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The Automated Rotating Shadowband Spectroradiometer

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Introduction

We are developing a photodiode array rotating shadowband spectroradiometer (RSS) as part of the Instrument Development Program (IDP) of the Atmospheric Radiation Measurement (ARM) Program of the United States Department of Energy (DOE). This instrument uses the automated rotating shadowband technique to separate and measure the spectrally resolved direct-normal, total horizontal, and diffuse horizontal irradiances in the 360 to 1060 nm wavelength region. It is intended as an instrument for the central facility of each of the cloud and radiation testbed (CART) sites, and will complement the array of multi-filter rotating shadowband radiometers (MFRSR) currently being deployed by ARM and other research programs including TOGA/COARE.

I. The Automated Rotating Shadowband Technique

The RSS uses the technique developed for the automated rotating shadowband radiometer (RSR) (Michalsky et al. 1986), and builds on the experience gained first with single passband instruments (LeBaron et al. 1989), and subsequently with multiple filter instruments (Harrison et al. 1993), to measure surface irradiances and atmospheric optical depths. The basic rotating blocking-band method was introduced by Wesely (1982). Instruments have been developed by Guzzi et al. (1985), and by Ascension Technology Inc. (Stoffel et al. 1991) to automate the Wesely method. An RSR differs from these in that it uses a computed ephemeris to position the band for the blocking measurements, rather than depending on the detection of a minimum irradiance. The RSR method permits much longer integration times for each measurement because it needs measurements at only four positions rather than a "continuous" scan across the sky.

The longer measurement duration (and fewer required measurements) of the automated RSR technique permits the development of narrow passband and spectrometric instruments. This substantially improves measurement precision, and permits what would otherwise be impossible wavelengths or passbands. This is critical to the RSS instrument; without the use of this method the scan times would be too long.

The automated RSR technique also improves accuracy. It implements a first-order correction for "excess sky blockage" caused by the shadowing band, which is necessary to obtain correct optical depths, and also significantly improves the measurement accuracy under skies with fractional cloud coverage. A disadvantage of the RSR technique is that the instrument must be accurately aligned, however the accuracy needed for the method to operate properly is also required of any Lambertian detector intended to make total horizontal irradiance measurements to an accuracy of better than 5% (Harrison et al. 1993).

II. The RSS

The instrument is shown in Fig. 1. Light enters the instrument through the integrating cavity diffuser. This design is derived both from the MFRSR instruments, and work in progress on the development of high accuracy Lambertian fore-optics for ultraviolet spectroradiometers. The diffuser is coupled to an integrating cavity that improves both light-throughput, and Lambertian

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response. The slit is a 250 µm by 5 mm airgap followed by the spectrometer's controlling slit that is 50 µm wide and 3.0 mm long. Light exiting the slit passes through an electronically controlled shutter, a double prism spectrograph, and is focussed on the 256 channel silicon photodiode array. The RSS shadowband position, shutter control, sampling strategy and data acquisition and storage are controlled by a microprocessor-based data acquisition system.

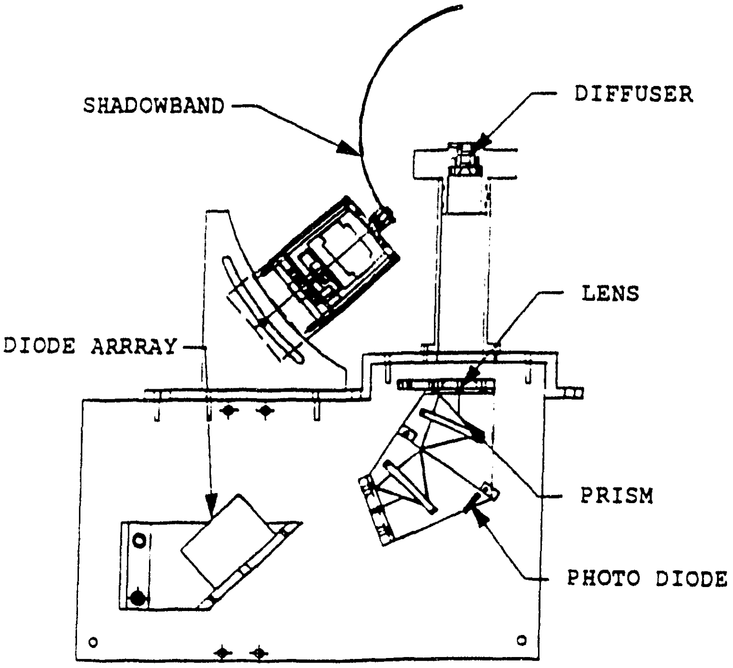


Fig. 1. The rotating shadowband spectroradiometer (RSS)

The RSS uses a double-prism spectrograph; all optical elements are fused silica. This all-quartz design permits observations below 400 nm. This design has been chosen for simplicity, the extreme stability and ruggedness of the optical elements, and because the non-linear dispersion of the system is advantageous for the intended measurements.

