High-Resolution Ultra-Wideband Material Penetrating Radar (UWB-MPR) using Modified Configuration of Receiver Antennas

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***Abstract*─** In this paper, in order to implement the see through the wall and ground penetrating radars using vector network analyzer at the first step we present a modified UWB Tapered Slot Antenna (TSA) and Wilkinson power combiner. In the following the main purpose of this paper is employing a new technique using modified UWB antennas and power combiner to improve the reflected signal of localizing underground metal for 1D visualization of material penetrating radar results. In the last section two scenarios of GPR profiles with a single receiver antenna and dual receiver antennas over ground surface with buried metal target are presented to validate the accuracy of the proposed approach. This signal collecting technique collect more energy form reflected signals in contrast with conventional MPR. Hence, stronger reflection is available to achieve higher chance for target localization.

***Index Terms*─** Material Penetrating Radar (MPR), See through the Wall, Tapered Slot Antenna (TSA), Wilkinson Power Combiner.

I. INTRODUCTION

Material penetrating radar (MPR) is a nondestructive testing (NDT) technique which uses electromagnetic waves to investigate the composition of non-conducting materials either when searching for buried objects or when measuring their internal structure. Information that can be obtained from GPR includes the depth, orientation, size and shape of buried objects, and the density and water content of soils [1]. The GPR performance is associated with the electrical and magnetic properties of local soil and buried targets. The choice of the central frequency and the bandwidth of the GPR are the key factors in the GPR system design. Although the higher frequencies are needed for better resolution and detailed echo to determine small size objects, the lower frequencies are preferred to detect something buried too deep because of the dramatically increased attenuation of the soil with increasing frequency. Thus, the pulsed GPR is used in order to benefit from both low and high frequencies [2-3]. The pulsed GPR systems acquire pulse response in time domain directly. It is the simplest and understandable method that allows getting unique operation flexibility of the GPR system. Tapered slot antennas/arrays are good candidate for UWB radar system because of their wideband performance and directional radiation characteristic. But the phase center variation with frequency may bring few mm errors in target localization [4-5].

In this paper, we explore the advantages of generating a novel collecting reflected signal technique, similar to the ordinary receiver but instead of single receiver antenna, two modified antennas will be employed. The advantage conferred by "dual-antenna GPR" is that more energy is available at reflected signal than with conventional GPR, subsequently a relatively higher resolution in identifying the reflected signal is achieved. Measured results using vector network analyzer are presented to validate the effectiveness of the proposed method for precisely calculating the time-dependent location of underground targets.

II. MODIFIED UWB TAPERED SLOT ANTENNA AND WILKINSON POWER COMBINER DESIGN

One of key issues in ultra-wideband (UWB) imaging systems is the design of a compact antenna while providing wideband radiation characteristics over the whole operating band. It is a well-known fact that printed TSA antennas present really appealing physical features, such as simple structure, small size and high gain [6]. The configuration of the two-element TSA array is depicted in Fig. 1. A Rogers RT5880 substrate was used, with a relative permittivity of 2.2 and a thickness of 31 mils [7]. The proposed structure is designed based on the antenna presented in Ref. [8]. In this type of antennas, phase center location is shifted by changing frequency. Therefore, one of the advantageous of our proposed structure is solving this phase center

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shifting problem in based on using exponential tapered curve instead of elliptical curve [9]. In addition, the proposed antenna has 16% size reduction in comparison of the antenna in reference [8].

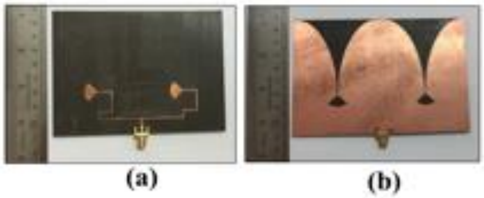


Fig. 1. Photograph the realized tapered slot antenna: (a) top view and (b) bottom view.

