Enabling Technologies to Map Precipitation with Near-Global Coverage and Hour-Scale Revisit Times

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Abstract - The Tropical Rainfall Measuring Mission (TRMM) is a joint NASA/NASDA mission intended to produce rainfall accumulation maps using a combined active radar and passive radiometer set of sensors. The TRMM orbit inclination of 35 deg limits coverage to the tropics. The single satellite limits sampling (revisit time) to at best 15 hours. A new measurement concept is presented which extends and improves on the performance of TRMM. Global, rather than tropical, coverage is provided by a polar orbit inclination. The concept is comprised of a "core" spacecraft, which is an upgraded version of TRMM, together with ~8 smaller constellation satellites which carry a subset of radiometers. Proper orbital phasing of the core and constellation satellites will improve temporal sampling to ~3 hours. An overview of the concept is presented, followed by a description of current technology development projects which are underway to enable the measurement.

MISSION OVERVIEW

Accurate retrievals of rain rate from microwave thermal emission requires a level of a priori knowledge about the drop size distribution (DSD) and physical temperature of the rain drops. The DSD can be adequately constrained by a concurrent combination of active radar and passive radiometer measurements of the same rain cell. A profiling precipitation radar (PR) also provides altitude information about the rain, from which temperature can be adequately estimated. Thus, radiometer and PR sensors are complimentary components of precipitation measurement [1,2]. The core satellite for the proposed concept will carry upgraded versions of both the PR and TMI radiometer flown on TRMM. The technologies necessary to build such a platform are largely available today; no significant technology enabling research is needed.

The constellation satellites must meet very stringent mass, power, size, and, ultimately, cost constraints in order to permit a sufficient number to be flown. This immediately rules out a PR-class active sensor and suggests a scaled down (in terms of number of channels) version of the TMI. The TMI includes channels at 10.7, 19.4, 22.2, 37.0, and 85.5 GHz (all V&H-pol except 22.2 V-pol only). A minimum subset of channels deemed necessary to provide precipitation estimates is 10.7, 37.0, and 85.5 GHz, for heavy, medium, and light rain conditions, respectively. In addition, the cumbersome conical mechanical scanning approach used by TMI would impose too costly a requirement on the constellation satellite bus. For this reason, cross-track mechanical scanning is proposed for the smaller aperture 37 and 85.5 GHz channels. Electronic cross-track scanning is proposed at 10.7 GHz, via one-dimensional interferometric aperture synthesis [3].

The orbits of the core and constellation satellites must be properly oriented and phased to assure a sufficiently short revisit time. This, in turn, imposes significant requirements on the orbit deployment strategy and the satellite buses. Nominally, 8 constellation satellites are required to provide nearly 100% global coverage every 3

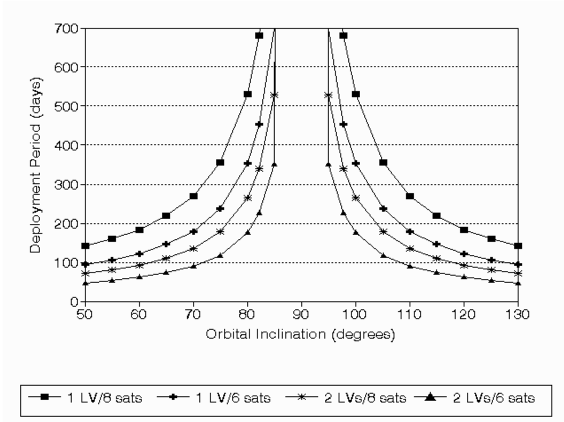

Figure 1. Constellation deployment scenarios

hours. These satellites are arranged in 4 highly inclined planes with 45 deg nodal separations. There are two satellites per plane with an in-plane spacing of 180 deg to ensure overlapping observing swaths at the equator. In Walker terminology this is an 8/4/0 constellation. Nominal altitude is 600 km - a compromise between spatial resolution and antenna size and swath width. An orbital inclination of greater than 75 deg is required. The core satellite underflies the constellation satellites in a lower inclination orbit to provide rain rate training for the constellation radiometers.

As in any multi-satellite constellation, launch vehicle (LV) costs are significant in the overall life cycle cost (LCC). Consequently, minimizing the number of LVs with multiple satellite launches is desirable and feasible. Figure 1 describes deployment periods for a range of different deployment single or dual LV scenarios as a function of orbital inclination utilizing differential nodal drift due to transfer orbit altitude variations. These scenarios have modest delta V requirements (< 100 m/s).

Alternatively, reducing the number of constellation satellites can potentially lower LCC and be accomplished by using existing operational meteorological satellites (*e.g.* DMSP/SSMI) or international contributions. This dictates that the remaining constellation satellites be in complimentary frozen sun synchronous orbits. Orbital deployment of these constellation satellites becomes more complicated and will likely require one LV for each orbital plane populated. Some “gap filler” satellites may be required if existing satellites are constrained to orbits with non-optimum nodal crossing times.

