COMPARISON OF RADAR EXPLORATION FROM GROUND AND LOW ALTITUDE FOR FAST ARCHAEOLOGICAL DISSEMINATION

Dragos ENE[1], Roxana RADVAN[2]

Cercetarea în arheologie a evoluat spectaculos odata cu dezvoltările posibilităților tehnice de explorare. Investigațiile radar sunt unanim acceptate ca fiind o soluție eficienta de identificare a neomogenităților din sol, cu referire nu doar la obiecte îngropate ci chiar şi la variațiile constantelor electromagnetice. In această lucrare este prezentată o posibilitate de investigare arheologica, înlocuind tradiționalul radar de sol cu un radar aeropurtat, cu zbor la mica înălțime (1-2 metri).

Research in archaeology evolved spectacular with development of technique mean. Radar investigation are unanimous accepted as being an efficient method used for non-homogeneity identification in ground, referring here not just localization of possible buried objects but also electric or magnetic constants variations. In present paper is presented a possibility of archaeological prospection replacing the traditional ground penetrating radar with an airborne (1-2 meters) radar.

Keywords: ground radar, archaeology

1. Introduction

Research in archaeology evolved spectacular with development of technique means, but is still far from maximum exploitation of offered facilities. As an example, regarding archaeological discharge - activity of maximum interest in nowadays, on large surfaces, equipped and perfect sustainable from technically point of view by proposed means - it can ensure at least halving time needed for prospection's, by making radar (GPR) recordings in a time schedule as up to 24 hours /day (classic, operation more slowly and dependent by the ability to exercise of the manipulator) and in conditions of superior mapping.

Radar investigation, more precisely in UHF / VHF domain (0.1 ... 1 GHz) from electromagnetic spectrum, are unanimous accepted as being as an efficient method used for non-homogeneity identification in ground, referring here not just localization of possible buried objects but also electric or magnetic constants variations (for materials with similar mass density) which offer useful information for very old sites.

[1] National Institute of Research and Development for Optoelectronics, e-mail:dragos@inoe.ro
[2] National Institute of Research and Development for Optoelectronics, e-mail: radvan@inoe.ro

Ground penetrating radar it's a technique that uses electromagnetic pulses, from UHF-VHF domain of e.m. spectra, pulses that are directed into the ground and records the signal that is reflected from buried objects. More precisely the radiation is reflected by the discontinuity of the dielectric constant, discontinuity that is represented by a buried object, interface between 2 ground layers, a void, a tunnel, mines, graves, or much other non-homogeneity.

Radar investigations of subsurface ground layers are done either by ground coupled radar (GPR -Ground Penetrating Radar) or air launched antennas.

Air launched antennas are used in two main applications. First application consist in road prospection, is used for pavement thickness inspections, identification of voids, crakes or other defects, where the antennas, with central frequency between 1 and 2.5 GHz, are mounted in front of a vehicle, at a height of 1 meter. [1]

The second application, known as SAR (Synthetic Aperture Radar), uses frequency between 0.1 and 1.5 GHz, antennas that are mounted on a plane, and applications are made on large surfaces, dry, with the investigated area up to the skin of dept of used wavelength. [2]

Radar methods advantages are well known and used in Romania, even though not for long time (first specialized equipment and reports containing systematic measurements on archaeological sites are dated from 2008, including location like Hoisesti - Neolithic, Cucuteni - Neolithic, Silistea - Bronze Age, Tinosu - Bronze Age [3], Mariuta - Neolithic [4], Saveni - Neolithic, Bordusani - Neolithic, Luncavita - Neolithic) [5], tested and agreeable both by archaeologist and restorers.

The inspection technique propose to upgrade of the base available laboratory means, specialized autolaboratory - ART4ART [6], a mobile laboratory, equipped with techniques for in situ interventions, one of the items considered in designing this mobile laboratory was to be in compatibility with immovable heritage.

Unfortunately classical investigation methods are strongly depending on physical effort capacity of the operator and are very sensible to bad weather conditions, conditions that can be reduced by automatic / computational of some of the operations and by this protecting the operator.

2. Short background

With the first ground radar application, in the '60 by the defensive department of US army, and application in mine detecting, GPR had been tested and used in more domains, including in archaeology, civil engineering, forensic application, geophysical application and many others.

A general propagation equation of electromagnetic field $\mathbf{E}_0$ originating at $z=0$ and $t=0$ in a conducting dielectric is given by

$$\mathbf{E}(z,t)=\mathbf{E}_0 e^{-\alpha z} e^{i(\omega t-\beta z)}, \quad (1)$$

with $z = 1/\alpha$ skin depth.

