The Airborne Earth Science Microwave Imaging Radiometer (AESMIR) - NASA’s New Passive Microwave Airborne Imager

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Abstract—NASA’s Airborne Earth Science Microwave Imaging Radiometer (AESMIR) is a new sensor for satellite calibration, geophysical algorithm studies, and technology development. Its unique single-package design covers 6 microwave bands (6, 10, 18, 23, 36, 89 GHz) with 4-Stokes capability (except at 23 GHz). Separate parallel filters enable simultaneous simulation of the passbands of multiple satellite sensors. Various aircraft installations options are available. Design and flight details are presented.

I. INTRODUCTION
Passive microwave radiometry involves measuring “blackbody” emission from natural Earth targets: oceans, the atmosphere, land, snow, and ice. The “signal” is actually broadband thermal noise, and the microwave region from approximately 1 to 100 GHz is well-suited for the remote sensing of water in gaseous, liquid, and solid states on the Earth’s surface. Passive microwave satellite sensors are essential workhorses for operational weather forecasting as well as for a wide variety of research applications, and have a long history beginning in the 1960’s [1].

Underflights with airborne versions of these sensors (Figure 1) are needed to calibrate these satellite sensors and to validate the geophysical retrieval algorithms used. At the same time, new algorithms and sensor hardware can be tested and refined at much lower cost and/or risk vs. having to perform these activities in space. The performance of such airborne simulators is closely tied to the design of the aircraft installation. In this paper, we examine the design of the AESMIR’s single-package design covering 6 microwave bands (6, 10, 18, 23, 36, 89 GHz) is unique, requiring very efficient use of available space and careful attention to calibration considerations with multiple options for aircraft installation.

II. SENSOR DESIGN
One of the original basic design goals was to squeeze radiometers for all 6 desired microwave bands into a single mechanically-scanned package. The advantages include needing only one set of the large, heavy, and expensive external calibration targets, needing only one gimbal to point and scan the sensor, etc., vs. needing multiple copies of everything in terms of mass, volume, and power. The need to provide reasonably narrow antenna beamwidths (7-10 deg at the -3dB points) set the antenna apertures. At the lowest frequency of 6 GHz, the aperture is 40 cm. The need to have simultaneous co-bore sighted views at all 6 bands, meant that all antennas had to be mounted on the same plate. Here we were fortunate to be able to find dual-band antennas for 6 + 10 GHz and for 18 + 23 GHz, reducing the total number of antennas from 6 to 4. The photograph in Figure 2 shows the layout of the 4 antennas as well as windows for a video camera and a thermal infrared radiometer. At this point in the design, the minimum sensor package dimensions are set. We chose a cylinder over a sphere for practicality of calibration, smaller size, and easier gimbal design, despite some aerodynamic advantages of a sphere. AESMIR’s 65-cm cylinder is in-between the sizes of PSR’s 50-cm cylinder and APMIR’s 90-cm sphere [2, 3].

The AZ-EL gimbal was sized to hold & position the cylinder to within pointing and structural + aerodynamic tolerances (typically a 10-G envelope, and 0.05 degrees). The number and rating of sliprings was selected according to a “power-in-bits-out” design philosophy. The resulting AESMIR’s
gimbal is “elevation under azimuth” (same as PSR and APMIR).

At the same time, and very importantly, the overall package of sensor plus gimbal has to fit on enough potential aircraft to be practical. And, this competing requirement creates a design tradespace faced by any airborne passive microwave sensor that attempts to cover the same observing bands—a large total package (e.g., APMIR) and the instrument can only fly on certain large expensive aircraft, a smaller design (e.g., PSR), and multiple packages are required to cover the same observing bands, thus also requiring an aircraft with large spaces for installation. The AESMIR design occupies an in-between point in this tradespace.

AESMIR can be mounted on an aircraft in different configurations depending on the options specific to that particular aircraft (bomb bay, hanging below the fuselage, wing pod, etc). If a large bomb bay is available, AESMIR can largely go inside the aircraft (e.g., P-3). Otherwise, if sufficient ground clearance is available, AESMIR can mostly hang below the fuselage and requires only a 35-cm mounting hole. In the event a large cargo aircraft (e.g., C-130) is used, AESMIR can “hang” off the rear cargo ramp. An aerodynamic fairing is required on any aircraft to minimize force inputs to the gimbal controller, and to maximize achievable airspeed.

Environment requirements include being able to operate at altitudes up to 30 km (100,000 feet), ambient temperatures down to -80 C, and humidity up to 100% (flying through clouds). Aerodynamically, the part of the sensor exposed to the airstream in flight must survive forces associated with airspeeds as high as 600 knots, although in practice, the actual force is less through the use of fairings and air dams.

