IJSET International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.2, Issue No.1, pp : 26-29 1 Jan. 2013

Detection of Buried Object By Electromagnetic Shock Waves Radiated Through Slotted Parallel Plate Transmission Lines

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Abstract— **A method for detection of buried object by the transmission of electromagnetic (EM) shock waves is presented. The system has two parallel plate transmission lines inserted inside the ground. A transmitter is connected to one of the lines and a receiver is connected to another of the lines. Gaussian pulse is injected into one of the lines in which plate facing the unknown object is slotted. The pulse gradually leaks out. If the speed of propagation in the line in which the pulse is injected is faster than speed of propagation in the ground, a shock wave is transmitted through the ground, called a transmitted signal, and received as a received signal at another of the lines. If any object is present between the two lines, it diffracts the shock wave. By comparing the signals with and without scattered by that object at the received port, the location of the object is determined.**

Keywords - Parallel plate transmission line, Gaussian pulse, electromagnetic shock wave, FEM, buried object detection, wave scattering.

I. INTRODUCTION

Underground localization remains a technically challenging problem, in exploitation of ground water resources, exploration of caves, maintenance of old tunnels, exploration of minerals and chemicals etc. While numerous methods for underground detection exist, practical considerations such as resolution, speed of detection, attenuation through the ground, and system size determine which method or combination of methods should be used.

The metal detector is used for sensing of landmines. The Ground Pulse Radar is used to detect the nonmetalic object. In acoustic method, sound waves, which are sensitive to the contrast in the acoustic impedance of the anomaly, are transmitted through the ground to detect anomaly[1].Acoustic impedance indicates how much sound pressure is generated by the vibration of molecules of a particular medium at a given frequency. But it is applicable for shallow underground buried objects only.

The magnetic method is an effective way to search for small metallic objects, such as buried ordnance and drums, because magnetic anomalies have spatial dimensions much larger than those of the objects themselves [2]. This method generally involves the measurement of the earth's magnetic field intensity or vertical gradient of the earth's magnetic field. Anomalies in the earth's magnetic field are caused by induced or remanent magnetism. Induced magnetic anomalies are the result of secondary magnetization induced in a ferrous body by the earth's magnetic field. The shape and amplitude of an induced magnetic anomaly is a function of the orientation, geometry, size, depth, and magnetic susceptibility of the body as well as the intensity and inclination of the earth's magnetic field in the survey area.

Ground-penetrating radar (GPR) is a high-frequency electro-magnetic method commonly applied to a number of engineering and environmental problems. A GPR system radiates short pulses of high-frequency EM energy into the ground from a transmitting antenna [3]. This EM wave propagates into the ground at a velocity that is primarily a function of the relative dielectric permittivity of subsurface materials. When this wave encounters the interface of two materials having different dielectric properties, a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display. This method, however, has limited penetration ability in a ground with high conductivity. In order to increase the depth of penetration, lower frequencies, which suffer less from attenuation, have to be used. However, low frequencies result in low resolution.

The method described in this paper uses the transmission of an EM shock wave from transmitting end to receiving end. By comparing the signals, with and without scattered by that object, at the received port, the location of the object is determined. Transmitting and receiving the signal from underneath the ground can reduce the man-made noise level, thereby achieving better performance.

II PROPOSED MODEL

A transmitter is connected to one of the slotted transmission lines named transmitting TL and a receiver is connected to the another one named receiving TL. Both of them are inserted through ground. An EM Gaussian pulse is injected into transmitting TL [6]. The shock wave is generated because the Gaussian pulse propagates along the transmitting TL faster than in the ground that surrounded it [4]. This shock wave propagates conically, scans the ground around the transmitting TL, and part of it couples to the receiving TL. The shock wave is radiated at an angle of $\cos^{-1}(\sqrt{\varepsilon_{rg}})$. In the receiving TL some of the signal will propagate downstream, and some of it upstream towards the receiver. If the ground has an anomaly such as a metallic pipeline between the two lines, it will scatter the shock wave.

The transmission lines are represented by perfectly conducting parallel-plate transmission lines with width w between the plates. In each line, the plate facing the unknown object is slotted, thus had coupling holes along it. The distance between the slotted plates is L_X. The line periodicity, i.e., the distance between the coupling holes along the direction Y, is D. Each coupling hole has an opening of d. Table I shows the parameters used in the simulation. The transmission lines are assumed to be made up of perfect conductors.

