THE SUBSURFACE ULTRAWIDEBAND RADAR STUDY OF A SURFACE LAYER OF THE SOLAR SYSTEM PLANETS

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Radar experiments are widely used for remote sensing of planetary surfaces. However, the traditional (single wavelength) radar techniques are rather inefficient for study of subsurface structure. Under Earth conditions the use of ultra wideband (video pulse) radar turns out to be more productive for these purposes. Future applications of an ultra wideband radar located on a surface are examined in this paper for purposes of studying of a subsurface vertical structure to a depth of some hundreds meters.

INTRODUCTION

Radar experiments are widely used for remote sensing of planetary surfaces. However, the traditional (single wavelength) radar techniques are rather inefficient for study of subsurface structure. Under the Earth conditions for these purposes the use of ultra wideband (video pulse) radar (UWBR) turns out to be moreproductive. The methods used for the video signal detection are not optimal and make difficulties in the signal accumulation under the low signal-to-noise ratio.

In this paper the future applications of UWBR located on a surface are examined. We use here the lunar surface as an example. The new theory of the optimal video signal reception presented here allows obtaining more reliable estimations of distance to underground objects.

UWBR spans the wavelength range from 30 cm to of about 6 m. Emitted pulses are of about 30 cm long ($\sim$ 1 ns). Their repeating frequency is of about 1 MHz. In Fig. 1 the emitted pulses (a) and their representation in frequency domain (b) are shown. The Fourier spectrum of the single emitted pulse is presented in Fig. 1b as a dash line.

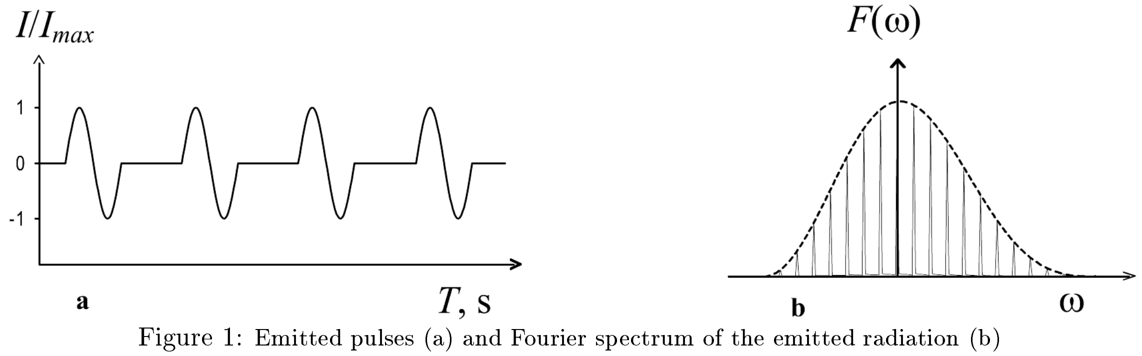

Figure 1: Emitted pulses (a) and Fourier spectrum of the emitted radiation (b)

THE THEORY OF OPTIMAL VIDEO SIGNAL RECEPTION

The upper layer of the lunar surface is a medium with dispersion and absorption. Hence, the shape of a received pulse differs from that of the emitted one. This leads to difficulties in the analysis of the received information. New theory of optimal video signal reception is free of this difficulty [1]. All calculations are carried out in the frequency domain. The theory uses the approach based on the theory of optimum statistical solutions and the classic theory of probability. Key assumptions used in the theory of the optimal video-pulse reception are those both the distance x to the object under study and detection noise ($|n\rangle$) are random. Detection noise is a stationary Gauss process with spectral density $I(\omega)$. Probability of a noise realization is: $p_N(|n\rangle) \approx e^{-\langle n|\hat{\beta}|n\rangle/2}$, where $\hat{\beta}$ is an operator which is diagonal in the frequency domain; its eigenvalues are $1/I(\omega)$. We used the $|u_0\rangle$ notation for the initial pulse and $|v\rangle$ for the received one. A reception pulse is described as $v(t) = u_1(t) + n(t)$, where $|u_1\rangle$ is the scattered pulse at the radar. $u_1(t) = e^{2i\hat{K}x}\hat{S}u_0(t) = \hat{G}(x)u_0(t)$, $\hat{K}$, $\hat{S}$ being operators, which are diagonal in the frequency domain; eigenvalues of the operators are $\varepsilon(\omega)^{0.5}\omega/c$, and $s(\omega)$, respectively. The $\hat{K}$ operator describes absorption in the medium and the $\hat{S}$ operator characterizes the scattering from the object under study. The most probable distance to the object can be found through the maximum of the logarithmic function of plausibility:

$$L(x) = 2\left\langle v \middle| \hat{\beta}\hat{G}(x) \middle| u_0 \right\rangle - \left\langle u_0 \middle| \hat{G}^{+}(x)\,\hat{\beta}\hat{G}(x) \middle| u_0 \right\rangle. \qquad (1)$$

The distance estimate obtained with this theory is not biased. The standard deviation of the estimate depends on the spectral density of both pulse and noise. It does not depend on the pulse shape and, therefore, on any pulse distortion in the medium.

APPLICATION OF UWBR FOR STUDY OF THE LUNAR SURFACE

Absorption in the lunar soil limits the penetration depth of a pulse. Absorption length l_e at the wavelengths of interest λ (30 cm – 6 m) is shown in Fig. 2 for (a) regolith (the density ρ is 1.0 g/cm^3), and for (b) rocks (ρ = 3.32 g/cm^3). These curves were obtained using the data for permittivity of lunar soils from [3] and the specific loss tangent data from [2]. At a 6 m wavelength the absorption length l_e is of about 160 m. Therefore, the objects located at a depth up to hundreds meters under the lunar surface can be found by UWBR. The upper limit for object detection is specified by the shortest wavelength. It is of about 30 cm.

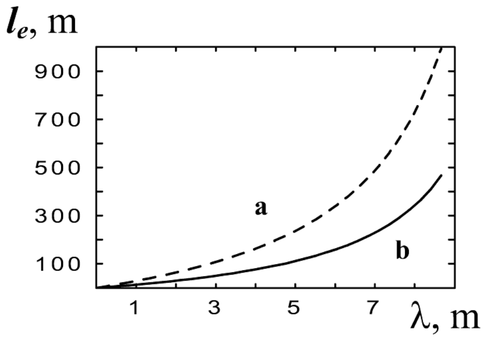

Figure 2: Absorption length for (a) regolith (ρ = 1.0 g/cm^3), and for (b) rocks (ρ = 3.32 g/cm^3)

According to the seismic data [3], the depth range from 30 cm to hundreds meters can be roughly divided into two layers: the upper, regolith layer, extended up to 10–20 m depth, and a layer of fractured bedrock ("megaregolith") extended up to 1 km depth [3]. The upper (regolith) layer has a stratified structure too. The deposits consist of rock fragments of different size [3]. The difference in average density leads to the difference of permittivity of some layers within the regolith. Such interfaces can be considered as objects for UWBR.

CONCLUSION

UWBR can feel interfaces up to hundreds meters deep under the lunar surface. It can provide with information about the regolith-megaregolith interface, some deposits inside the regolith layer, and the structure of the upper part of the megaregolith layer. With UWBR, some isolated objects (rocks) can be detected.

In addition, the UWBR has the following advantages.

- UWBR located on the surface needs much less power than remote radar equipment.
- The video pulse equipment is rather simple in comparison with a conventional radar providing a wide frequency range.
- Distance estimations obtained by the theory of the optimal video signal reception do not depend on the shape of the received signals.

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