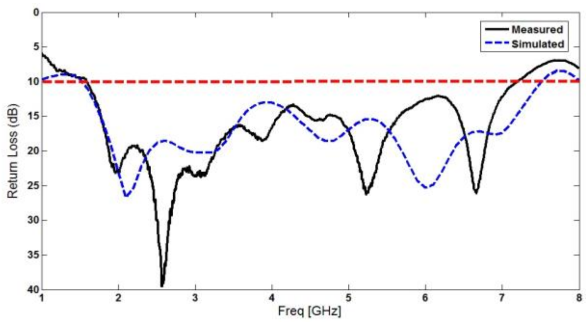


Fig. 2. Measured and simulated return loss results for the proposed antenna.

Figure 2 shows the measured and simulated return loss characteristics of the proposed antenna. The fabricated antenna has the frequency band of 1.57 to over 7.0.4 GHz. As shown in Fig. 2, there exists a discrepancy between measured data and the simulated results. This discrepancy is mostly due to a number of parameters such as the fabricated antenna dimensions as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated, the wide range of simulation frequencies. Figure 3 shows return loss measurement setup for the Wilkinson power combiner. Two 50Ω terminations at output ports; input port connected to an Agilent network analyzer. Also, measured return and insertion losses for the proposed power combiner are shown if Fig. 4.

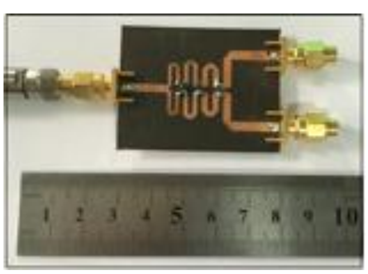


Fig. 3. Return loss measurement setup for the Wilkinson power combiner.

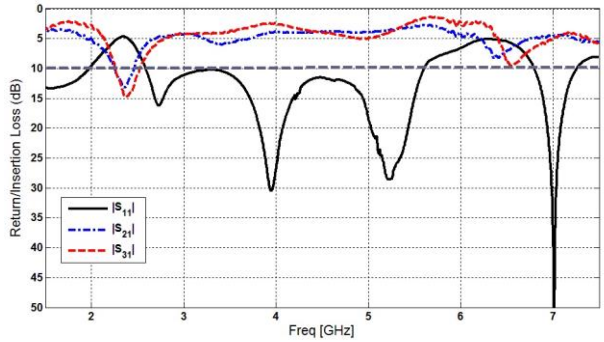


Fig. 4. Measured return and insertion losses for the proposed power combiner.

III. THEATRICAL BACKGROUND OF MATERIAL PENETRATING RADAR

The MPR schematic for the proposed wooden wall surface with metal plate target is shown in Fig. 5. Typically, for ideal impulse excitation we can calculate exactly the amount of reflected energy at an interface as follow:

$$\Gamma_{i,i+1} = \frac{\sqrt{\varepsilon_{r(i+1)}} - \sqrt{\varepsilon_{r(i)}}}{\sqrt{\varepsilon_{r(i+1)}} + \sqrt{\varepsilon_{r(i)}}}, \tag{1}$$

where Γ is the reflection coefficient and $\varepsilon_{r(i)}$ and $\varepsilon_{r(i+1)}$ are the dielectric constants. Similarly, for ideal impulse excitation signal we can calculate precisely the thickness of a layer as follow:

$$d_i = \frac{C.t_i}{\left(2\sqrt{\varepsilon_{r,i}}\right)}, \tag{2}$$

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

In the ground penetrating radar's scenario, the penetration depth of GPR waves (in a low-loss medium) can be approximated as:

$$\delta(m) = 25\lambda = 25\frac{c}{f\sqrt{\varepsilon_r}}. \tag{3}$$

The vertical resolution (in a low-loss medium) is around 0.01δ [3].

For ideal impulse as excitation signal we can calculate exactly locations of discontinuities as follows: but in practice one can see that the waveform is distorted after the reflection and propagation. Because GPR receives signals already reflected from some distance, the time needed for passing the way back to the object and forth is longer than in a case when the antenna is situated slightly above the examined object. Because of this the cross-section of a pipe will be presented in the reading as a hyperbole [9].

