The HYDROS Radiometer/Radar Instrument

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Abstract **The science objectives of the HYDROS mission are to provide frequent, global measurements of surface soil moisture and surface freeze/thaw state. In order to adequately measure these geophysical quantities, the key instrument requirements were determined by the HYDROS science team to be: 1) Dual-polarization L-Band passive radiometer measurements at 40 km resolution, 2) Dual-polarization L-Band active radar measurements at 3 km resolution, and 3) A wide swath to insure global three day refresh time for these measurements (1000 km swath at the selected orbit altitude of 670 km). As a solution to this challenging set of instrument requirements, a relatively large, 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 electronics by employing a single L-Band feed.**

Keywords-soil moisture, freeze/thaw, radiometer, radar.

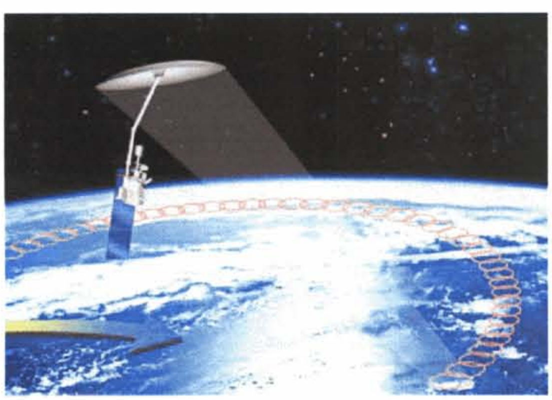

Fig.1: Artist depiction of HYDROS mission in orbit.

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I. INTRODUCTION

The HYDROS (Hydrosphere State Mission) has recently been directed to proceed with mission formulation as part of the most recent NASA Earth System Science Pathfinder selection (ESSP-3). The science objectives of the HYDROS mission are to provide frequent, global measurements of surface soil moisture and surface freeze/thaw state. These measurements will be used to enhance understanding of the 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 needed [1].

The key instrument requirements were determined by the science team to be: 1) Dual-polarization (linear H and V) L-Band passive radiometer measurements at 40 km resolution, 2) Linear HH, VV and HV L-Band active radar measurements at 3 km resolution, and 3) A wide swath to insure global three day refresh time for these measurements (1000 km swath at the selected orbit altitude of 670 km). In addition, these science requirements must be satisfied under the stringent cost-cap imposed on all ESSP missions.

As a solution to this challenging set of requirements, a relatively large, 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 electronics by employing a single L-Band feed. Whereas the radiometer resolution is defined in the standard manner as the real-aperture antenna footprint, the higher resolution radar measurements are obtained by utilizing unfocused synthetic-aperture (SAR) processing (see Fig. 2).

Instrument partners include Jet Propulsion Laboratory (JPL), California Institute of Technology (overall instrument management and radar electronics), NASA Goddard Space Flight Center (radiometer), and the Canadian Space Agency (antenna design and feed assembly).

In this paper, the HYDROS instrument design trade-offs and selected instrument design features will be described. A characteristic theme of the HYDROS instrument design is the utilization of proven technologies and techniques in an innovation fashion to meet the mission requirements. Although large deployable mesh antennas have been used in communication applications, this will mark the first time such technology is applied in a rotating configuration for high-resolution remote sensing. The unique aspects associated with extending standard SAR techniques to the conically scanning radar geometry will also be addressed.

II. ANTENNA SUBSYSTEM

A. *Overall Antenna Architecture*

As with most microwave instruments, the antenna is the dominant instrument subsystem that both determines the ultimate measurement performance and governs spacecraft accommodation. In order to meet the 3-day revisit requirement at the equator, a wide measurement swath is necessary. The radiometer and radar resolution requirements at L-Band also dictate that a relatively large antenna aperture must be employed. As determined by previous trade-off studies (see [2]), 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. As shown in Fig. 2, rotating the reflector in a conical fashion about the nadir axis provides a wide swath of measurements at a constant incidence angle. A variety of other instrument architectures were considered (phased array, separate antennas for radiometer and radiometer, etc.), but the scanning, shared reflector approach was found to be optimum in terms of maximizing performance while minimizing implementation cost and risk.

