

An Airborne Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR)

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Abstract- An airborne Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR) for high-altitude observations from the NASA ER-2 is discussed. The primary application of the CoSMIR is water vapor profile remote sensing. Four radiometers operating at 50 (3 channels), 92, 150, and 183 (3 channels) GHz provide spectral coverage identical to nine of the SSMIS high-frequency channels. Constant polarization-basis conical and cross-track scanning capabilities are achieved using an elevation-under-azimuth two-axis gimbals.

INTRODUCTION

The airborne Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR) will provide measurements for calibration and validation (cal/val) of the high-frequency channels of the DMSP Special Sensor Microwave Imager/Sounder (SSMIS). The SSMIS is a next-generation orbiting microwave imager/sounder, a series of which are designed to monitor the Earth's environment for the next decade. The sensor combines the capability of the currently existing Special Sensor Microwave/Imager (SSM/I) (at 19-85 GHz) and Special Sensor Microwave/Temperature-2 (SSM/T-2) (at 91-183 GHz) and covers a wide frequency range of 19-183 GHz. Instead of imaging using cross-track scanning like the SSM/T-2 or the Advanced Microwave Sounding Unit-B (AMSU-B), the new sensor scans conically at $\sim 54^\circ$ incidence angle for all frequency channels.

In the past, the Millimeter-wave Imaging Radiometer (MIR) was used for airborne cal/val efforts of the aforementioned sounding instruments [1, 2]. The MIR, however, is a cross-track scanning instrument with rotating polarization basis and is not well suited for SSMIS cal/val studies. On the other hand, the new CoSMIR instrument is conical scanning, providing the constant incidence-angle and polarization-basis observations needed for comparison to the next generation spaceborne radiometers (i.e., DMSP SSMIS and NPOESS CMIS).

INSTRUMENT DESCRIPTION

The CoSMIR consists of four radiometers operating at 50 (3 channels), 92, 150, and 183 (3 channels) GHz. The radiome-

This development was supported by the Defense Meteorological Satellite Program and the NASA Goddard Space Flight Center.

ters are housed in a cylinder that is mounted in an elevation-under-azimuth gimbals such that constant incident-angle conical scanning is the normal mode of operation. (This scanning configuration is similar to the NOAA PSR aircraft instrument [3].) Two calibration targets rotate with the azimuth axis such that the radiometer scanhead needs to be rotated only in the elevation axis to complete a two-look calibration sequence – a unique feature of CoSMIR. Two embedded computers are co-located with the radiometers and calibration targets for data acquisition. The computers are networked to third computer, the control and archival system. The scanning motion of the gimbals is achieved using a programmable two-axis closed-loop DC brushless servo-motor system. All the data collected by the archival system is stored on solid-state disk.

Radiometers

The four radiometers operate near 50, 92, 150 and 183 GHz. The 50 GHz radiometer has three 400-MHz wide bands for atmospheric-temperature sounding located at 50.3, 52.8, and 53.596 GHz. The receiver is a super-heterodyne architecture with an image reject filter and an IF triplexer for band separation. The window channel radiometers at 91.655 and 150.0 GHz are double sideband receivers with 1500 MHz of IF bandwidth. The 183 GHz radiometer is a double sideband system with an IF triplexer that defines three channels for water-vapor sounding at 183.3 ± 1 , 183.3 ± 3 , and 183.3 ± 6.6 GHz.

Each of the radiometers has a lens-feedhorn antenna with 4° 3-dB beamwidth. This beamwidth corresponds to a ~ 1.4 -km nadir footprint at 20-km below the aircraft. At $\sim 54^\circ$ incidence, the footprint size is $\sim 2.4 \times 4.0$ km. The 92 GHz antenna is dual-polarization while the other channels are all horizontally polarized. The antennas, radiometers and associated data-acquisition system are housed in a 21×28 cm scanhead drum. The packaging required the construction of a detailed three-dimensional solid model containing all the microwave and electrical hardware as well as mounting brackets and fasteners. A rendering of the model is shown in Fig. 1.

Electro-mechanical system

The scanhead is mounted in a set of elevation-under-azimuth two-axis gimbals (see Fig. 2). Such a mechanism allows the radiometers to be scanned in several scanning patterns during flight (e.g., conical, cross-track, along-track, nadir stare). The natural scan mode is conical scanning, which has both constant incidence angle and polarization basis. A pair of DC brushless

