**Development of the Space Exploration SAR (SESAR) for Planetary Science Missions.** Lynn M. Carter[1] , Rafael R. Rincon[2], Cornelis F. du Toit[2], Martin Perrine[2], Daniel Lu[2], Roger Banting[2], David M. Hollibaugh Baker[2], Peter Steigner[2], Kenneth Segal[2], Babak Farrokh[2], David Caruth[2], Michael Choi[2], Iban Ibanez[2], William Alberding[2] and Tasneem Khan[2] [1]University of Arizona, Lunar and Planetary Laboratory (lmcarter@arizona.edu), [2]NASA Goddard Space Flight Center (rafael.f.rincon@nasa.gov).

**Science Goals and Objectives:** Many important planetary science and human exploration goals require measurements of the subsurface. In particular, the upper tens of meters contain stratigraphic evidence of climate change (buried fluvial channels, ice), volcanic history and evolution (lava flows, channels and tubes) and regolith development (including pyroclastic deposits and volatiles). Synthetic aperture radar (SAR), is the best geophysical tool to provide both the meter-scale resolutions needed for comparison with other remote sensing techniques (optical imaging, IR spectroscopy), as well as providing penetration depths of several meters or more.

Conventional Synthetic Aperture Radars (SAR) are often massive and power-hungry (thousands of Watts), even at relatively short wavelengths (e.g. 4 cm, 13 cm). These shorter wavelengths also cannot sufficiently penetrate into the near subsurface to meet science goals such as detecting subsurface ice, lava flows, or lava tubes (Fig. 1). Our goal is to design a P-band (435 MHz, 70 cm wavelength) SAR that has high-resolution imaging, penetration depths of several meters, multiple science modes (polarimetry, altimetry, scatterometry, nadir sounding), and that would have substantially lower power demands and lower mass than other similar SAR systems.

SESAR is being specifically designed to meet science goals and strategic knowledge gaps for the Moon and Mars, but its modular design and low power compared to other SAR systems make it a candidate for other objects as well, including Venus, Earth, asteroids, and comets.

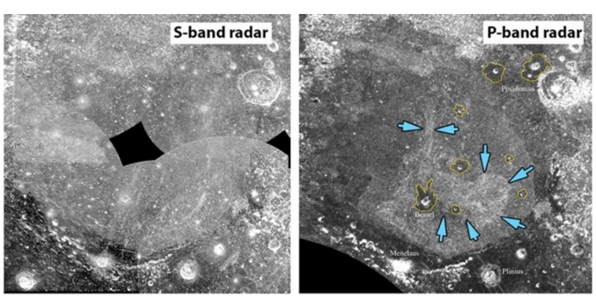


**Fig. 1:** Longer wavelength P-band (70 cm wavelength) radar observations are needed to detect subsurface structures. P-band data of the Moon acquired with Arecibo Observatory reveal lava flows beneath meters of regolith in Mare Serenitatis (right) [1]. S-band (12.6 cm wavelength) data show primarily bright crater ejecta (left).

**Radar Design and Advantages:** SESAR is a digital beamforming SAR based on a modular programmable panel design [2]. Most of the radar electronics are distributed with the active antenna panels, leading to a high level of possible customization for orbit distance and other mission requirements (e.g. fewer panels are used for low orbits). One SESAR "panel" (2.84 m x 1.505 m) is made up of 40 (8 x 5) dual polarization antenna elements grouped into 5 subarrays of 8 elements each, as shown in Fig. 2. With a bandwidth of 100 MHz, SESAR can achieve slant range resolutions of 2-20 m with a Noise Equivalent Sigma Naught of -25 dB to -40 dB depending on the target body and selected resolution.

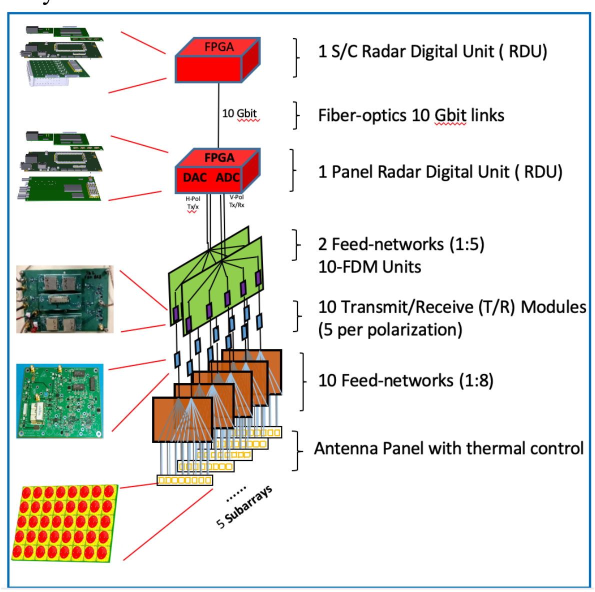


**Fig. 2:** SESAR is modular instrument approach consisting of "smart panels" made up of lightweight antenna elements and power-efficient radar electronics. This approach enables the same design to be scaled to match the science goals and orbit of different planetary targets.

