A Spaceborne L-Band Radiometer-Radar Concept for Land and Ocean Surface Monitoring[1,2]

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Abstract—An L-band radiometer-radar concept has been studied for spaceborne remote sensing of land surface wetness, freeze-thaw state, and ocean surface salinity. The integrated design provides simultaneous passive and active measurements with potential for enhanced geophysical retrieval accuracy and spatial resolution. The design takes advantage of cost savings achievable using shared subsystems and hardware. The baseline system concept has been evaluated to determine the feasibility of the technical approach and as a point of departure for system trade-offs. The unique features of this concept are the integration of the radiometer and radar sensors, the use of a deployable-mesh conically-scanned reflector antenna, and the use of unfocused SAR processing. Taken together, these features represent a significant departure from conventional radiometer, scatterometer, and SAR approaches. The conical wide-swath scan is a desirable feature that provides constant incidence angle and antenna pattern characteristics across the swath, simplified data processing (passive and active), and frequent global sampling. The concept is targeted for a low-cost, short-development-cycle mission, suitable for NASA's Earth System Science Pathfinder (ESSP) series.

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1. INTRODUCTION

This paper describes a combined L-band radiometer-radar concept for global remote sensing of the Earth's surface. The concept is designed to measure soil moisture, freeze-thaw state, and ocean salinity from space. These measurements are high priorities for land surface hydrology, oceanography, and climate research, but cannot currently be measured by any spaceborne system. The science needs and rationales for these measurements are outlined in NASA's Earth Science Enterprise Research Strategy [1] and Strategic Plan [2]. The present study is an outgrowth of an earlier task to evaluate the technology of large, lightweight mesh antennas for remote sensing applications requiring low frequency and/or high spatial resolution [3], [4]. Soil moisture, freeze-thaw, and ocean salinity sensing all require low frequency (L band) large-aperture antennas to achieve the desired measurement sensitivities and spatial resolutions [5]-[7].

Concept Overview

The baseline concept is a combined radiometer and radar system operating at 1.4 GHz (radiometer) and 1.2 GHz (radar). The radar is an unfocused synthetic aperture radar (SAR) that provides resolution enhancement over a conventional scatterometer but does not utilize the full high-resolution SAR capability. The antenna is a 6-m-diameter deployable-mesh parabolic reflector with dual feedhorns. The antenna beams are offset at 40° from nadir, and the entire system rotates about the nadir axis providing a conical scan and wide swath (Figure 1). The radiometer resolution is 40 km. The processed radar resolution varies from 1 km at the edge of the swath to 20 km at the center of the swath (see discussion, Section 4). Global repeat coverage is obtained in approximately 3 days. By optimally combining the passive and active data, the goal is to

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[1] 0-7803-6599-2/01/$10.00 © 2001 IEEE.
[2] Updated October 12, 2000

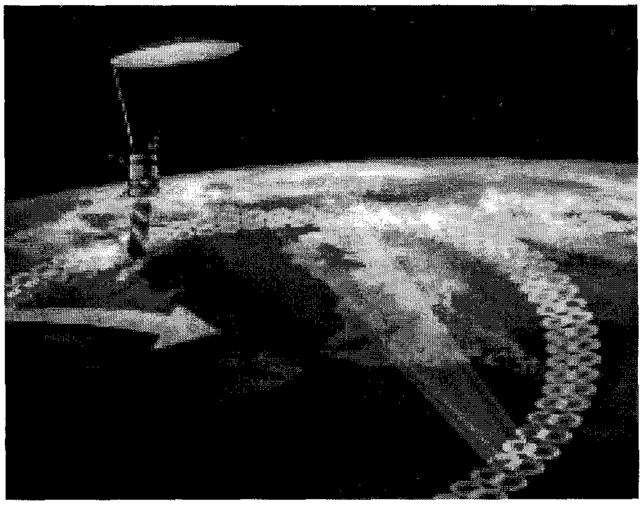

Figure 1: Antenna and conical scan configuration

estimate soil moisture at a resolution of 10-40 km, and freeze-thaw state at a resolution of 1-3 km, every 3 days. Ocean salinity will be retrieved as space-time averages, at 100-km resolution and weekly or monthly time intervals. Final specifications of the output products are determined by trade-offs between estimation accuracy and space-time resolution.

Concept Rationale

There are a number of advantages to be gained by integrating the L-band radiometer and radar sensors into a single instrument with a conical scan configuration.

