3.2 THE CONICAL MICROWAVE IMAGER/SOUNDER (CMIS): NEXT GENERATION CONICAL-SCANNING MICROWAVE RADIOMETER FOR NPOESS

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1. INTRODUCTION

The Conical Microwave Imager/Sounder (CMIS) is the United States' next-generation space-borne operational microwave radiometer. The Integrated Program Office (IPO) is the Presidentially-directed tri-agency office chartered with the responsibility of developing, acquiring, and operating the United States' new National Polar-orbiting Operational Satellite System (NPOESS) upon which CMIS will fly. The IPO consists of members from NASA, NOAA and DoD. In addition to the above responsibilities, the IPO also operates the immediate predecessors to NPOESS: POES and DMSP.

CMIS, itself, was conceived in the mid-1990's, conceptually refined over the next four years, and a production contract was awarded in the summer of 2001. The first CMIS sensor is currently planned for launch in 2009, and the last CMIS flight unit is expected to be operational beyond 2020. This paper provides the history, mission and goals of CMIS. In addition, the major aspects of the current sensor design on contract will be described.

2. CMIS AT A GLANCE

2.1 *Design Overview*

Over the past several years, the IPO has worked closely with the operational and scientific meteorological communities in developing performance requirements for the environmental data products generated by the NPOESS system.

The environmental data products of NPOESS are labeled Environmental Data Records (EDRs) and the system is required to produce 66 unique EDRs from the full complement of sensors on the spacecraft. Individually, the CMIS sensor is the primary source for 20 of the 66 EDRs. The CMIS sensor design has been optimized over the past three and half years, within certain constraints such as limits on mass, power and cost, to best fulfill the requirements of the 20 EDRs assigned to it. The EDRs on CMIS are assigned three relative levels of importance as shown in Table 1 below, with Category I being the most important.

TABLE 1

EDR Title	Category
Atmospheric Vertical Moisture Profile (Surface to 600mb)	I
Sea Surface Winds (Speed)	I
Soil Moisture	I
Atmospheric Vertical Moisture Profile (600 to 100mb)	II
Atmospheric Vertical Temperature Profile	II
Cloud Ice Water Path	II
Cloud Liquid Water	II
Ice Surface Temperature	II
Land Surface Temperature	II
Precipitation	II
Precipitable Water	II
Sea Ice Age and Sea Ice Edge Motion	II
Sea Surface Temperature	II
Sea Surface Winds (Direction)	II
Total Water Content	II
Cloud Base Height	III
Fresh Water Ice	III
Imagery	III
Pressure Profile	III
Snow Cover / Depth	III
Surface Wind Stress	III
Vegetation / Surface Type	III

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Optimization of the CMIS design was carried out by two competing industry teams through the use of a Government assigned Integrated Requirements Prioritization List (IRPL), shown in Table 2, which assigned relative priorities to certain sensor parameters and all EDRs.

TABLE 2

Integrated Requirements Prioritization List

1. Category I EDRs
2. Category II EDRs/Cost
3. Volume
4. Category A EDRs/Mass
5. Power
6. Category III EDRs
7. Category B EDRs
8. Data Rate

The attributes of the highest priority EDRs determined the key design attributes of the CMIS sensor design including aperture size, number and selection of channels, channel bandwidth and calibration accuracy. The CMIS is designed to improve upon the resolution, measurement range and accuracy of most heritage operational EDRs such as Sea Surface Wind Speed, Precipitation and Cloud EDRs, and to produce several new EDRs operationally such as Sea Surface Wind Direction, Sea Surface Temperature, Soil Moisture and Cloud Base Height. Due to the requirements for improved resolution and the need for lower frequency channels, the CMIS sensor is substantially larger than its heritage sensors, the Special Sensor Microwave/Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS).

On 30 July, 2001, the U.S. Government awarded a production contract to Boeing Satellite Systems (BSS) for the production of up to 6 CMIS flight units. Figure 1 shows a full-scale mock-up of CMIS behind full-scale models of the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the SSM/I.

The CMIS utilizes a dual-primary reflector to facilitate measurements across a large frequency range of 6 to 190 GHz. The two parabolic reflectors are oriented 180° apart about the sensor spin-axis. Each reflector is optimized for a particular frequency range. The larger reflector has an aperture of 2.2 m (effective aperture of 2.06 m) and is utilized by the Lower Frequency (LF) CMIS channel set (≤ 89 GHz). The smaller reflector antenna has an aperture of ~0.7 x 0.5 m and covers the Higher Frequency (HF) range (> 89 GHz). The associated feedhorn clusters are positioned at two separate locations near the focal point of each reflector. However, all channels are calibrated using a single warm calibration target and a single cold sky reflector, consistent with heritage conical-scanning microwave radiometers. While one channel set is observing the Earth, the other channel set is observing the calibration targets, resulting in each channel being calibrated once per scan.

FIGURE 1

The LF cluster contains 12 separate feedhorns arranged in a 2 dimensional group rather than along an arc containing the focal point of the reflector. This results in multiple off-nadir angles of 45.4°, 47.0°, and 48.7° and Earth Incidence Angles (EIA) of 53.6°, 55.7° and 58.1° respectively. The HF cluster contains only 4 feedhorns, 2 each for the 166 GHz and 183 GHz channels. Accordingly, these are arranged to provide a single off-nadir angle of 46.8° and an EIA of 55.5° respectively. Co-registration of the LF channel effective fields of view is facilitated by designing the offsets in elevation angle such that precise overlap occurs at an integer number of scans. Furthermore, co-registration between the HF channel set and the 50 GHz sounding channels in the LF channel set is aided by introducing a slight EIA offset that allows the channels to view the same ground location one-half rotation later.

