FDTD ANALYSIS OF A POST-RECEPTION SYNTHETIC FOCUSING SURFACEPENETRATING RADAR PERFORMANCE IN VARIOUS GROUND CONDITIONS.

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INTRODUCTION

Surface Penetrating Radar (SPR) is a non-destructive sub-surface surveying technique that is used extensively in civil-engineering, geophysical, archaeological, forensic applications and the detection of buried land-mines and other unexploded ordnance - a non-contact operation is required to avoid setting off trip-wires or other trigger devices. The SPR technique is limited, however, due to various ground conditions such as attenuation in ground, clutter arising from pebble like objects, operation in stratified ground, non-flat ground etc. The technique of Post Reception Synthetic Focusing (PRSF) can substantially reduce the impact of these limitations [1,2]. In PRSF, the elements of an antenna array are stimulated one at a time, whilst all other relevant antenna elements record the reflected signal. These reflected signals are then processed and used to focus retrospectively onto all relevant 3D resolution cells in the subsurface. PRSF enhances the resolution, processing gain and performance in practical ground conditions, compared to more conventional alternatives.

While simple PRSF situations can be modelled analytically, a detailed, realistic analysis of post-reception synthetic-focusing surface penetrating radar is best accomplished using numerical techniques such as the Finite Difference Time Domain (FDTD) method. A FDTD model has therefore been developed [3] to assess the basic properties of PRSF-SPR, and this technique has been validated by comparison with practical measurements.

This paper analyses the performance of the PRSF-SPR in various ground conditions using FDTD methods. The calculated reflected signals from buried objects are used to investigate the performance of the PRSF-SPR in realistic operational environments. Analyses include, reverberations associated with the PRSF-SPR, clutter effects due to pebble-like objects, operation in sloping and stratified ground condition

FDTD MODELING

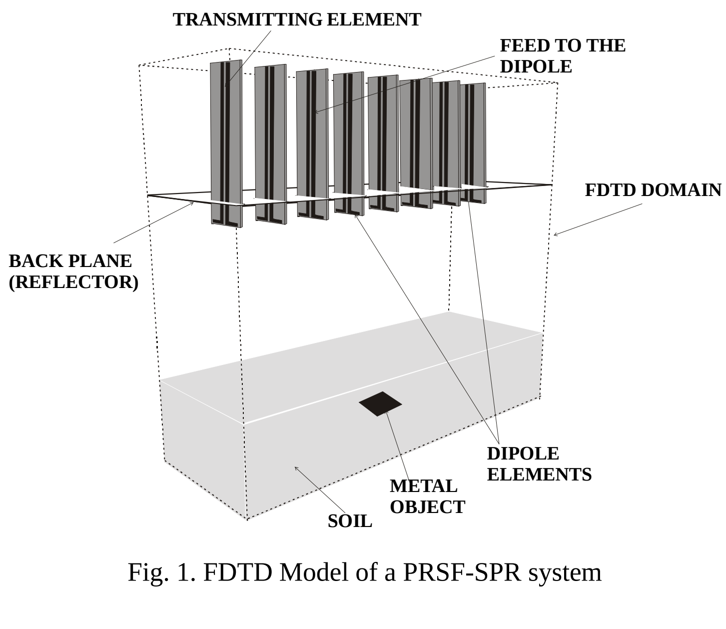

Fig. 1. FDTD Model of a PRSF-SPR system

The basic PRSF-SPR FDTD model developed to analyse these complex problems is shown in Fig 1. The soil was modelled with uniform dielectric constants and a buried object was simulated with a flat metal plate. The problem space was divided using a non-uniform mesh and terminated with Mur's 1st order boundary conditions [4]. The antenna array model comprised 8 printed dipole elements having wideband radiation characteristics (better than -10 dB reflection of 35%). The antenna array is displaced 2 free space wavelengths from the air-soil interface. A single antenna element was excited with a modulated square pulse of ≈2ns width and 2.1 GHz carrier, all 8 elements were used to receive the signals. The signals received at the antenna elements contain the mutual coupling between the transmitter-receiver reflections from the air-soil interface, the reflected signals from the buried object and signals due to multiple reflections.

REVERBERATIONS

An antenna back plane (reflector) is important to screen the system from interference and to enhance antenna gain. But reverberations between the metallic antenna back plane and the air-soil interface in a PRSF-SPR system will interfere with the detection of the buried objects. In SPR systems, shallowly buried targets often suffer from the air-soil interface reflections (first bounce). The strong surface reflections, which do not undergo attenuation as the signals from the buried targets, only mask the signals of shallowly buried targets, but the reverberating signal energy will interrupt the detection of deeply buried objects. The weak signals emerging from deep targets further contribute to this problem. One way of overcoming this problem is to use attenuating layers in front of the antenna array. Thus the wanted signals will be attenuated twice and the reverberating energy more. An alternative to this technique is to use an absorbing back plane, which will attenuate the reverberating energy with some degradation of the transmitted signal. The system performance with an absorbing back plane has been analysed with a modified FDTD model, which incorporated an absorbing layer on the metallic back plane. Initially antenna input characteristics were analysed with an absorbing back plane to make sure that the antenna input response was not degraded by the absorber.

