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MULTI SPECTRAL PUSHBROOM IMAGING RADIOMETER (MPIR) FOR REMOTE SENSING CLOUD STUDIES

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ABSTRACT

A Multi Spectral Pushbroom Imaging Radiometer (MPIR) has been developed as a well-calibrated, imaging radiometer for studies of cloud properties from an Unmanned Aerospace Vehicle (UAV) platform. The instrument is designed to fly at altitudes up to 20 km and produce data from nine spectral detector modules. Each module has its own telescope optics, linear detector array, spectral filter, and necessary electronics. Cryogenic cooling for the long-wavelength infrared modules as well as temperature regulation of the visible modules is provided by a liquid nitrogen system designed to operate the system for multi-day missions. Spectral channels are optimized to obtain maximum information about cloud physical and micro-physical properties, as well as reflected and radiated energy. Pre- and post-flight calibration, combined with an on-board calibration chopper provide an instrument with state-of-the-art radiometric measurement accuracies. Each module has a ±40° across-track field-of-view and images a curved footprint onto its linear detector array. The long-wavelength array types have 256 detector elements while the short-wavelength arrays can have 512 elements. All are co-aligned so that they view the same object space. The nine telescopes provide a modular design allowing individual spectral bands to be changed to match the requirements for a particular mission.

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1. INTRODUCTION

A Multi Spectral Pushbroom Imaging Radiometer (MPIR) has been developed as a relatively inexpensive (~$1M/copy), well-calibrated, imaging radiometer for aircraft studies of cloud properties. The instrument is designed to fly on an Unmanned Aerospace Vehicle (UAV) platform at altitudes from the surface up to 20 km. MPIR is being developed to support the Unmanned Aerospace Vehicle portion of the Department of Energy's Atmospheric Radiation Measurements program (ARM/UAV). Radiation-cloud interactions are the dominant uncertainty in the current General Circulation Models used for atmospheric climate studies. Reduction of this uncertainty is a top scientific priority of the US Global Change Research Program and the ARM program. While the DOE's ARM program measures a number of parameters from the ground-based Clouds and Radiation Testbed sites, it was recognized from the outset that other key parameters are best measured by sustained airborne data taking. These measurements are critical in our understanding of global change issues as well as for improved atmospheric and near space weather forecasting applications.

2. OPTICAL DESIGN

MPIR requires that a ±40° across-track field-of-view be imaged onto a 25.6 mm-long linear detector array. The forward motion of the UAV provides the 'pushbroom' motion to form a two-dimensional image of

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the scene as depicted in Figure 1. Each spectral band has its own detector with separate optics, detectors, and electronics packaged as an interchangeable module. Co-registration is provided by aligning all modules so that they image the same scene footprint. The all-reflective optics design chosen is a derivative of WALRUS[2] which provides the needed wide field-of-view in a compact design. The optical elements are rotationally symmetric allowing the aspheric surfaces to be manufactured by a relatively inexpensive diamond turning process. All of the mirrors were diamond turned, nickel plated, diamond turned a second time, and post polished under interferometric control. Optical surface coatings are silver for the shortest wavelengths and gold for the infrared. The design has several interesting optical features. The pupil distortion is such that the pupil size increases with off axis distance, an effect that helps to counteract the natural cosine falloff. The barrel distortion in the image plane has multiple consequences: The instantaneous field-of-view (IFOV) in the scene changes as a function of field position in a manner that helps compensate for the normal IFOV variations expected from a comparable whiskbroom imager. Also, since image magnification varies laterally, by adjusting the position of the linear array the magnification in the image can be exactly matched to the specific array being used. One disadvantage is that for a linear detector array, the distortion results in a curved footprint in the cross track direction, a pixel at the edge of the field (+40° degrees off-axis) has an along track angular displacement of 11.4°. The image reconstruction process must re-map the curved lines onto a Cartesian grid.

