Lightweight Rainfall Radiometer STAR Aircraft Sensor

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Abstract - **The X-Band Lightweight Rainfall Radiometer using Synthetic Thinned Aperture Radiometer technology (LRR-X STAR) is an aircraft microwave sensor that is jointly under development by the NASA Goddard Space Flight Center and the University of Michigan. It operates at 10.7 GHz with 86+ simultaneous 2.1° HPBW antenna beams distributed over a ±45° cross track field of view to permit pushboom imaging. It is intended to address several pressing issues related to the Global Precipitation Measurement (GPM) Mission, for which it is a science and technology testbed instrument. In terms of technology readiness, LRR-STAR will evaluate and validate the design approaches being taken by each of its critical subsystems. At the system level, it will validate the calibration methodology used to produce Level 1 brightness temperature imagery. All electrical, mechanical and thermal subsystems of the LRR-STAR are currently in development and several key subsystems have had successful prototype fabrication and laboratory testing. An overview of the instrument design is presented, together with a status report on the hardware development.**

1. Introduction

The US/Japan Tropical Rainfall Measuring Mission has led to the initiation of a new international satellite precipitation mission, the Global Precipitation Measurement (GPM) mission, to be led primarily by NASA and NASDA [1]. One of the main objectives of GPM is high frequency global sampling of rainfall. Our work develops passive microwave radiometer technology that is suitable for high quality rain measurement but is also lightweight and low power, and follows a technology path that leads to significantly reduced per unit recurring costs. Taken together, these improvements will permit multiple sensors to be flown in a constellation of small satellites, thereby increasing the sampling frequency of global precipitation.

2. System design overview

The LRR-X prototype aircraft sensor is functionally equivalent to a candidate space flight sensor design [2]. The prototype will provide high fidelity estimates of the image resolution and field of view, absolute calibration, ΔT sensitivity and data rate requirements for the space flight version. LRR-X can be divided into a number of major subsystems: (a) The antenna consists of 14 slotted waveguide antenna array elements that are mounted below a solid ground plane that extends out 3λ beyond the outermost waveguide edges in order to ensure repeatable antenna backlobe behavior whether undergoing characterization testing in an anechoic chamber or mounted on the aircraft in operation. (b) The receivers are discrete component versions of the flight MMIC design with functional equivalence. They amplify an RF signal centered at 10.7 GHz and with a 30 MHz bandwidth, demodulate it to an intermediate frequency range centered at 41 MHz, and digitize it at 125 MHz with 2 bits of resolution. (c) The correlator performs real and complex self and cross correlations on the signal pairs. (d) The Control & Data Handling (C&DH) subsystem interfaces between the sensor and a user computer and it archives data. (e) The calibration subsystem includes uncorrelated reference loads and correlated injected noise diodes to monitor system gain and offset parameters. Calibration also includes the image reconstruction algorithm used to convert raw measurements into a brightness temperature image. (f) The power supply convert aircraft power to regulated and conditioned DC voltages. (g) The thermal/mechanical housing controls sensor temperature, packages and protects the sensor, and provides the mechanical interfaces to the aircraft. Fig. 1. shows a preliminary design for the housing.

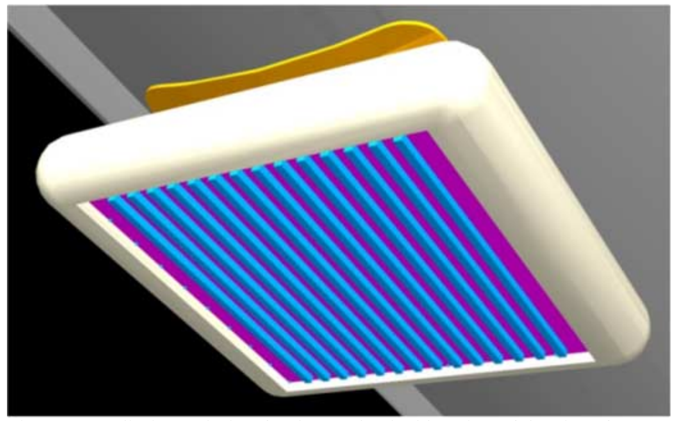

Fig. 1. A preliminary design for the mechanical housing of the aircraft LRR-X sensor is shown. The long thin antennas provide a wide (fan beam) field of view perpendicular to the direction of aircraft motion. (Actual antenna positions are non-uniformly spaced, see [3].)

