EPSC Abstracts
Vol. 6, EPSC-DPS2011-382, 2011
EPSC-DPS Joint Meeting 2011

Direct reconstruction of the crust permittivity profile from orbital based radar sounder data

D. Kartashov (1), V. Turchin (2), O. Shchuko (3) and **R. Orosei** (4)
(1) Photonic Institute Vienna University of Technology, Vienna, Austria, (2) Institute of Applied Physics RAS, Nizhny Novgorod, Russia, (3) Radiophysical Research Institute, Nizhny Novgorod, Russia,(4) Istituto di Fisica dello Spazio Interplanetario, Rome, Italy (daniil.kartashov@tuwien.ac.at / Fax: +43-1-58801-38799)

Abstract

We suggest an effective numerical procedure for direct reconstruction of dielectric constant profile from radar sounder data. Application of this procedure to MARSIS data analysis is simulated for a model random layered structure. We discuss the influence of the dispersion of dielectric constant and losses, noise and surface clutter on the stability of the reconstruction routine.

1. Introduction

Detecting discontinuities in the crust presents many challenges for orbital radar sounder: one that must be overcome is the presence of radar scattering from the surface (clutter), expected to be detected by the sounder antennas at the same time as echoes arising from subsurface interfaces. Assuming that the problem of surface scattering is solved due to an efficient data processing, there is a problem how to reconstruct dielectric properties of a crust from a radar echoes sequence.

2. Geological and electrodynamical crust model

As a test crust geological structure we consider layers of porous materials with random thickness (mean thickness 200m with uniform random deviation within 50m) and mean dielectric constant 4.5 with uniform random deviation in the range 3.5. Loss tangent value was adapted somehow to permittivity in accordance with the properties of rocks in the 1-5 MHz frequency region [1]. Each layer is characterized also by the value of porosity ν and pores saturation η. For the calculations of an effective dielectric constant and losses in the porous media we used the TP model [2] which is shown to be a good model for Earth rocks porous samples [3]:

$$\sqrt{\varepsilon_{eff}} = (1-\nu)\sqrt{\varepsilon} + \eta\nu\sqrt{\varepsilon_{fil}} + \nu(1-\eta) \qquad (1)$$
$$\sqrt{\varepsilon'_{eff}} = (1-\nu)\sqrt{\varepsilon'} + \eta\nu\sqrt{\varepsilon'_{fil}}$$

where ε_{fil} is the real part of permittivity of the material filling pores and ε' is the imaginary part which is related to the losses tangent by the relation $\varepsilon' = 2\sqrt{\varepsilon} tg\delta$. As the detection of water buried or frozen under the surface is one of the main goals for MARSIS observations, we consider a case of zero porosity ("Dry" model) and porous structure with pores filled by water ("Wet" model) with permittivity ε_w=65 and losses tangent 0.5. Values of porosity correspond to the typical values for earth rocks samples. The details of the models are presented in Tab.1.

Electrodynamical model of the crust is a one-dimensional inhomogeneous medium with refractive index $n(z) = \sqrt{\varepsilon(z)\mu(z)}$ where $\varepsilon(z)$ and $\mu(z)$ are the permittivity and permeability respectively. It is

Table.1 Test layered model.

Layer thickness, m	Porosity, ν		Saturation, η	ε	tgδ
	Dry	Wet			
150	0	0	1	5.945	0.019
231	0	0.05	1	6.095	0.048
185	0	0.03	1	8.272	0.082
225	0	0.2	1	3.219	0.0086
221	0	0.1	1	5.595	0.030
151	0	0.5	1	6.240	0.0036
base	0	0	1	7.5	0.02

assumed that $n(z) = 1$ in a homogeneous half-space (vacuum) $z < 0$ and $n(z) = n(H) = n_H$ at $z > H$.

