ON THE HETEROGENEIETIES OF ELECTRO-MAGNETIC PROPERIES OF ROCKS.

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Introduction: Subsurface structures of solid solar bodies, such as Mars, the Moon, and asteroids, would provide critical information for understanding their formational and evolutionary histories. In addition to geological investigations based on image analyses, seismic observations and passive electro-magnetic measurements have been performed for the above purpose. Recently, a subsurface souding radar method of a wide range of wavelength is becoming a popular way to provide further information of the subsurface structures.

Mars advanced radar for subsurface and ionosphere (MARSIS) [1], Lunar radar sounder (LRS)[2], and Mars shallow radar sounder (SHARAD)[3], for example, have proven that a souding radar instrument onboard an orbiter can provide significant dataset of subsurface structures of a solid body. Such success increases expectations of radar measurement near the surface such as onboard a rover and a lander. In either cases, the radar system radiate the electromagnetic wave from an antenna and receive the reflected wave from an interface of the material. From the reflected waves, we can geuss a possible subsurface distribution of permittivities. However, to reconstruct the subsurface structures from the possible permittivities, we further need to know the electro-magnetic properties of rocks forming the subsurface. Electro-magnetic properties of rocks have been intensively studied especialy for terrestrial mining purposes, however, those of waterless environment are not catalogued for the purpose of the solar-system exploration. For this reason, we are measuring the electro-magnetic properties of a wide variety of rock samples stocked in the museum backyard collected all over the world by the coaxial probe technique.

One of the major problems on developing a catalogue of permittivity of rocks comes from the heterogeneity of rocks. In this study, we evaluate the effect of heterogeneity of rocks in the measurement of permittivity by using FDTD method [4] and propose a realistic technique for measuring the permittivity of heterogeneous materials at high accuracy.

Numerical analyses on heterogeneiety of rocks: In this study, we use coaxial probe technique with 8753ES s-parameter network analyzer and 85070 dielectric probe kit. The permittivity is measured by a probe attached to the flat face of a solid material. Fig 1 shows the permittivities of granite ranging from 1MHz to 2GHz, which covers the most popular wavelengths of the sounding radar instruments. The measured permittivities depend largely on the locations at the sample.

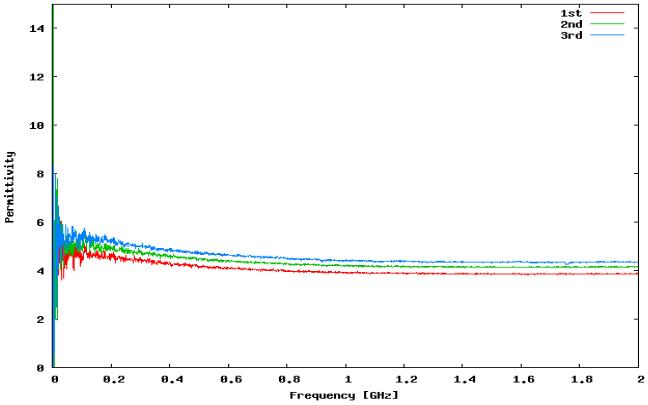


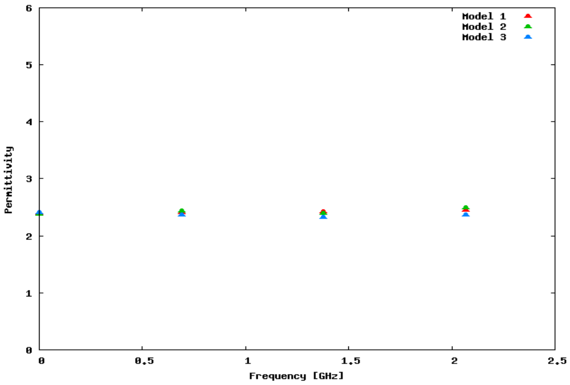
Fig 1. The permittivity of granite.

