Rover-Mounted, Real-Time and High-Resolution Microwave SAR Imaging System for Evaluation of Shallow Martian and Lunar Regolith

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Microwave signals span the frequency range of ~300 MHz-30 GHz corresponding to wavelength ranges of 1000 mm - 10 mm. Signals at these frequencies readily penetrate dielectric materials and interact with their inner structures. The intrinsic nature of the interaction of these signals with the material media, the relatively small wavelengths and the available wide bandwidth associated with these signals enable evaluation of a variety of materials with high degree of sensitivity. In the past two^{+} decades, significant advances have been made in the field of Synthetic Aperture Radar (SAR) imaging system development for nondestructive evaluation (NDE). This has resulted in developing robust 1D and 2D imaging arrays, over a wide range of frequencies extending into the millimeter wave (30 GHz-300 GHz) region. These systems can produce real-time, high-resolution and 3D images of a wide range of materials and structures. These imaging systems can be optimally designed as a rover-mounted system, to address several critical questions as it relates to *in-situ resource utilization* (*ISRU*) on the Martian and Lunar surfaces, namely:

- detecting water and CO_2 ice, clathrates, etc.,
- validating proper microwave sintering of the regolith,
- as a quality assurance/quality control metric for 3D printing of infrastructure using indigenous materials, and
- detecting variable-sized rocks just beneath the regolith surface where microwave sintering takes place.

Unlike a conventional airborne SAR that collects data from and produces images of targets far from its imaging array, these specific imaging systems produce images of targets in the near-field region of the imaging array resulting in substantially improved sensitivity and image resolution. Consequently, there are several critical design and image reconstruction issues that must be considered and accounted for. Additionally, when the array moves (i.e., when attached a rover) variations in distance to the target, the size/length of the array, array element antenna pattern, and its height above regolith affect parameters such as system spatial resolution, image noise level, etc. All these issues have been thoroughly investigated in the past two decades resulting in a *mature technology*. Pictures of several such systems, designed specifically for NDE applications, are shown in Figure 1.

These systems were designed to produce along-range and cross-range resolutions in the several millimeter ranges. However, when evaluating and imaging Martian and Lunar shallow regolith for the purpose mentioned above, millimeter size resolutions are not needed. For such a system, there are trade-offs to be considered (e.g., resolution and depth of signal penetration), as required by a specific application. In this case, system parameters, namely: operating frequency and bandwidth, array antenna element, array size and element spacing, etc., can be readily modified to design a rover-mounted and real-time imaging systems for evaluation of Martian and Lunar shallow regolith.

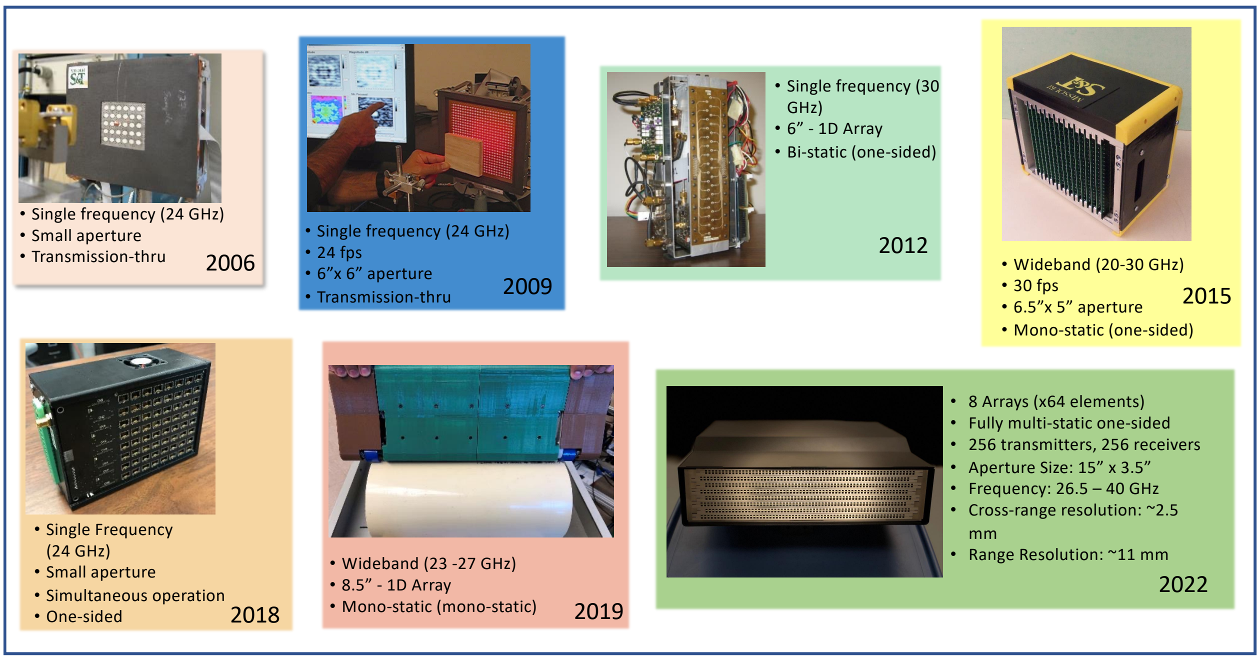

Figure 1: Chronology of developed imaging systems for NDE applications.

In addition, there exists a microwave spectroscopy approach that can directly detect H_2O molecules once buried water ice has been detected. For instance, in the almost non-existing atmospheric pressure in the Lunar environment, slight increase in the ice temperature, facilitated by microwave heating, can instantly sublime water ice into water vapor, which possesses unique microwave frequency resonance characteristics. Crucially, this approach provides for immediate and *in situ* detection of the mapped water ice deposits. In collaboration with a colleague (expert in this area and at a different university), this spectroscopic approach can be readily integrated with the SAR imaging system described here, so that once buried deposits have been detected, their compositions (e.g., water ice or other materials) can be quickly ascertained (i.e., for *ISRU* purposes). This can certainly be a consideration if there is sufficient interest for doing so.

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