Neither flint achromats nor flint dispersing prisms can be employed, and careful optical trade-off studies were necessary to arrive at an acceptable design A solution was found that is very straightforward to construct: it uses only simple plano-convex lenses. Coma and spherical aberrations are controlled by making the f-number of the system ≈ 7. Chromatic aberration "controls itself" because the prism material is identical to that of the lenses, and the lenses *are not* chromatically corrected. The result is that the entire effect of chromatic aberration manifests itself as a planar tilt in the focal surface of the dispersed spectrum, which can be readily accommodated simply by tilting the detector. In contrast to high-resolution diode array spectrographs this instrument has only one diode per slit-width at the image plane. Thus the geometric limiting resolution of the instrument is set by the pixel width and the mapping of the spectrum across the array, rather than the theoretical resolving power of the spectrograph. The geometric spectral resolution ranges from 0.6 nm at 360 nm to 8 nm at 1060 nm; the real instrument resolution is slightly degraded by the electronic "cross-talk" between neighboring pixels.

The RSS uses a Hamamatsu NMOS silicon photodiode array model S3901-256Q detector with a Hamamatsu model C4350 amplifier/driver assembly. The diodes have 50 µm center-to-center spacing and a width of 2.5 mm. We have developed a microprocessor controller/datainterface that uses an Analog Devices AD1380KD 16-bit analog-to-digital converter. Each pixel's analog-to-digital conversion takes 20 µs and therefore a total of 5.12 ms is required to convert all of the 256 channels. The microprocessor generates the timing signals needed by the array and the analog-to-digital converter, and stores the data. It also controls the shutter.

When operated as an RSR a measurement is made at each of the four positions needed for the RSR algorithm. Each measurement starts with the shutter closed and three rapid "destructive readouts" of the diode array. These data are not stored: the purpose is to refresh the charge state of the diode array pixels. An integration is then made for the planned exposure duration, read out, and stored temporarily by the diode controller. The shutter is then opened for the exposure: the exact shutter interval is monitored by the controller to an accuracy of 1 µs using a photodiode that sees a reflection from a face of the second prism. The shutter is closed, and the measurement readout is performed. The data can then be corrected by dark subtraction, and normalized for the exposure.

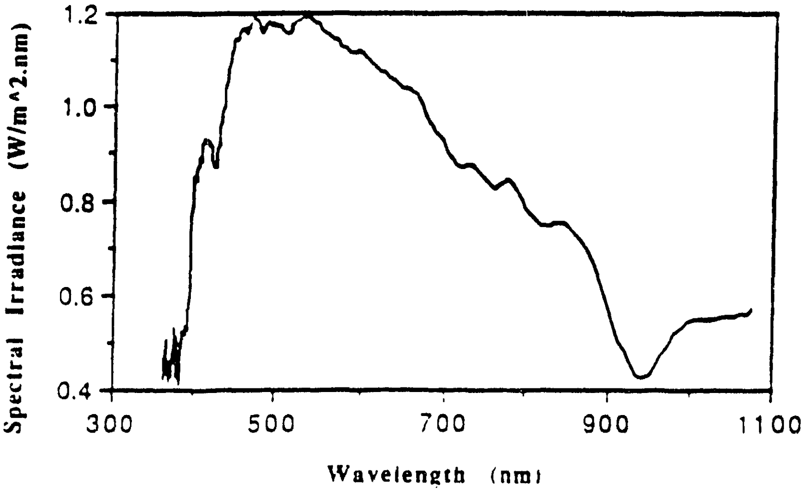
Maximum exposures are limited to less than 3 seconds by the charge leakage of the array, that is not cooled below ambient. However the system light throughput is sufficiently high that exposure times longer than 1 second will saturate the near-infrared pixels even on an overcast day. Longer exposures are needed only for the ultraviolet under dim circumstances.

III. Testing, Calibration, and Preliminary Data

We are starting to operate the RSS. The spectral calibration is performed using standard low pressure gas discharge lamps. Our selection of lamps allow us to find spectral lines over most of the spectral range covered by the instrument. The mercury lines, ranging from 366 to 1014 nm are particularly useful. These lines provide sufficient data to map the geometric passbands of all remaining pixels using a least-squares fitting process and the known refractive index of fused silica as a function of wavelength. The actual slit-functions can be directly determined from the apparent linewidths. Our irradiance calibrations to date have been done using a LI-COR 1800-02 Optical Radiation Calibrator.with a limiting accuracy of ≈ 5%.

A total horizontal spectral irradiance plot for a partially overcast day is shown in Fig. 2. This represents our first calibrated solar spectrum from this instrument. Better calibration of the instrument for wavelengths shorter than 400 nm is required. The LI-COR calibrator has a very low output for those wavelengths and therefore is not suitable for this task.

Fig. 2. Response of the RSS to Solar Radiation



VI. Conclusions

Our prototype has demonstrated the necessary throughput and spectral performance needed for this instrument, and all the basic subsystems are developed and working to the predicted levels of performance. Many engineering problems not discussed here have been overcome. Nonetheless we have considerable work remaining. We are currently redesigning the housing and optical mount system to improve stability (a critical requirement for a field instrument). We must also complete the software needed for the instrument to operate autonomously.

The principal reason for developing the rotating shadowband spectroradiometer has been to improve the measurements of absolute spectral irradiance in the shortwave spectral region. The RSS provides fast time resolution, wavelength resolution, and simultaneous data on the direct normal, diffuse horizontal, and total horizontal components of shortwave radiation. The data that this instrument gathers will enable us to develop improved models of the cloud radiation properties and provide information on water vapor, aerosols and cloud and ground albedos using inversion methods (King et al. 1978, King et al. 1979, Shaw et al, 1979). Additionally we hope to test inversion methods to extract ozone abundance from the Chappuis band by comparing such efforts against a high-accuracy UV spectroradiometer to be deployed at the first CART facility.

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