Although it is anticipated that the WindSat Coreolis mission will provide the first space-borne measurements of Sea Surface Wind Direction (SSWD) from a passive microwave radiometer, CMIS is required to measure SSWD as part of an operational environmental satellite system. CMIS, too, will produce SSWD EDRs by passive polarimetric measurements of upwelling brightness temperatures. The CMIS utilizes vertically- and horizontally-polarized brightness temperature measurements at 10, 18 and 37 GHz with two additional linearly-polarized measurements (45° and –45°) at 18 and 37 GHz, and two circularly-polarized measurements (LH and RH) at 10 and 18 GHz to derive SSWD. These measurements are obtained by utilizing separate feedhorns at each frequency and for each dual-orthogonal polarization pair.

Another important aspect of CMIS is its moisture and temperature sounding capability. CMIS has 9 channels centered between 50 GHz to 60 GHz. These were selected to support the atmospheric vertical temperature profile (AVTP) EDR requirements below ~20 mb. However, CMIS is also required to measure the AVTP up to 0.01mb at reduced spatial resolution. This is primarily achieved by a set of 40 channels within a bandwidth of 20 MHz centered near 60.43476 GHz (7+ O_2 line). The individual channels in this set vary in bandwidth from 1.5 MHz at the edges to 250 kHz at the center of the range. The channel characteristics are determined through sampling of the RF amplitude and application of a Fast Fourier Transform (FFT). The conical-scan geometry of CMIS results in varying Doppler shift as a function of the scan line-of-sight with respect to the velocity vector of the spacecraft. Compensation for Doppler is accomplished within the AVTP retrieval algorithm. Removal of channel-to-channel biases within the FFT suite of channels is critical to maintain uniform brightness temperature measurements over the CMIS swath.

The entire CMIS sensor has a projected mass of 257 kg. A significant portion of this mass is spun and must have its momentum compensated. CMIS uses a 3-for-2 redundant momentum wheel assembly and an on-orbit adjustable static and dynamic balancing mechanism to minimize disturbance torque transfer across the sensor/spacecraft interface. CMIS is required to transfer no more than 0.01 N-m of periodic torque disturbance to the spacecraft.

The CMIS sensor is designed for high reliability (> 0.9) after 7 years on-orbit and up to 8-year storage (total of 15-year mission lifetime). The design has substantial redundancy to eliminate critical single point failures.

2.2 *Data Products/Algorithms*

Boeing Satellite Systems, the CMIS provider, and its subcontractors Atmospheric Environmental Research (AER) and Remote Sensing Systems (RSS) are responsible for providing science algorithms for the 20 atmospheric, land, and ocean Environmental Data Records (EDR) (Table 1) assigned to CMIS. However, representatives from the operational and scientific meteorological communities are working closely with the CMIS provider to ensure the quality and utility of the environmental data products.

The EDR algorithms under development by the BSS CMIS team are detailed in several Algorithm Theoretical Basis Documents (ATBD) that are also under development. Under the current NPOESS plan, the NPOESS system integrating contractor will assume Total System Performance Responsibility (TSPR) for all of the NPOESS sensors and EDRs when that contractor is selected in the fall of 2002. The TSPR contractor will also develop and execute a detailed calibration/validation plan before the operational phase of NPOESS can begin.

Based on their individual expertise, RSS is responsible for the ocean EDR algorithms and AER is developing all of the other EDR algorithms. AER is also responsible for the temperature and sensor data record algorithms used to convert digitized output from the CMIS radiometers into calibrated brightness temperatures. AER utilizes a unified retrieval approach in which all available radiometric and auxiliary/ancillary data are supplied to a physical retrieval scheme that optimizes its solution based on the internal model. This process is performed by the “core module” of the algorithm and is the first step in the retrieving all of the non-ocean EDRs. The core module produces vertical moisture profile and vertical temperature profile at a pre-determined set of altitudes along with several other important parameters including surface temperature and emissivity. The output of the core module is in a standard format and is then input into a suite of algorithms to produce ice, land, cloud, and other parameters required by CMIS.

The CMIS Ocean EDRs are produced from CMIS calibrated brightness temperatures by a process executed in advance of the unified retrieval algorithm. The resulting ocean retrieval data are then supplied as an additional input to the core module. The CMIS Ocean EDR suite utilizes the methodology employed by RSS in their development of the Advanced Microwave Scanning Radiometer (AMSR) ocean algorithms. A key aspect of CMIS is the measurement of Sea Surface Wind Direction (SSWD). This algorithm requires precise characterization of the CMIS antenna polarization cross coupling, typically to ~< 40dB. Close attention is being given to understanding the potential errors in the antenna measurements and characterization process.

Soil moisture is a new EDR that has not been obtained operationally in the past. AER is relying on an AMSR-type algorithm for its retrieval. Given the proposed CMIS channel sets, the soil moisture availability is presently limited to bare and lightly vegetated areas. The data product retrieval will have to compete heavily with the growing presence of Radio Frequency Interference (RFI) in the C and X-bands.

3. SUMMARY

The CMIS sensor will soon become the next-generation conical-scanning microwave imaging and sounding radiometer. Its development presents many technical challenges, particularly in the area of antenna characterization, sensor calibration, and signal and data processing. Boeing Satellite Systems and its teammates AER and RSS are working to master these difficulties, further the design, integrate it into NPOESS and prepare for the final pre-production milestone: Critical Design Review (CDR). As described in Section 2.1, the CMIS sensor offers several new operational products (Sea Surface Wind Direction, Soil Moisture, and Cloud Base Height), and quantifiable resolution and measurement range improvements over existing remotely-sensed environmental products from polar-orbiting platforms. Therefore, CMIS is expected to advance the state of the art of microwave remote sensing, and will become a valued contributor to the operational meteorology community before this decade is out.