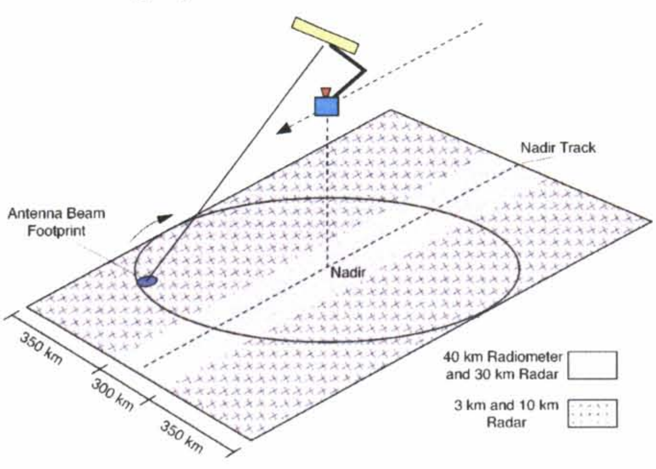

Fig. 2: HYDROS measurement geometry showing radiometer swath, and high and low resolution radar swaths.

Large, rotating antennas have been proposed for L-Band remote sensing in the past (see [2]). Typically, these proposals have involved construction of a spin table upon which the antenna, supporting structure, feeds, and microwave electronics are mounted. The entire table is then rotated to form the swath. Telemetry and power between the de-spun spacecraft and spun electronics is passed through a slip ring interface. With such a design, it is often advantageous to locate the high power radar electronics on the de-spun spacecraft side. When this is the case, an RF rotary joint must also be provided across the spun/de-spun interface. Such a spin table approach therefore involves a relatively massive rotating structure and numerous interfaces between the spun and de-spun sections.

In contrast to the spin table antenna architecture, the baseline HYDROS approach involves rotating the antenna reflector only (see Fig. 3). The feed and instrument electronics are all fixed to the de-spun spacecraft. The single feed is aligned with the rotational axis of the antenna, so when the reflector is spun, the resulting beam forms a conical scan. This approach has the advantage of minimizing the total spun mass, as well as eliminating all spun/de-spun electrical interfaces. Note, however, that for a fixed feed with a fixed set of linear polarization axes, the polarization with respect to the surface will rotate with the reflector position and will not be aligned with the desired horizontal and vertical axes. Compensation for this effect is straightforward, but handled differently for the radiometer and radar, and is discussed in II-C.

B. *Antenna Reflector/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 [2]. The unique aspect of the HYDROS application is the necessity for rotating the antenna. At the nominal HYDROS altitude of 670 km, the reflector must be rotated at a rate of 14.6 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 residuals imbalances must be sufficiently small as to not effect overall pointing or impart excessive loads to the spin motor bearings. Two designs for the reflector/spin assembly are being developed in parallel for eventual down-selection (see Fig. 3). Both designs are based on flight-proven mesh reflector technology. One involves application of a radial rib reflector design, and the other the application of a perimeter truss reflector design.

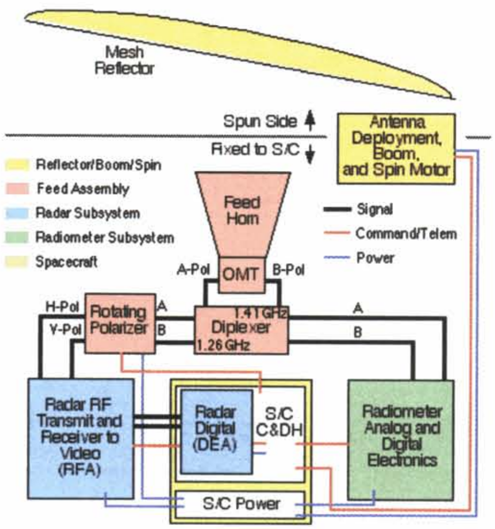

Fig.3: HYDROS instrument functional block diagram.