To describe the propagation of a radar pulse in the crust it is sufficient to solve this problem for a plane monochromatic wave. Finding the reflection coefficient for monochromatic wave we can find the reflected signal by the Fourier transformation. Each spectral component from the pulse spectrum satisfies the Helmholtz equation inside the inhomogeneous media $0 \le z \le H$:

$$\frac{d^2E}{dz^2} + k_0^2 n(z) E = 0 \qquad (2)$$

Here $k_0 = \omega/c$, ω is the frequency, c is the light speed in vacuum, $E(z)$ is the transverse component of the electric field in the plane wave. Applying a finite-dimensional approximation, we split the interval $0 \le z \le H$ into M layers and assume that for each layer $z_m \le z \le z_{m+1}$, $m = 0,1,\dots,M$, the refractive index has a constant value n_m. We developed an algebraic procedure to solve the inverse problem for the equation (2) to reconstruct the refractive index distribution $n(z)$ from the known time series of the reflected radar echoes. This procedure is exact in case of a layered structure of the crust with sharp discontinuities of the refraction index between the layers. In the case of a continuous change of the refraction index with a depth such splitting arises naturally from the radar resolution $\chi = \frac{c}{n\Delta\nu}$ where $\Delta\nu$ is the radar frequency bandwidth. The numerical routine for our reconstruction algorithm needs a total number of operations $\sim M^2/2$ if a time sequence of length M is computed.

We simulated propagation of a Gaussian-shape radar pulse with a carrying frequency 1.9 MHz and bandwidth 1 MHz. One can check that the bandwidth is broad enough to detect layers from the model in Tab.1. A reflected signal after detection of the carrier frequency is presented on Fig.1. This echoes sequence is used for the reconstruction procedure. The result of reconstruction is presented on Fig.2. Reconstructed refraction index profile coincides very well with the model distribution.

References

[1] Belov, R., Bondar, L., Goronina, K. Lubyako, L. and Schmulevich, S.: Investigation of dielectric properties of earth rocks samples at ultrahigh frequencies, International Symposium Physics of Moon and Planets, pp. 118-123, Moscow, 1972.

[2] Wharton, R.P., Hazen, G.A., Rau, R.N., Best, D.L.,: Electromagnetic propagation logging: advances in electromagnetic propagation logging, Soc. Petrol. Eng., AIME, p. 9267, 1980.

[3] Rust, A.C., Russell, J.K., Knight, R.J.: Dielectric constant as a predictor of porosity in dry volcanic rocks., Journal of Volcanology and Geothermal Research, Vol. 91, pp. 79-96, 1999.

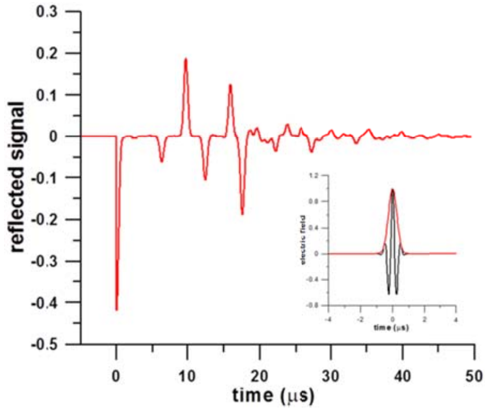

Figure 1: Reflected echo sequence from a model layered crust. The insert is an incident radar pulse.

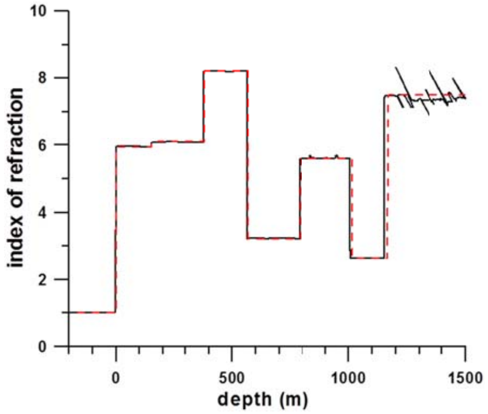

Figure 2: Dotted line is the layered structure from the Tab.1. Black solid line is the result of reconstruction.