

Tunnel Detection and Visualization Using the Method of Auxiliary Sources

V. Tabatadze, B. Baratashvili, I. Petoev, R. Zaridze

Laboratory of Applied Electrodynamics and Radio-Engineering
Iv. Javakhishvili Tbilisi State University
Chavchavadze Av. 3, 0176, Tbilisi, Georgia
E-mail: vasilitabatadze@gmail.com

Abstract -Motivation of the paper in big frame is to determine some anisotropic properties under surface of the earth like tunnels, empty areas or dielectric pipelines. It is well known, that for some frequencies of the electromagnetic waves the earth is pretty transparent and field penetrates into the ground. Reflected outgoing wave must contain information about the structure underground surface. This article concerns to the investigation of the complete reflected field from the ground in order to detect anisotropy under surface, particularly (farther), the tunnel, located inside ground using the incident electromagnetic waves. The goal of the work is to determine whether the tunnel is inside the ground or not. The Method of Auxiliary Sources (MAS) is used to solve the stated problem. As a sensitive method, the resonant properties of the tunnel are studied. The investigation is based on the fact that reflected field frequency characteristic measured in the point above the ground contains information (approximately the size and orientation) about the tunnel inside the ground.

Index Terms- tunnel, resonances, MAS.

1. INTRODUCTION

The investigation of the ground using the electromagnetic radiation for detecting the objects located inside is very topical problem. It has application in wide area, like archaeology, geology, military and other areas. Also, it has application in border security systems in order to avoid the illegal cross of border using tunnels.

Many publications with references exist for this problem solution. In [1] The Synchronized Electromagnetic Gradiometer is used for the enhanced conductivity associated with tunnels, as compared to the surrounding medium, to detect the tunnels. In [2] multimodal detection of subsurface targets such as tunnels, pipes, reinforcement bars, and structures are investigated using both ground-penetrating radar (GPR) and seismic sensors with signal processing techniques to enhance localization capabilities. In [3] Radio frequency (RF) tomography is proposed to detect underground voids, such as tunnels or caches, over relatively wide areas of regard. All this indicates on actuality of the problem and needs alternative approaches to solution similar problems.

In the past we have solved the problem of Buried Object Recognition [4]. The novelty of our article for problem

solution is usage of the MAS methodology [5] and possible resonant phenomena in inhomogeneous areas. The specific version of MAS for this particular problem is given below.

2. PROBLEM STATEMENT

In this paper we are going to discuss the next problem's solution: the cylindrical shape tunnel is located inside the ground with axis parallel to ground surface. As the source we use the EM field point source (Fig.1) which is located above the ground. We measure the complete reflected field in the points around to initial source position and construct frequency characteristics of the structure. Reflected field will be depending on the orientation of the incident wave field's polarization and tunnels axes. Besides, standing waves could be excited in tunnels.

Our goal is to find tunnel's existence inside the ground. We illuminate the ground using electromagnetic wave with the swept frequency. We consider, on some frequency the empty areas under ground behaves as a resonator. So, the measured reflected field should have peaks at the resonant frequencies corresponding to tunnel resonances. All characteristic of the ground tunnel system: the size, location and orientation of the tunnel, as well as the ground permittivity and conductivity must contain reflected field. We investigate several cases of tunnel position and size also source position in order to get some statistical regularity. Because of the limit of paper size in this article we have presented only the resonant properties of the tunnel at different source polarization.

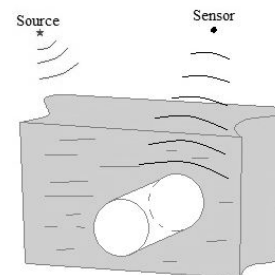


Figure 1. Problem statement

During real experiment the source with circular polarization is needed because in this case we don't know tunnel orientation. Circular polarization will give all the resonances of the tunnel.

3. THEORETICAL PART

Let's consider the S planar part of the ground, billow of which the cylindrical shape tunnel S_0 is located (Fig. 2). The point electromagnetic time harmonic electromagnetic wave $\vec{E}_{inc}$, $\vec{H}_{inc}$ falls to the S surface. Our goal is to find the reflected field $\vec{E}^{out}$, $\vec{H}^{out}$ above the ground, the field between ground and tunnel $\vec{E}^{bet}$, $\vec{H}^{bet}$ and the field inside ground $\vec{E}^{in}$, $\vec{H}^{in}$.

