Propagation Model for RF Geotomography

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Abstract

A novel RF Geotomography system is introduced. RF geotomography may become a powerful tool to detect tunnels and underground cavities, thus increasing underground surveys and allowing for more efficient rescue missions.

RF geotomography is based upon a set of transmitters/receivers deployed above the ground according to a known geometry. Using Diffraction Tomography techniques, a 3D image of the ground is constructed, thus providing the capability to easily detect tunnels and cavities below the ground.

This paper addresses the issues of: 1) Propagation models specifically designed for our RF Geotomography geometry. 2) Appropriate frequency ranges for detection of tunnels and cavities using RF Geotomography. 3) Suitable scattering model of tunnels for RF geotomography.

1. Propagation Model

We intend to design a *RF Geotomography* (RFG) system for remote sensing. RFG offers promising new advances to acquire 3D images of below ground objects, to detect the presence of tunnels or cavities, and to explore for sinkholes and natural resources. RFG systems can be extremely useful for mining, search & rescue, and monitoring areas of interest.

Normally, remote sensing information concerning ground targets is obtained via seismic sensors or GPR, although some experiments of *Electromagnetic Geotomography* have been performed using boreholes [1-5]. Usually, higher resolution and deeper ground penetration are achieved by lowering frequency of operation, and increasing both signal power and bandwidth. The latter, however, is in contrast with the restricted bandwidth allowed and it also yields an overall increase of complexity and cost of the system. Furthermore, larger bandwidth leads to an increase in EMI and thermal noise power at the receiver, forcing the designer to transmit drastically more energy to detect very weak scattered signals. GPR generally use frequencies above 100 MHz and extremely wideband signals: this inevitably leads to a drastic reduction of the maximum range distance. Conversely, seismic tomography employs very low frequency spectrum that is unable to detect relatively small scatterers such as adits, mining tunnels or mini-cavities. Recent developments in geotomography through borehole operations have shown promising performance in detection of change in substrate layers: however, to the best knowledge of the authors no ad hoc experiments using electromagnetic geotomography aimed at detecting tunnels or cavities have ever been published. Moreover, geotomography through the use of boreholes can be a very expensive and inadequate approach for both commercial or government applications.

A way to overcome the aforementioned drawbacks is to employ RFG technology. In fact, with RFG, only several frequencies are transmitted into the ground from different emitters, and multiple receiving sensors are placed in and around the area of interest; in this way, geometric diversity is exploited to improve the performance of the sensor. While GPR systems are usually UWB systems, and larger bandwidth provides for improved resolution (provided propagation attenuation does not severely degrade signal-to-noise), RFG systems are intrinsically ultra-narrowband (operating at a single frequency in the limit), where lower signal bandwidths provide greater benefits [6-7].

RFG systems require extensive signal processing of measured radar data [8], and due to the fact that the wavelength of the signal is comparable with the dimension of the scatterers (e.g. adits and tunnels), RFG systems rely heavily upon the concept of diffraction tomography imaging [9-10]. RFG is a novel approach and to fully exploit its potential, major investigations are required from both an electromagnetic and signal processing perspective.

With this work, we focus our attention on developing a suitable propagation model. Our goals are:

- Determine a suitable range of frequencies in which the RFG system can operate efficiently. It is well known that higher frequencies lead to better resolution, but shorter range of operation due to propagation attenuation, and vice-versa. Our goal is to find a trade off between the two contrasting situations, finding the limit for which Born and Rytov approximation are still valid, and providing useful values for the propagation attenuation coefficient of several materials at the HF frequencies.
- Determine the percentage of electromagnetic power that flows into the ground using an HF antenna placed above the ground. The formula is dependent upon the height of the antenna from the ground, and it also includes antennas buried in the ground.
- Determine the propagation effect of a low-frequency signal transmitted into a dense medium half space (the ground) at low grazing angles from a source in free space (the air).
- Determine the field scattered from a tunnel or adit using the low-frequency assumption. The formula takes into account the direction of arrival of the incoming signal. At the present time, multiple scattering from object will be not considered.
- Determine the power loss and the phase error at the receiver. Determine optimal positions for transmitters and receivers.
- Determine the proper ratio between the incident field and the scattered field at the receiver.
- Determine the advantages of using regular clock face geometry with respect to other geometries.
- Determine the actual noise power that is measured at the receiver.

Our results are expected to benefit the designer of RFG systems to easily dimension the whole system, and accurately predict the maximum range of operation, the cancellation efficiency and the signal processing needed to correct for errors due to propagation.

2. References

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