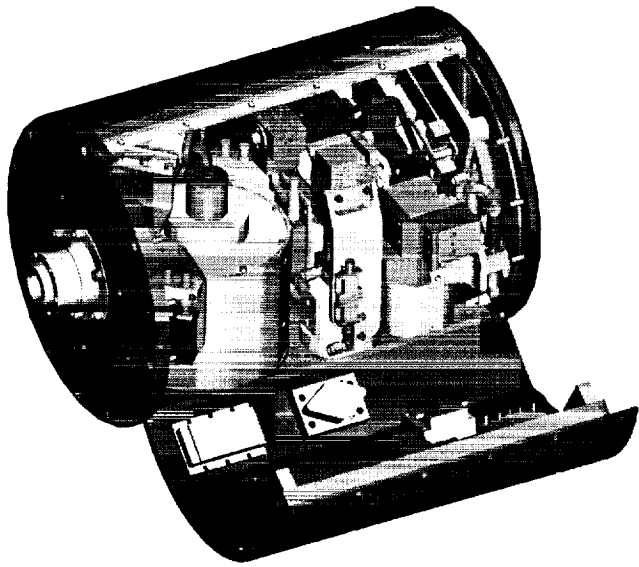


Figure 1: Solid model of scanhead showing radiometers, other electronics and mounting brackets.

servo motors and optical feedback encoders is used to position the antennas. The motors are controlled using a two-axis programmable digital PID controller. Slip-rings are used on both axes to transmit power, control, and data signals, allowing for unlimited rotation in both degrees-of-freedom. These gimbals are mounted in the un-pressurized area of a pressure cylinder that mounts inside wing-pod forebody on the NASA ER-2 aircraft. The control electronics are mounted in the pressurized area on a wing-pod instrument rack. The pressure cylinder uses bellows to minimize the loading on the nadir-viewing window of the wing pod and transfer the load to the wing-pod mounting rails. The interface structure includes a manual-controlled translation joint that allows the pressure cylinder and gimbals to be raised and lowered into the wing-pod window frame for installation. The complete interface structure and pressure cylinder is seen mounted in the wing pod in Fig. 3.

Data system

The data system is composed of three embedded computers: radiometer computer, calibration target computer, and archival and control computer. Each system is running a POSIX-compliant real-time operating system and is networked on a 10-base-T local area network. Radiometer voltages are acquired and buffered every 10 ms and transmitted over the network when requested by the archival system. Housekeeping data is likewise collected on a 1-second basis and includes voltages and temperatures throughout the scanhead. Calibration target temperatures are acquired at 1-second intervals, transmitted over the network, and stored on the archival machine. The archival and control computer acquires elevation and azimuth pointing data, as well as aircraft pitch and roll data, with

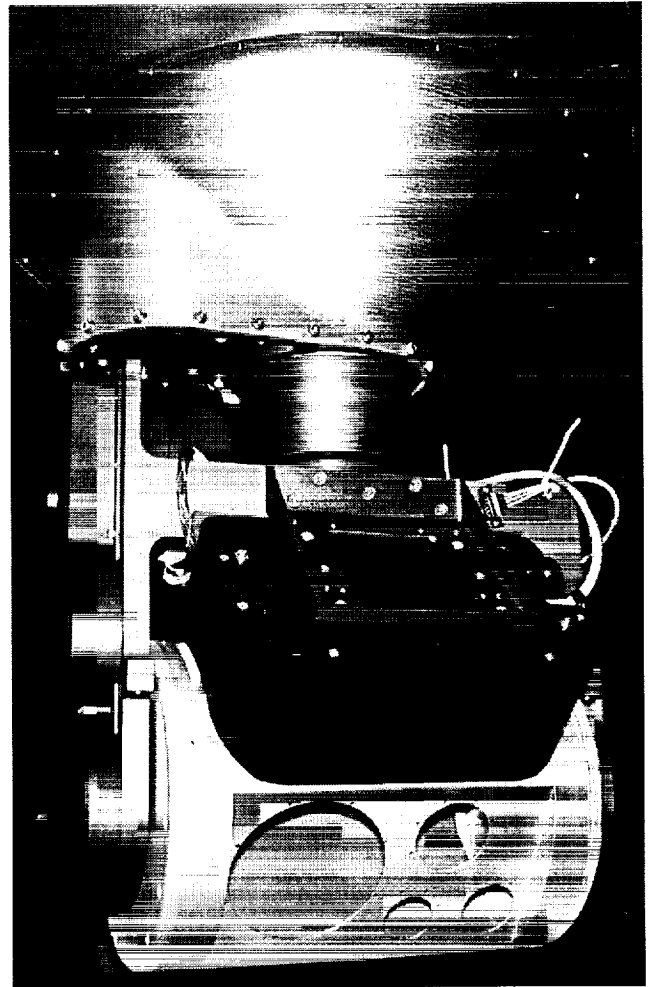


Figure 2: CoSMIR elevation-under-azimuth two-axis gimbals.

a 50-ms period. Other aircraft navigation data is collected at a 1-second rate. All data collection is performed asynchronously and timestamped using clocks synchronized to 2 ms accuracy. The master clock is set to the ER-2's IRIG-B time feed. The total data rate is ~ 18 MB/hour and all data is stored on solid-state flash disk. Data can be downloaded over the network after a flight, or if a quick off-load is required, the flash disk card can be removed and a fresh disk installed in a matter of seconds for the next flight.

