A laboratory experiment on estimation of homogeneity of subsurface media by Polarimetric Ground Penetrating Radar

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Abstract : Laboratory experiment of polarimetric GPR measurement was conducted for the purpose of estimating subsurface inhomogeneity. Tow realization of inhomogeneous subsurface media were made by burying stone objects of different dimensions in homogeneous dry sand. Polarization ratio of cross polarization to co polarization data were examined to find their obviously distinguishable behavior.
Keywords : GPR, polarimetric, inhomogeneous medium

1. Introduction

Asteroids are in general as big as only 10^0km or smaller in its dimension yet have rich variation in their geologic surface features such as impact craters, escarpments and fault systems, grooves and etc. despite their tiny gravity(Asphaug *et al*, 2002). In order to understand the generation process of those rich alien geologic features, we need information of their subsurface structure in addition to available surface information.

The most suitable candidate tool for providing this untouchable information is a Ground Penetrating Radar (GPR). GPR is well known for its ability of subsurface sensing, subsurface detection and subsurface visualization. We introduce a GPR with polarimetric technique in order to investigate the inhomogeneity of subsurface media. A laboratory experiment of polarimetric GPR is conducted with using two subsurface inhomogeneity models. This paper is the preliminary report of the experiment result.

2. Polarimetric GPR system

A stepped frequency radar system was constructed on a vector network analyzer (Agilent technology 8753). A polarimetric GPR system was realized by using Vivaldi antennas (Langley *et al*, 1996) (Fig. 1). The metal antenna element was patterned on both side of the epoxy resin substrate (1.5mm thick). Considering the antenna characteristics, the operation frequency range was set from 385MHz to 5.985GHz (801 points with 7MHz step) at measurements and lower cut off of 1.085GHz was applied at data processing.

Figures 2 and 3 show the waveform of the radar pulse (flat surface reflection at the range of 13cm) of co-polarization and cross-polarization, respectively. The power spectra of both polarization pulse are shown in fig. 4. The figure shows relatively flat spectra of both polarization pulse components over 5 GHz range

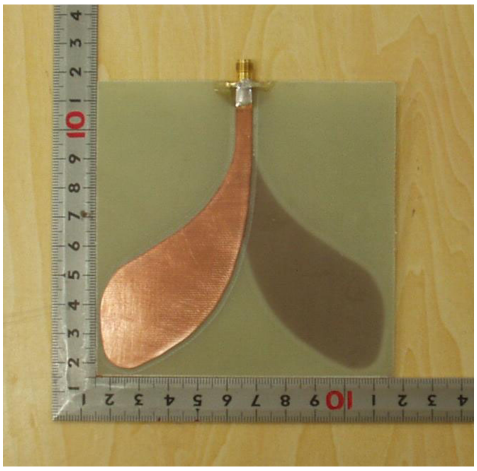

Fig. 1. Vivaldi antenna.

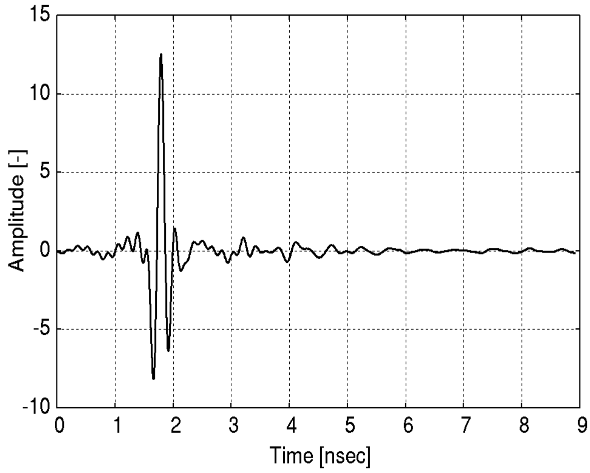

Fig. 2. GPR pulse waveform of co-polarization.

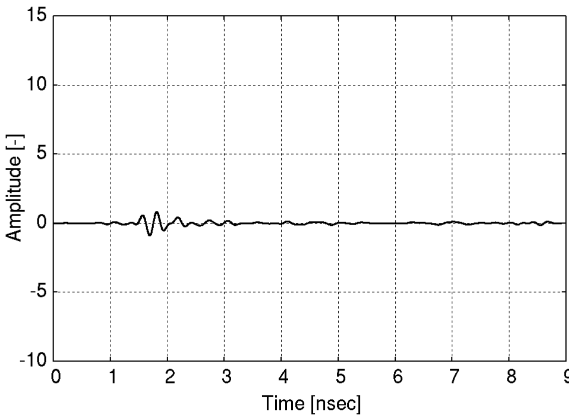

Fig. 3. GPR pulse waveform of cross-polarization.

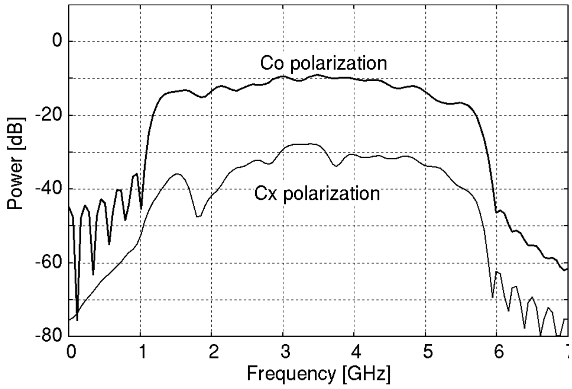

Fig. 4. Power spectra of GPR pulse of both polarizations.