(1) Surface roughness adversely affects radiometric estimates of ocean salinity and soil moisture. Radar measurements are sensitive to surface roughness, and can be used to improve the accuracy of radiometric estimates if the radar data are acquired simultaneously and at similar frequency and spatial scale to the radiometric data.

(2) Synthetic aperture processing is commonly used to improve the spatial resolution of the radar signal. Radar estimates of soil moisture and freeze-thaw state can thus be derived at higher spatial resolution than radiometric estimates. However, the radar signal is more significantly influenced by roughness, vegetation, and topographic effects. By combining the two types of data, the coarser-resolution radiometric estimates can be used as constraints on the radar-derived estimates, leading to better estimation accuracies at the higher resolution.

(3) The conical scan configuration provides constant incidence angle and antenna pattern characteristics across the entire swath. This considerably simplifies the data processing, interpretation, and geophysical retrievals. The wide swath capability also provides frequent repeat coverage for global monitoring.

(4) Significant cost savings can be achieved operationally by integrating radiometer and radar sensors in a single instrument rather than launching them as separate missions.

2. CONCEPT DESCRIPTION

The general characteristics of the system concept are listed in Table 1. The specific radiometer and radar characteristics are shown in Tables 2 and 3. The antenna system has two feedhorns that reduce the required antenna spin rate to a reasonable 6 rpm with overlapping footprint coverage. A pre-dawn equator crossing is desired so that sampling occurs when the soil temperature and moisture profiles are at their most uniform, i.e. before solar-induced surface heating and evaporation occurs. During the pre-dawn hours, the extent of the ionosphere and resulting Faraday rotation effects are also at a minimum. A 6am/6pm equator crossing orbit is optimum for spacecraft power management since the solar panels can be fixed in orientation with respect to the sun. The orbit altitude of 450 km and beam offset angle from nadir of 46° provide a swath width of 975 km. Due to earth curvature the incidence angle at the surface is 50°. Global coverage is obtained in 3 days with this orbit and swath. The antenna one-way 3-dB footprint resolution is 30 x 46 km. The radiometer measures the third Stokes parameter (U) in addition to the vertical (V) and horizontal (H) polarizations. This provides a capability for Faraday rotation correction, enabling data from the 6pm orbit overpasses to be utilized in addition to data from the 6am overpasses [8]. The radar measures three polarization modes (VV, HH, and HV). These modes are required by the soil moisture retrieval algorithms in order to compensate for surface roughness effects and to discriminate vegetation.

Table 1: System Characteristics

Antenna type	Offset-fed, deployable, parabolic mesh reflector
Reflector aperture diameter	6 m
Number of feedhorns	2
Beam offset angle	46°
Spin rate	6 rpm
Orbit type	Circular, sun-synchronous, 450-km altitude, 6am/6pm equator crossing
Earth-incidence angle	50°
Swath width	975 km

Table 2: Radiometer Characteristics

Frequency	1.41 GHz
Polarizations	V, H, U
Accuracy	0.2 K
Stability	0.5 K
Resolution	30 x 46 km
Coverage	3 days
Data Rate	8 Kbps
Power	

Table 3: Radar Characteristics

Frequency	1.26 GHz
Polarizations	VV, HH, HV
Precision (12-100 looks)	1-0.5 dB
Stability	0.2 dB
Noise Equivalent σ°	< -30 dB
Footprint Resolution	
Low-res	3-20 km
High-res	1-3 km
Coverage	
Low-res	3 days
High-res	4 days
Data Rate	16 Mbps peak, 5 Mbps average
Power	400 W peak, 300 W avge

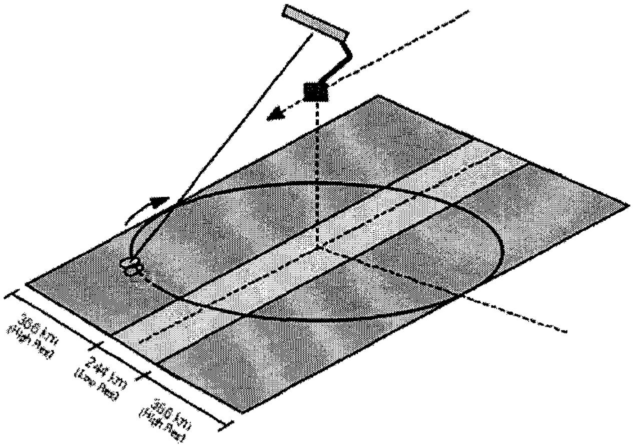

Figure 2: Swath dimensions showing “high”- and “low”-resolution regions

As discussed in Section 4, the radar spatial resolution varies continuously across the swath as a function of the capability for synthetic aperture processing. For convenience the outer swath regions with resolution in the range 1-3 km are designated as “high-res”, and the center portion of the swath with resolution in the range 3-20 km is designated as “low-res” (Figure 2). Global coverage at high resolution is not 100% achieved in 3 days due to the reduced swath.

