Detection by RF Techniques for Earth Layers Using GPR Software

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Abstract — **Ground Penetrating Radar (GPR) is widely used for detecting and monitoring subsurface objects. To detect the geological subsurface layers, location and its types using RF techniques and to present the analysis that examines the effect of ground-contacting GPR. This has been developed, validated, and subsequently used to find the water resources under the subsurface layers. In the surveyed material, An EM pulse is penetrated through an antenna; a portion of the energy is reflected back to the antenna when an interface between the materials of dissimilar dielectric constants is encountered. Scattering from the objects in general has been studied extensively, because of its many applications including archaeology, law enforcement, remote sensing, and geological exploration. The target of interest includes both dielectric and conducting objects. This can be simulated using "GPRSim.net" software for various permittivity, conductivity and thickness up-to ten layers with different frequencies among the geological subsurface.**

Keywords – ground penetrating radar; electromagnetic pulse; dielectric permittivity; electric conductivity.

I. Introduction

Ground-penetrating radar (GPR) is a geophysical method that employs an electromagnetic technique. The method transmits and receives radio waves to probe the subsurface. Ground penetrating radar (GPR) also known as surface penetrating radar (SPR), was initially designed for locating targets deep underneath the ground or detecting targets that are not visible [1]. A rapid development in hardware, measurement and analysis techniques, and the method has been extensively used in many applications, such as archaeology, civil engineering, forensics, and geology and utilities detection.

The most important applications of GPRs are highway constructions, identify defects behind retaining walls, locating moisture damage, detecting corrosion of reinforcing steel in concrete, assessing the thickness of pavement layers and detecting objects such as pipes, cables, mines and unexploded ordnance buried under the ground [2].

GPR must achieve certain criteria in order to operate successfully, that include a sufficient signal to clutter ratio, signal to noise ratio (SNR), resolution of the target and also depth resolution of the target [3].

In the previous research, A numerical simulator based on the discrete dipole approximation, which is an integral-equation-based method, was developed, validated, and subsequently used to compute scattering from root structures modeled by an ensemble of buried cylinders [4], [5] is restricted to a single object and limited ranges of permittivity and object sizes. GPR transmits EM waves into the soil, and the moisture content can be retrieved by analyzing the travel time of the wave reflected at a permittivity contrast interface [6], to evaluate the shallow soil water content variations from standard fixed-offset GPR data by simulating the data over different likely EM soil conditions [7]. This technique is mainly based on a linear dipole model that uses a thin-wire approximation is assumed for the transmitting and receiving antennas. The homogenous half-space model is used to calculate the waveform instantaneous amplitude values averaged over different time windows.

A quantitative method for evaluating these techniques is also presented. Through this evaluation, the approach could be conveniently used to map, rapidly and at high spatial resolution (on the order of the antenna separation), soil water content variations at the medium scale, without some of the limitations of other GPR methodologies applied for the same purpose. The depth range of GPR is limited by the electrical conductivity of the ground, the transmitted center frequency and the radiated power. As conductivity increases, the penetration depth decreases. This is because the electromagnetic energy is more quickly dissipated into heat, causing a loss in signal strength at depth. Higher frequencies do not penetrate as far as lower frequencies, but give better resolution. The frequency range of (200-2000) MHz, the increase in depth of penetration has determined.

II. PRINCIPLE

An EM pulse is sent through an antenna, penetrating into the surveyed material. A portion of the energy is reflected back to the antenna when an interface between materials of dissimilar dielectric constants is encountered.[9] The Ultra-wideband frequency modulated continuous wave for the synthetic aperture radar has carried out.

The reflected signal has information on 1) how quickly the signal traveled, 2) how much was attenuated. These quantities depend on spatial configuration and materials. The thickness of a layer is given by

$$d_i = \frac{Ct_i}{2\sqrt{\varepsilon_{r,i}}} \qquad (1)$$

Where d_i is the thickness of layer *i*, ti the total travel time through that layer, C is the speed of light and $\varepsilon_{r,i}$ the dielectric constant of the layer.

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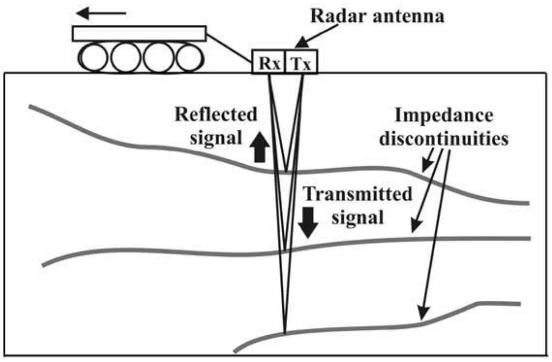