Fig. 5. CASE 1. The mean dimension of rocks is 8cm

Fig. 6. CASE 21. The mean dimension of rocks is 15cm

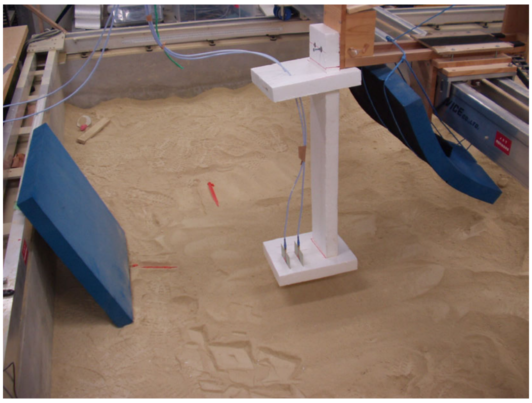

Fig. 7. GPR measurement of co-polarization.

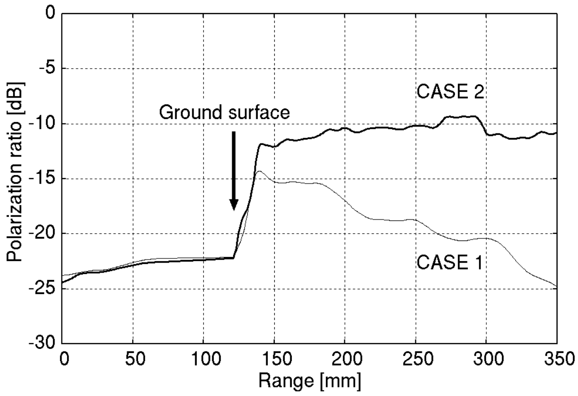

Fig. 8. Polarization ratio.

3.1 Measurement

The GPR antenna was set on the moving head of XY-positioner which enables horizontal scan of the antenna. Measurement was done at lattice grid points with the spatial interval of 2.5cm in both X and Y direction. The number of measurement points was 225 (15 x 15). The scanning plane (the lower end of the antenna) was 13cm off the ground surface. Two inhomogeneous subsurface media were realized by burying objects in homogeneous dry sand as follows:

CASE 1: Smooth surface rocks of round shape were buried in homogeneous dry sand (fig. 5). The mean dimension of the rocks was about 13cm.

CASE 2: Fragments of dry sand lump with edges (fig. 6).

The objects were buried in the depth range from slightly bellow the surface down to 30cm. In both cases, the ground surface was finished flat (Fig. 7).

3.2 Diffraction stacking

Acquired data was frequency domain data. In order to process the data in the time domain, Inverse Fourier transform was applied first. Then diffraction stacking technique was applied to the time domain data to produce 3D image data of subsurface space. The applied migration radius was 5cm. The image data was complex image data. The power of each image pixel calculated for polarization ratio analysis.

3.3 Polarization ratio

From the 3D subsurface image data, we derived polarization ratio of received subsurface echo. We defined the polarization ratio as

$$R(z) = \frac{\sum_x \sum_y \sum_{z'} \left[P_{Cx}\left(x,y,z+z'\right) \right]}{\sum_x \sum_y \sum_{z'} \left[P_{Co}\left(x,y,z+z'\right) \right]}. \quad (1)$$

$P_{Co}(x,y,z)$ and $P_{Cx}(x,y,z)$ are the power of the image pixel at (x,y,z) in dB unit. A volume average of $P_{Co}(x,y,z)$ and $P_{Cx}(x,y,z)$ was taken at every depth step for the volume of 25cm x 25cm x 15cm. Figure 8 compares the polarization ratio of CASE1 and CASE2 as functions of depth. The depth was defined from the lower end of the antenna, therefore the ground surface is found at the depth of about 130mm in the figure.

The difference of the behavior of the polarization ratio of two cases is obvious. In CASE1, the polarization ratio once enhances at the ground surface but then monotonously decreases thereafter. On the other hand, in CASE2, the polarization ratio also enhances at the ground surface but enhancement is larger than that of CASE1 and seems to be saturated then.

4. Conclusive remarks

We reconstructed subsurface image of both co-polarization and cross-polarization for two subsurface media realizations. So far, we studied the polarization ratio of those image pixels as a preliminary investigation. Although this is a rather primitive way of utilizing polarimetric information, the result showed a distinguished difference between the behavior of the polarization ratio of two cases, which implies that a polarimetric GPR is suitable tool for investigation of subsurface medium inhomogeneity.

In the field of polarimetric SAR study, there have been well studied polarimetric behavior of radar pulse scattering and have been developed techniques to discriminate/determine the target by defining the polarimetric scattering property of the target (Cloude and Pottier, 1996). Such techniques should be further applied to this study in order to extract more information of scattering property of the subsurface inhomogeneity then estimate its characteristics, scale and spatial distribution.

This technique does not stay only in the application to the planetary missions but also be applied to terrestrial geology (estimation of gravel or porosity of lava) or civil engineering practice (such as health diagnosis of concrete structure).

Acknowledgement

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