3. ANTENNA SYSTEM

Mesh Reflector

The key antenna component is the lightweight deployable mesh reflector. Deployable mesh antennas are now mature technology with extensive flight heritage in military and civilian space telecommunications. The reflectivity and transmission loss characteristics of mesh antennas have been studied in detail [9]. However the use of these antennas for remote sensing applications is novel and challenging. This is due to: (1) the requirements for radiometric precision and accuracy that demand a highly reflective and geometrically accurate mesh surface; and (2) the additional requirements for momentum compensation and spacecraft attitude control imposed by a large mechanically-scanned antenna. These aspects have been studied as part of an ongoing NASA instrument incubator technology task at the Jet Propulsion Laboratory. The results of the study show that the radiometric performance, momentum compensation, and attitude control capabilities of the antenna and spacecraft designs considered are more than adequate to meet the requirements of the mission under study.

The mesh reflector design used for this study is the perimeter-truss reflector developed by TRW Astro. This design provides high surface accuracy and reflectivity up to 40 GHz. The construction provides high stiffness, low mass, and high aerodynamic and solar transmissivity. A 12.25-m-diameter version of this antenna was launched in October, 2000 on the commercial geosynchronous communication satellite Thuraya-1. Figure 3 shows the 12-25-m reflector during ground testing in stowed and deployed configurations.

A 6-m version of the perimeter-truss antenna design was considered for this study. An antenna subsystem design and structural analysis was performed, and the vibrational modes determined. From the centripetal acceleration at 6 rpm there is a maximum deflection of no more than 4 mm at the far end of the antenna major axis. This can be corrected by the boom design in the final configuration. Based on the momentum compensation and attitude control system analyses carried out with candidate small-spacecraft platforms, no problems with pointing or stability are anticipated.

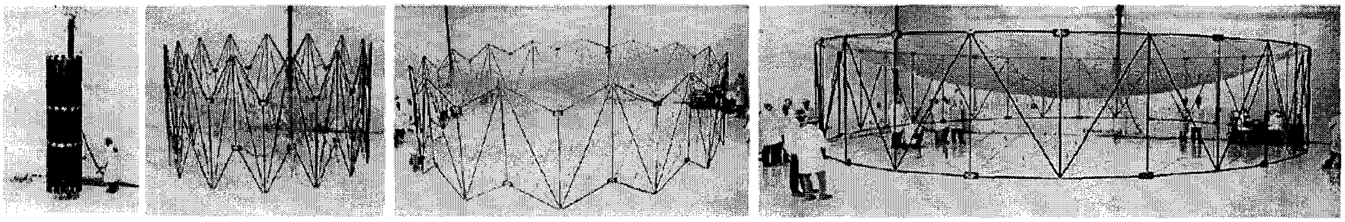

Figure 3: TRW Astro 12-25-m-diameter perimeter–truss reflector in stowed and deployed configurations