The first step in design material penetrating radar is selecting the operation frequency. High frequency leads to high azimuth resolution, while relatively low frequency allows penetrating through walls. 2-6 GHz is regarded as the optimal frequency band for seeing through high-loss materials, such as brick-wall and concrete wall.

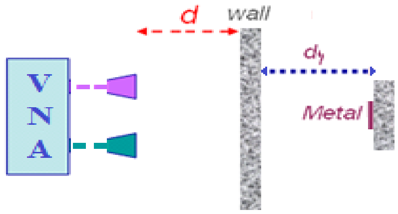


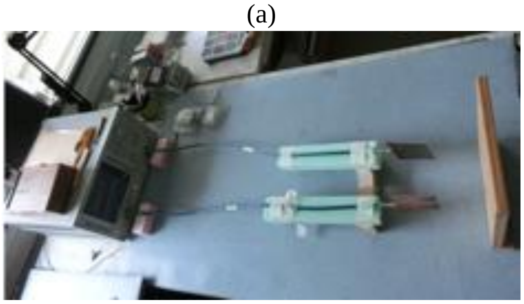
Fig. 5. The MPR schematic for the proposed wooden wall surface with metal plate target.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. See through the wall radar prototype

Experiments have been carried out to measure the radar prototype using vector network analyzer as a frequency modulated continues wave transceiver. The first experiment was performed by using a metal plate target, as the floor plan of the experimental setup presented in Fig. 6. The VNA was placed in the Antenna Laboratory as shown in Fig. 6 (b), with the transmitting and receiving TSA facing the same direction. The spacing between the transmitting antenna and the receiving antenna is 10 cm. The metal plate's size is 10×8 cm^2 and it is put at 25 cm standoff distance to wooden wall. The wooden wall is put at 15 cm standoff distance to the radar system to acquire the radar response.

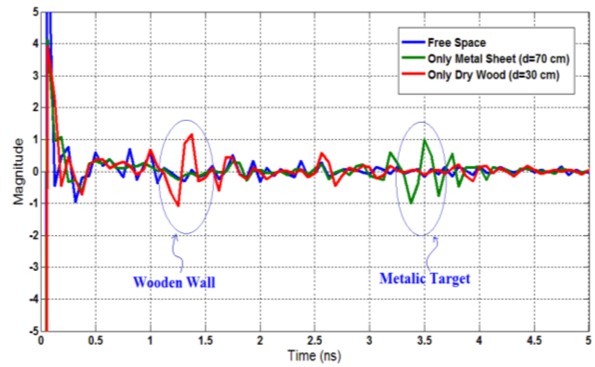
(a)



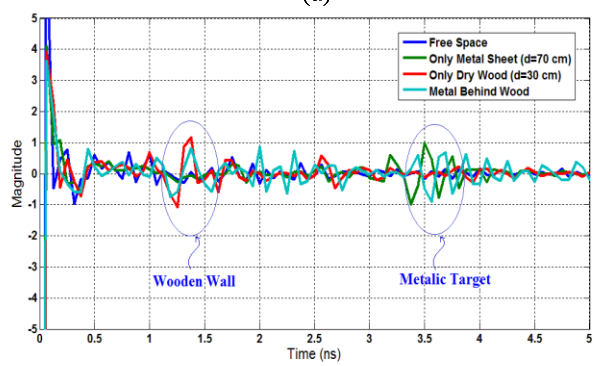
(b)

Fig. 6. Experimental setup of the down range resolution measurement using dihedral as radar object: (a) antennas, wooden wall and metal target, and (b) VNA using as a FMCW transceiver.

Most of the UWB imaging algorithms reported in literature have used the time-domain signals [4]. This approach requires transforming of the earlier acquired frequency-domain reflection coefficient data. Therefore, a short and efficient CAD procedure for the design is performed. This is done using an inverse Fourier transform (IFT) from the impulse response. The CAD procedure has mainly two steps. The first step is a frequency to time domain transformation. The inverse discreet Fourier transform program is used for matching between time steps and frequency steps [10]. The second step is to implement a sampling Hamming window so as to get a smooth time response. Using the [S] parameters of the environment and by getting from Agilent Vector Network Analyzer (VNA), the design of the material transceiver is performed using our full-scale computer simulation program.