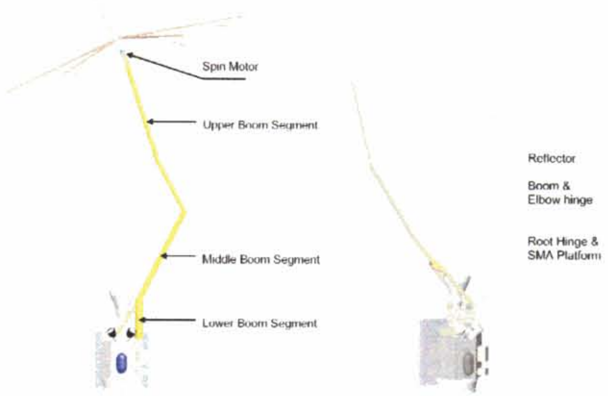

Fig. 4: Two concepts for HYDROS rotating 6 meter deployable mesh reflector. Radial rib type reflector will be rotated at central hub at upper tip of boom (image courtesy of Harris Corp.). Perimeter truss type antenna to be grasped by boom on reflector edge and rotated by motor positioned down on zenith deck of spacecraft (image courtesy of Astro Aerospace, Northrop-Grumman Space Technologies).

C. Antenna Feed Assembly

The baseline feed assembly design employs a single smooth-wall horn, capable of dual-polarization and dual frequency (radiometer frequency at 1.41 GHz, and the radar frequencies at 1.26 and 1.29 GHz). As shown in Fig. 3, the radar and radiometer frequencies will be separated by diplexers and routed to the appropriate electronics for detection. As mentioned previously, because the feed is fixed and the reflector is rotating, the two linear feed polarizations (denoted A and B) will rotate relative to the desired horizontal and vertical polarizations (denoted H and V) with respect to the surface. For the radiometer measurements, the strategy is to measure the first three modified Stokes parameters T_A, T_B, and U_{AB}. These measurements, together with knowledge of the antenna position, can then be used to rotate the polarization basis to achieve a constant polarization basis orientation with respect to the surface and obtain the desired measurements T_H and T_V.

In general, the problem of rotating a set of radar measurements from one polarization basis to another requires that a fully polarimetric quad-pol system be implemented. Such an implementation is being studied for HYDROS, but the current baseline system is not fully polarimetric (see Section IV), and therefore the radar measurements cannot be rotated to the desired polarization basis during ground processing in an analogous manner to the radiometer measurements. As a solution to this problem, a polarizer unit —implemented with a pin-polarzer rotating synchronously with the reflector —is used to launch linear polarized signals in the desired horizontal/vertical basis with respect to the surface (see Fig. 3).

III. Radiometer Electronics Subsystem

Measurement precision for a radiometer is proportional to the square root of the bandwidth and the measurement integration time (the time-bandwidth product). Given a reflector rotation rate of 14.6 rpm, the available integration time for each measurement is 42 ms. That value, however, will effectively be doubled when both fore and aft looking radiometer measurements are combined. Choosing a measurement bandwidth of 25 MHz and a system noise temperature of 590 K, the resulting precision is 0.4 K. The radiometer calibration stability is estimated to be 0.5 K. Calibration stability is achieved by frequent observation of internal calibration sources and stable thermal design. The root-sum square of 0.5 K and the 0.4 K stability and precision specifications yield a total random error of 0.64 K, satisfying the 1 K requirement of the soil moisture science objective.

Table 1: HYDROS instrument parameters.

Antenna Key Parameters	
Beamwidth (1-way, 3 dB)	2.6°
Look Angle, Incidence Angle°	35.0°, 39.3°
Peak Gain	36 dBi
Rotation Rate	14.6 rpm
Radiometer Key Parameters	
Center Frequency	1.41 GHz
Resolution (root footprint area)	38 km
Channels	T_A, T_B, U_{AB}
Bandwidth, Integration Time	25 MHz, 84 msec
Precision	0.4 K
Calibration Stability	0.5 K
Total Relative Error	0.64 K
Radar Key Parameters	
Transmit Frequencies	1.26 GHz (H), 1.29 GHz (V)
Channels	HH, VV, HV
PRF, Pulse Length	3.5 kHz, 15 μsec
Maximum Aperture Length	37 ms
Transmit Bandwidth	1 MHz
Peak Transmit Power	500 W
Single-look res (broadside)	250 m x 400 m
Noise Equivalent σ^o	-38 dB

The radiometer is calibrated in two stages. The first stage is internal calibration of the polarimetric receiver. Internal matched-loads and noise diodes provide warm and hot calibration noise temperatures. Details of the receiver calibration are given in [3]. The second stage of calibration deals with antenna corrections. Self-emission and cold-space contributions are removed, cross-polarization is corrected, and finally sidelobe contributions are subtracted.