We mean that the ground between S and S_0 surfaces is the dielectric with losses which has complex permittivity $\epsilon_c = (\epsilon', \epsilon'')$. The space above the ground and inside the tunnel is vacuum with permittivity ϵ_0 , μ_0 .

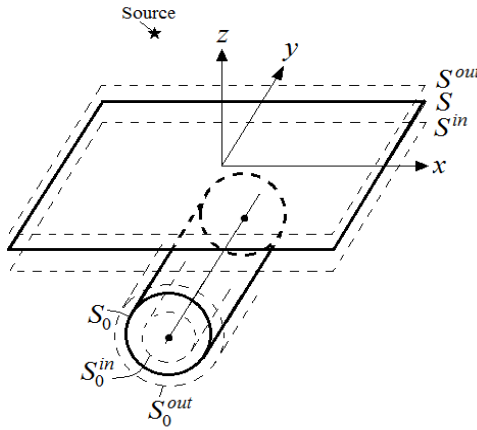


Figure 2. The geometry of the ground with tunnel

The considered problem is solved using the MAS [5], for which inner S^{in} and outer S^{out} auxiliary surfaces parallel to the S surface are equally-spaced positions to the S surface. The auxiliary surfaces S_0^{in} and S_0^{out} are also constructed inside and outside of the tunnel as it is shown on the fig.2. The equal number of collocation points for the both side on the plane surfaces of the ground and cylindrical - tunnel we denote as M and N correspondingly. In order to consider all possible directions of scattered EM field's polarizations, as the auxiliary sources the two perpendicular Hertz dipoles are chosen. The polarization vectors of these dipoles coincide to the tangent vectors of the ground and tunnel surface.

The total field above the ground contains incident $\vec{E}_{inc}(\vec{r})$, $\vec{H}_{inc}(\vec{r})$ field and reflected $\vec{E}_{S^{in}}(\vec{r})$, $\vec{H}_{S^{in}}(\vec{r})$ fields. The reflected field is described by the auxiliary sources distributed

on the S^{in} surface. The field between S and S_0 surfaces contains transmitted $\vec{E}_{S^{out}}(\vec{r})$, $\vec{H}_{S^{out}}(\vec{r})$ fields and the fields reflected from ground $\vec{E}_{S_0^{in}}(\vec{r})$, $\vec{H}_{S_0^{in}}(\vec{r})$. These fields are described correspondingly with auxiliary sources, located on S^{out} and S_0^{in} surfaces. Therefore,

$$\begin{aligned}\vec{E}^{out}(\vec{r}) &= \vec{E}^{inc}(\vec{r}) + \vec{E}_{S^{in}}(\vec{r}), \quad \vec{H}^{out}(\vec{r}) = \vec{H}^{inc}(\vec{r}) + \vec{H}_{S^{in}}(\vec{r}), \\ \vec{E}^{bet}(\vec{r}) &= \vec{E}_{S^{out}}(\vec{r}) + \vec{E}_{S_0^{in}}(\vec{r}), \quad \vec{H}^{bet}(\vec{r}) = \vec{H}_{S^{out}}(\vec{r}) + \vec{H}_{S_0^{in}}(\vec{r}), \\ \vec{E}^{in}(\vec{r}) &= \vec{E}_{S_0^{out}}(\vec{r}), \quad \vec{H}^{in}(\vec{r}) = \vec{H}_{S_0^{out}}(\vec{r}),\end{aligned}$$

where $\vec{E}_{S^{in}}(\vec{r})$, $\vec{H}_{S^{in}}(\vec{r})$, $\vec{E}_{S^{out}}(\vec{r})$, $\vec{H}_{S^{out}}(\vec{r})$, $\vec{E}_{S_0^{in}}(\vec{r})$, $\vec{H}_{S_0^{in}}(\vec{r})$, $\vec{E}_{S_0^{out}}(\vec{r})$, $\vec{H}_{S_0^{out}}(\vec{r})$ are the auxiliary surfaces fields.