The microwave radiometers are built on aluminum plates for thermal stability as well as packaging ease within the tightly packed cylinder (Figure 4). Each plate has heaters and temperature sensors for active thermal stabilization under computer control. The cylinder itself is heated and desiccant is used to prevent condensation. The 89 and 36 GHz radiometers use waveguide components until after the mixers. All other bands use coaxial components. To provide 4-Stokes capability (all bands except 23 GHz), quadrature signals are generated and a hybrid combining network is used to produce +45 and -45 degree linear polarizations as well as right and left circular polarizations. Analog-to-digital conversion of detector diode outputs is performed inside the cylinder. The modified Stokes parameters are then computed in software. Separate parallel filters enable simultaneous simulation of the passbands of multiple satellite sensors.

The 2 calibration targets are of the pyramidal array type, and have -40dB return loss at all the bands of interest. Both targets are identical mechanically, and electromagnetically. One is heated above ambient (up to 80C) and the other is used at ambient to provide hot and cold calibration points for all of the microwave radiometers. Each target has heaters, 26 precision temperature sensors, and is enclosed on all sides by thermal insulation. The targets are also carefully shrouded and tightly coupled to the antennas to minimize entry by any stray radiation.

New for the 2009 flights was a correlated noise injection circuit for additional calibration capability related to the 3rd and 4th Stokes parameters.

The design of the control & data handling system (CDHS) followed a “divide-and-conquer” philosophy, resulting in a collection of 7 dedicated computers communicating over Ethernet. Commercial-off-the-shelf (COTS) PC104 embedded controller boards are used running COTS real-time Unix. Programming is in plain C for simplicity. Each PC104 computer handles a small number of related tasks—for example, temperature control and monitoring of the external calibration targets. Data is periodically sent back to the Master computer for archiving on solid state memory cards (mechanical hard disks can fail from the vibration & shock environment on many aircraft). All data is synchronized to GPS time distributed via IRIG-B signals. One interesting feature of the CDHS design is the intentional use of slow-speed CPU clocks (some are below 100 MHz) in order to reduce the generation of radio frequency interference inside the sensor itself—recall that microwave radiometers are essentially wideband ultra-sensitive radio receivers. Other sensors built in our laboratory use the same CDHS design, simplifying software coding, debugging, hardware maintenance, and spare parts inventories. More than once, this commonality has been a great benefit during field deployments.

### III. FLIGHTS

AESMIR’s maiden flights were conducted in 2003 on NASA’s C-130 aircraft based at the Wallops Flight Facility. As the sensor package was mounted “hanging” off the end of the cargo ramp door, the aircraft was flown unpressurized, airspeed was limited to 130 knots, and altitude was limited to 3000 m (10,000 feet) for practical reasons and to avoid issues with electronics in the control equipment rack that was located in the cargo bay. For these flights, only the vertical and horizontal polarizations of each of the 6 bands were recorded. A 10 GHz H-pol image is shown in Figure 3.

Additional flights were conducted in January, 2009 with a focus on 4-Stokes operation of the 10 and 18 GHz radiometers, and exploring the environmental envelope of AESMIR. These flights used the NASA P-3 aircraft, again based at Wallops. The altitude envelope was successfully increased to 7500 m (25,000 feet), including ambient air temperatures below -30 C. The endurance envelope was demonstrated to over 7 hours, and the airspeed envelope was increased to 200 knots (300 knots without conical scanning). Microwave images and analysis of the instrument calibration will be presented at the conference.
IV. SUMMARY

AESMIR is NASA’s newest passive microwave airborne imager covering the 6-100 GHz bands that are essential for observing key Earth System elements such as precipitation, snow, soil moisture, ocean winds, sea ice, sea surface temperature, vegetation, etc. AESMIR is the only such sensor to cover these bands in a single mechanical package, enabling efficient use of aircraft mounting space & thus maximizing science return, especially when synergistic sensors can occupy the remaining space. AESMIR can perform conical & cross-track scans to simulate multiple satellite microwave imagers and sounders, and features state-of-the-art calibration plus fully-polarimetric (4-Stokes) observations. As such, it is an Earth Science facility for post-launch calibration & validation of satellite sensors and as well as for pre-launch algorithm development & new microwave remote sensing discovery. It is uniquely suited as an intersatellite calibration tool for constellation missions & for monitoring of long-term climate trends.

ACKNOWLEDGMENT

AESMIR is the result of years of work by dozens of people at Goddard, Wallops, and elsewhere, whose critical contributions are gratefully acknowledged. Many design lessons were also learned from our PSR and APMIR colleagues, as well as from Goddard colleagues with other airborne sensors.

REFERENCES

Fig. 1: NASA P-3B research aircraft carrying AESMIR during 2009 flights. Observations can be conducted worldwide for verification of satellite measurements as well as new algorithm development.

Fig. 2: Closeup exterior view of AESMIR instrument. Width is 1.3m. Circles are microwave horn-lens antennas covering 6, 10, 18, 23, 36, & 89 GHz. Also on the flat plate are windows for a video camera and thermal infrared sensor.

Fig. 3: Example of AESMIR imagery from 10 GHz horizontal polarized observations. Redder colors correspond to warmer brightness temperatures over land areas and bluer colors correspond to colder brightness temperatures over water areas.

Fig. 4: Interior view of AESMIR drum showing microwave and power components. Drum mass is over 200 kg in the current configuration. Total AESMIR mass is 450 kg including the gimbal.