Dual Frequency Synthetic Aperture Radar (SAR) Mission for Monitoring Our Dynamic Planet

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Advances in spaceborne Synthetic Aperture Radar (SAR) remote sensing technology make it possible to acquire global-scale data sets that provide unique information about the Earth's continually changing surface characteristics. Short duration missions such as the Spaceborne Imaging Radar-C (SIR-C) and the Shuttle Radar Topography Mission (SRTM) have established the vast potential of SAR for expanding our knowledge of Earth (Ref. 1-3). A long-duration (≥ 5 year) free-flying SAR mission is essential to routinely provide valuable information about the dynamic characteristics of our planet. This paper describes such a globally preeminent SAR mission concept, based on a dual frequency, polarimetric, interferometric SAR that has broad scientific, environmental preservation, operational, and commercial utility.

The system is uniquely capable of addressing a wide range of NASA Earth Science SAR measurement objectives such as surface deformation, environmental management objectives such as rapid response to oil spills, operational objectives such as ice navigation, plus a broad range of commercial applications such as mapping, surveillance, forestry, agriculture, resource exploration, and land use and urban planning. A powerful feature that greatly reduces the potential for tasking conflicts is the instrument's ability to operate both frequencies independently and simultaneously.

The implementation approach includes an innovative government-industry collaboration that has the potential to lead to the creation of new information industries, and emulate the many examples of successful industrial segments initiated by government investment, such as the Internet, GPS and commercial space telecommunications.

Keywords: Radar, interferometry, topography, vegetation, remote sensing, synthetic aperture radar, SAR.

1. INTRODUCTION AND REQUIREMENTS

This paper presents is a technical summary of a dual-band synthetic aperture radar (SAR) system design performed by JPL. This system concept was developed after the LightSAR Project was unable to obtain an industry partner with acceptable risk to the governement (Ref. 10). It is one of the mission concepts studied as part of NASA's effort to develop an Earth-imaging radar satellite system that will return valuable science data, demonstrate advanced technologies, and revolutionize commercial radar imaging from space[1].

Because a dual-band SAR offers important benefits both to the science and civil operations community and to U.S. industry, an innovative government-industry teaming approach is being explored in which NASA puts the system in orbit and private industry operates a commercial ground segment and produces data products for scientists in return for commercial rights to the data, (Fig. 1). This approach leverages experience from previous commercial space-based imaging radar efforts and government studies (Ref. 8-10).

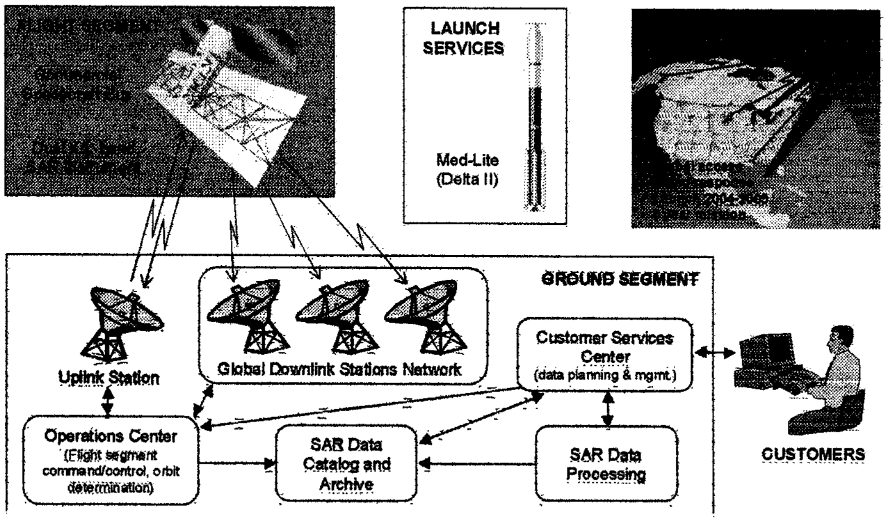


Figure 1. L/X –SAR system concept.