(a)



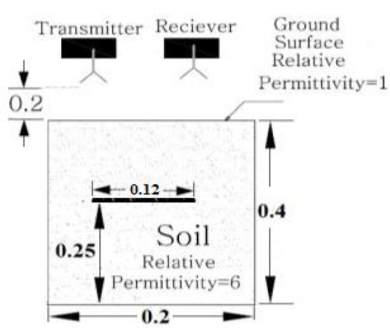
(b)

Fig. 7. Measured reflected signal from see through the wall experimental setup: (a) detection of the wooden wall and the metal target separately, and (b) detection metal target behind the wooden wall.

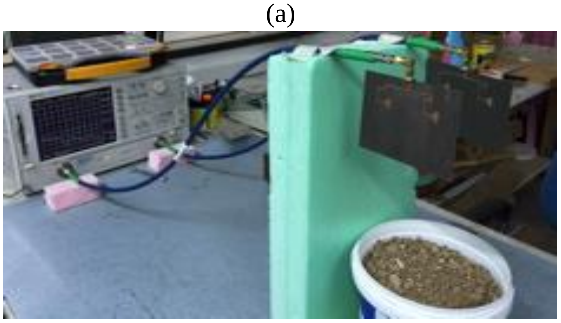
Figure 7 shows measured reflected signal from see through the wall experimental setup. The measured results in Fig. 7 (a) predict the outline of the wooden block target, as well as its location. In order to illustrate the proposed method performance Fig. 7 (b) describes the reflected voltages of wooden wall, metal targets using the proposed experiments setup and makes a comparison among them. Figure 7 (b) introduces the recovered signal of the metal plate when it was placed at a distance of 75 cm in the back of the wooden wall. The acquired radar signal indicates a down range resolution of approximately 2 cm, validating the theoretical analysis result. It is worth mentioning that the recovered signal also predicts the locations of the wooden wall, in addition to the metal target. The experiment is performed in a low-contrast condition to emulate the true situation that most of the metal plates.

B. Ordinary ground penetrating radar

The schematic and realized configurations of the UWB ground penetrating radar, which is investigated here, is illustrated in Fig. 8. In the GPR radar experimental setup, we have collected the signals at two scenarios: the first from background only using single-receiver antenna, and the second using with dual-receivers' antenna. The ordinary GPR test field with metal plate located underground is shown in Fig. 8. Figure 9 present the scan A which represents the passing over a zone in which measured GPR was buried in vertically position. Figure 9 shows the original signal, before using the dual-receiver antennas technique. It can be observed that in the case of real measurements, the reflected signal is very noisy, containing, in addition, clutters. The stronger lines are from the strong direct wave form soil surface and background reflection. As shown in Fig. 9, in the ordinary GPR case the metal object isn't clearly distinguished.



(a)



(b)

Fig. 8. Experimental setup of the ground penetrating radar with single receiver antenna: (a) schematic and (b) realized.

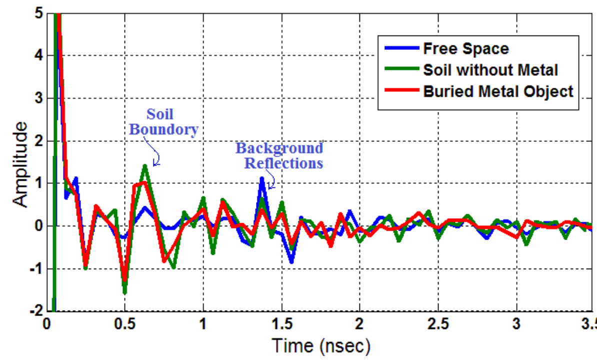
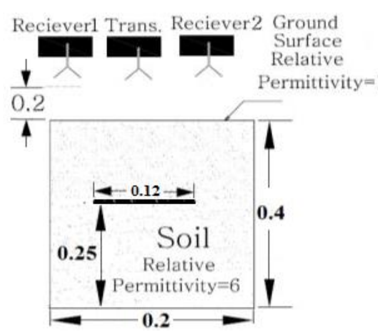