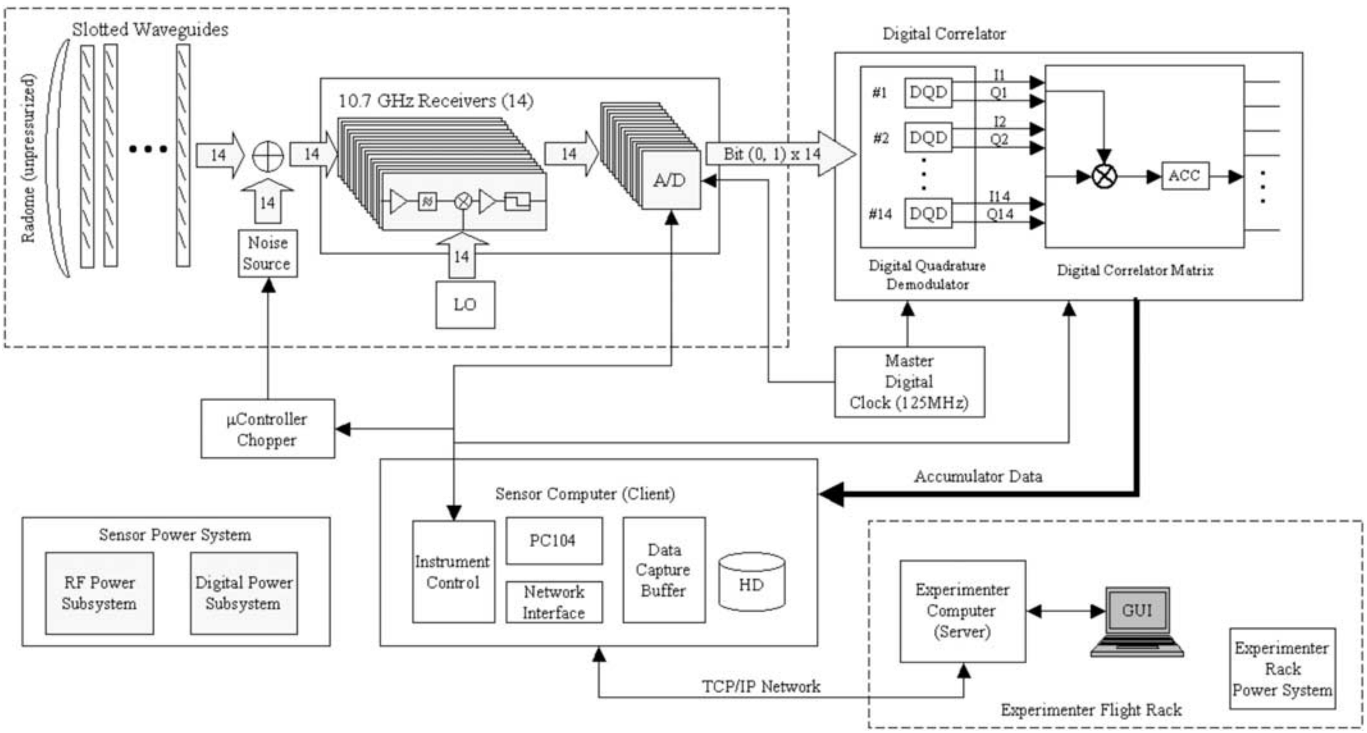

Fig. 2. LRR-X aircraft sensor system block diagram.

The LRR-X system block diagram is shown in Fig. 2.

3. SUBSYSTEM DESIGN DETAILS

A. Antenna

The antenna consists of 14 fan beam antenna elements in an optimally thinned configuration distributed over a ~110x110 cm plane [3]. Each antenna element is a 36 slot slotted waveguide antenna. Fig. 3 shows a single 36 element slotted waveguide antenna installed in the ground plane assembly that will eventually be populated by all 14 fan beam antennas.

B. Receivers

The output from each of the 14 antenna array elements passes first through a directional coupler that can inject a correlated noise signal from a common calibration noise diode. Next is a SPDT PIN switch that can switch the receiver between either of the antenna signal or a blackbody coaxial termination. Following that is the receiver's low noise amplifier, band definition filtering and additional gain, a down conversion mixer, an IF gain stage and additional filtering, and finally a 125 MHz 2 bit digitizer (30 MHz RF bandwidth with x2 oversampling to permit digital quadrature demodulation).

C. Correlator

The digital correlator will be implemented using Programmable Logic Devices that are capable of supporting 14 parallel input lines from the individual digitizing receivers at their full 125 MHz clock rate. In the first stage of thedigital correlator board, each input is quadrature demodulator into separate In Phase (*I*) and Quadrature (*Q*) channels. An array of self- and cross-correlators next perform the necessary multiplications between channels, followed by accumulations of 100 ms prior to data archiving. Fourteen self-correlations of each *I* channel will be performed, together with 91 each of I_iI_j, Q_iQ_j, I_iQ_j, and Q_iI_j