The given model contains 4 ports. Transmitting TL has 2 ports named port 1 (input port) and port 2. Receiving TL has 2 ports named port 3(output port) and port 4. The excitation is injected in the input port, Port 1, of the transmitting TL. The received pulse is measured at Ports 3. Port 2 is matched in order to prevent reflection of waves back into the transmitting line. The area inside the slotted TLs is defined as having the free-space permittivity and permeability, ϵ_0 and μ_0 respectively. The ground is represented by μ_0 ,$\varepsilon_g=\varepsilon_0\ \varepsilon_{rg}$ and conductivity σ_g, and the anomaly is represented by , μ_0 $\varepsilon_a=\varepsilon_0\ \varepsilon_{ra}$ and conductivity σ_a, as shown in Fig. 1.

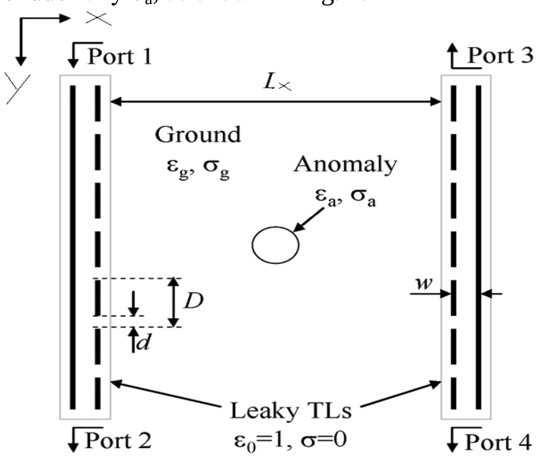


Fig 1: Vertical cross section of the ground with two slotted parallel plate transmission lines.

TABLE I:

SIMULATION PARAMETERS

Design Parameter	Values
Distance between two TLine Lx	9m
TLine Length	19.5m
Width of TLine, w	1m
Grid Resolution Δ	$0.05/\sqrt{\varepsilon_{rg}}$
Periodicity of TLine ,D	6Δ
Ground Relative Permittivity,ε_{rg}	5
Ground Conductivity, σ_g	10^{-3}S/m
Coupling hole aperture d	2Δ
Anomaly conductivity , σ_a	58×10^6 S/m
Anomaly Relative Permittivity	1

III THEORY with MATHEMATICAL DESCRIPTION

A bipolar Gaussian pulse is injected at Port 1

$E_y(t)=0.5(t-to)Zo*Ao*F(t)$

$H_x(t)=0.5(t-to)*Ao*F(t)$

The Gaussian pulse is $F(t)=\exp[-(t-to)^2/(2a)^2]$, Where Gaussian full width at half maximum is set to $2a\sqrt{(2\ln 2)}=0.5/c$.

to→1/c

= $1/(3*10^8)$

=3.334 ns

t → 0 to 2to

= 0 to 6.668 ns

The exciting mode is TE_{10}. For this cut off frequency is given by, fc=0.154GHz.The velocity of pulse inside TL, v_1 is calculated as 6.896×10^8 m/s.The velocity of pulse in the ground, v_2 is calculated as 3.08×10^8m/s. Here $v_1 > v_2$. So Shock wave forms inside the medium while the electric pulse propagates along the TL. This shock wave scans the ground around the transmitting TL, and part of it couples to the receiving TL. The shock wave is radiated at an angle of 63 degrees with respect to y axis.

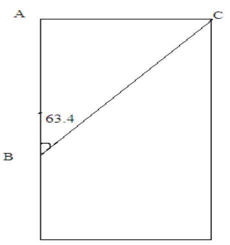


Fig. 2 Model geometry without anomaly

In Fig.2, A is the input port (port 1) and C is the output port (port 3). The distance between A and C is 9m . So time required for earlier pulse to travel from port 1 to port 3 is the sum of the same from port 1 to the point along transmitting TL where emitted shock wave can reach port 3 and from there to port 3 along radiation direction in the ground. It is calculated as 38.8ns. Now this signal is treated as the signal without scattered by anomaly.

It is expected that the earlier pulse reaching port 3 after scattered by anomaly is following the paths. 1.From port1 to the point along transmitting TL, where emitted shock wave radiated towards anomaly,2.From there to anomaly location, 3.Then to port 3.

