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# Near-Subsurface Science from a Digital Beamforming Polarimetric Synthetic Aperture Radar

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## Abstract

Many important questions in planetary science depends on our ability to detect and map surface and subsurface layers of planetary bodies. We are developing a P-band (435 MHz, 70 cm wavelength) digital beamforming radar, called Space Exploration SAR (SESAR), capable of providing the measurement flexibility needed to address multiple types of science goals. SESAR will provide high spatial resolution imaging, full polarimetry, multi-beam scatterometry and altimetry of planetary targets such as the Moon and Mars by using beamforming technology that can adjust the radar experiment to meet the specific science goals of each target.

## 1. Introduction

Planetary science objectives include mapping the surfaces and near-surfaces of planets to determine how they are shaped through different processes (volcanism, cratering, fluvial activity, etc.), comparing the development and evolution of cryospheres across planets, determining how regoliths develop through time, and locating regions that are (or were) hospitable to life. Low frequency Synthetic Aperture Radar (SAR) is the only remote sensing technique capable of imaging buried surfaces at meter-scale spatial resolution.

The SESAR instrument will be modular and can be easily adapted for Discovery (or New Frontiers) missions to the Moon, Mars, Mercury, Venus, and asteroids (including Ceres and Phobos).

The lunar surface is covered in a ~2-10 m of regolith (dust and small rock mixture). SESAR will be able to image through the regolith to characterize the near-surface stratigraphy of the Moon in unprecedented detail not available to any other instrument. P-band radar data acquired with Earth-based systems have revealed rough buried flows in mare regions that are not visible to any other type of instrument [1]. SESAR will also be able to image buried channels [1] and possibly detect near-surface lava tubes.

Locating habitable regions, finding water, and determining the evolution of the Martian cryosphere are primary goals of Mars exploration. Because water and all ice outside of the polar regions is buried, radar is a key technology for cryosphere studies. Radar also has a long history of detecting buried fluvial channels on the Earth and Mars and could be used to search for these features in the upper tens of meters of the Martian surface.

## 2. Radar Parameters

Using a P-band wavelength will ensure that SESAR will image features below 2-3 m (and as much as 10-15 m) of surface cover on the Moon and Mars (Fig. 1), and many tens of meters into water ice on Mars. P-band is an ideal wavelength because it provides high-resolution, meter-scale imaging, and it will not

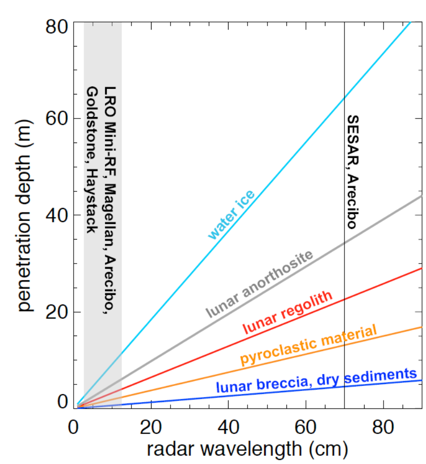


**Figure 1** SESAR will have a greater penetration depth than most prior radars (orbital and Earth-based). Penetration depth is defined as the point at which the wave power has been reduced by 1/e relative to original power.

reflect from centimeter-sized rocks that are prevalent in near-surface regolith.

SESAR’s polarimetric data products will provide important information about the nature of the surface and subsurface that cannot be obtained solely with backscatter power images [2]. SESAR’s polarimetry will also be critical for distinguishing mantling deposits from smooth uncovered surfaces, and for determining the roughness and continuity of geologic units.

# 3. Instrument Concept

The SESAR instrument employs 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 key systems into instrument panels composed of active subarrays, as illustrated in Fig 2.

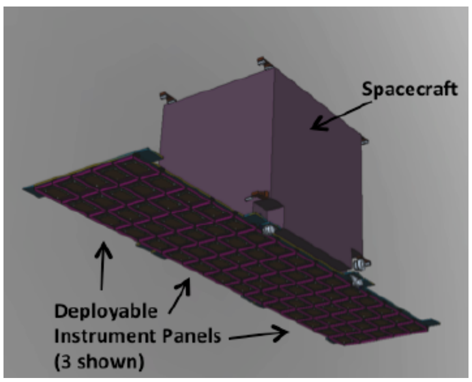


**Figure 2** SESAR's distributed architecture enables instrument customization for a given planetary mission, and the implementation of advanced operational modes.

SESAR's architecture will be fully programmable and capable of multi-mode radar operation including unprecedented 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.

One of SESAR's main features will be its operation using electronic beamforming on transmit, and digital beamforming on receive [3]. Both beamforming techniques employ interference among the signals from each of the radar antenna subarrays to generate far-field beam patterns with predefined and selectable look angles, beamwidths and sidelobe levels, and without the use of moving parts.

Using beamforming, 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 [3,4]. 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.

In the SAR imaging mode, SESAR will image the ground with fine resolution pixels in the order of up to 2 m over one or multiple beams to permit geologic analysis. Each of the beams will measure up to four polarizations to facilitate retrieval of the Stokes parameters, from which a broad suite of scattering mechanisms associated with particular geological processes can be assessed.

# 6. Summary and Conclusions

The digital beamforming and full polarimetry capabilities of SESAR will provide a very flexible radar system that can be used to tailor radar experiments to the science questions for a given planetary target.

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