A GROUND-PENETRATING RADAR AND RADIOMETER TO STUDY THE SHALLOW SUBSURFACE OF MARS AND OTHER SOLAR SYSTEM BODIES.

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Introduction: The shallow subsurfaces of solar system bodies can hold important clues to their evolution, including their physical properties and the structure of buried geological features. Exploration of these regions can provide insight into possible habitable zones by revealing layering, discontinuities, and the lateral variability of sedimentary materials[1]. Here we present the Mars Radar and Radiometry Subsurface Investigation (MARRSI), an example of a low-cost scientific instrument concept for studying the shallow subsurface of solar system bodies.

MARRSI can provide detailed information on the subsurface and geological context for surface measurements and sample collection. It could also motivate further investigations of interesting areas by other onboard instruments. We envision this type of instrument becoming a common feature on many future missions, perhaps with the scientific instrument functions built into future communication systems, thus providing key science at minimal additional mass and cost.

Instrument Measurement Principle: This instrument uses the radio communication systems on planetary missions to perform two types of investigations:

(1) Bistatic radar measurements in which Earth-based radio antennas transmit a signal that is received by an existing radio communication antenna/receiver on a spacecraft (see Fig. 1). The receiver would detect interference patterns that are formed by the combination of direct signals from the Earth and signals scattered from the surface and subsurface.

(2) Passive microwave radiometry measurements with the same onboard antenna/receiver to measure the lateral and temporal variations of ground brightness temperature (see Fig. 2). For example, temporal changes in ground temperature can identify the thermal inertia of subsurface material [2].

Science Goals and Objectives: MARRSI's overarching goal is to unveil the shallow martian subsurface in support of the assessment of past habitability and possible biosignature preservation and to inform sample collection. From bistatic radar measurements we can determine the following properties/quantities: dielectric properties of the subsurface materials and buried stratifications caused by past aqueous and non-aqueous processes. MARRSI's microwave radiometer measurements provide a convolved signal of thermal and electrical properties of the shallow surface. When combined with forward thermal models and dielectric observables from the bi-static radar measurements, these signals will provide a unique density and thermal inertia measurement of the upper 10's of cm of the surface [3].

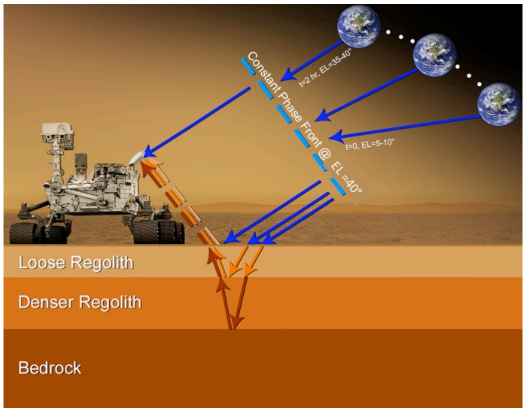

Figure 1. MARRSI bi-static radar probes the shallow martian subsurface by examining variations in the amplitude and phase of interference patterns between direct DSN signals and DSN signals scattered from around the specular reflection point at the surface and the near subsurface.

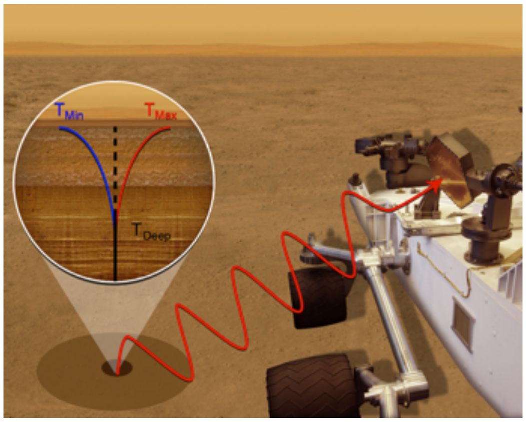

Figure 2. MARRSI radiometry uses diurnal variations in ground temperature (blue & red curves) brightness to estimate the thermal inertia of the shallow subsurface (Image: Image of Curiosity showing the unobstructed field of view of the X-band antenna).

