The Planned Soil Moisture Active Passive (SMAP) Mission L-Band Radar/Radiometer Instrument[1]

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ABSTRACT

The Soil Moisture Active/Passive (SMAP) mission is a NASA mission identified by the NRC "decadal survey" to measure both soil moisture and freeze/thaw state from space. The mission will use both active radar and passive radiometer instruments at L-Band. In order to achieve a wide swath at sufficiently high resolution for both active and passive channels, an instrument architecture that uses a large rotating reflector is employed. The instrument system has completed the preliminary design review (PDR) stage, and detailed instrument design has begun. In addition to providing an overview of the instrument design, two recent design modifications are discussed: 1) The addition of active thermal control to the instrument spun side to provide a more stable, settable thermal environment for the radiometer electronics, and 2) A "sequential transmit" strategy for the two radar polarization channels which allows a single high-power amplifier to be used.

Index Terms— Soil-Moisture, Radar, Radiometer

1. INTRODUCTION

In January 2007, the U.S. National Research Council (NRC) released the first decadal survey of Earth science, Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond [1]. The Soil Moisture Active/Passive (SMAP) Mission was recommended to be implemented as one of the first in this series of missions, and is currently being developed for a late 2014 launch. The science objectives of SMAP are to provide frequent, global measurements of surface soil moisture and surface freeze/thaw state. These measurements will be used to enhance the understanding of water, energy, and carbon cycles, as well as improve weather and climate prediction.

To measure both soil moisture and freeze/thaw state at the required resolution, a combined active/passive L-Band microwave instrument is employed [2]. The key instrument requirements were determined by the SMAP Science Working Group to be: 1) Dual-polarization L-Band radiometer measurements at 40 km resolution, 2) Linear HH, VV and HV/VH L-Band radar measurements at 3 km resolution or better, and 3) A wide swath to ensure global three-day refresh time for these measurements (1000 km swath at the selected equatorial orbital altitude of 685 km).

Previous publications have provided high-level descriptions of the SMAP instrument [3]. To accomplish the challenging set of requirements, a 6-meter, conically-scanning reflector antenna architecture was selected for the instrument design. The deployable mesh antenna is shared by both the radiometer and radar instruments by using a single L-Band feed. (An artist rendition of the mesh antenna, rotating spot beam, and associated wide swath is shown in Fig. 1.)

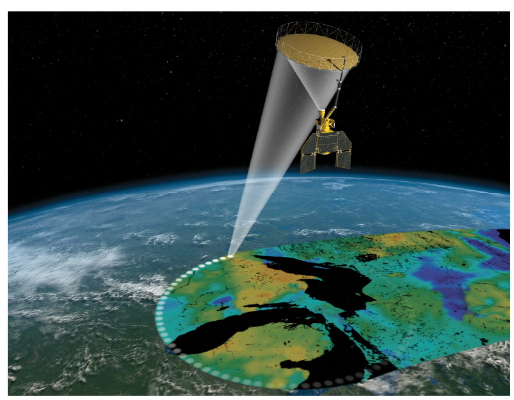

Figure 1 - Artist rendition of SMAP in orbit, showing the mesh antenna, antenna spot beam, and wide swath.

[1] The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this document related to SMAP is for information purposes only.