A main factor that affects reflected data from the ground is represented by the large amount of data received at the ground - air interface. The reflection coefficient at the boundary between two medium is

$$R=\frac{\sqrt{\varepsilon_{r2}}-\sqrt{\varepsilon_{r1}}}{\sqrt{\varepsilon_{r2}}+\sqrt{\varepsilon_{r1}}}. \quad (2)$$

For example, if it's considered the first medium air and the second medium a soil with electric constant of $\varepsilon_r = 9$, results that half of the radiated energy would not be useful in further recordings.

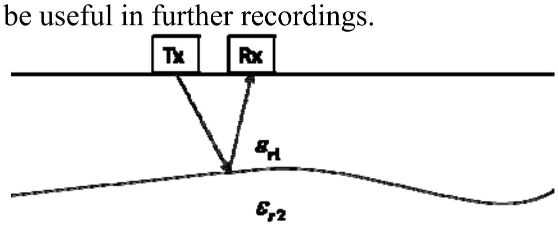


Fig. 1 Emitting - receiving schemme

Electromagnetic radiation is propagating in ground under the shape of a cone, the investigated area at a defined depth being dependent by the used wavelength and dielectric constant as follows:

$$A=\frac{\lambda}{4}+\frac{D}{\sqrt{\varepsilon_r+1}} \quad (3)$$

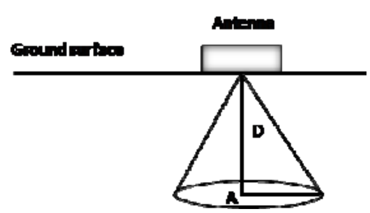


Fig. 2 e.m. cone's propagation

3. Simulation

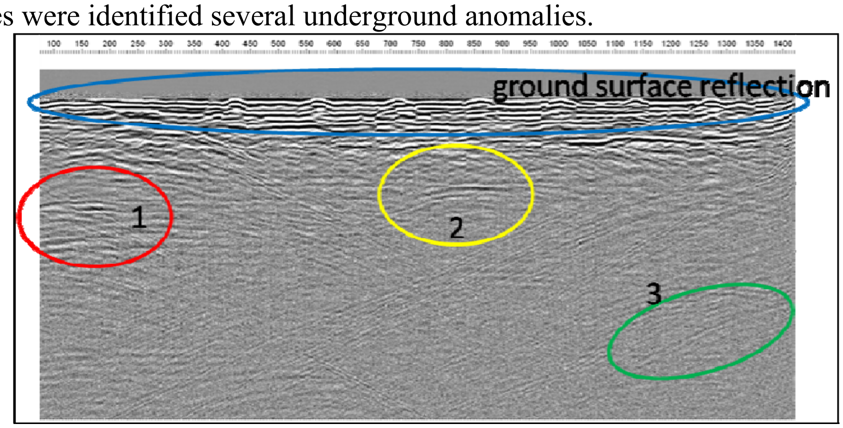
Possibility of 3D mapping of ground heterogeneity, without diggings or coring of the entire inspected surface, in a systematic way, as classical archaeological procedures does, and just only or with higher priority in ranges with maxim probability in detecting archaeological remains or past modification in ground, efficiencies in a direct way archaeologist interventions and substantially decreases his effort.

Placing the antenna at low altitude, between 1 and 2 meters, presents both advantages and disadvantages. First of all it is keeps the field were antenna operates, radiating near and far field, with a larger investigating cone, since the footprint at the surface of the ground is incremented, lowering in this way the number of necessary investigations to cover the interest area. A negative aspect is represented by ground reflection, reflections that must be considered in data processing, with exponential amplifying filter of data recorded after this arrival, data referring in actual zone of interest.

In the considered example, with dielectric constant of 9, at the depth of 2 meters in ground, and with 800 MHz antenna, irradiated area will be 0.7 m^2 and the incident angle of 13^0. If the antenna is suspended at 2 meters from the ground, cone's footprints at ground interface is 1.5 m^2, with incident angle of 19^0, and at the depth of 2 meters in ground, the footprint is approximately 5 meters.

This information is useful to have an idea about how radiated power is spread on ground's surface, which is 50% furthermore reflected. In order to have the same power per area with the antenna placed at 2 meters above the ground, at a depth of 2 meters, in the case of a direct coupling between antenna and ground, the investigated area should be at depths more than 15 meters, with the antenna of 800 MHz, while this antenna is suitable mostly for investigation up to 5 meters.

An experiment was made, in order to simulate an acquisition with an antenna placed at several meters above the ground. For experiments was considered a commercial GPR. Firstly were made acquisition with the system place on ground, with different antennas (250, 500 and 800 MHz). All acquisition parameters were standard (antenna separation, frequency sampling, distance interval and time window), with triggering from a calibrated wheel. On the radar images were identified several underground anomalies.



