Ultra-Wideband Antennas for Ground Penetrating Radar

A.G. Yarovoy, L.P. Ligthart
International Research Centre for Telecommunications-transmission and Radar,
Faculty of Information Technology and Systems, TU Delft,
Mekelweg 4, 2628 CD Delft, The Netherlands
Tel.: +31-15-278-2496, Fax +31-15-278-4046, e-mail: a.yarovoy@ITS.TUDelft.NL

Abstract: It is believed that the main breakthrough in GPR hardware can be achieved in the antenna system. Recently three new antenna types have been developed in IRCTR: a dielectric filled TEM horn, a dielectric embedded shielded dipole and a capacitively-loaded bow-tie. Capacitively-loaded bow-tie provides very small ringing and can be used for deep subsurface sounding at low frequencies. The dielectric embedded dipole can be used in high resolution GPR systems providing excellent isolation from external EMI, low-level Tx-Rx coupling and wide antenna pattern in the ground. The dielectric filled TEM horn with its stable performance by different elevation, small footprint in the ground and good matching to both air and the ground can be successfully used in specialized GPR systems, e.g. for landmine detection.

INTRODUCTION

Antennas for impulse Ground Penetrating Radar (GPR) should be designed to radiate pulses with given properties into the ground and receive pulses scattered from subsurface objects. Due to its application in a short range impulse system, the antenna should be ultra wideband with linear phase characteristic and with constant polarization [1]. An additional demand to GPR antenna is to keep its performance independent from the type of ground and elevation above the ground despite of operation in the vicinity of the ground.

Using antenna measurement facilities in time-domain developed in IRCTR a number of ultra-wideband antennas have been tested. Among them were bow-tie, spiral antenna, TEM horns, etc. [2]. The radiation patterns of antennas have been measured in air and in the ground (sand) [3]. Special attention has been paid to the EM field waveform in the ground by different elevations of the antennas above the air-ground interface. On the basis of achieved knowledge and general understanding of physical processes in antennas three new antenna types have been developed: a dielectric filled TEM horn, a dielectric embedded shielded dipole and a capacitively-loaded bow-tie. Prototypes of these antennas have been manufactured to be used together with a 0.8ns monocycle pulse generator.

THE DIELECTRIC FILLED TEM HORN

This antenna is based on a dielectric wedge [4]. It was expected that such design will reduce the sensibility of the antenna for external EMI and will reduce the antenna's physical dimensions. Besides, with such design it is easier to match the antenna to the ground and to reduce the reflection from the antenna aperture. The value of dielectric permittivity has been chosen equal to 4 in order to obtain good matching to sand. The shape of the metal flare has been optimized so that the characteristic impedance in each cross-section of the antenna gradually changes from 50Ohm (impedance of the feeding line) near the feed point to 60π (impedance of the medium with dielectric permittivity 4) near the aperture. More specifically we have tried to minimize reflection from all antenna cross-sections, so that only reflection from the aperture can take place. The latter will not cause late time ringing if the antenna is perfectly match to the feeding line and there are no other centers of reflection within the antenna. As result we have achieved the following transient reflection from the antenna (Fig. 1). The signal, which is observed in Fig. 1 at the time interval between 2ns and 3ns, is the reflection from the feed point. Reflection from the aperture takes place at the time interval between 5ns and 7ns. It can be seen that for the ground based antenna the reflection from the aperture is considerably less than that for the air-based antenna. So the matching to the ground is better than that to air.

The radiated signal in the far-field is an approximate derivative of the exciting voltage (Fig. 2). In the waveform four different parts can be distinguished. First, an air-wave response is observed at the time interval from 1ns till 1.5ns. This wave propagates outside the dielectric wedge and thus arrives to the observation point earlier. Second, the main signal (1.5ns - 2.5ns), which is similar to the derivative of the exciting voltage. Third, short time ringing (2.5ns - 4ns). Finally, re-radiated reflection from the aperture can be seen at the time interval from 4.5ns till 5.3ns. From the measurements of pulse transmission through two identical antennas at different distances in the far field the gain of the dielectric filled TEM horn has been experimentally determined (Fig. 3). It can be seen that on 10dB level the bandwidth of the antenna is larger than 4GHz starting at 600MHz and ending at 5GHz. The ripples on the curves are caused by the aperture reflection.