The unknown complex amplitudes of the auxiliary sources can be found using the boundary condition satisfaction the tangential components of the electric and magnetic field should be continuous along the ground and the tunnel:

$$\begin{cases} \vec{E}^{out}(\vec{r}_m) \cdot \vec{x} = \vec{E}^{bet}(\vec{r}_m) \cdot \vec{x} & \vec{H}^{out}(\vec{r}_m) \cdot \vec{x} = \vec{H}^{bet}(\vec{r}_m) \cdot \vec{x} \\ \vec{E}^{out}(\vec{r}_m) \cdot \vec{y} = \vec{E}^{bet}(\vec{r}_m) \cdot \vec{y} & \vec{H}^{out}(\vec{r}_m) \cdot \vec{y} = \vec{H}^{bet}(\vec{r}_m) \cdot \vec{y} \\ \vec{E}^{bet}(\vec{r}_{0,n}) \cdot \vec{\varrho}_n = \vec{E}^{in}(\vec{r}_{0,n}) \cdot \vec{\varrho}_n & \vec{H}^{bet}(\vec{r}_{0,n}) \cdot \vec{\varrho}_n = \vec{H}^{in}(\vec{r}_{0,n}) \cdot \vec{\varrho}_n \\ \vec{E}^{bet}(\vec{r}_{0,n}) \cdot \vec{y} = \vec{E}^{in}(\vec{r}_{0,n}) \cdot \vec{y} & \vec{H}^{bet}(\vec{r}_{0,n}) \cdot \vec{y} = \vec{H}^{in}(\vec{r}_{0,n}) \cdot \vec{y}. \end{cases}$$

The given boundary condition represents the linear algebraic equation system. Solving this system, we determine unknown amplitudes and then, the field in all areas.

4. NUMERICAL SIMULATION RESULTS.

By means of above mentioned mathematical algorithm we have created user-friendly program package for numerical experiments realization. This program package gives ability to choose ground and tunnel parameters also source position and other parameters and calculate near field distribution. We can construct frequency characteristics for different cases and compare each other. Main idea of these numerical experiments is to create the stated problem's methodology.

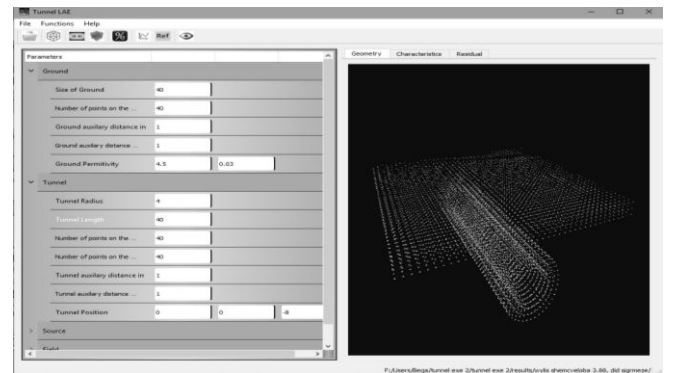


Figure 3. Program package interface

If we create the library of such characteristics, during real experiment we can compare the measurement results to the data in library and decide if the tunnel is inside the ground. Program package also gives ability to look at field dynamics in 3D space. Also we calculate error of solution in order to better choose auxiliary parameters.

Fig. 3 shows the program package's interface which gives ability easily manage the input parameters: to construct the geometry of the problem with its material properties; to choose type the source and frequency range of the incident EM field as well as output parameters like reflected field, near and far field distribution inside and around the study system.

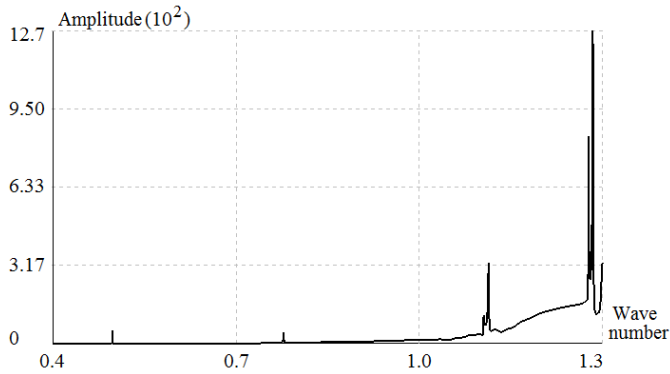


Figure 4. Field measured in point above ground dependence on the wave number

First we consider the case, when the ground has no losses and permittivity $\varepsilon=4$. The polarization of the incident field is parallel to the tunnel's axis. In this case the frequency characteristic of the reflected field has the form (fig.4).

