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Stokes Reflectometer for Soil Moisture, Subterranean Voids, and Subsurface Ice

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Extended Abstract: The Stokes Reflectometer concept presented here takes a novel approach to microwave remote sensing of soils. It relies on low power, low mass, continuous wave (CW) UHF transmitters and receivers, operating in a forward scattering configuration, over a range of angles of incidence and scattering crossing the Brewster angle to retrieve soil properties. Radar remote sensing responds to soil moisture and voids in soils through changes in the reflection coefficient and its dependence on the dielectric constant, itself a function of soil moisture content. The relationship between reflection coefficient and angle of incidence varies measurably with water content and degree of polarization of the probing beam. It is the variation between these two parameters that will be exploited to extract soil moisture content. The use of CW eliminates the need for time synchronization among sensors. In our measurement approach, multiple pairs of sensors hosted by separate smallsats illuminate a region of interest at a fixed angle of incidence in the orbit plane. The plane of the transmitting fan-beams is orthogonal to the orbit plane and contains the line-of-sight (LOS) to the ground. Receiving antennas are fan-beams whose plane contains the LOS and are orthogonal to the transmit fan-beams. To enable distinction between different angles of incidence, each spacecraft transmits at a unique frequency, f_i, corresponding to its angle of incidence, θ_i, i = 1, 2, 3, ..., n, where the offset between the pairs exceeds the bandwidth of a single pair. To afford reasonable penetration depths into the soil as well as to be somewhat immune to soil roughness, the frequencies, f_i, were selected to be around 430 MHz. The polarizations of the transmit beams are circular and each receive beam is dual linear. This combination permits reliable estimation of moisture content through the Stokes vector. The component S_0 of the Stokes vector measures backscatter that includes de-polarization, and the angular profile of S_1/S_0 has a peak at the Brewster angle. The angle of incidence at the peak is sensitive to moisture content.

Proof of concept for the Stokes Reflectometer is provided by a series of COMSOL Multiphysics finite element runs to model forward-scattered RF signals through soils of varying compositions, dielectric constants [1, 2], and surface roughnesses. The first situation simulates wet temperate soil using a layer of saturated soil on top of dry soil. The second simulates permafrost using a four-layer stack of snow on pure water ice on saturated soil on dry soil. The simulations reported results for angles of incidence ranging from 32°-67° and scattering angles ranging between ±20°. Significant variations for all four Stokes components were seen. Subsurface voids, both directly below and offset by several meters from the specular point induced strong differences in scattering profiles out to angles of incidence of 57° for both soil situations, but had less impact at higher angles of incidence. With these promising results, modeling of the Stokes reflectometer concept will be extended to frozen and saturated soils at variable depths to provide representations of lunar and martian regolith in polar and equatorial regions.

References

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