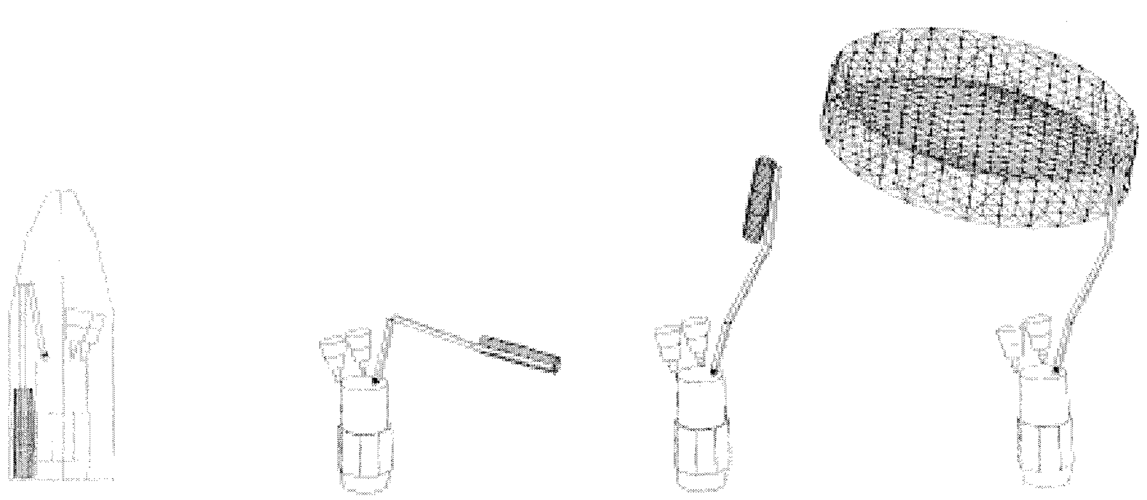

Figure 4: Launch vehicle accommodation and deployment sequence

The stowed 6-m antenna on the spacecraft bus can fit comfortably within the Taurus launch vehicle. Figure 4 shows schematically the stowed configuration within the launch vehicle and successive stages in the deployment sequence.

Feedhorn Design

A key aspect of the overall lightweight antenna design is the feedhorn design and construction. Operating at L-band the feedhorns are necessarily large in dimension. A study has been done to optimize the feedhorn design and construction such that the volume and mass of the feedhorns are minimized while maintaining the beam performance (symmetry, gain, beam efficiency, cross-polarization) of the overall antenna system. Figure 5 shows a profiled corrugated horn design which provides the desired radiation patterns and has reasonable length. It has good overall performance in terms of symmetric patterns, edge taper, and low cross-polarization. A major portion of the mass is due to the corrugation walls. In this design the number of corrugations (14) and wall thickness (2.54 mm) are minimized, and the mass contribution due to the corrugation walls is only 2.9 kg. The total feedhorn mass is less than 4.5 kg.

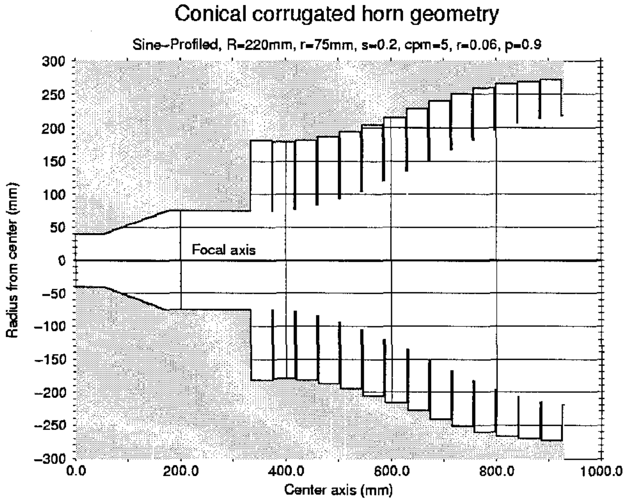

Figure 5: Profiled corrugated horn geometry

4. RADAR PROCESSING

The dimensions of the 3-dB antenna footprint on the surface essentially determine the spatial resolution of the radiometer measurements. The resolution of the radar measurements can be improved significantly by applying familiar signal processing techniques. Specifically, simultaneous range and Doppler discrimination can be employed to sub-divide the radar footprint into higher resolution pixels, as shown in Figure 6. This basic technique has been used extensively on previous synthetic aperture radar (SAR) missions. In the present case, there are unique issues presented by the conically scanning geometry that make the performance of the radar different from previously-flown systems [10]. Because the antenna is rotating at 6 rpm, the footprint dwell time over the target region is much shorter than would be the case with a conventional side-looking system. This constrains the Doppler-dimension resolution to be on the order of one kilometer. This resolution, however, is adequate to address the desired global scale measurement of soil moisture, freeze/thaw, and sea surface salinity, as discussed earlier. Furthermore, the relatively coarse resolution allows significant simplification of the radar processing relative to conventional SAR systems.

Another performance characteristic that results from the conically scanning geometry is the dependence of radar resolution on the antenna azimuth angle. As shown in Figure 6, the measurement pixels are delineated by the intersection of lines of iso-range and iso-Doppler on the surface. When the antenna is rotated to the side-looking position, these contours are perpendicular and the measure-