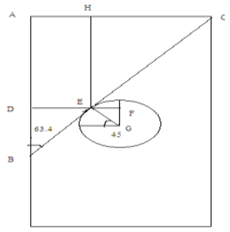


Fig. 3 Model geometry with anomaly

In Fig 3,the geometry is considered with a circular anamoly in the center of the model with diameter of 1m.From this, time taken by the pulse to travel from port1 to anomaly location is calculated as 31.6 ns. So earlier pulse scattered by anomaly takes 65.6ns to reach the port 3 from port 1.

IV RESULTS AND DISCUSSION

The system setup is modelled using ANSYS Multiphysics software. Two boreholes are modelled using 3D FEA technique in the ground .A slotted transmission line (TL) is placed along each borehole. The direction of pulse is down into the ground. The boundary of the calculation space was formulated by the perfectly matched layer method in order to absorb waves propagating outside of the problem's region [7].Finite element method is used to solve Maxwell equations to compute electric and magnetic field strength at problem region, after applying boundary conditions [5].

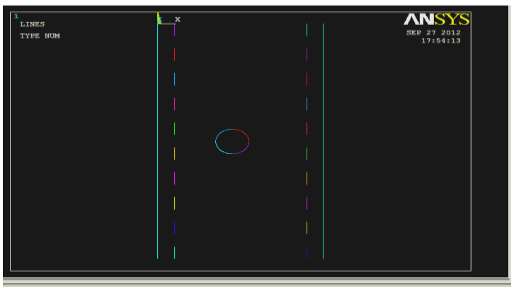


Fig.4 2D model of given problem with anomaly located at the depth of 9.75 m from ground surface

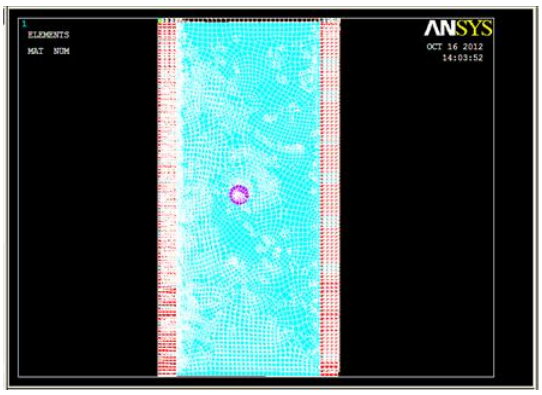


Fig.5 2 D model with 3 different areas ground, anomaly and free space inside slotted parallel plate transmission line.

Fig.4 shows the 2D model of given problem with the anomaly located at the centre (4.5,-9.75,1) . Fig.5 shows the same model with 3 areas ground, anomaly and free space inside slotted parallel plate transmission line having different properties. The anomaly is assumed as conductive anomaly. The specifications are set as Grid resolution Δ = .02232, Periodicity of TLine D = 0.13392m and Coupling hole aperture d = 0.04464m.The remaining parameters are as given in table I.It is simulated to obtain contour plot of field strength.

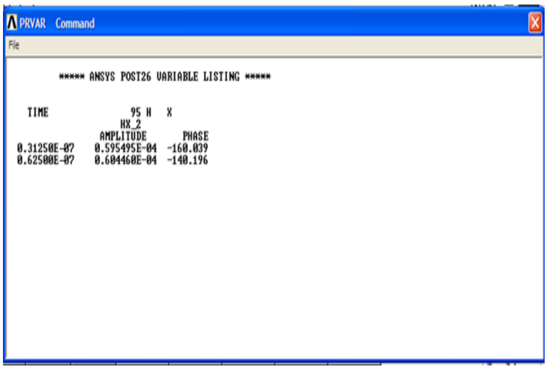
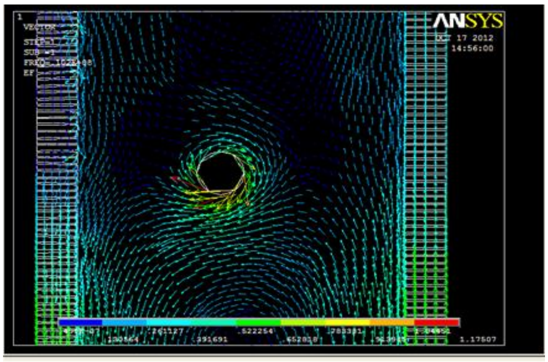
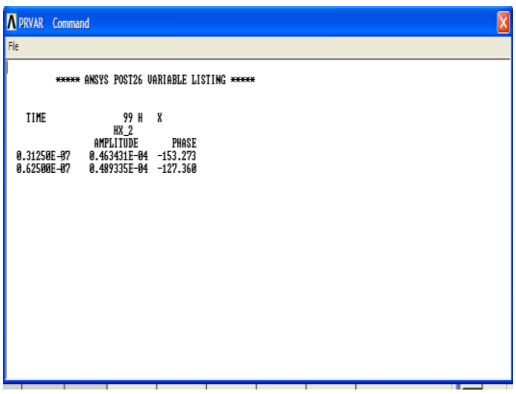