The design presented here is a non-optimized engineering solution, which has been examined in sufficient depth to establish confidence that it can be produced and will meet a broad set of requirements. The design achieves reduced cost by using advanced radar technology components with a proven commercial spacecraft bus, by using commercial launch and operations services, and by following a fast-paced schedule. Conclusions from the design exercise are: (1) the dual-band system is technically feasible, and (2) costs can be reduced to 25 percent of those of any previous free-flying, space-based imaging radar (including launch services).

Because of its planned long-term (5yr) operation, the system would collect large amounts of valuable information about our changing planet. It would provide an important contribution to NASA's Earth Science Enterprise (ESE) and to civilian environmental operational monitoring programs (Ref. 9). The goal of the NASA ESE is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. A new SAR mission is essential to help address the fundamental ESE question of "how is the Earth changing and what are the consequences for life on Earth?"

One key science application of this new SAR mission is measuring motion of the Earth's surface to help to better understand earthquakes and volcanoes and to support emergency management efforts. Other applications include studying the movements and changing size of glaciers and ice floes to better understand long-term climate variability; developing highly detailed and accurate elevation maps; monitoring floods and predicting where they are likely to occur; assessing terrain for the likelihood of discovering oil or other natural resources; early recognition and monitoring of oil spills; assessing the health of crops and forests; planning urban development and understanding its likely effects; studying land cover and land-use change. Because of advances in radar and spacecraft technology, the spacecraft under study would provide greater capability than comparable systems that are now in orbit, or are being planned.

The satellite would provide nearly complete coverage of the Earth's surface every 8-10 days. This repeating coverage gives the system the unique capability of continuously monitoring changes in the Earth's topography as small as a few millimeters. Capabilities under study would enable the radar to measure features as small as a few meters, offering significant potential for commercial use in topographic mapping, land management, planning, and development.

2. MISSION DESCRIPTION

The mission will generate data for commercial, Earth science, and civilian applications. It is capable of detailed mapping of Earth surface change using its repeat-pass interferometry technique for continuous monitoring of Earth's dynamic topography to a height accuracy of a few millimeters. Moreover, the system will have the ability to map large areas of the Earth's surface, especially oceans, using a ScanSAR technique. It can also provide both high-resolution measurements for commercial interests and large-scale geophysical measurements. Because of federal regulations restricting the bandwidth available at L band, resolution greater than 3 m is not realizable.

The flight segment consists of a commercial spacecraft bus carrying an L and X band SAR instrument. The radar operating modes include high resolution (3 to 5 m ground resolution with swath width of 20 km for both L and X-band), dual and quad-polarization L-band modes with 25 m resolution and 50 km swath, ScanSAR (500 km) and ultra- wide swath (900 km) low-resolution ScanSAR for mapping large areas. Other system features include Global Positioning System (GPS) receivers to help provide precision orbit control to enable repeat pass interferometry for millimeter-level surface deformation measurement. The satellite will operate at an 800 km sun-synchronous, polar orbit, after being launched by a Delta-II or equivalent vehicle. The nominal exact orbit repeat is 8 to 10 days, and the orbit will be maintained in a 250 m tube to enable the required surface deformation measurement accuracy (Ref 4,5,6).

2.1. Radar design

A parameterization of the L-band and X-band radar designs considered is presented in Table 1. Note that the table shows not only the frequency diversity but the polarization and operational mode diversity as well.

The longer (L-band) wavelength radar and use of multiple polarization modes will allow better distinction of textures, vegetation structures and water content, soil moisture, ice thickness, and other parameters. Imaging swaths 100 km wide will provide 25-m horizontal resolution, accurate to within a few millimeters vertically. As shown in Table 1, even higher resolution, 1-3 meters, is being considered in order to provide opportunities for

Table 1 . L/X SAR System Design.