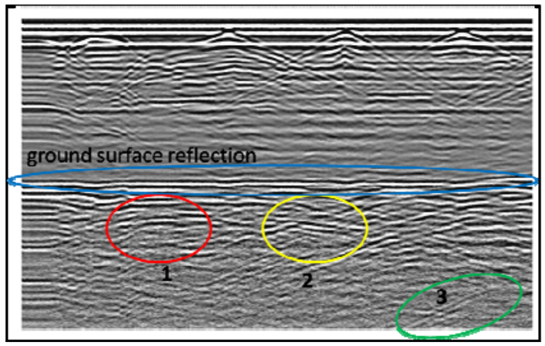


Fig. 3 Top image: direct coupling antenna - ground investigation, bottom image: 4 meters distance between air and ground

For the aerial radar the system was placed on wooden scaffolding, at a distance of 4 meters from ground. Were chosen the same acquisition parameters as in the case of direct antenna - ground coupling, with only 2 modifications: was preferred automatic triggering, at 0.1 s, and a temporal recording window of 200 ns.

Another major problem that must be treated with priority in antenna designing will be represented by electromagnetic waves directionality. In the case of direct coupling antenna/ground, electromagnetic waves are transmitted to ground, in the case of airborne antennas, which include an air layer, with dimension comparable with e.m. waves a significative loss is caused with the lack of directionality of the pulses.

As it may see in figure 3, in the air layer between antenna and ground the recording are noisy, with several reflections caused by the supporting elements of the scaffolding. Ground reflected data are noisier than direct coupling antenna-ground, but the interesting areas are still recorded (1, 2 and 3). In this case, with recordings made at 4 meters high, footprint on ground's surface is twice as bigger as in the case of 2 m placing antenna, meaning that the useful radiation in half from 2 m recording. This is a promising fact for the future recordings, with measurements made at 1- 2 meters, for the weak reflecting objects.

Proposed experiment was possible due to an open restoration yard inside of a historical church. Even this test was done indoor for later outdoor application; the experimental condition had the benefit of soil humidity, a possible perturbance factor.

4. Conclusion and further work

It's well known the loose rate, still very high, of information due to inherent disorientation on field, caused by traditional archaeological research deployments, also as the slow speed, quite often very slow, which makes surveying to lie on two years (with significant interruption of in situ activities due to bad weather conditions).

This idea can be further exploited, by equipping of a low altitude UAV with a special designed antenna, that assure subsurface investigations with a medium resolution, at an approximate depth of 5 meters, area that is interested from archaeological point of view, with compensation of noisy signals from air layer (layer between airborne antenna and ground). To precisely record the position, the unmanned automated vehicle should be geared also with a DGPS.

Placing the antenna at low altitude, between 1 and 2 meters, presents both advantages and disadvantages. First of all it is keeps the field were antenna operates, radiating near and far field, with a larger investigating cone, since the footprint at the surface of the ground is incremented, lowering in this way the number of necessary investigations to cover the interest area. A negative aspect is represented by ground reflection, reflections that must be considered in data processing, with exponential amplifying filter of data recorded after this arrival, data referring in actual zone of interest.

Since radar inspections techniques uses as investigation tool electromagnetic waves and studying displacement currents, in designing of the antennas will be considered additional noise - air radiations sources (radio, TV, emission / receptions units, mobile phones antennas, power cables and others), interference sources that usually doesn't affect the recordings in a direct antenna / ground coupling.

Another major problem that must be treated with priority in antenna designing will be represented by electromagnetic waves directionality. In the case of direct coupling antenna/ground, electromagnetic waves are transmitted to ground, in the case of airborne antennas, which include an air layer, with dimension comparable with e.m. waves a significative loss is caused with the lack of directionality of the pulses.

REFERENCES

[1] *T. Saarenketoa and T. Scullion*, "Road evaluation with ground penetrating radar", in Journal of Applied Geophysics, Volume 43, Issues 2-4, March 2000, Pages 119-138, doi:10.1016/S0926-9851(99)00052-X

[2] *D. J. Daniels*, Ground penetrating radar, 2nd Edition, Institution of Electrical Engineers, ISBN-10: 0863413609

[3] http://arheoinvest.uaic.ro/, 2011

[4] *C. Lazăr, D. Ene, V. Parnic, D. N. Popovici, M. Florea*, "Ground Penetrating Radar Survey at the Măriuța-La Movilă Necropolis, Romania", in Mediterranean Archaeology & Archaeometry, 2011, in press

[5] http://inoe.ro/CARPO/, 2011

[6] *M. Simileanu, W. Maracineanu, J. Striber, C. Deciu, D. Ene, L. Angheluta, R. Radvan and R. Savastru*, "Advanced research technology for art and archaeology – ART4ART mobile laboratory", in Journal of Optoelectronics and Advanced Materials, vol.10, nr.2, feb.2008, pg. 470-473