Fig 1. Principle of Ground Penetrating Radar

A. Electromagnetic wave propagation in soil

In this model, the propagation velocity *v* of the electromagnetic wave in soil is characterised by the dielectric permittivity ε and magnetic permeability μ of the medium:

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \quad (2)$$

B. Dielectric Permitivity

The Permittivity describes the ability of a material to store and release electromagnetic energy in the form of electric charge and is classically related to the storage ability of capacitors. Permittivity greatly influences the 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.

$$\varepsilon = \varepsilon_0 . \varepsilon_r \quad (3)$$

where ε0 is the permittivity in air or vacuum and ε_r is the relative permittivity. The frequency-dependent dielectric permittivity of water affects the permittivity of soil. Within the GPR frequency range, the frequency dependence is caused by polarization of the dipole water molecule, which leads to relaxation.

C. Electric Conductivity

The Electric conductivity describes the ability of a material to pass free electric charges under the influence of an applied field. The primary effect of conductivity on electromagnetic waves is energy loss, which is expressed as the real part of the conductivity. The imaginary part contributes to energy storage and the effect is usually much less than that of energy loss. In highly conductive materials, the electromagnetic energy is lost as heat and thus the electromagnetic waves cannot propagate as deeply. Therefore, GPR is ineffective in materials such as those under saline conditions or with high clay contents.

The conductivity is defined as the inverse of resistivity, ρ ,

$$\sigma = \frac{1}{\rho} \quad (4)$$

D. Characteristics of various materials

The following table provides the relative permittivity, electric conductivity and attenuation constant for various materials.

MATERIALS	RELATIVE PERMITIVITY	CONDUCTIVITY [S/m]	ATTENUATION CONSTANT
DRY SAND	2-6	0.001-0.004	0.01-1
WATER	81	0.01-0.04	0.01
WET SAND	10-30	0.02-0.08	0.5-5

Table 1. Typical range of dielectric Characteristics of various materials measured between (200-2000) MHz

II. SYSTEM MODELS

A. GPR Systems

A GPR system is conceptually simple and consists of four main elements: the transmitting unit, the receiving unit, the control unit and the display. The basic type of GPR is a time-domain system in which a transmitter generates pulsed signals and a receiver samples the returned signal over time. Another common type is a frequency-domain system in which sinusoidal waves are transmitted and received while sweeping a given frequency. The time-domain response can be obtained by an inverse Fourier transform of the frequency-domain response.

GPR systems operate over a finite frequency range that is usually selected from 1 MHz to a few GHz, depending on measurement requirements. A higher frequency range gives a narrower pulse, yielding a higher time or depth resolution (i.e., range resolution), as well as lateral resolution. On the other hand, attenuation increases with frequency, therefore high frequency signal cannot propagate as far and the depth of detection becomes shallower. If a lower frequency is used, GPR can sample deeper, but the resolution is lower. [8]This system model has been used to investigate the rail road.

Antennas are essential components of GPR systems that transmit and receive electromagnetic waves. Various types of antennas are used for GPR systems, but dipole and bowtie antennas are the most common. Most systems use two antennas one for transmitting and the other for receiving, although they can be packaged together. Some commercial GPR systems employ shielded antennas to avoid reflections from objects in the air. The antenna gain is very important in efficiently emitting and receiving the electromagnetic energy. Antennas with a high gain help improve the signal-to-noise ratio. To achieve a higher antenna gain, the size of an antenna is determined by the operating frequency. A lower operating frequency requires larger antennas. Small antennas make the system compact, but they have a low gain at lower frequencies.

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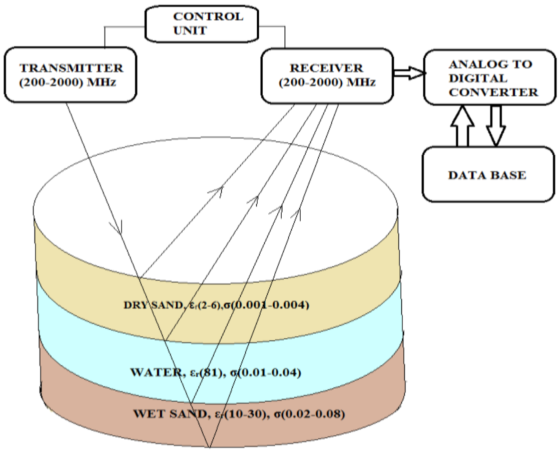

Fig 2. Block Diagram

The control unit receives the survey parameters from the interface and generates the timing signals for the transmitter and receiver. It also receives the data from the receiver and does the initial processing before sending it to the storage device. In some systems the interface, data storage, displays and control unit are all incorporated into one unit. In other systems, the control unit is separate and a laptop or palmtop computer is employed to enter the survey parameters, store the data, and provide real-time data display.