Fig.6 The Distribution of Electric field Ey within the model



From fig.6 it is inferred that the signal from the port 1



is scattered by the anomaly. The signal can't penetrate the anomaly. It is scattered in all direction.

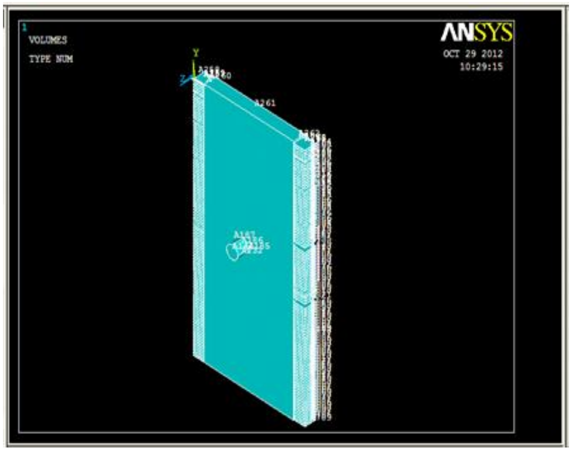


Fig.7 3D model of given problem extended along Z axis by 1m

Fig.7 shows the corresponding 3D model simulated to obtain timing information of the arrived pulse at port 3. Hx is evaluated at port 3 and at anomaly location by simulating the above model in the time window of 0-160ns. The amplitude of the Hx is unity when it enters the port1.It is further reduced due to scattering. Fig.8 Amplitude and phase of Hx at anomaly location Fig.8 shows that the magnitude of magnetic field Hx is $0.595*10^{-4}$ A/m at t = 31ns and $0.604*10^{-4}$ A/m at t= 62 ns at anomaly location. Fig.9 Amplitude and phase of Hx at port 3 Fig.9 shows that the magnitude of magnetic field Hx at port 3 is 0.463×10^{-4} A/m at t =31ns and 0.489×10^{-4}A/m at t = 62 ns. The localization of the anomaly could be determined by analysing the above data. At port 3 Hx has non zero values at t=31ns and 62ns.If there is no anomaly, the earlier pulse that reaches port 3 from port 1,occurs at t=38.8ns which is calculated from the given geometry. So ,it is inferred that, from the values at port 3,the pulse occurring at t=31ns is due to signal reaching port 3 directly without scattered by the anomaly. The second pulse which occurs at later instant t=62ns is due to the scattered signal coming from the anomaly. From this, depth of anomaly L_Y is calculated as 9.6m from the ground surface.

V.CONCLUSION

Buried object detection by the EM shock wave which is formed between two slotted transmission lines is presented, followed by a mathematical description. The circular conductive anomaly is considered in this model. By means of slotted TL, radiation is induced in the ground in the form of shock wave. It is received at the port 3 with and without scatter by the anomaly. By comparing these two the anomaly location is found out

The TL periodicity has to be small in order to allow the electric pulse to generate a smooth shock wave. However, a too small value would result in an unnecessarily denser mesh and a longer simulation time. The ratio D/d should be chosen in a way as to allow sufficient out-coupling of the pulse energy into radiation while maintaining enough peak power in the electric pulse while it propagates along the entire length of the transmission line.

VI. FUTURE WORK

Buried object detection is done using two slotted parallel plate Transmission Lines.. Also prediction of the material type of the anomaly is possible based on the received signal strength. Multiple Leaky TLs (one is transmitter and the others are receivers) can be utilized to improve accuracy.

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