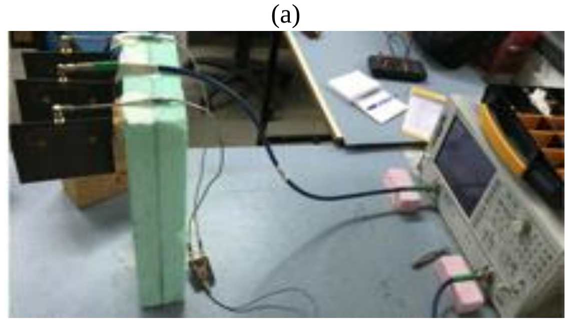
Fig. 9. Measured reflected signal from ordinary GPR setup in the first scenario.

C. Modified GPR configuration

To improve the resolution of the GPR results and extract the target reflection, the received signals are collected using the proposed reflected signal collecting method using dual-receiver antennas as shown in Fig. 10. By subtracting the two signals with and without the target, the newly acquired signals are used in the signal recovery process to remove the clutters. In order to show the effects of on this new method improvement, Figure 11 shows the measured reflection waveform with different scenarios. In other hand after an initial guess of the target location, it is found out from Fig. 11 that the desired signal is totally immersed in the noise signals due to the low-contrast problem.



(a)



(b)

Fig. 10. Experimental setup of the ground penetrating radar with dual receiver antennas: (a) schematic and (b) realized.

As shown in Fig. 11, measured results of the proposed method are compared by free space reflection, ones with only soil without target and the ordinary GPR. It is clearly shown to that GPR results with this proposed collecting reflected signal have very good localization resolution and the peak amount errors at the center of target locations from ideal GPR results are small in this case in our measurement [11]-[12]. It is apparent from this figure, that the energy in the modified GPR reflection exceeds the energy in the ordinary GPR reflection. Therefore, the modified GPR results follow the target more closely than does the ordinary GPR results. Also several small scatters were founded. According to the resolution, the depth resolution in the vertical plane and the distance resolution between two objects can be considered. The depth resolution of the ten of centimeters is obtained. The reason of higher depth resolution is that the lower frequency range is used.

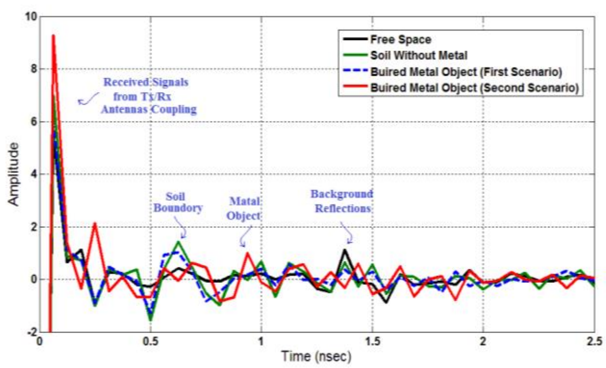


Fig. 11. Measured signal returns after using the proposed reflected signal collecting method.

V. CONCLUSION

This paper has presented UWB microwave imaging system to detect and locate small targets in a see through the wall and ground penetrating radar setups using the frequency-domain data acquired by a VNA and TSA. Additionally, a novel approach for high resolution GPR system using a modified receiver antenna configuration to improve the reflected signal of localizing underground metal target is presented. The validity of the presented system and its target detection algorithm has been verified via experiments in examples. Results obtained by our GPR system prove that our system has a good ability to finding buried targets. The proposed modified GPR is very practical as it is based on more realistic reflected signals from various angles rather than assuming single reflected signal. The measurements show that the developed UWB-GPR system has a good ability in detecting buried metal object, even small targets of several centimeters.

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