Calibration and image formation

The unique feature of the CoSMIR gimbals is location of the calibration targets, which rotate with the azimuth axis. Additionally, the targets are close-coupled with aluminum shrouds, which reject stray radiation from the scene below. The targets can be viewed by merely rotating the radiometers around the elevation axis. This feature allows for an efficient scanning algorithm, in which $\gtrsim 75\%$ of the scan cycle is used for view-

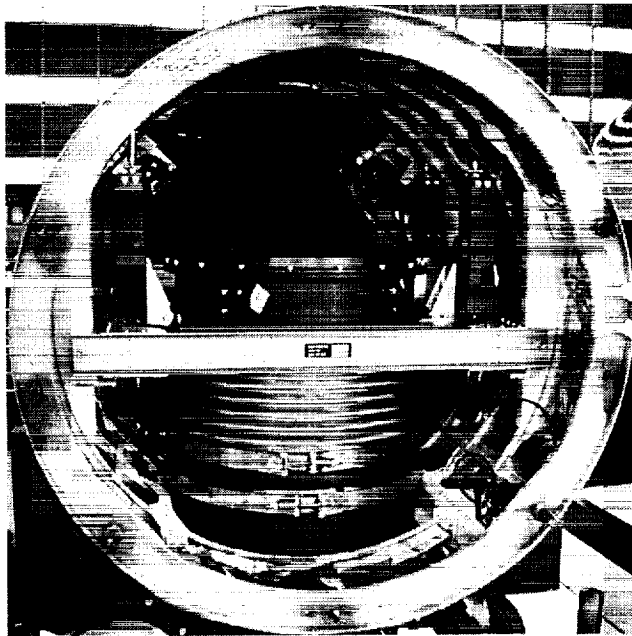


Figure 3: CoSMIR interface structure and pressure cylinder mounted in the NASA ER-2 wing-pod forebody.

ing the scene. The azimuth axis rotates the antenna patterns to generate the conical scan during which time the elevation axis maintains the antenna pointing at the prescribed angle of incidence. Every five seconds, twice during each revolution of the azimuth axis, calibration is performed followed by an across-track scan. The elevation axis is used to rotate the antennas to point at the calibration references and then to sweep the antenna patterns through nadir back to the prescribed incidence angle.

Fig. 4 shows the geometry of the scan pattern as projected onto the earth's surface. The points on the plot represent center of the beam positions. Two complete scan cycles are shown. The aircraft travels at 200 m/s at an altitude of 20 km. The azimuth axis rotates at a constant 36° per second. Thus, each scan cycle takes 10.0 seconds providing contiguous coverage for the conical scan at 10 km for a 4° beamwidth. The scan pattern as shown starts directly forward of the aircraft. The antenna rotates 60° in azimuth when the first calibration sequence begins. After staring at each calibration target for 200 ms, the antenna patterns are scanned across the aircraft track back to $\sim 54^\circ$ incidence to begin the scan aft of the aircraft. Calibration and a second across track scan is performed at the end of the aft-side scan. The scan cycle is complete when the azimuth axis rotates the antenna forward of the aircraft.

SUMMARY

CoSMIR integration is to be completed by May 2001 with

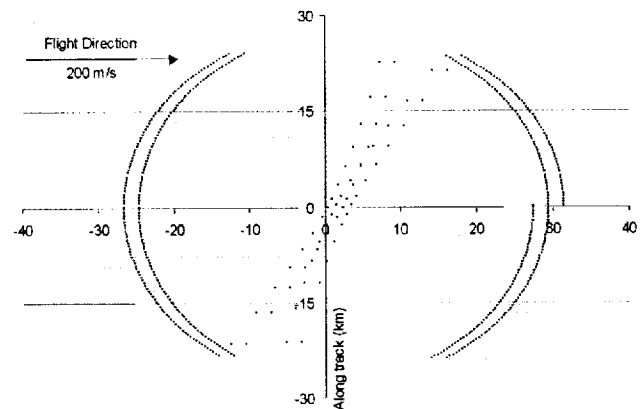


Figure 4: Surface projection of the CoSMIR antenna scanning pattern.

first SSM/I underflights occurring in June of the same year. SSMIS cal/val underflights will commence approximately two months after the satellite launch. In addition to providing unique cal/val measurements, the conical and cross-track scanning CoSMIR will provide important data necessary for the improvement of water-vapor remote sensing techniques. Furthermore, a second scanhead that contains submillimeter-wave radiometers (from 183 to 640 GHz) is under development. The Submillimeter-wave CoSMIR (SCoSMIR) will be a valuable tool for cirrus cloud and upper atmospheric remote sensing.

ACKNOWLEDGMENTS

The authors wish to acknowledge V. Golla of Genesis Engineering Corp. for his valuable contributions in the scanhead layout and packaging; and W. Barber and D. Aldridge of GSFC for technical assistance during system integration.

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