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ANALYSIS OF RADIO WAVE PROPAGATION IN SOIL WITH APPLICATION IN ARCHAEOLOGY

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Abstract. The paper is divided in two parts, first part presents how the propagation of electromagnetic wave is influenced by the local condition of the propagation medium, in our case the soil, and by the central frequency of the transmitter antenna. The second part contains the results of a GPR survey on an archaeological site from Malaiesti, Prahova County.

Key words: ground penetrating radar, survey, roman site prospection.

1. INTRODUCTION

Photonic techniques gain more and more applicability in various domains. These techniques are non-contact, non-destructive and can offer a real time response [1]. Their portability and versatility with different application and materials are several advantages compared with traditional techniques [2]. These advantages are in perfect harmony with immovable heritage, were all the recording and prospection are made *in situ* [3].

One techniques that uses electromagnetic radiation as an exploration mean is ground penetrating radar (GPR). Its operating principle is based on the emission of electromagnetic waves from microwave domain, using frequencies between 30 MHz and 3 GHz, toward the ground and recording the reflected signal by buried features. By analyzing the time of flight and the propagation mode of the radiation the user can identify any changes in stratigraphy and/or the presence of artifacts. The fact that this technique allows the detection of various types of materials and with a high accuracy of object’s position, has led to its use in many fields of activity [4]. One of them is archeology, in which traditional land surveying, such as visual inspection of the soil, is complemented by modern investigation techniques like geochemical, electrical, magnetic and geophysical surveying.

A typical ground radar system is made by: a transmitting antenna, a receiving antenna, a control unit, which commands the parameters of the antennas (triggering, time window etc.) and a processing unit that acts as storage unit and incorporates also a display for data visualization.

2. PROPAGATION ANALYSIS

Radar exploration of ground is based on the study of the velocity of electromagnetic waves as the radiation travel into the ground. As the radiation travels into the ground, meets different structures a part of radiation is reflected and travels back to the system. It is recorded the flying time of the radiation since the moment it is emitted and is detected.

Investigations performed with GPR, based on electromagnetic waves propagation, are influenced by several parameters that affect the transmission of radiation, from which we mention the most important: dielectric characteristics of the medium and the oscillation frequency of the wave.

Permittivity influences the most electromagnetic wave propagation in terms of velocity, intrinsic impedance and reflectivity. In natural soils, dielectric permittivity might have a larger influence than electric conductivity and magnetic permeability [5]. With this statement as a starting point, calculations were made in order to highlight the dependency between the wavelength, the relative permittivity and the oscillation frequency.

Using the formula for obtaining the wavelength in a certain medium, wavelengths were calculated for four different frequencies, respectively 100, 250, 500 and 800 MHz and relative permittivity between 1 and 100, while in literature is well known that GPR can be used on materials with the electric constant up to 80 [6].

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \text{ [m]} \tag{1}$$

$$\lambda_0 = \frac{c}{f} \text{ [m]} \tag{2}$$

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}} \text{ [m]} \tag{3}$$

where λ_0 – wavelength in vacuum [m], c – speed of light in vacuum [m/s], ε_r – relative permittivity, f – wave oscillation frequency [Hz].

The obtained values are shown in Table 1.

Table 1

The wavelength dependency of relative permittivity and oscillation frequency

ε_r	λ_{100MHz} [m]	λ_{250MHz} [m]	λ_{500MHz} [m]	λ_{800MHz} [m]
1	3	1.2	0.600	0.375
4	1.5	0.60	0.300	0.188
9	1	0.400	0.200	0.125
16	0.750	0.300	0.150	0.094
25	0.600	0.240	0.120	0.075
36	0.500	0.200	0.100	0.063
49	0.429	0.171	0.086	0.054
64	0.375	0.150	0.075	0.047
81	0.333	0.133	0.067	0.042

Analyzing the obtained values, the inverse dependence of the wavelength with the square root of the relative permittivity can be observed. Also the values reflect the decrease of the wavelength as the frequency of oscillation increases.

The wavelength represents the resolution with which the GPR can scan the soil depth, limiting the size of the artefacts that can be discovered. When investigating with a small frequency antenna, the spatial resolution will be low. This can be compensated by using a high frequency antennas, but with the disadvantage of decreasing the maximum depth of surveying.