Investigations were conducted with a small metal plate buried at 150mm deep in soil. The total reflected signals including the reverberating energy between the back plane and the air-soil interface, was used to focus into the soil to investigate the target location. Signals from models with and without the absorbing back plane are compared in fig 2 with the results from target returns, calculated by background subtraction. The focused signal when target is not present is also included in fig 2. The reverberating energy alters the target location when it is significant compared to the target echo. Fig 2 demonstrates the absorbing back plane absorbs the reverberating energy and identifies the target at its correct location. But the employment of the absorbing back plane also reduces the focussed signal power by 2.5 dB since the absorbing back plane widens the radiation pattern of the dipole elements and also absorbs part of the transmitted signal power. Considering the gains that can be achieved with the employment of the absorbing back plane against the degraded transmitted power this technique is a possible solution to enhance detection.

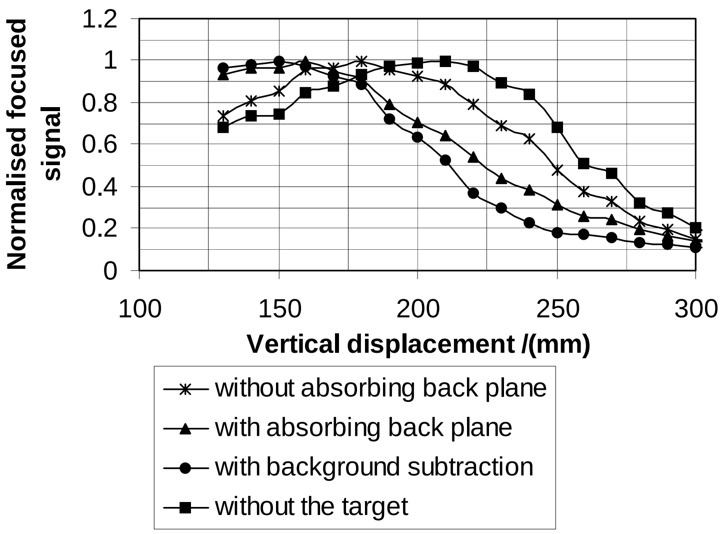

Fig. 2. Vertical focusing through target location

CLUTTER EFFECTS DUE TO PEBBLE LIKE OBJECTS

Clutter arising from pebble like objects will compete with the wanted signal. Hence the detection of low echo targets needs clutter reduction algorithms which can be easily implemented in the PRSF technique. To implement clutter reduction, it is important to analyse the nature of clutter returns.

FDTD simulations were performed on a model with random clutter distribution. This model consisted of soil and clutter objects with the 8 element antenna array. Surface reflections were eliminated from the analysis by performing a background subtraction with results from a model without the clutter objects. An absorbing antenna back plane was also included in the FDTD model in order to eliminate the reverberating energy. The calculated reflected signals were used to obtain the mean synthetically focussed signal at each depth. The mean signals were calculated by focusing at different lateral displacements at these depths.

Clutter in PRSF-SPR system arises from the *common delay-common view volume* for an element pair [5]. Signals from the set of reflectors whose effective reflecting points are exactly on the same common-range surface would combine coherently, as would any separated by exactly 2π (i.e., for a 4 cycle pulse). Similarly signals from shells separated by exactly π (or 3π) would give rise to coherent cancellation. However the probability of either occurring depends on the random distribution of the pebbles in the common range clutter volume. Hence the non-coherent summation of signals from pebble like targets would give the mean clutter expected. With a large number of pebbles within each common range clutter shell and a large number of element pairs, the mean power would be a very good estimation of the clutter return. The non-coherent summation of clutter signals can be estimated by the calculation of the number of pebbles within the *common range-common view clutter volume*. For an even clutter distribution this will be proportional to the *common range-common view clutter volume*.