B. Tool used

GPRSim.net is a basic GPR time domain simulation tool. It is partially based in the transmission line model and allows up to ten layers to be simulated with frequencies ranging from 200 to 2000 MHz It can be used to try out different real world survey scenarios and understand how different center frequency antennas could perform, as well as getting an idea of how the ground penetrating radar A-scan might look like in the given conditions.

1. Conductivity/Loss tangent: Select with the radio button which parameter shall be entered and displayed for each layer.

2. Frequency: Enter the operating frequency of the antenna in megahertz. The range of allowed frequencies is between 200 MHz and 2000 MHz

3. Permittivity: Enter the value of the permittivity (relative dielectric constant) for every layer.

4. Spectrum: This window displays the spectrum of the time domain plot results of the simulation.

III. RESULT AND DISCUSSION

Thus, after specifying these models the simulated signal is obtained. Each simulated waveform contains both the amplitude and time view values between frequencies in the range of (200-2000) MHz. Fig 3. Shows the simulation result for 2000MHz in the time view ratio of 1:1.

The result shown here are different layers of materials with different combinations. Out of that combination, one is shown here with transient analysis. The same can be done for frequency domain analysis. The combinations are air-dry sand-wet clay-water.

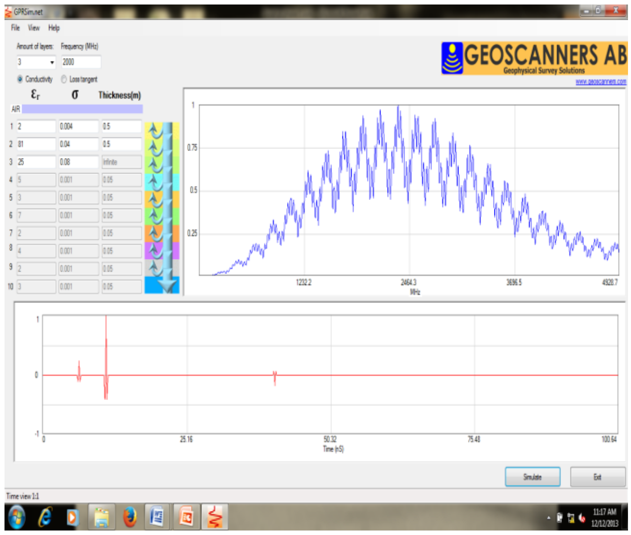

Fig 3. Simulation for F=2000 MHz, 1:1

Now, the Fig 4. Shows the simulation result for 2000MHz in the time view ratio of 1:4.

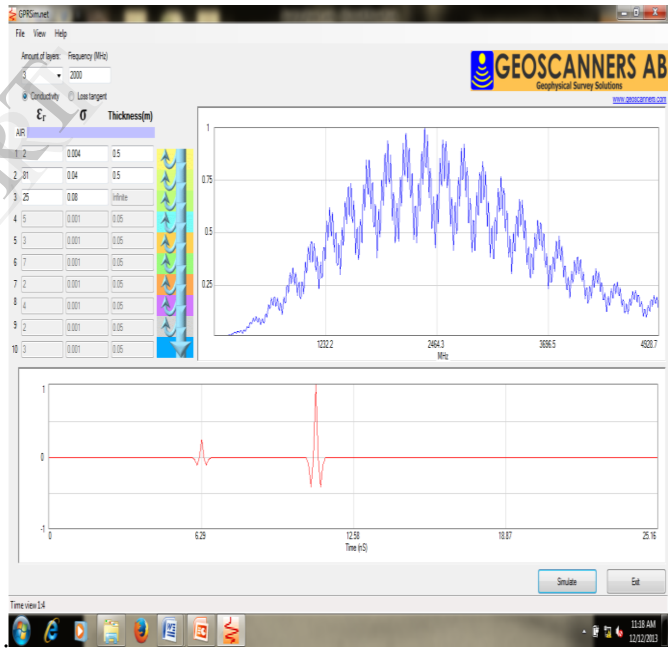

Fig 4. Simulation for F=2000 MHz, 1:4

The simulation result for the frequency of 200 MHz in the frequency domain shows the deep penetration of the signal in the subsurface layers with the known relative permittivity, electric conductivity and thickness of the three layers. This is shown in Fig. 5. For the time domain view of the ratio 1:1.

After the simulation is done it is possible to analyze the data in the time domain plot or in the frequency domain plot by moving over the plot area. If the properties of the materials to survey are not distinct enough then it becomes hard to detect them. By using the concept of reflection coefficient to understand better the idea behind the materials contrast. The resolution and penetration that can be achieved with GPR are depending on many factors. GPRSim.net is a very basic

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simulator good enough for simplified concepts only. The concept of GPR resolution in its simplest form is nothing else than the smaller object the radar is capable to detect at a specific antenna operating frequency.