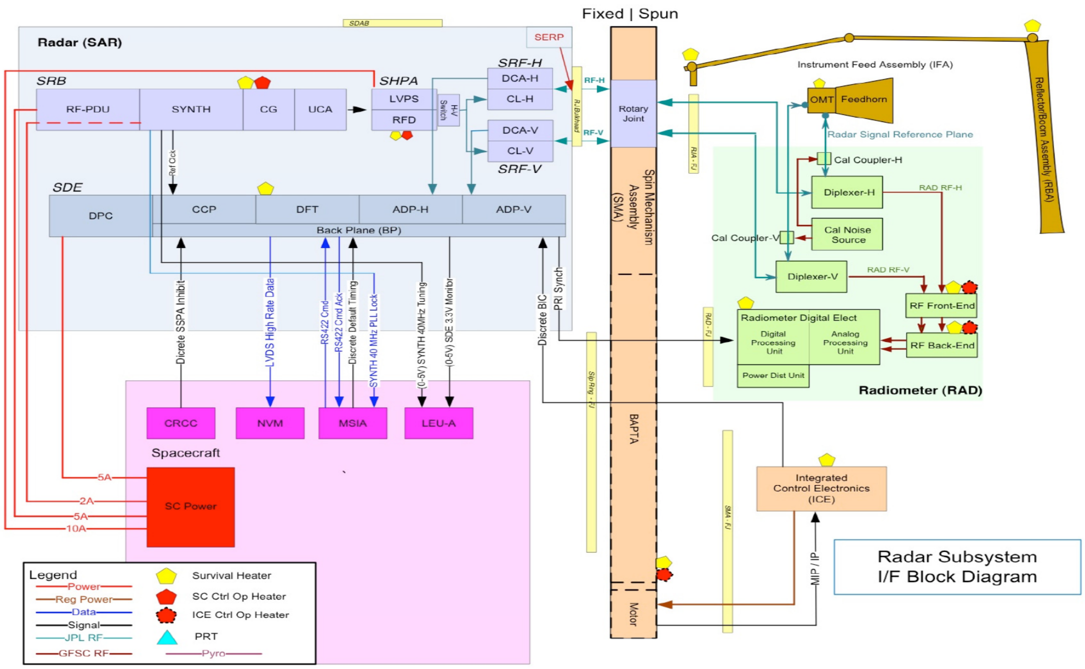

Figure 2 - SMAP instrument functional block diagram.

Whereas the radiometer resolution is defined as the real-aperture antenna footprint, the higher resolution radar measurements are obtained by utilizing synthetic aperture radar (SAR) processing. There have been two significant design changes since the instrument was last described in the literature. Active thermal control has been added to the SMAP spun side electronics in order to provide a more stable environment for the radiometer. This measure was taken to lower the risks of antenna temperature calibration associated with internally calibrated radiometers. Secondly, the SMAP radar has been modified to utilize a single high power transmitter to generate both linear polarizations.

2. INSTRUMENT ARCHITECTURE

The overall SMAP instrument architecture is shown in Fig. 2. The antenna subsystem, which includes the reflector/boom assembly and instrument feed assembly, is colored gold. The radiometer and radar electronics are highlighted in green and blue respectively.

As with most microwave instruments, the antenna is the dominant instrument subsystem that determines both the ultimate measurement performance and governs spacecraft accommodation. In order to meet the 3-day refresh requirement at the equator, a wide measurement swath is necessary. The requirement for radiometer and radar spatial resolution at L-Band dictate that a relatively large antenna aperture must be employed. As determined by previous trade-off studies [4], the most economical approach for accomplishing the required simultaneous radiometer and radar requirements is to utilize a shared antenna/feed approach. A reflector antenna was chosen to ensure that system calibration requirements, primarily for the radiometer, are met. Large, rotating antennas have been proposed for L-Band remote sensing in the past [4]. As shown in Fig. 1, rotating the reflector in a conical fashion about the nadir axis provides a wide swath of measurements at a constant incidence angle. Because the rotating reflector is shared by the radiometer and radar, the RF signals from the Earth must be separated by diplexers into the active and passive bands respectively. These diplexers are located on the spun side and are shown as part of the radiometer subsystem in Figure 2. Note that all of the radiometer electronics are located on the spun side of the interface to minimize front-end losses, with slip rings providing a telemetry, signal, and power interface to the spacecraft. The more massive and more thermally dissipative radar electronics are on the fixed side, with the transmit/receive pulses routed to the spun side via a two channel RF rotary joint.