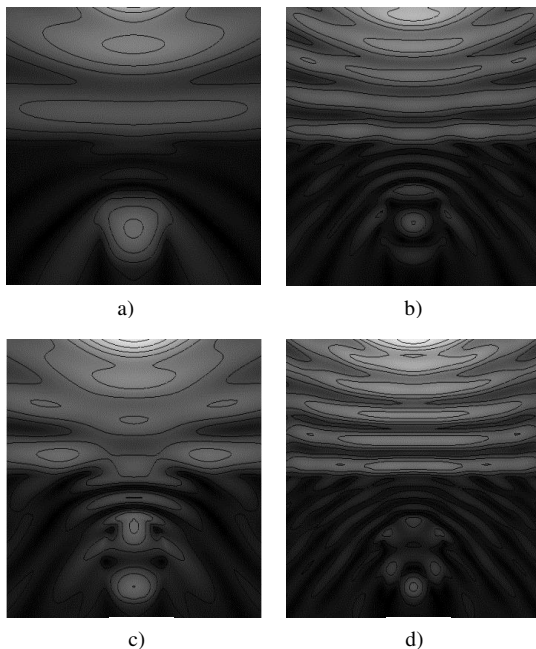


Figure 5. Near field distribution at the resonant frequencies XOZ section: a) first resonance $k=0.498$, b) second resonance $k=0.778$, c) third resonance $k=1.11$, d) forth resonance $k=1.2$

On this characteristic we see several peaks which correspond to resonances of the underground empty spaces (cylindrical tunnels forms). At the resonant frequencies energy is accumulated inside tunnel and then reradiated. Generally, resonant frequencies contain information about sizes and volumes of the inhomogeneity underground. It is obvious, that the near field distribution at these peaks frequencies has the form given on the fig.5. Presented field distribution inside the tunnel corresponds to the eigen fields and, the value of the wave number in the fig. 4 is the eigen value of the tunnel's space.

We have also considered the polarization perpendicular to tunnel's axis. The frequency characteristics in this case has the form (Fig. 6)

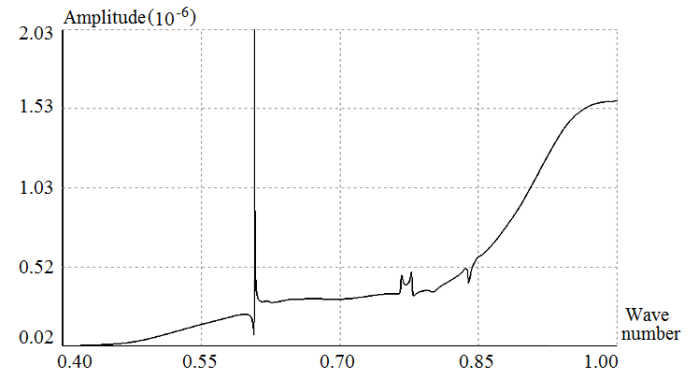


Figure 6. Field measured in point above ground dependence on the wave number in case of perpendicular polarization

As we see the characteristic is very different from the fig.4. The first resonance is higher than the other ones. On the fig.7 there is near field distribution in ground and in the tunnel at the first resonance.

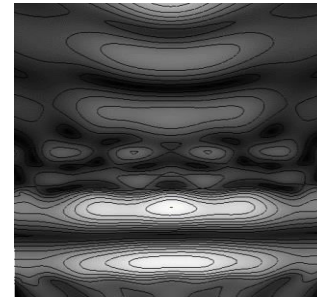


Figure 7. Near field distribution at the first resonance $k=0.61$ YOZ section (along the tunnel) some field's levels are cut away in order to better see others

We have also investigated the case when the ground has the losses to EM field. Real soil permittivity and loss tangent is given on the fig.8 as we see on these graphs there exist the frequency range for which the soil is more transparent [6]. It is obvious, that in case of the real experiment these characteristics could be considered.