Figure 1 shows the obtained data from Table 1 as a plot. This facilitates the understanding of the wavelength dependence on the relative permittivity and antenna frequency. Sudden asymptotic decrease reflects that, except for vacuum, propagation environments lead to considerable energy attenuation and losses.

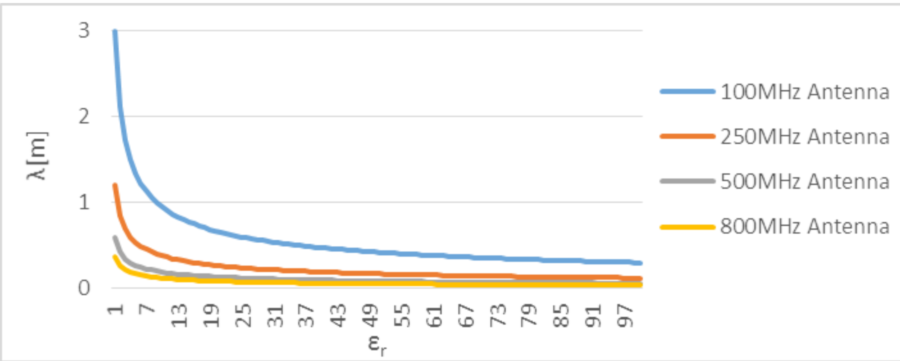

Fig. 1 – Plotted wavelength dependence on the relative permittivity and antenna frequency.

Table 2 is used for an easier assignment between the relative permittivity values used in case study and materials.

Table 2

Relative permittivity of different materials at 100 MHz [7]

Material	Relative permittivity ε_r
Air	1
Dry clay	2–6
Dry sand	3–6
Ice	4–8
Cement	5–6
Snow	8–12
Wet sand	10–30
Wet clay	15–40
Water	80

The presence of water ε_r = 80, composed of polar molecules, leads to loss of energy. Even in very dry conditions, the water present at the capillary level can negatively influence the propagation of electromagnetic radiation.

High concentrations of salt, limestone soils (due to accumulation of calcium sulfate which has a high permittivity) and clay also leads to energy losses. Metals have very high relative permittivity, radiation being reflected by these, this is why vestiges made of metal are easily identified. When using GPR in areas with buried metal objects, the area under them it is shielded, limiting thus the depth of exploration.

3. APPLICATION OF GPR ON HISTORICAL SITES

The older an archaeology site is, the more difficult are the investigations to be realized there. For example medieval walls or newer buildings are easy to be identified. Their consistency, materials from what are made, size and the fact that they are at the surface of the ground, makes these sites ideal to be studied with ground-radar. As the age of the site is greater the shapes are getting more difficult to be identified. For example, the Neolithic sites are the harder ones to be explored with radar technique. The constructing materials and lacks of metal, or presence in small quantities, are the main explanation for this. Furthermore, their burring into the ground, covering them for such a long a time, makes the artifacts to be hard identifiable using GPR.

Principle of detection of GPR is based on identifying the changes in the speed of electromagnetic waves. The factors that influence the speed of electromagnetic waves are the electric and magnetic constants of the materials. So the more difference of constants of adjacent materials, the higher contrasts is recorded by the radar system and the better the objects are identified [8].

Being buried for several thousands of years, covered by different types of soils, that over time large quantities of water fell, the boundary of materials tends to uniform with the host-ground itself, thus it is harder to be identified.

In Romania application of GPR for Neolithic sites surveying wave been reported [9]. On most of the sites are grown agricultural crops, for this reason the half of meter in depth is compromised while the interesting region is up to 5 meters in depth. These sites can be explored only on early spring or late autumn, when vegetation is either still small or is dried, but keeping in mind that the presence of water strongly affects GPR recording. This aspect, correlated with the fact that these seasons are the most affected by rains, which leads to an effective time for in situ prospection of several weeks.

As we are approaching to newer historic times, from detection of view, the sites are easier to be mapped. Presence of metals, dimensions of the walls, construction technique are several items which leads to an easier mapping of more recent sites compared with the prehistoric ones.