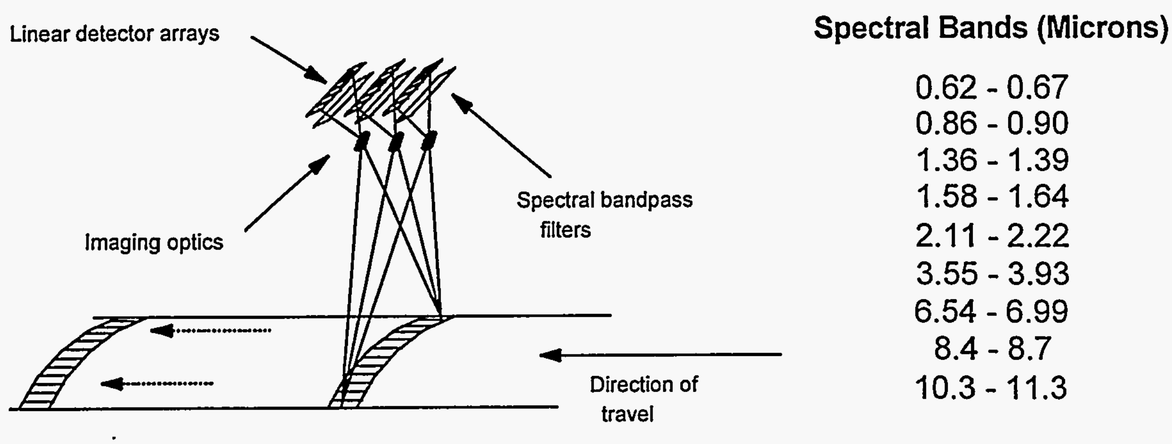

Figure 1. Schematic of Coincident, Spectral Imaging Using the MPIR Instrument

3. MECHANICAL DESIGN

The major components of a detector module are illustrated in Figure 2. The diamond-turned mirrors have a common axis of symmetry tilted by 55° from the center of the field-of-view. The system is f/3.5, with a 5 mm on-axis entrance pupil diameter and is nearly telecentric in image space allowing the interference filters to operate at near normal incidence over the entire FOV. At visible wavelengths the 50 μm detector element spacing was determined by geometric aberrations: 86% of the energy from a visible, collimated input beam is contained within a 50 μm square. The long-wavelength pixel size of 100 μm was chosen to match the diffraction limited performance: at 11 microns 85% of the energy falls within a 100 μm-square pixel. Spectral bands between 0.4 and 12 microns are defined by internal, cooled interference filters used with one of the four different detector module types: Silicon, InGaAs, InSb, and HgCdTe. The cooling system allows each module to be individually and optimally controlled at any temperature from room temperature to 80K. High emissivity chopper blades coated with Orlando Black[3] are used to provide a dark reference for the short wavelength channels and a calibration reference for the thermal channels. The chopper blades are mounted on a torsionally-suspended, momentum-compensated structure driven at its 4 Hz resonate frequency. Each module views and measures its own chopper blade every 0.25 seconds. The temperature of each thermally isolated blade is precisely measured and is used as an on-board blackbody calibration source for the infrared channels. This on-board calibration update in conjunction with extensive pre- and post-flight ground and laboratory calibration[4] is used to achieve the radiometric accuracy design goals of 1% in the infrared and 3% in the visible wavelengths. A goal of the mechanical design was to allow interchangability between the modules. Diamond turning of all critical surfaces within each module allowed for a mechanical "bolt-together" optics alignment while attention to mechanical detail during assembly allows for fully interchangeable modules.

