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Permittivity Estimation of Layers Beneath the Northern Polar Layered Deposits, Mars

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Abstract

Martian Polar Layered Deposits, most likely dusty ice are transparent to radar waves. The reflected signal is generally above the noise and can be used to estimate the dielectric properties of the bedrock. Assuming the permittivity of the first layer is known, we use a simplified inversion method to extract the bedrock relative dielectric permittivity below the North PLD's.

1. Introduction

The Polar Layered Deposits (PLD's) are geological formations unique to the poles of Mars. The different albedo of the layers are interpreted to be caused by variable proportions of dust and water ice [1], the result of cyclical variations in the orbit and rotation of Mars that affected insolation, and thus water ice and dust deposition and removal rates at the poles [2]. Both the North [3] and the South [4] PLD's have been observed by the MARSIS [5] and SHARAD [6] subsurface sounding radars, which operate in the HF and VHF bandwidth. The transparency of the PLD's has allowed the underlying bedrock to be detected to depths of more than 2 Km in the North [3] and 3.7 Km in the South [4]. Ice is highly transparent at MARSIS and SHARAD frequencies, and thus a mostly icy composition with only a few percent of dust has been inferred for the PLD's [7]. Determination of subsurface dielectric permittivity through the inversion of the radar echo is an approach to determine subsurface composition. We present a somewhat simplified inversion method to find the dielectric properties at the base of the North PLD's.

2. Inversion Technique

The subsurface structure can be schematically represented with three homogeneous layers (see Fig. 1). The upper medium is assumed infinite and made up of air whose dielectric permittivity is equal to ε_0; the second layer (here assumed to be predominantly made up of ice) has a finite thickness d and has relative dielectric permittivity and conductivity denoted by ε_1 and σ, respectively. The third layer has dielectric permittivity ε_2, which is the unknown quantity to be determined. The magnetic permeability is the same for all the layers and is equal to that of free space.

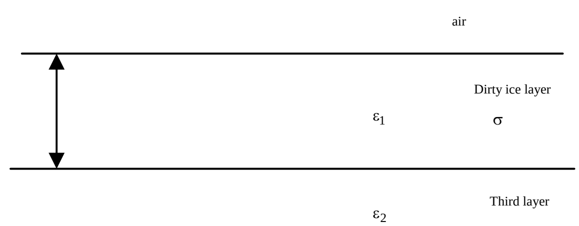

Figure 1. Geometry of the inversion problem.

The field impinging on the model stratigraphy is approximated as a plane wave with the direction of the propagation normal to the interfaces between the layers. The attenuation of the electromagnetic wave in the medium is low, i.e., $\sigma/(\omega\varepsilon_0\varepsilon_1) << 1$, and thus the wave-number in the ice-rich layer can be written as $k_1 = \beta - j\alpha \cong (\omega/c)\sqrt{\varepsilon_1} - j\,60\pi\sigma/\sqrt{\varepsilon_1}$ (being c the velocity of light in vacuum).

In this approach we use available information in terms of the ratio $R = |\Gamma_s|^2 / |\Gamma_{ss}|^2$ where Γ_s is the local reflection coefficient at the interface air/dirty ice layer while Γ_{ss} is the reflection at the dirty ice layer/third layer and is given by:

$$|\Gamma_{ss}|^2 = |(1-\Gamma_s^2)\exp(-2\alpha d)\Gamma_{12}|^2 \quad (1)$$

where $|\Gamma_{12}| = \left|\left(\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}\right) / \left(\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}\right)\right|$.

The other information that can be gained by the frame is the two-way travel time associated with the propagation in the ice-layer after the reflection at the interface ice-rich layer/third layer, and is given by $\tau = 2d / c_1 = 2\beta d / \omega \simeq 2d\left(\sqrt{\varepsilon_1} / c\right)$ (being c_1 the velocity of wave in the dirty ice layer). This expression allows the determination of the thickness d once we have made an assumption for the value of the relative dielectric permittivity ε_1.

The goal of the inversion problem can be stated as the determination of the relative dielectric permittivity ε_2 of the third layer from the ratio R. To make this problem tractable, we have to make use of any a priori information on the relative dielectric permittivity ε_1 and conductivity σ of the dirty ice layer, in this way the local reflection coefficient $\Gamma_s = \left(1-\sqrt{\varepsilon_1}\right) / \left(1+\sqrt{\varepsilon_1}\right)$ can be determined together with the attenuation coefficient α and the thickness d.

Finally, using eq. (1) it is possible to determine the permittivity value of the third layer:

$$\varepsilon_2 = \varepsilon_1 \left(1+|\Gamma_{12}|\right)^2 / \left(1-|\Gamma_{12}|\right)^2 \quad (2)$$

3. Results

The inversion technique described above has been applied to the data collected along orbit 2500, from sample 395 to sample 401. This orbit has been chosen because the observed area is characterized by very smooth terrains and does not exhibit any appreciable variation in surface elevation [8]. The complex relative permittivity for the dirty ice layer has been calculated using a two-phases (trachy-basalt and ice) Maxwell-Garnett mixing formula. For each analysed frame, Table 1 summarizes the time depth of the interface between PLD's and bedrock, the power ratio between the subsurface and the surface reflection peaks, and the dielectric permittivity obtained from data inversion. As shown in Table 1, the interface between PLD's and bedrock is well detectable and the two-way travel time is quite constant, confirming that the inversion is applied always on the same interface. The estimated permittivity of the third layer is consistent with the typical range of basaltic rocks, depending on the porosity and/or the iron content [9].

Table 1 Retrieved Permittivity, Two way travel time, Power ratio values for 7 samples of the orbit 2500.

Sample	Relative Permittivity		Two-way travel time (μs)		Power Ratio (dB)	
	5 MHz	*4 MHz*	*5 MHz*	*4 MHz*	*5 MHz*	*4 MHz*
395	5	5	13	15	10	11
396	5	6	14	14	13	8
397	5	6	13	14	10	9
398	5	6	13	15	12	9
399	5	8	13	14	13	5
400	7	6	14	13	7	9
401	20	7	13	14	-2	7

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