To evaluate the effect of heterogeneity of rocks in the measurement of permittivity, we conduct numerical simulations by TEM waveguide model [5]. The sample composed of host material and inclusions is put in a TEM guide and fields are solved by FDTD method. With the help of transmission line theory, the effective permittivity can be determined. Based on the transmission line theory, the rerationship of the reflection coefficient and the effective permittiviy is described by

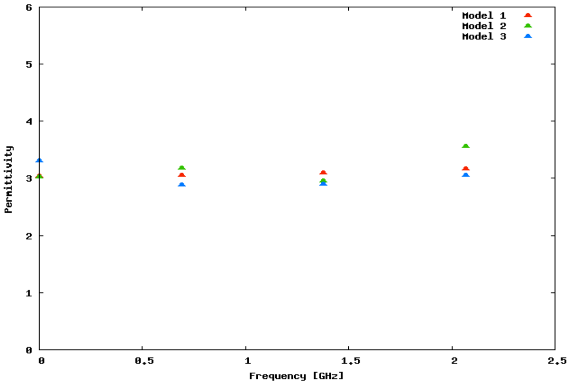
$$|R| - \frac{\left|\tan\left(\frac{2\pi f}{c_0}\varepsilon_{eff}^{1/2}\right)(1-\varepsilon_{eff}^{1/2})\right|}{\sqrt{4\varepsilon_{eff} + \tan^2\left(\frac{2\pi f}{c_0}\varepsilon_{eff}^{1/2}\right)(\varepsilon_{eff}^{1/2}+1)^2}} = 0 \qquad \ldots(1)$$

Thus, the effective permittivity can be acquired by numerically solving the equation (1).

In this simulation, we evaluate the effect of the shape and the size of inclusions and the contrast of permittivity between host material and inclusions. Fig 2 shows that, with increasing the contrast of permittivity between host material and inclusions, the discrepancy of effective permittivities of material is enlarged. Note that the discrepancy becomes larger at a higher frequency. These result consistent with the Jun Sun' study [6]. Fig 3 shows that, if the size of inclusions is small, the effective permittivities are almost the same at any frequency, while if the size of inclusions is large, the effective permittivities varies. These indicate that the size of inclusion critically affects the effective permittivity.



(a) $\varepsilon_h=2$, $\varepsilon_e=4$



(b) $\varepsilon_h=2$, $\varepsilon_e=16$

Fig 2. The effective permittivity of heterogeneous material.

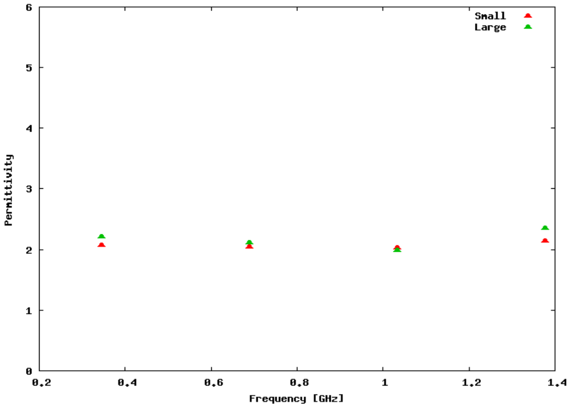


Fig 3. The effective permittivity of small inclusion model and large inclusion model.

Measurements and discussions: Given the above numerical result, we assume that if the target rock is fragmented at particle size much smaller than the wavelength, the heterogeneity can be ignored. Thus, we process the rock using a hammer mill to reduce the particle size. Fig 4 shows the permittivities of powder granite, which indicate that the permittivity of granite powder stays at the same value at any region of the sample. By calculating the porosity of the powder and solving the mixing rules [7], we can accurately obtain the permittivity of the sample. We are systematically measuring the permittivities of many other types of rocks, whose results will be summarized as a catalogue of electro-magnetic properties of terrestrial rocks.

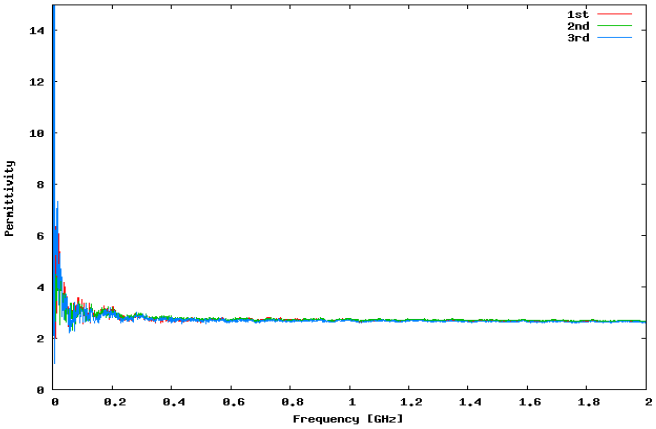


Fig 4. The permittivities of powder granite

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References:

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