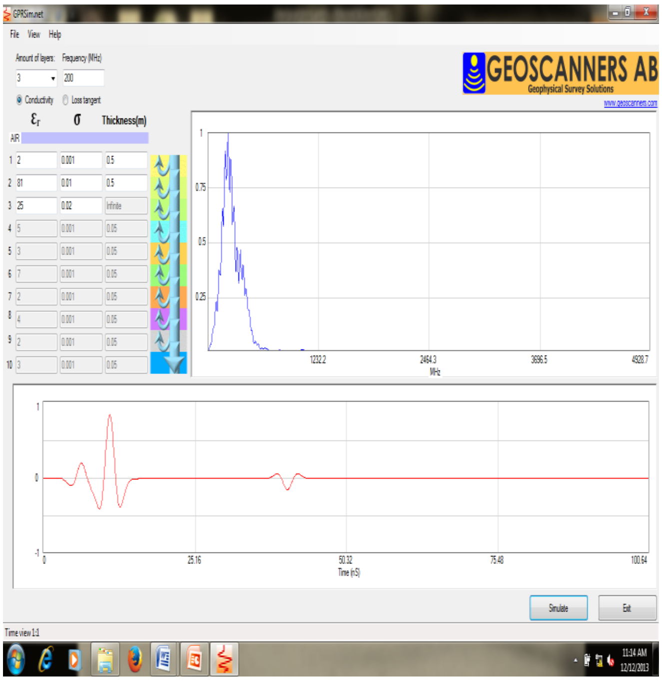

Fig 5. Simulation for F=200MHz, 1:1

Now, for the same frequency the ratio of the time domain has been changed and shown in Fig. 6.

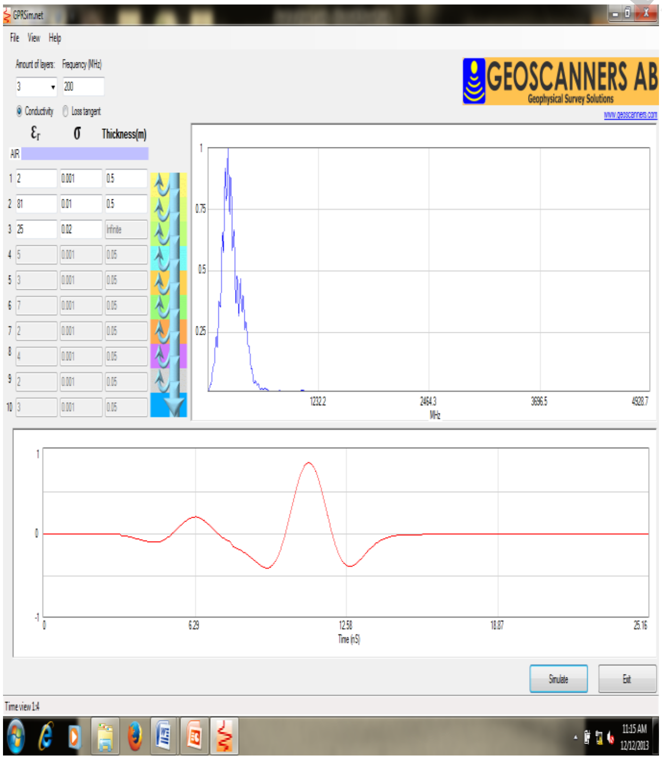

Fig. 6. Simulation for F=200 MHz, 1:4

IV CONCLUSION

Thus, the GPR for the frequency range of 200- 2000 MHz has been achieved using the software tool “GPRSim.net”. This will detect the depth penetration of the dry and wet sand along with the in-between layer of fresh water. The penetration depends on the parameters called Permittivity, Conductivity, Loss Tangent, Thickness, for the amount of layers up to 10 varied layers, which has determined using the parameters defined.

GPR depicts changing ground conditions and buried anomalies. Interpretation of results will offer guidance as to the nature of the materials returning signals. However, similar signals may be returned by different conditions/anomalies and supplementary information (test excavation, coring, other geophysical methods, repeat patterning) may also be necessary. Combined with supplementary information, GPR can be a very powerful tool.

V FUTURE SCOPE

Time slices are horizontal maps drawn from the output of all the radar runs in a given direction. Provided that the survey trajectories are parallel to one another and can be related to one fixed line, a series of time slices at specific depths can be produced. There will be an extra charge for this service since it involves further processing of the data. This does not, however, have to be carried out at the same time as the survey since the maps are drawn from the raw survey data.

Recent advances in GPR hardware and software have done much to ameliorate these disadvantages, and further improvement can be expected with ongoing development. GPR has a great potential for use in investigations of irrigation and soil science.

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