3. ANTENNA AND SPIN ASSEMBLY

Due to the relatively large size of the required reflector (6-meter projected aperture), a deployable structure is necessary. Deployable mesh reflector technology is quite mature for spaceborne communications applications, and analyses of the mesh material have indicated its acceptability for remote sensing applications [4]. The unique aspect of the SMAP application is the necessity for rotating the large antenna. At the nominal SMAP altitude of 685 km, the reflector must be rotated at a rate of 13.0 rpm to maintain contiguity (i.e., minimum overlap) of the measurements in the along-track direction. Key requirements that must be met by the reflector assembly include: 1) All RF performance requirements (gain, beam efficiency, etc.) must be met under the spinning conditions, 2) The total momentum generated must be within the amount the spacecraft is capable of compensating, and 3) The disturbances resulting from residual imbalances must be sufficiently small as to not affect overall pointing or impart excessive loads to the spin motor bearings.

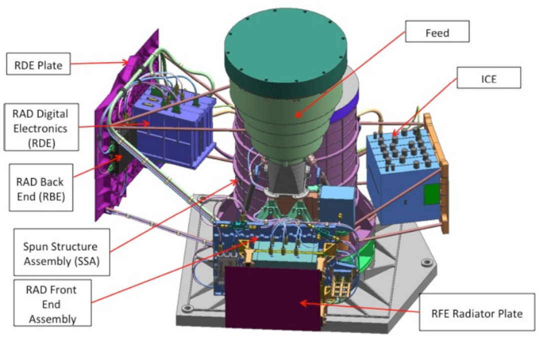

Figure 3 – Spun platform assembly and electronics on spun portion.

Table 1 - SMAP instrument parameters.

Antenna Key Parameters	
Beamwidth (1-way, 3 dB)	2.7°
Look Angle, Incidence Angle	35.5°, 40.0°
Peak Gain	36 dBi
Rotation Rate	13.0 rpm
Radiometer Key Parameters	
Center Frequency	1.41 GHz
Resolution (root footprint area)	40 km
Channels	T_v, T_h, T_3, T_4
Bandwidth, Integration Time	22 MHz, 65 ms
Precision (T_v and T_h)	0.93 K
Calibration Stability (T_v and T_h)	0.65 K
Total Error (T_v and T_h)	1.1 K
Radar Key Parameters	
Transmit Carry Frequencies	Tunable from 1.22 to 1.30 GHz
Channels	HH, VV, HV (or VH)
PRF, Pulse Length	2.9 kHz, 15 μsec
Azimuth Dwell Time	42 ms
Transmit Bandwidth	1 MHz
Peak Transmit Power	500 W (at output of amplifier)
Single-look res (broadside)	250 m x 400 m
Noise Equiv. σ^o (broadside)	-29 dB

The deployable antenna is attached to the structure of the spun platform assembly (SPA). The SPA includes the primary and secondary structures. The former provides the backbone of the SMAP instrument, while the radiometer electronics and integrated feed assembly (IFA) are supported by the secondary structure. The feed assembly design employs a single horn, capable of dual-polarization and dual frequency (the radiometer frequency at 1.41 GHz, and the radar frequencies between 1.22 and 1.30 GHz). In order to minimize the moment of inertia, the horn is designed to be as small, compact, and lightweight as possible. To meet measurement performance requirements, the antenna beamwidth of the radiometer frequency band is between 2.3° to 2.5°, and the antenna gain at the radar band is better than 35.5 dBi.

4. RADIOMETER DESIGNS AND PARAMETERS

Measurement precision for a radiometer is principally affected by NEDT. NEDT (0.65 K) is set by the system noise temperature (777 K), bandwidth (22 MHz), and net integration time (65 ms for a 30 x 30 km grid cell, including both fore and aft looking radiometer samples). Many other factors contribute to measurement imprecision, including antenna pattern instability. Altogether, measurement precision is 0.93 K. The radiometer calibration stability is 0.65 K. Calibration stability is achieved by frequent observation of internal calibration sources, observation of stable earth and space targets, and stable thermal design. The root-sum-square of the 0.65 K stability and the 0.93 K precision estimates yields a total error of 1.1 K, satisfying the 1.3 K requirement of the soil moisture science objective.

