the light of a relatively narrow band filter. The monitor consists of an optical stack of four elements.



Figure 7. Optical Layout for Extinction Monitor (edit drawing to show only 3 filters)

6.1.1 Filters

The first elements are the filters. The filters consist of four interference filters and a glass filters. The center band pass of the four interference filters are: (note need to update with values to be used)

950 nm BP ~ 10 nm 857 nm BP ~ 10 nm 672 nm BP ~ 10 nm 420 nm BP ~ 10 nm

The fifth filter is colored glass with a peaked band pass at \sim 530 nm. Colored glass is used for the fifth filter due to cost considerations. We tried to use off the shelf filters, but it would have been necessary to have a filter custom manufactured to fit the current design.

6.1.2 Mask

A thin metal mask is inserted below the three filters, to form the three sub-apertures.

6.1.3 Imaging Lens

An 18 mm, 90 mm FL lens (here FL refers to lens mount standard for 35-mm cameras or it is something else?) forms the three images of the solar disk on the CCD, each 100 pixels across.

6.1.4 Steering Prism

It is necessary to separate the three images, since the imaging lens forms three over lapping images on the CCD. Four 2 degree wedge, steering prisms are placed below the outer three sub-apertures. Each steering prism has the center portion removed to allow the center sub-aperture, to form its image directly on the center of the CCD.

6.1.5 Software

To utilize the images acquired by the extinction monitor, software is necessary to analyze the images quickly. The camera operates at approximately 15 Hz. The software monitors each image for changes in the solar gradient and overall signal level. In practice, the control computer examines a frame just before an ISS integration for both gradient and level. If a large gradient exist, the ISS integration is delayed until the gradient returns to nominal levels. If the gradient is acceptable, the level is examined and the ISS integration time is modified as necessary to obtain a specific signal-to-noise ratio (SNR). The extinction monitor image is attached to the ISS frame for further offline examination by the user.

7.0 References

Toussaint, R.M., Harvey, J.W., Toussaint, D.: 2003, Improved Convergence for CCD Gain Calibration Using Simultaneous-Overrelaxation Techniques. *Astron. J.* 126, 1112 – 1118. doi:10.1086/376846.