Instrument Overview: As an example, if MARRSI is implemented on a future rover it could make dual use of the telecommunications system for both science and engineering purposes. MARRSI simply augments the rover's existing receiver system by providing the subsystems necessary for the implementation of the radar's Interference Pattern Technique (IPT) and the passive radiometry functions. The instrument hardware includes a Radar and radiometer Processor Board (RPB) added outside the telecommunication system and a Noise Source Unit (NSU) to improve the stability of the radiometer measurements. In the future, the use of reprogrammable software-defined communications transponders may even eliminate the need for a dedicated RPB. In either scenario, only a slight adaptation of the onboard communication system would make this concept an extremely low cost way to investigate the subsurface structure and composition of a planetary surface. A block diagram of the modified telecommunications system is included in Fig. 3.

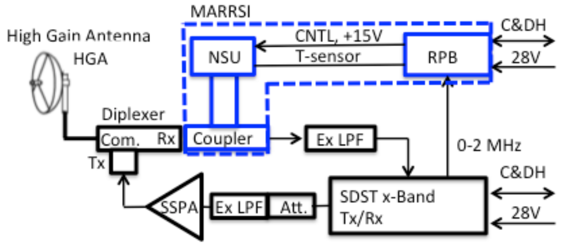

Figure 3. The MARRSI payload augments a spacecraft's receiver in order to provide bi-static radar and radiometry measurements.

Predicted Performance and Preliminary Results: MARRSI's standard mode of operation consists of bi-static radar measurements at the uplink communications frequency of 7.2 GHz with the antenna fixed at elevations between -5° and -20° (below the horizon) while the Earth elevation angle increases from 5-10° to 35-40°. In a second mode of operation the antenna scans vertically while the Earth is at specific elevations.

Simulations of the interference fringe amplitudes produced between the direct DSN signal and that reflected from the ground indicate that accuracy of about 0.5 dB and a precision of about 0.1 dB is needed to detect layering buried under a 3-m-deep layer of dry regolith [1]. The predicted performance of MARRSI's bistatic radar is estimated to provide an accuracy of 0.4 dB and a precision of 0.01 dB, suggesting that MARRSI would be able to detect these features. This allows the search for layering and the estimation of the dielectric properties of materials buried by typical martian regolith. Similar interferometric beating of the downlink communication signal from the Opportunity rover on Mars has already been observed [4], even though the signal strength is hundreds of times weaker than the uplink communications signal proposed for MARRSI.

Interpretation of bi-static radar data will be hypothesis based. We will identify interference patterns that best match the observations from numerical simulations and laboratory measurements of features of interest, such as layering, graded beds, cross beds and ripples in the shallow subsurface.

Thermal inertia is estimated by fitting diurnal variations in ground temperature to a model of the shallow subsurface. This requires measurements of ground temperature covering the diurnal cycle. In order to meet this requirement, MARRSI's radiometric measurements will consist of 5-10 min of measurements four times per sol to capture the amplitude of the diurnal cycle. Hourly measurements to characterize the full diurnal cycle are desirable but not required.

Fig. 4 shows predictions by our IPT radar model without the rover antenna beam pattern to simplify the signatures of the geological features. Our simulations assumed typical (dry) regolith [5] simulating ancient lake deposits.

Fig. 5 shows results of simulations for a 3-cm-thick layer of various materials These results show that buried layers of dry regolith, sandstone, bedrock and wet regolith can be distinguished from each other.

Fig. 6 shows laboratory measurements of 7 GHz signals reflected from layers of materials of interest, buried by a 5-8 cm thick layer of sand, normalized by the power of the incident signal. The data is in excellent agreement with the IPT model predictions.

References: [1] Renno, N., R. Backhus, A. Camps, G. Krieger, F. Maiwald, G. Martinez, K. Oudrhiri, M. Paik, M. Panning, K. Papathanassiou, J. Plaut, R. Preston, C. Ruf, M. Siegler, L. Tamppari, and J. Thomas (2014) *NASA Mars 2020 Proposal*, University of Michigan. [2] Martinez, G., N. Renno, E. Fischer, C.S. Borlina, B. Hallet, M. de la Torre, A.R. Vasavada, J. Gomez-Elvira and the REMS Team (2014) *JGR,* submitted. [3] Cuzzi and Muhlmann (1972) *Icarus*, 17, 548-560. [4] Taylor, J., A. Makovsky, A. Barbieri, R. Tung, P. Estabrook, and A. G. Thomas (2005) *DESCANSO Design and Performance Summary Series*, Article 10, JPL. [5] Hallikainen, M. T., Ulaby, F. T., Dobson, M. C., El-Rayes, M. A., and Wu, L. K. (1985) *IEEE Transactions on Geoscience and Remote Sensing*, 25-34.