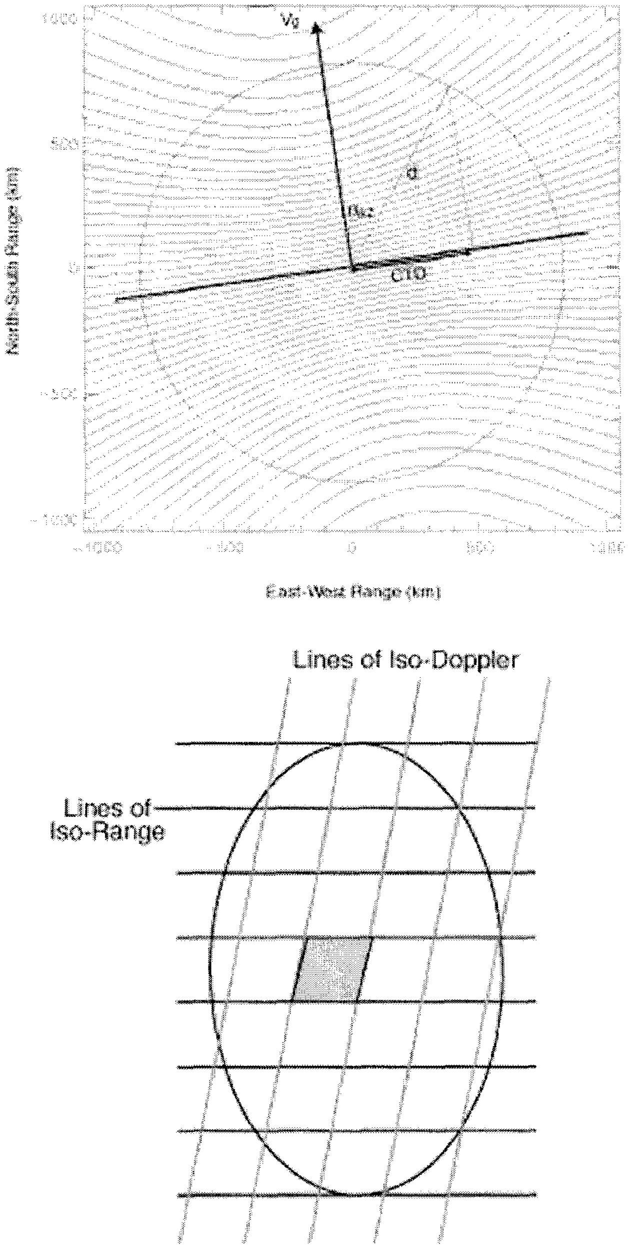

Figure 6: In the upper diagram, the iso-Doppler contours are shown for the radar scan geometry. The lower diagram illustrates how simultaneous range and Doppler discrimination are used to achieve sub-footprint high resolution radar measurements.

ment cell is effectively rectangular. As the antenna is rotated forward or aft if this position, however, the Doppler contours rotate with respect to the range contours and the intersecting region which forms the measurement pixel is consequently elongated. This elongation effect continues to occur until, when the antenna is forward looking, the Doppler and range lines are parallel and two-dimension resolution of the surface is no longer possible. The ultimate implication of this "squint elongation effect" is that resolution is a function of cross-track position (i.e. distance from the subsatellite track). Near the subsatellite track, therefore, there is a region of swath where the desired higher resolution cannot be obtained, as shown in Figure 2. Note that in this "center gap" region lower resolution radar measurements are still obtained. For this system the center gap region is approximately 25% of the total swath.

5. DATA ANALYSIS

The combined passive and active L-band system described here has the potential for providing enhanced retrieval accuracies, at high spatial resolution, for measurements of soil moisture, freeze-thaw state, and ocean salinity under varied surface conditions. To realize this potential, additional algorithm development work is required that would involve optimal estimation techniques applied to the multichannel multi-resolution data types. Few historical data sets currently exist of the type required for this analysis. New experimental data have been acquired recently using the Passive-Active L-/S-band (PALS) airborne sensor which was flown for the first time during the SGP99 field experiment in Oklahoma [11], and over the Atlantic Ocean Gulf Stream [12], in summer 1999. Synthetic data sets can also be generated to analyze the effects of temporal and spatial sampling, spatial resolution, instrument noise, and model uncertainty on the scientific utility of the retrievals [4], [13]. These efforts are continuing and will be expanded in the near future.

6. CONCLUSIONS

This paper has described an innovative system for passive and active spaceborne sensing at L band. The system uses a large-aperture reflector antenna optimized for low mass and low stowed volume, and providing the on-orbit spatial resolution, swath width, global coverage, measurement accuracy and stability required by the scientific objectives of the mission. The analysis of the baseline system design indicates that the system is feasible and can provide the performance characteristics desired. The concept fits within the scope of the Earth System Science Pathfinder (ESSP) program which focuses on low-cost research missions with rapid development and implementation paths. The system would contribute important new measurements on soil moisture, freeze-thaw, and ocean salinity for applications in Earth science and global change studies.

ACKNOWLEDGMENTS

This work represents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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