In addition to calibration, radio-frequency interference (RFI) is important to the design. Multiple methods of handling RFI are being considered: simple filter, limiting, and pulse detection and temporal blanking. These methods are compatible with the basic radiometer design; temporal blanking as an RFI mitigation technique is attractive because a blanking scheme is already planned for mitigating the HYDROS radar pulses in the radiometer. These techniques will be useful for mitigating ground-based radar interference such as from air-route surveillance radars.

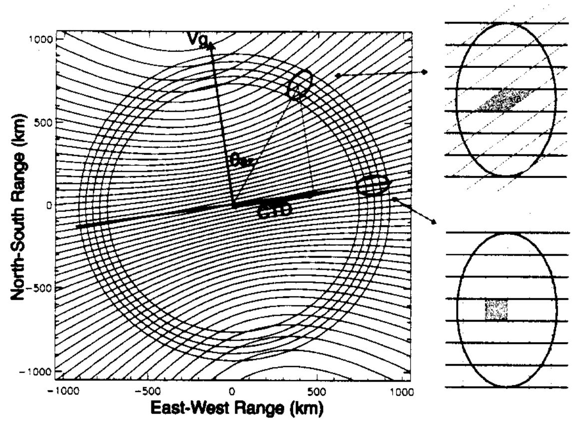

Fig. 5: Radar measurement geometry as a function of scan angle. The spacecraft velocity vector is shown as v_g. Also shown are the iso-range and iso-Doppler contours that govern the radar azimuth resolution.

IV. Radar Electronics Subsystem

To obtain the required 3 km and 10 km resolution for the freeze/thaw and soil moisture products, the radar will employ range and Doppler discrimination to sub-divide the antenna footprint. This is equivalent to the application of synthetic aperture radar (SAR) techniques to the conically scanning radar case [4]. Due to squint angle effects, the high-resolution products will not be obtained within the 300-km band of the swath centered on the nadir track (see Fig. 2 and Fig. 5). In order to minimize range/Doppler ambiguities with the baseline antenna and viewing geometry, separate carrier frequencies are used for each polarization (1.26 GHz for H-Pol and 1.29 GHz for V-Pol). An additional channel measures the HV cross-pol return. This frequency separation approach allows both polarization channels to be operated simultaneously with the same timing.

There are two requirements placed on the radar relative error. The soil moisture measurement requirement places a 0.5 dB relative error requirement for both vertical and horizontal co-polarized backscattering coefficient measurements at 10 km resolution. The freeze/thaw state measurement places a 1 dB requirement on the relative error of each vertical and horizontal co-polarized backscatter measurement at 3 km resolution. 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 for 3 km cells and 40 looks for 10 km cells.

As shown in Fig. 5, 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 decrease 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 HYDROS instrument performance requirements.

The electronics subsystem is mounted on the zenith deck of the spacecraft, as close to the feed assembly as possible. A digital interface with the spacecraft C&DH is provided to transfer the radiometer science measurements and telemetry to the spacecraft recorder for transmission to the ground. The radiometer receives a timing signal to protect the receiver during radar transmit events. The radar RF electronics assembly, which creates the transmit pulses and amplifies and down-converts the return echoes, is also mounted on the zenith deck of the spacecraft. The radar digital electronics assembly, which governs the radar timing and performs digital processing on the return echoes, is located within the spacecraft avionics VME card cage, yielding a lower cost integrated design. In the baseline design, the software necessary to command the radar timing and high-rate data collection is implemented on the spacecraft CPU. Radar data are transferred to spacecraft recorder via the high-speed interface within the VME cage.

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