Acknowledgments: The MARRSI Instrument Concept was developed and tested at the University of Michigan with support from the Jet Propulsion Laboratory, California Institute of Technology.

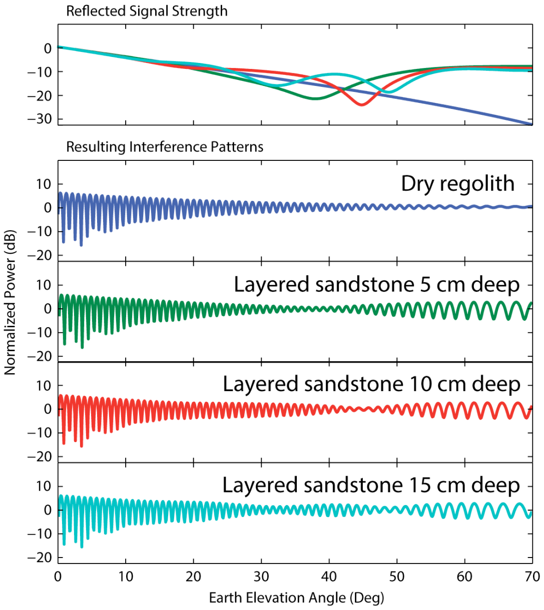

Figure 4. Signals caused by dry regolith (ε = 2.5 - 0.01i F/m, blue), layered sandstone (randomly generated layers with relative permitivity between 2.5 - 0.01i F/m and 7.0 - 0.14i F/m) below 5 cm (green), 10 cm (red) and 15 cm (cyan) of dry regolith can be distinguished using the IPT.

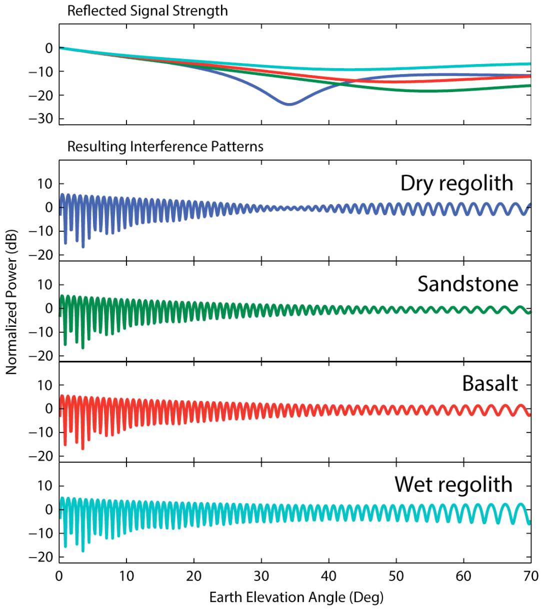

Figure 5. Signals caused by 3-cm thick layers of materials . (e.g., dry regolith ε = 2.5 - 0.01i; sandstone ε = 5.0 - 0.14i; basaltic bedrock ε = 7.8 - 0.4i; wet regolith ε = 20.0 - 6.3i) over basaltic bedrock can be distinguished using the IPT, even when buried by 2 cm (or more) of dry regolith.

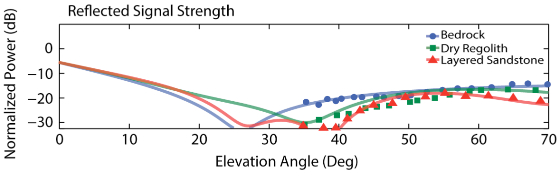

Figure 6. Results from laboratory measurements (symbols) and numerical simulations (solid lines) indicate that signals caused by simulants of materials of interest buried by sand can be detected by MARRSI.