A REDUCED POWER DIGITAL ELECTRONICS SYSTEM FOR A DIGITAL BEAMFORMING SPACE EXPLORATION SYNTHETIC APERTURE RADAR.

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Introduction: We are designing a P-band (70 cm wavelength) digital beamforming radar system that is modular and can be used for imaging polarimetry of Earth and rocky planets and moons, as well as asteroids and comets. This radar (Space Exploration SAR, SESAR) is based off the successful P-band EcoSAR airplane radar that was developed at NASA Goddard for biomass measurements [1]. A major design problem with orbital beamforming radars is the power required to drive and steer the multiple beams. To adapt the airplane radar to an orbital format, it is particularly important to reduce the power of the digital electronics and RF elements.

Science Goals: Synthetic aperture radar (SAR) is the only remote sensing technique capable of penetrating through meters of material and imaging buried surfaces at high (meter-scale) spatial resolution. Multiple decadal survey science goals require a high-resolution view of subsurface stratigraphy, and in dust-covered environments it is critical to be able to expose bedrock and search for buried features that hold clues about the geologic history.

SESAR is particularly well-suited to studies of Mars and the Moon. Locating habitable regions, finding water, and determining the evolution of Martian hydrology and cryosphere is a primary goal of Mars exploration. Because ice and water outside the polar regions will be buried, radar is a key technology for cryosphere studies. Ice has a distinct radar polarization signature (high backscatter and Circular Polarization Ratio values) that can be used to locate buried ice deposits. A P-band radar instrument could map subsurface ice deposits [2]. P-band polarimetric radar would also reveal the internal structure in the upper tens of meters of the polar deposits, which is needed to detect seasonal changes and decipher how recent changes in climate have affected the cryosphere. High-resolution radar mapping has the potential to reveal buried fluvial systems on Mars (Fig. 1).

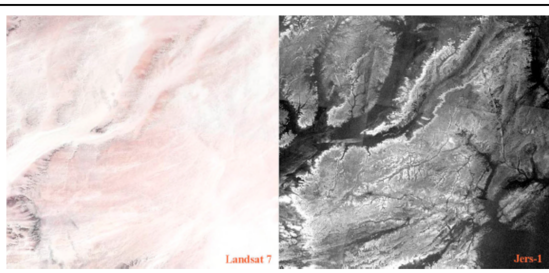

Fig. 1: Radar (right) reveals buried fluvial networks in southern Sudan that are not visible in Landsat imagery (left). SESAR would provide meter-scale imaging of buried channels on Mars. Image from [3].

The lunar surface is covered in a ~2-10 m of regolith that often hides geology that is crucial to our understanding of lunar processes. Radar can image through the regolith to characterize the near-surface stratigraphy of the Moon. High-resolution (<5 m) morphologic mapping and polarimetry would provide details about the volcanic processes that built the mare (e.g. size of flows, emplacement scenarios) and would enable comparisons to terrestrial analogs. The radar images could be used to locate and track lava tubes [4], which is important for both science and future exploration purposes. P-band will provide a new depth of penetration and rock population measurement that can be used to determine how the regolith varies across the Moon. Mapping the column structure of the regolith will provide new data on how airless surfaces age [5] as well as provide critical information for future landed missions that involve digging and/or sampling.

P-band (70 cm) is an ideal wavelength because 1.) it is capable of seeing beneath 2-15 m of material, 2.) it penetrates to a depth that is reachable by human and robotic explorers, 3.) it provides high-resolution, few meter-scale imaging, and 4.) it will not scatter off cm-sized rocks that are prevalent in near-surface regolith. Although P-band requires a larger antenna than prior shorter wavelength radar systems (Mini-RF on Lunar Reconnaissance Orbiter, the Magellan radar), P-band provides the penetration depth needed for science goals like mapping buried ice on Mars and looking for lava tubes and mapping buried lava flows on the Moon.