For example, in order to map a roman or newer site, to identify how it is continued in an unexplored area, it is not necessary to survey under a high resolution, tens of centimeters, a sampling resolution of several meters it would be sufficient for detecting a construction, which would have dimensions of walls of several meters, thus a lower recording time.

4. CASE STUDY: SITE FROM MALAIESTI

The site from Malaiesti is located west of Dumbravesti on the right side of the Teleajen valley. It consists of two areas: the fort and the roman baths, dating from the period of 101–118 AD. Their construction was made by roman soldiers in the conquering campaigns of Emperor Trajan, campaigns that led to the conquest of the Dacian kingdom. The archaeological site has national importance and has been ranked in the list of Historical Monuments in 2010, also being included in the National Archaeological Record.

From the five areas investigated, only two showed on obtained images – radargrams – clusters which represent the existence of buried objects or structures. In the first area, on two of the records taken appear hyperboles at 0.7 meters and 0.8 meters depths, hyperboles which mark the existence of two buried objects.

In the second area several phenomena appear on radargrams. They represent the approaching and moving away from two adjacent structures, depending on the equipment’s direction of movement during measurements. They appear as parts of the hyperbole because the structures are buried at the limit of the investigated area, the approximate depth of them is 0.8 meters.

Also, the records taken of this area expose two hyperboles, at the same depth, 0.8 meters and approximately the same position, so it is believe that they mark the existence of the same object.

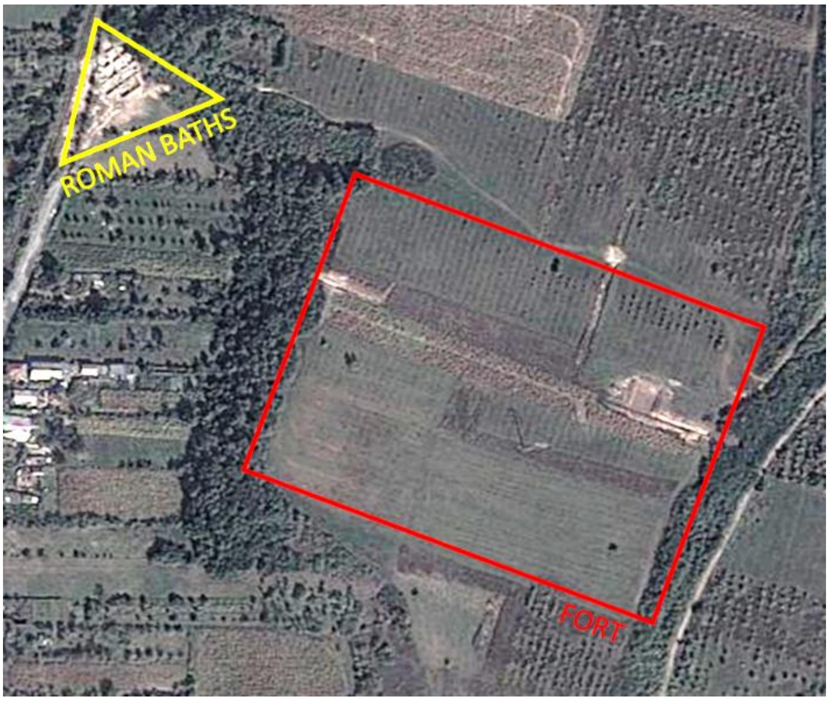

Fig. 2 – Malaiesti site overview.

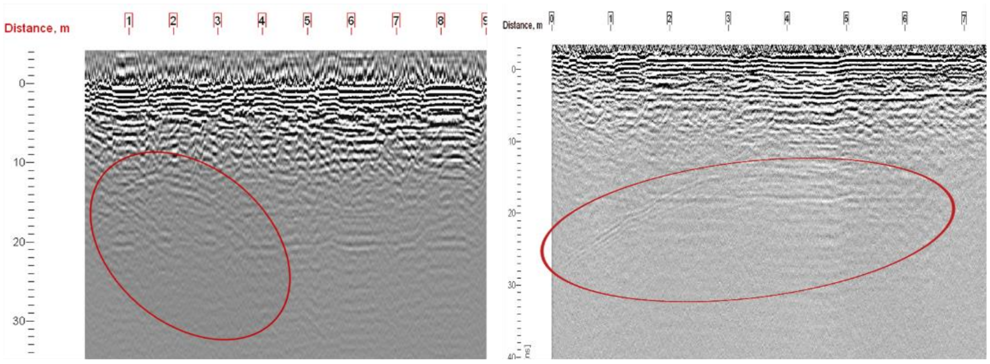

Fig. 3 – Hyperboles occurred in two radargrams.