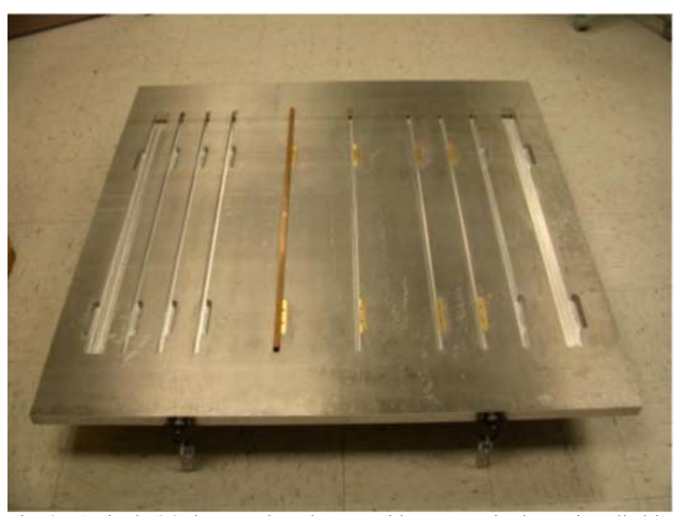

Fig. 2. A single 36 element slotted waveguide antenna is shown installed in the ground plane assembly that will eventually be populated by all 14 fan beam antennas.

cross-correlations between receiver channels *i* and *j*.

D. Control & Data Handling

The C&DH subsystem will perform several tasks. It will archive correlator data products. It will manage thermal control of the a/c sensor using a real time P.I.D. controller. It will configure the digital correlator and calibration switching controllers as a state machine to raster through the sequence of modes of operation in the proper order and with the proper individual dwell times. The nominal sequence of modes is: 1) clear Earth view; 2) clear Earth view plus injected calibration noise diode; and 3) reference calibration load view. Finally, the C&DH subsystem will provide a real time data and system configuration interface between the sensor and a separate user interface computer (nominally a portable laptop computer). C&DH CPU and Experimenter Laptop – PC104 stack inside sensor and user control laptop inside the aircraft cabin. The CPU module is built using a PC104: P266 CPU running QNX realtime Unix OS, Solid State hard drive, GPS, and Ethernet card. The prototype assembled, OS installed, and the ethernet interface to user control laptop are working. •Thermal monitoring & control interface board will be designed for 64 input channels (temps, voltages). This board will also have Independent PID zone heater controls for each receiver. Design requirements and interfaces have been established.

E. Calibration

There are three major components of the calibration subsystem. A controllable, highly repeatable source of partially correlated thermal noise is needed as a calibration standard for ground testing and characterization. The Correlated Noise Calibration Standard (CNCS) uses two synchronously clocked digital arbitrary waveform generators capable of producing two highly reproducible noise sources with arbitrary quadrature components of partial correlation [4]. It has been developed specifically to evaluate the performance of the receiver modules but is also intended for use as a more general piece of test equipment. Specifically, the CNCS will be used to: 1) evaluate benchtop performance of all receivers and correlators; and 2) determine the calibration information contained in on-board calibration noise diodes and reference loads (used in both aircraft and spacecraft designs).

The second component of the calibration subsystem is the on-board calibration that is a part of the instrument hardware. This includes individual uncorrelated black body warm loads assessable by each receiver via a calibration switch and a single noise diode that provides correlated noise to each receiver via a directional coupler inserted between each antenna and its receiver. These devices are intended to monitor and allow for correction of instrument gain and offset drifts, including those due to changes in the relative phase and amplitude matching between receivers.

The third component of calibration of a synthetic aperture radiometer is the image reconstruction algorithm. Image reconstruction takes the measured correlations as inputs and produces brightness temperature images as outputs. These images are, to first order, simple Fourier transforms of the measured correlations. However, this first order relationship only holds given ideal antenna characteristics. In practice, the overall accuracy of a synthetic aperture radiometer's images is dominated by the accuracy with which actual antenna element and interference patterns can be accounted for. It is for this reason that the proposed antenna design has been optimized with respect to stabilizing as much as possible the behavior of the element and interference patterns.

Absolute accuracy of the image reconstruction algorithm will be tested and demonstrated by a series of system-level tests. Ground Integrated System Testing will include a Sky cal on a rooftop instrument pedestal to exercise instrument internal cal with a cold, zero reflection antenna scene. This will measure antenna losses, ΔT, injected cal brightness, test ground plane effectiveness, and establish spacecraft accommodation requirements for antenna clearance. A Compact range anechoic chamber will be used to measure antenna-pair interference patterns. This will produce the G-matrix needed for image reconstruction. Aircraft Integrated System Testing will overfly an open ocean test site instrumented with a ground based upward directed noise beacon and full surface met data. This will provide a model TB scene from surface instrumentation to verify LRR absolute calibration.

F. Mechanical/Thermal Housing

Thermal analysis is on-going for an instrument operating specification of -50 to + 50 ^{o} C. A liquid-based chiller/heater system is under consideration as part of the thermal control system. Controller specifications will be further refined once a more precise definition of physical model, power dissipation, environmental parameters, and instrument calibration requirements are reached.

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