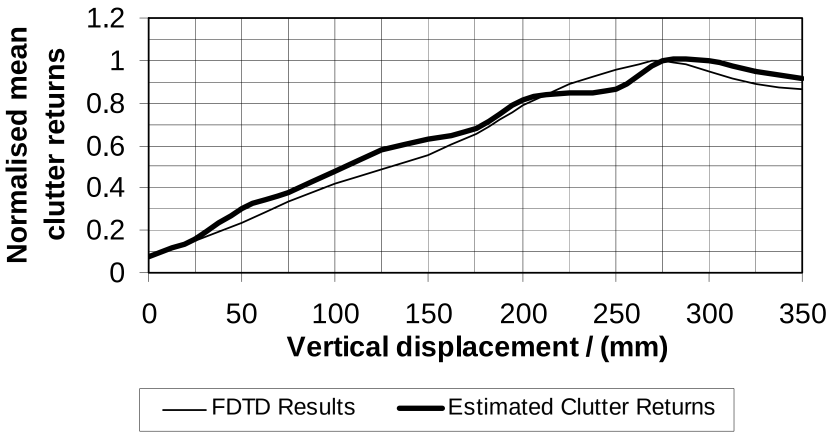

Fig. 3. Comparison of FDTD clutter echoes with the estimated clutter

Fig 3 compares the calculated (FDTD) mean signal strengths with the estimated clutter strengths. In these comparisons the mean clutter returns were calculated by considering different lateral displacements. This analysis shows that the non-coherent combination of clutter is a good estimation of the mean clutter expected. Hence for an even clutter distribution the *common range-common view clutter volume* can be used to estimate the clutter returns.

SLOPING AND STRATIFIED GROUND CONDITIONS

The PRSF-SPR FDTD model was further developed to analyse the system capabilities in sloping and stratified ground conditions. A sloping air-soil interface with a slope of 10^{O} was modelled and the computed reflected signals were focused to investigate the target detection capabilities. Simulations were carried out with soil dielectric constants of 3 and 8. These analyses indicated,

- Target location is slightly offset by the slope with less dependence on the dielectric constant: This is expected as the converging cone becomes narrower with high dielectric constants, thus reducing the variation in path lengths.
- Reduction in processing gain is not much significant if the path length variations are minimal.

Stratified soil conditions were analysed using similar FDTD techniques. Signals reflected from a buried metallic target and the media interfaces (shown in fig 4) were used to investigate the effects of a realistic stratified media.

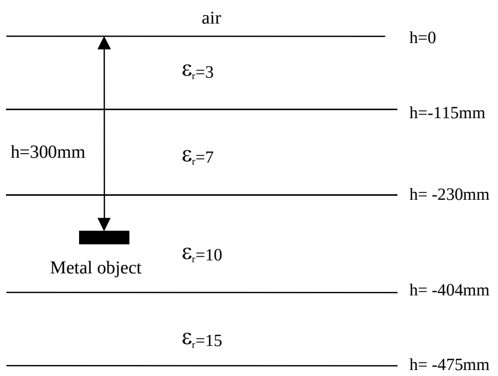

Fig. 4. Stratified media model

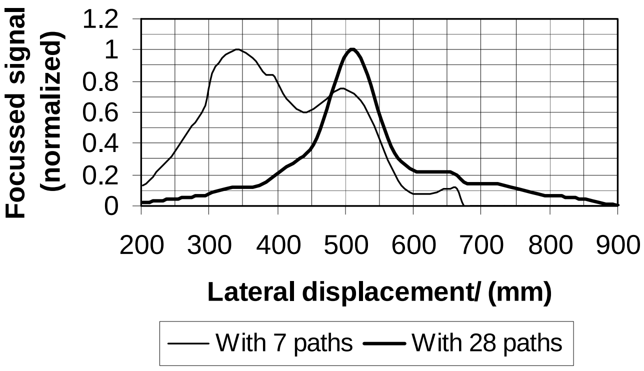

Fig. 5. Lateral focusing with 7 and 28 paths

Analysis with the return signals including the interface reflections showed that low impedance ratios (≈ 1.25) had negligible effects in the synthetic focusing process. However high impedance ratios (> 1.5) interfered with the target detection. Fig 5 shows a target at location x=500mm, observed in stratified ground (impedance ratio ≈ 1.5) with 7 and 28 paths respectively. It shows that the target detection is severely limited with less number of paths. Employing the full line array with 28 paths helped detect the target at its location. This is due to the fact that the reflections from the interfaces in the stratified media add non-coherently while the signals from the target coherently. These results demonstrate the ability of the PRSF system in detecting targets in complex environments.

CONCLUSIONS

The analysis of a PRSF-SPR system in various ground conditions using FDTD models has been presented. Reverberations, clutter arising from pebble like objects and operation in sloping and stratified ground have been investigated. Employment of an absorbing antenna back plane has been shown to reduce false detection with some reduction in power reaching the target. The nature of clutter returns from pebble like objects have been analysed and the non-coherent combination of the clutter returns are shown to be a good estimation of the mean clutter strengths. Thus for an even clutter distribution the *common range-common view clutter volume* can be employed to estimate the clutter strengths. Finally the PRSF-SPR operation in sloping and stratified ground conditions have been investigated and its effects on the focusing process have been estimated. It has been observed that the sloping ground condition slightly offset the target location with less dependent on the dielectric constant and in stratified conditions, only high interface reflections interfered with detection.

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