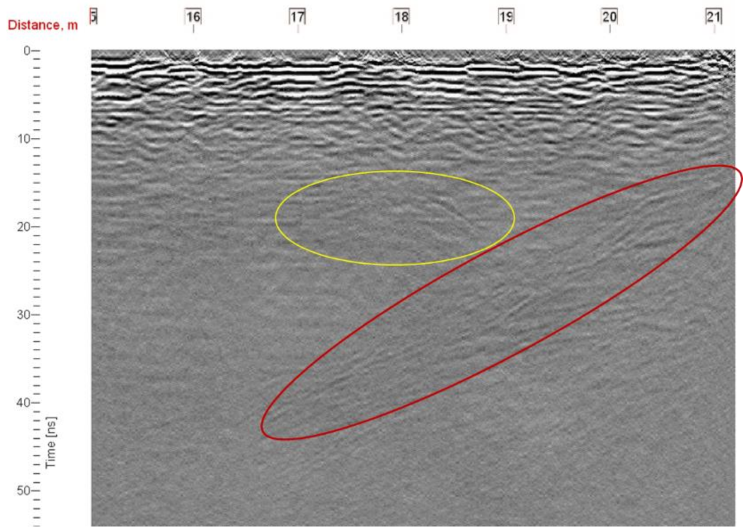

Fig. 4 – Radargram for the second area, yellow circle marks one of the hyperboles, red circle marks the phenomena that represent the structure approaching.

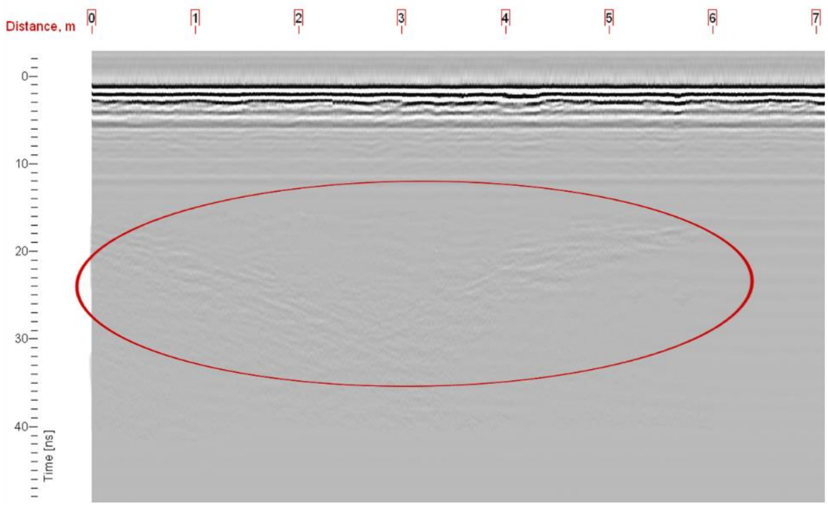

Fig. 5 – Radargram from the second area marking the departure from the structure, same structure market with red in Fig. 4.

5. CONCLUSIONS

Ground penetrating radar is a relative new technique, used for different application, starting with forensic, civil engineering and even archaeology. It's fast surveying, in a non-destructive manner make from this technique ideal for archaeological prospections. Advantages of GPR over other prospecting techniques and compatibility with a vast number of materials results in possibility of using GPR on different types of sites.

The use of GPR in archaeology resulted in mapping unexplored archaeological sites, in discovering buried features, information useful for decision takers in order for establishing the strategy of how a site is further research.

In this paper is presented a case study, consisting in exploration using a radar system on a roman site. There were investigated five zones, in two of the zones, after preliminary processing, being discovered features could represent another construction connected to the existent artifacts discovered.

Results obtained at the Malaiesti site are very promising from the point of view of archaeologist. Information generated after radar prospection show how the site is continued under the unexplored areas, the further effort will be concentrated in these areas.

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