FDTD電磁界シミュレーションに基づくUHF帯GPRによる月表層の氷検出可能性の検討

Feasibility study of detection of the lunar subsurface ice with UHF-band GPR based on FDTD electromagnetic simulation

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Detectability of the subsurface ice by UHF-band (0.5-3 GHz) ground penetrating radar (GPR) onboard the rover in the lunar polar region was investigated based on electromagnetic simulation using finite-difference time-domain (FDTD) method. The water brought on the lunar surface is lost within 1 day due to photodissociation. However, if a part of water molecules jump to polar region within 1 day, they can be kept in the polar shadowed region [Arnord, 1979]. Some observations such as impact experiment in LCROSS mission [Colaprete et al., 2010] and SAR polarization measurements in Chandrayaan mission [Spudis et al., 2010] suggests the existence of the water in the lunar polar region.

In this study, we used Meep code [Oskooi et al., 2010] for FDTD simulation. The simulation space with a size of 0.25 m x 1.25 m is divided into meshes with a size of 0.3 mm x 0.3 mm. The uppermost part with a height of 0.5 m is filled with vacuum (permittivity: 1). The second part with a thickness of 0.5 m is filled with dry regolith, basalt (permittivity: 7) including voids (vacuum). The lowermost part with a thickness of 0.25 m is filled with several kind of media such as (i) cavity (vacuum), (ii) rocks (basalt without pores), (iii) pure ice (permittivity: 3), and (iv) icy regolith, regolith whose voids are filled ice. The porosity of the dry and icy regolith layers was determined based on the report from Apollo missions on the vertical profile of the bulk density of the lunar subsurface soils up to depth of 3 m [Carrier et al., 1991]. Chirp pulse in a frequency range from 0.5 to 3 GHz was transmitted for 167 ns from 0.4 m above the dry regolith surface. The electromagnetic fields in simulation space were evolved with time step of 0.52 ps. At the transmission point, the waveform of electric field component of the echoes was recorded at an interval of 33 ps.

Calculation results suggests that subsurface echoes from (i) cavity, (iii) rocks, and (iv) icy regolith at a depth of 0.5 m can be detected with enough echo powers while the echo power from (iii) pure ice were as large as volume scatters due to inhomogeneity in the regolith. They are a little different from the results of our previous calculation performed in a frequency range 1-15 GHz with subsurface materials at a depth of 0.1 m: The echo powers from ice and icy regolith were as large as volume scatters. We can consider that the difference is from (a) the decrease of the volume scatters power by changing the operation frequency range, and (b) the depth dependence of permittivity contrast in inhomogeneous regolith.

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