Digital beamforming allows for “smart” data collection [6], where one radar system can provide different data types (e.g. high- or low-res polarimetry, stereo imaging, altimetry, scatterometry, nadir sounding) depending on the science requirements defined for each surface target. Digital beamforming is also highly beneficial for spacecraft operations because it allows multiple look angles to be acquired without rolling the spacecraft. Nadir operations like scatterometry and sounding can also be performed with no rolls. The multi-mode and beamforming operation of SESAR SESAR’s onboard processing capabilities are a significant advancement over prior radars and can return quick-look processed products that can be used to assess which data to send back.

The SESAR Instrument Concept: SESAR is an advanced digital beamforming radar instrument concept that will enable a new class of observations suitable to meet Decadal Survey science goals for planetary exploration. The instrument design will employ a modular approach that allows for the customization of the instrument architecture to meet scientific mission requirements for a specific planetary body. The modular approach distributes the radar systems into instrument panels composed of active subarrays, as illustrated in Fig 2.

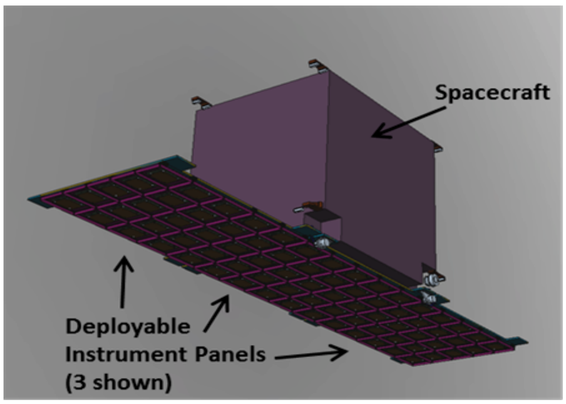

Fig. 2: SESAR employs a modular approach that permits customizing the architectures for a given planetary mission. SESAR's distributed architecture enables advanced operational modes.

SESAR's architecture will be fully programmable and capable of multi-mode radar operation including polarimetric SAR imaging, nadir SAR altimetry, and scatterometry. Some of its advanced programmable features include single, dual, or full polarimetry; multi-look angle data collection; simultaneous left and right of the track imaging; selectable resolution and swath width; digital beam steering (no moving parts); and beam pattern control; among others.

Under the technology-development program awarded by NASA's Planetary Instrument Concepts for the Advancement of Solar System Observations program (PICASSO), the SESAR team is developing innovative techniques to reduce the mass and power consumption of the radar.

The SESAR instrument will use a distributed digital electronics architecture that implements frequency domain multiplexing (FDM) techniques to provide the full beam steering agility while providing significant reductions in power consumption. The FDM approach reduces the number of digital-to-analogue converters (DACs) and analogue-to-digital converters (ADCs) and enables centralized waveform generation and data acquisition with reduced power and mass.

In addition, the SESAR team will use an ultra-wideband (UWB) tightly-coupled dipole array (TCDA) that will permit the reduction of the size and weight of the SESAR antenna. This is achieved by designing the element such that the sensing band lies at the lower range of the antenna's total operational bandwidth (approximately 2 GHz bandwidth).

Using these innovations, SESAR will be able to synthesize multiple antenna beams, simultaneously or interleaved, permitting the implementation of non-conventional imaging that can overcome fundamental limitations of conventional radar systems [6,7,8]. Some of its benefits include an increase in the measurement swath without reducing the received antenna gain, and the suppression of ambiguities or localized interference in the receiver signal by appropriate null-steering of the antenna pattern. The antenna gain, beam pointing angle, and sidelobe structure can be programmed in real-time for specific tasks. Furthermore, multiple beams can be synthesized on both sides of the flight-track, as well as nadir, using a single nadir-looking antenna, thus increasing the coverage area.

Summary: The SESAR instrument approach would be a first in planetary exploration. SESAR's agile radar operation, modularity, and multimode operation, while using technology that can be optimized to produce the best possible data set for the individual science goals, will help pave the way for the next generation planetary radar systems. SESAR's innovative approach to lower mass and power consumption will make these future missions feasible.

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Acknowledgement: Part of this work is funded by a NASA ROSES PICASSO grant.