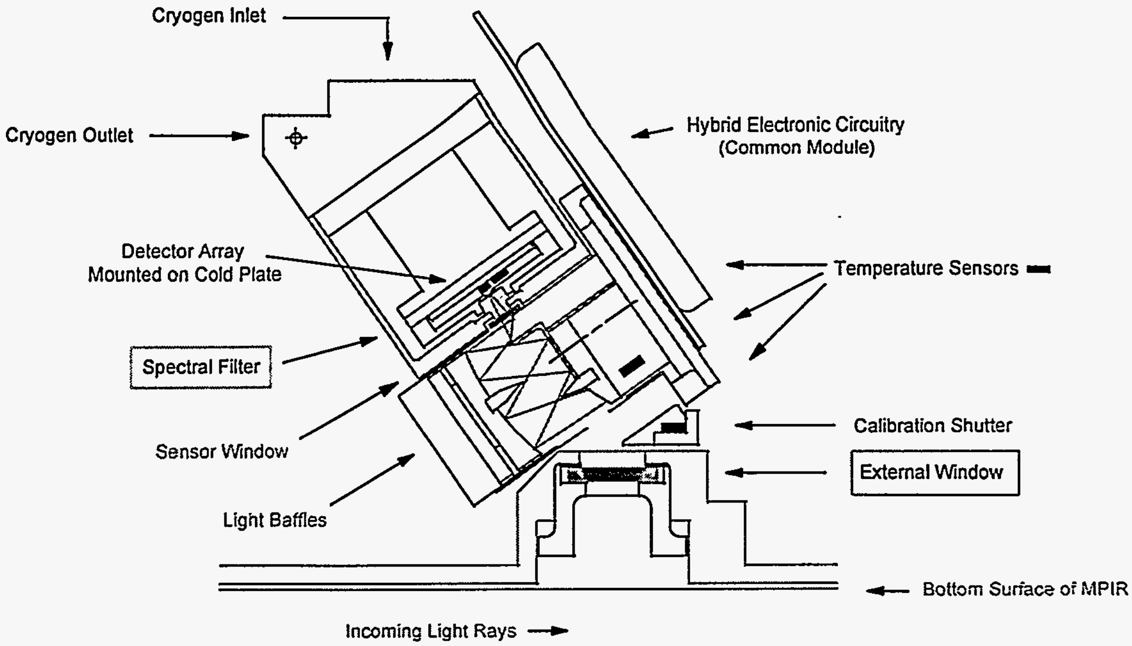

Figure 2. Internal Details of an MPIR Detector Module

The down-looking optical modules, associated electronics, and cooling hardware are included in the MPIR chassis illustrated in Figure 3 (the external LN_2 storage dewar is not shown). The amount of required LN_2 storage depends upon the mission length and type of modules flown. The 80K infrared modules require more cooling, and thus a larger supply of LN_2 , than do the warmer visible modules. The standard five liter dewar is designed to operate MPIR for a 48-hour mission with the standard complement of infrared modules. Total power consumption is 50 watts; main box weight is 30 kg. A filled, five liter storage dewar adds an additional 8 kg.

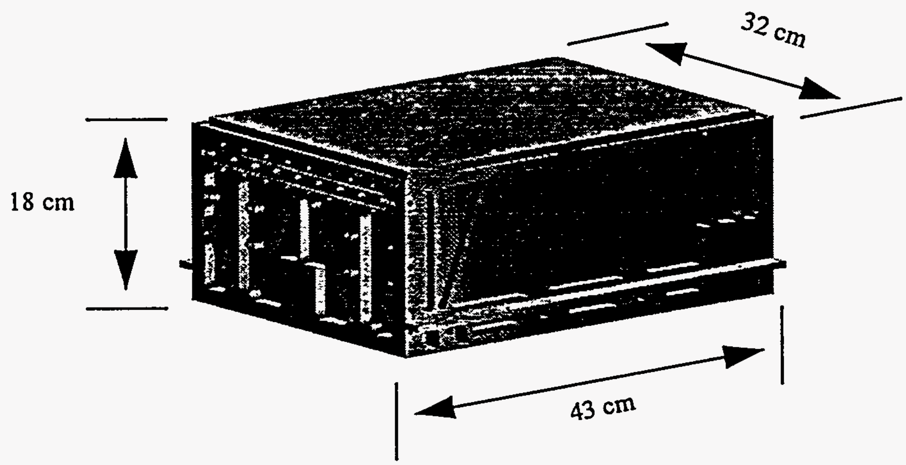

Figure 3. The 9-Channel MPIR Instrument

4. DATA ISSUES

Each modules has its own microprocessor controlled 'array specific' board with signal conditioning, detector read electronics, 12-bit digitization, and data communications capabilities. A main processor communicates with each module via a serial data link. The main processor controls all data queuing and communications, collecting sensor and temperature data for all nine modules, and combing it all into an 80 kbit/second serial data stream. The final serial data is telemetered to a ground receiving station for storage and later data analysis. The nine spectral bands have been chosen to answer questions about tropospheric clouds, provide a means for energy balance measurements, and also potentially allow re-calibration of presently used satellite sensors. A list of the spectral bands with the derived data products includes:

λ in μm	**Extracted Data Products**
0.62 - 0.67	Cloud identification, amount, thickness, particle size, and phase. Ground reflectance.
0.86 - 0.90	Cloud identification and amount, Ground reflectance.
1.36 - 1.39	Upper tropospheric water vapor, daytime cirrus detection.
1.58 - 1.64	Cloud microphysics and phase.
2.11 - 2.22	Cloud particle size, and phase.
3.55 - 3.93	Cloud particle size, microphysics, and phase.
6.54 - 6.99	Cloud top temperature and (indirectly) height of cloud tops
8.40 - 8.70	Cloud identification and amount, nighttime cirrus, cloud and surface temperatures
10.3 - 11.3	Cloud identification and amount, nighttime cirrus, cloud and surface temperatures

5. CONCLUSIONS

MPIR is a relatively inexpensive radiometric imager capable of collecting accurate data in nine simultaneous wavelength bands over the range of 0.4-12 μm. Each detector module has its own detector array, filter, reflective optics, and electronics making a highly modular design that can be reconfigured for the differing optimum detection wavelengths necessary for a particular task: cloud radiometry, crop assessment, detection of environmental contamination, satellite calibration, etc.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. Atmospheric Radiation Measurement Program Plan, February 1990, U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, DOE/ER-0441

2. U. S. Patent # 4,598,981 (1986)

3. A proprietary, ultra-black, dendritic copper coating produced by Lockheed Martin Corp., Orlando, FL.

4. Radiometric ground calibration of MPIR and other ARM/UAV instruments is being performed by NIS-2, Los Alamos National Laboratory, Los Alamos, NM.