Initially the radiometer was designed with passive thermal control, and analysis demonstrated that the required thermal stability could be met. Achieving anomaly free performance over a large thermal range, however, carries a development risk due to potential for thermo-mechanically induced calibration shifts associated with internally calibrated radiometers; these have been observed in the pre-launch testing of Aquarius, Jason-2, AMR, and Juno MWR. It was therefore decided to implement an active thermal control augmentation to the existing passive thermal design. The temperature of the RAD front end (see Fig. 3) is settable to within ±2°C over a 15°C range within the acceptable flight temperature range.

5. RADAR DESIGN AND PARAMETERS

To obtain the required 3 km and 10 km resolution for the freeze/thaw and soil moisture products, the radar will employ pulse compression in range and Doppler discrimination in azimuth to sub-divide the antenna footprint. This is equivalent to the application of synthetic aperture radar (SAR) techniques to the conically scanning radar case [5]. Due to squint angle effects, the high-resolution products will be somewhat degraded within the 300-km region of the swath centered on the nadir track, with azimuth resolution capability decreasing over this region as the pixel location approaches the spacecraft sub-satellite track. The baseline system has both V- and H-pol channels. An additional channel measures the HV (or VH) cross-pol return.

The radar relative error depends on the signal-to-noise ratio (SNR) and the number of independent samples (or "looks") averaged in each measurement, as well as the relative calibration error. Looks will be obtained by averaging in both range and azimuth. The 1-MHz bandwidth will yield a ground range resolution of approximately 250 m and will result in a minimum of 12 looks in range. The Doppler diversity will be maximized at a scan angle perpendicular to the platform velocity, leading to a single-look azimuth resolution of approximately 400 m. The single-look resolution will degrade as the scan angle approaches the platform velocity vector, reaching 1500 m at the inner swath edge (150 km cross-track). Table 1 provides a summary of the SMAP instrument performance requirements.

As last reported in the literature, the RF portion of the SMAP radar was essentially designed as two individual radars operating independently; with each linear polarization channel (V or H) having a separate set of electronics in its transmit chain, which included a chirp generator, up-converter and high power amplifier. To ease volume and mass issues encountered in the spacecraft design, a decision was made to generate both linearly polarized transmit signals sequentially by switching a single high-power amplifier. The current sequential transmit scheme is shown in Fig. 4. In this timing configuration, the duration of the total transmit event has been extended, and the nominal pulse repetition frequency (PRF) is lowered to approximately 2.9 kHz in order to accommodate the temporal width of both echo returns. As was the case in the previous design, the two polarized returns are isolated by transmitting signals at offset frequencies (f1 and f2) as shown in Fig. 5. This scheme maintains the same science performance.

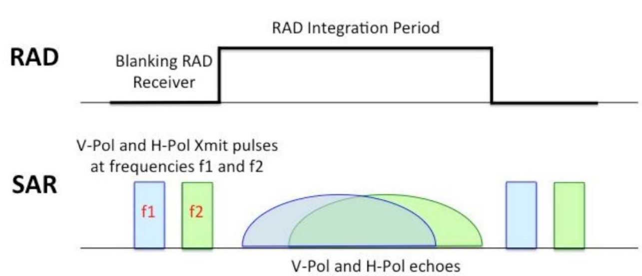

Figure 4 – Instrument timing in sequential transmit configuration.

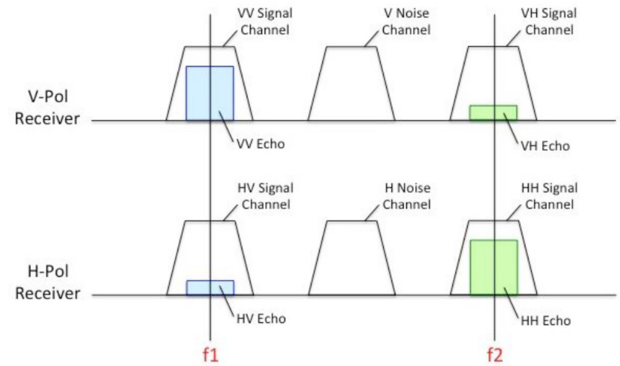

Figure 5 – Signals from V- and H-pol channels are isolated in frequency domain

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Acknowledgments

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