	L-band							X-band		
Mode of Operation	Repeat-Pass Interferometry	Quad Polarization	Dual Polarization	High Resolution	Spotlight	ScanSAR	Ultra Wide Swath ScanSAR	High Resolution	Wide Swath	ScanSAR
Ground Resolution (m)	25	25	25	a) 5 b)10	3 to 5	100	1000	a) 3 b) 5 c) 10	25	100
Ground Swath Width (km)	100	50	50	20	15 x 20	a) 280 b) 500	900	20	a) 100 b) 75	a) 280 b) 500
Field of View (range of incidence angles in degrees)	28 to 44	20 to 40	25 to 52	20 to 48	20 to 52	20 to 52	8 to 57	a) 15 to 43 b) 10 to 60 c) 10 to 60	20 to 52	20 to 52
Number of Looks	4	4	4	a) 1 b) 4	3	8	40	a) 1 b) 1 c) 4	4	8
Polarizations	HH or VV	HH, HV, VV, VH	HH & HV, or VV & VH	HH or VV	HH or VV	HH & HV, or VV & VH	HH or VV	VV	VV	VV
Noise Equivalent Sigma 0 (dB)	-31 to -40	-34 to -37	-30 to -37	-31	-25 to -31	a) -32 to -41 b) -31 to -44	-34 to -42	a) -20 to -24 b) -23 to -30 c) -23 to -30	a) -20 to -30 b) -24 to -29	a) -27 to -34 b) -27 to -34

additional commercial applications, such as high-resolution surface mapping and co-registration with electro-optical sensor data. The wide-swath ScanSAR mode will provide large-area mapping over the 500-km-wide area.

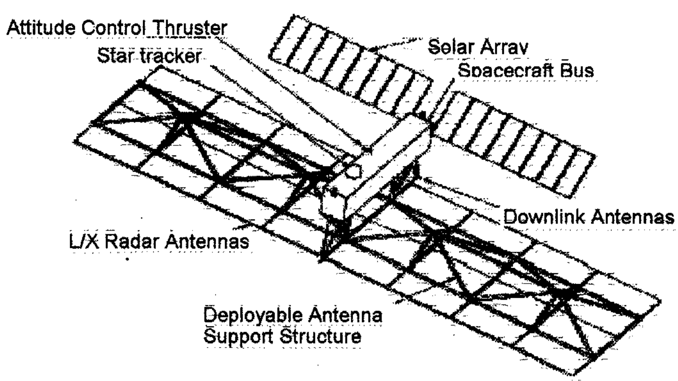
Characteristics of design concept under study include state-of-the-art technologies with significant reduction in mass and volume, as well as instrument and mission life-cycle costs. These technologies, such as monolithic microwave integrated circuits (MMIC), when applied to an L-band, multipolarization, high-performance SAR with multiple resolutions and swath imaging capabilities will increase the radar capability without increasing the mass. To meet the imaging agility needs, electronic beam steering has been included in order to maximize the targetable swath. In addition, as noted previously, X band is being considered for very high-resolution commercial applications, although, C band also has sufficient bandwidth allocated to meet some high-resolution imaging needs.

To make L/X SAR commercially viable and to obtain time series of data over multiple seasons, designs for missions with lifetimes of 5 years are being examined. The design life is important in terms of the reliability of the electronics, and sizing of propellant required to maintain the orbit over the mission life. In addition to greater costs for higher quality electronic parts and increased redundancy, additional electronics and propellant translate into additional mass. This may result in the need for a more costly launch vehicle with greater lift capability. Therefore, a balance must be achieved between the overall system performance and the scope of requirements.