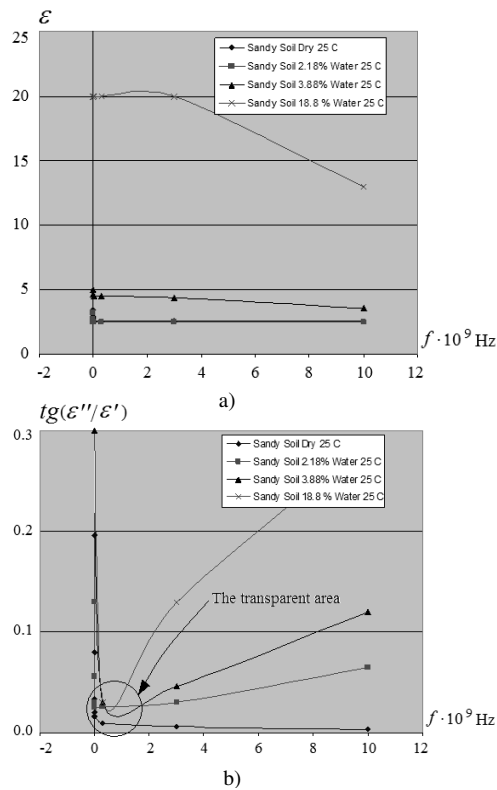


Figure 8. Frequency characteristics: a) soil permittivity, b) loss tangent
In case of some frequency when ground has high losses (wet ground and field do not penetrate) resonant peaks don't appear fig.9 and reflected field characteristics is smooth. $\varepsilon''=1.5$

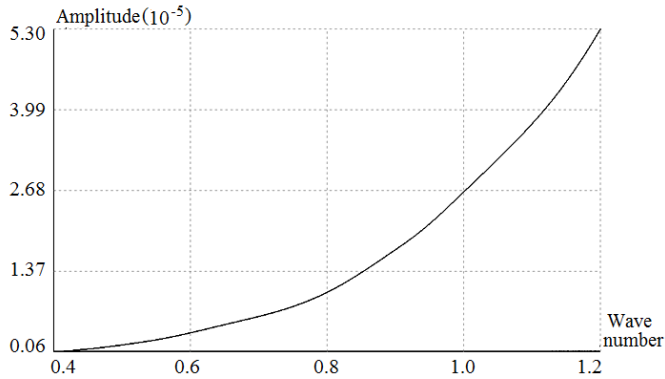


Figure 9. Field measured in point above ground dependence on the wave number when the ground has losses

4. CONCLUSION

In this article the resonant properties of the tunnel, located inside ground, was studied. The goal was to determine the presence of tunnel inside ground and its size and orientation using the electromagnetic wave radiation by means of the MAS. The program package for this reason was created and some numerical results were presented for different

polarization of source. Using this program package it is possible to consider many cases, change tunnel radius and location, ground conductivity and for each case calculate frequency characteristic. We suppose, that this is first step to study stated problem finally and it needs, at least, more numerical experiments. If we will create the library of these characteristics we can use it for real experiment. At the real experiment the frequency characteristics will be measured and compared to the library data, then we can find statistically which characteristics is closer to the simulated one and decide if the tunnel is inside the ground and what is its orientation. There must be also another type of study development.

REFERENCES:

- [1] Larry G. Stolarczyk, Robert Troublefield, James Battis "Detection of Underground Tunnels with a Synchronized Electromagnetic Wave Gradiometer" Proc. of SPIE Vol. 5778, 2005
- [2] Tegan Counts, Gregg Larson, Ali Cafer G'urb'uz, James H. McClellan and Waymond R. Scott Jr. "Investigation of the Detection of Shallow Tunnels Using Electromagnetic and Seismic Waves" Proc. of SPIE Vol. 6553 65531G-1, 2007
- [3] Lorenzo Lo Monte, Danilo Erricolo, Francesco Soldovieri, and Michael C. Wicks. "Radio Frequency Tomography for Tunnel Detection" IEEE Transactions on geoscience and remote sensing, Vol. 48, No. 3, March, 2010
- [4]. V. Tabatadze, D. Kakulia, G. Saparishvili, R. Zaridze, N. Uzunoglu "Development of a New Efficient Numerical Approach for Buried Object Recognition", Sensing and Imaging: An International Journal: Volume 12, Issue 1 (2011), Page 35-56, <https://link.springer.com/article/10.1007/s11220-011-0060-7>;
- [5]. R. Zaridze, G. Bit-Babik, K. Tavzarashvili, N. Uzunoglu, D. Economou, "Wave Field Singularity Aspects Large-Size Scatterer and Inverse Problems." IEEE Transactions on AP, vol.50, No. 1, January 2002, pp.50-58.
- [6] Arthur R. von Hippel, ed.: "Dielectric Materials and Applications", M.I.T. Press, Cambridge, MA, 1954