CONSTELLATION SATELLITE SENSORS

Each member of the constellation of constellation satellites is a cross track scanning microwave radiometer operating at 85.5, 37, and 10.7 GHz. It combines a single mechanically scanned offset reflector for 85.5 and 37 GHz with a thinned array synthetic aperture at 10.7 GHz. The real aperture has a 25 cm diameter which provides nadir resolution of 9x9 km at 85.5 GHz and 21x21 km at 37 GHz from 500 km altitude. The thinned array synthesizes a 90x90 cm aperture from 14 slotted waveguide antennas, each 90 cm in length, which provides nadir resolution of 20x20 km. Brightness temperature precision (NEDT) is estimated at 0.4 K or better for all channels. There is no mechanical deployment needed. Fig 2 shows a conceptual drawing of the instrument.

The cross track scanner uses an offset parabolic main reflector. The antenna is located near one end of the 90 cm slotted waveguide antennas used by the 10.7 GHz radiometer. Frequent (0.7 s) hot/cold cal permits the use of total power radiometers at 37 and 85 GHz.The radiometer electronics utilize Monolithic Microwave Integrated Circuit (MMIC) modules

The 10.7 GHz slotted waveguide design is based on current aperture synthesis antenna development work underway at NASA GSFC. Each array element has a dedicated MMIC receiver module. All possible combinations of pairs of receivers are digitally cross correlated. Synthetic aperture sampling produces a pushbroom collection of cross correlations every 0.71 s, resulting in 5 km along track spacing between samples.

CURRENT TECHNOLOGY DEVELOPMENTS

There are several projects currently underway which are intended to bring the hardware components of a constellation satellite design to a suitable Technology Readiness Level. A NASA Instrument Incubator Program (IIP) was begun in late 1998 with the critical technology goal of producing a pair of working MMIC receiver modules at 10.7 GHz that can perform the required IF digitization with sufficient sensitivity. These modules have passed their Critical Design Review, fabrication is proceeding, and acceptance testing is expected in late 2000. The modules will provide key benchmarks for mass, size, and power that are needed to develop a mature sensor design. The use of a MMIC approach can significantly lower the recurring costs associated with fabricating a large number of the constellation sensors and should also provide a large degree of uniformity between receiver elements of the interferometer array.

A second technology enabling project involves the fabrication, testing, field deployment, and end-to-end calibration of an aircraft prototype of the constellation sensor. All necessary antenna subsystem, RF receiver, digital correlator, command & data handling, and mechanical structure designs are being developed for an exact scale model of the eventual flight unit. The completed aircraft unit will then undergo extensive system characterization and testing, with the goal of producing a demonstrated set of test procedures and requirements for the flight units. A functional block diagram of the aircraft instrument is shown in Figure 3.

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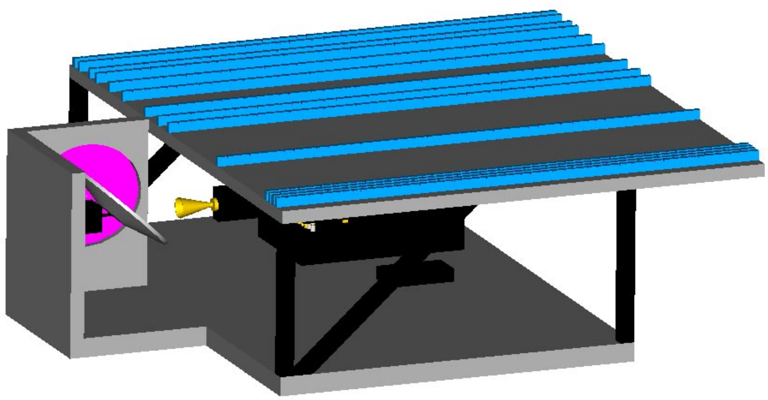

Figure 2. Conceptual drawing of constellation radiometer sensor.

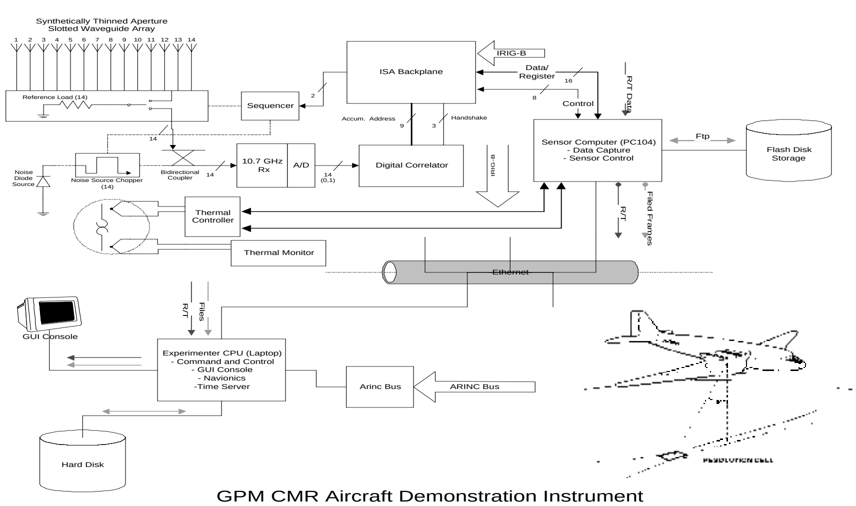

Figure 3. Functional block diagram of aircraft demonstration sensor.