2.2. Orbit considerations

An 8 to10-day repeating orbit maintained within a 250-m-diameter tube (determined by GPS), would provide visibility of most locations on Earth about once each day. The repeat period was defined to meet imaging requirements for glacier research. Flying within a 250-m tube is a challenging requirement that must be met in order to achieve global surface deformation measurements, with accuracies of a few millimeters, using repeat pass interferometry. For design purposes a sun-synchronous orbit at an altitude of 800 km, with an inclination of 97.8°, was evaluated. Orbits at lower inclinations were also examined. Moreover, the orbit must be known with an accuracy of <10 cm radially and cross-track and 1 m along-track. Commercial requirements for the orbit control and precise orbit determination are less stringent.

Figure 1. Mechanical Configuration



2.3. Spacecraft Bus

Several aerospace companies offer spacecraft bus designs that could meet the L/X mission design. Bus adaptations required to accommodate the radar instrument include: attachment structures for the radar antenna, deployment structure, and latch mechanism; installation of radar electronics in the bus; provision for unique memory and data handling capacity; tailored downlink transmitter(s)/ antenna(s); tailored solar array and battery provisions; tailored attitude control provisions; and tailored GPS configuration. Figure 1 illustrates a generic bus mechanical configuration used for design and cost evaluation purposes to convey one of many possible designs.

Table 2 summarizes the performance needed for a bus to support a radar mission. The current design requires that the bus be capable of rolling 70° (±35° from nadir) to perform high-latitude mapping near the poles (up to 80° N and 86° S). This capability also is required in order to provide maximum coverage and responsiveness to commercial imaging customers.

Table 2. Bus Performance.

Feature	Capability
Autonomy	Operate w/o commands 24 hr (typical), 7-day max
Mass	<710 kg (flight weight, without radar instrument, including 30% contingency – *Jeff; Let's put in L/X radar mass estimate here, and let's make sure Parag reviews this Table)*
Power	50 Amp-Hr batteries; 1-axis gimbaled solar array
Attitude Control	Pointing Accuracy: elevation 0.5°, azimuth 0.1°; knowledge: 0.01° Perform 70 degree roll in 10 min. (for right and left looking)
Propulsion	Maintain 250-m-diam. tube about the velocity vector
Data Storage	256-Gbit solid-state recorder, radar data recording for ~1 orbit (Spotlight mode), > 3 orbits (ScanSAR mode)
Command/Telemetry	S-band receiver/transmitter, with command encryption
Radar Data Link	X-band transmitter, up to 620 Mbps
Subsystems	Assumed design includes hot gas thrusters, reaction wheels, inertial reference unit(s), star tracker(s), sun sensors, magnetometer, and onboard (GPS)

2.4. Ground Segment

Commercial viability of the L/X SAR depends on the radar sensitivity and the ability to return data quickly. Commercial applications are dependent on fast turnaround of data products to meet commercial needs for oil spill response, storms, floods and other hazards. The ground segment architecture and operations concept have been tailored to provide unprecedented capability for responding rapidly to oil spills and other emergency management situations, and is based on a balance between leveraging existing capabilities and adding new facilities.

To enhance the return of data products to commercial users an Environmental Data Center is envisioned as part of the architecture. This center will provide value-added processing to produce unique products needed for commercial applications. The space segment and ground segment architecture provides an average time between observation opportunities of less than12 hours in most areas of interest, with over 95% probability of coverage in under 24 hours.

3. CONCLUSION

The L/X SAR would be the first NASA commercial/science SAR mission. An innovative NASA-industry partnership has been proposed that is commercially viable, while reducing the government's overall cost and increasing the capability. This partnership will utilize advanced MMIC devices and lightweight materials to develop a high-performance radar system that will meet both NASA's science goals and industry's commercialization goals. A new set of working relationships and technologies will be applied, and existing spacecraft, launch vehicles and an operations infrastructure will be used to reduce costs and maintain a schedule that will bring this innovative concept to orbit years sooner than was previously achievable.

8. ACKNOWLEDGMENTS

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors would like to thank members of the LightSAR project and the SAR Mission Studies project for their contributions.

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