The SESAR system achieves substantial power savings through the use of high efficiency electronics, and the application of a Frequency Domain Multiplexing (FDM) system that enables transmit and receive digital beamforming using a reduced number of - power-hungry - Digital-to-Analog and Analog-to-Digital converters.

The SESAR development is currently funded by NASA's Maturation of Instruments for Solar System Exploration (MatISSE) Program and builds off of prior

NASA technology developments including Earth Science instruments [4,5], NASA PICASSO (FDM technique), SBIR (Processor hardware) and NASA Goddard Space Flight Center's Internal Research and Development. Under MatISSE we are designing and building a SESAR panel (Fig. 2), testing it under relevant environmental conditions (thermal, RF, acoustic, vibration), and demonstrating its beamforming radar operation.

**Antenna Development:** The antenna element design (Fig. 3) is based on a dual-patch approach that employs composite materials to provide stiffness and structural integrity while exhibiting low mass. The RF, mechanical, and materials aspects of the design were completed. HFSS and Finite Element analysis were conducted that showed the design meets the instrument requirements. We are currently procuring and testing the materials with the goal of building and testing a single element, and, after successful verification, a prototype (1x5) sub-array.

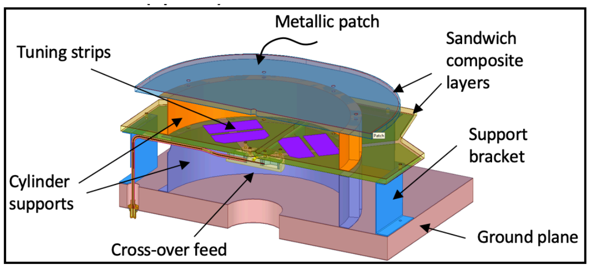


**Fig. 3:** Cross section of one antenna element with the composite design. We are currently building test elements to validate the design; a full SESAR panel is 5 x 8 of these elements.

**Radar Digital Unit's Firmware:** The SESAR RDUs, developed under the NASA's SBIR Phase II and Phase-X programs, are FPGA-based programmable digital electronics designed for high power efficiency and low mass. Under MatISSE, the RDUs firmware has been developed to implement SESAR's waveform generation and data acquisition (Fig. 4), timing and control, onboard data processing, and data archiving. The firmware is being rigorously evaluated.

**FDM:** The FDM subsystem, developed under PICASSO, was integrated and tested with the RDU. The test data collected is being used to optimize the FDM performance. After optimization, we will fabricate and assemble a second set of FDM units for the other radar polarization. The FDM mechanical enclosures are also being designed and will soon be fabricated.

**T/R Modules:** The design of transceiver "evaluation boards" was completed and boards were fabricated and assembled. Laboratory measurements of the evaluation boards are under way. The results will be used to optimize the final transceiver design and the final transceiver modules will be fabricated and assembled. The transceivers will then be integrated with the RDU and FDM for further evaluation.

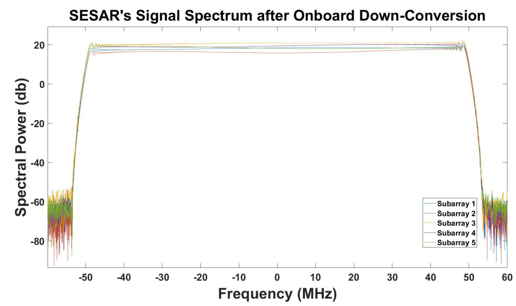


**Fig. 4:** RDU's firmware and hardware functionality demonstration in the laboratory. The five 100-MHz bandwidth (baseband) waveforms correspond to SESAR's single panel FDM waveform generation and data acquisition obtained with the RDU in transmit-receive loopback configuration.

**Thermal modeling:** The thermal modeling has focused on meeting requirements in the challenging lunar-orbit thermal environment (50 km orbit). The thermal subsystem was designed, including a thermal and mechanical system that will interface heat pipes with the electronics boxes on the panels.

**Future Work:** Upon verification of the performance of the single antenna element and the 1x5 subarray, we plan to build a full size (8x5) SESAR array. The array will be populated with the RDUs and the final FDM and Transceiver modules. The thermal control hardware will be purchased, tested, and integrated to the array. Once the system integration is completed, we plan to perform environmental testing and demonstrate full radar operation.

**Acknowledgements:** This work is funded through a NASA MatISSE grant.

**References:** [1] Campbell et al. (2014), *J. Geophys. Res.,* 119, 313-330, doi:10.1002/ 2013JE004486. [2] Rincon et al. (2017), NASA Patent Application #GSC-17016-1. [3] Lu and Rincon (2017), NASA NTR, GSC-17,960-1. [4] Rincon et al. (2011), *IEEE Trans. Geosci. Rem. Sens.*, 49, 3622-3628, doi:10.1109/TGRS.2011.2157971. [5] Rincon et al. (2015), IEEE Radar Conference (RadarCon), Arlington VA, doi:10.1109/RADAR.2015.7131086.