One from important characteristics of GPR antenna is the coupling between Tx- and Rx-antennas. This coupling can obscure reflections from shallow buried targets and can substantially limit the dynamic range of the whole GPR system. Coupling between two dielectric filled TEM horns is considerably smaller in magnitude and shorter in time than that of two conventional TEM horns (Fig. 4). Actual coupling starts at 2ns and lasts for more than 10ns. At 14ns the reflection from the ground is seen.

Signatures of the dielectric filled TEM horn by different elevation above the ground are presented in Fig. 5. In order to detect changes in waveforms all signatures are shifted in time to compensate time delay due to propagation. It can be observed that the main part of the signal as well as the resonant part of it remains stable by antenna elevation. This proves the stability of the antenna performance in different environmental conditions, which is a very important feature for GPR antenna. The footprint in the sand at the depth of 17.5cm of the TEM22 antenna elevated 1cm above the sand has a slightly elliptic structure with main axis 26cm and 36cm on 10dB level (Fig. 6).

THE DIELECTRIC EMBEDDED SHIELDED DIPOLE

This antenna is a broadband dipole, which is placed in a metal casing [5]. The dipole arms have an elliptic shape (optimized for maximum flat frequency response). The metal case acts as a waveguide and the dipole is used for its excitation. Because the propagation path in the waveguide is short, the dispersion (typical for a waveguide) is small. By covering the sidewalls and the bottom of the case with absorbing material, the antenna ringing due to internal resonances of the metal case was reduced. The dielectric embedding of the antenna has been used to match the antenna to the ground and to reduce the antenna size.

The response of the dielectric embedded dipole antenna (or DED) in the sand is shown in Fig. 7. The antenna radiates a non-exact derivative of the waveform of the generator pulse. By the elevation of the DED above the ground the waveform remains nearly the same if the elevation varies from 10 to 40cm. In order to compare transients radiated from the dielectric embedded dipole placed on the ground and above the ground the sensor responses are aligned in time and normalized in magnitude (Fig. 8). The mutual reflections between the ground and the aperture does not influence considerably on the field transmitted into the ground. The pulse shape itself is suitable for the GPR applications.

The footprint at a depth of 17.5cm in the sand of the DED antenna elevated 2cm above the sand is elongated in H-plane with characteristic dimensions 76cm and 58cm on the 10dB level (Fig. 9). The footprint size of the DED is approximately 2 times larger than that of the TEM horn. Such footprint is favorable for SAR-like processing of GPR data.

The DED radiation in sand is about 2 times smaller than that for the dielectric filled TEM horn. The footprint size of the DED is approximately 2 times larger than that of the TEM horn. However the DED possesses a number of advantages over TEM horn. The main of them is that DED antenna is shielded and thus it is much less sensitive to the external EMI. Furthemore, coupling between two DED antennas is considerably weaker and shorter than that between two TEM horns.

Both types of antennas (TEM horn and DED) have been successfully used in the video pulse GPR system. The dielectric filled TEM horn has been used as a Tx antenna and the dielectric embedded dipole as a Rx one. The optimal mutual position and orientation of antennas have been found experimentally. Coupling in such antenna system between Tx- and Rx-antennas is plotted in Fig. 10.

CAPACITIVELY-LOADED BOW-TIE

A common problem in the response of transient antennas is the late-time ringing which is caused by reflections at the antenna open end and the limited antenna bandwidth. A well-known technique to eliminate open-end reflections is the use of a tapered resistive loading [6] with its inherent drawback in the form of low radiation efficiency. An alternative technique – the use of a tapered capacitive loading, which does not possess this drawback – has been proposed in [7] to be used in non-dissipative wideband antennas. We propose a different approach: the use of a tapered capacitive loading in combination with microwave absorbers, which proves to be effective in eliminating open-end reflections while keeping the radiation efficiency high [8]. The technique is implemented on the simplest wideband antenna - the bowtie, resulting in a low-cost, light-weight and efficient ultra-wideband antenna.

The capacitively-loaded bow-tie has been manufactured and optimized for the lowest level of late-time ringing by excitation with an 0.8-ns monocycle pulse. It is experimentally found that using this monocycle as input pulse the lowest level of late-time ringing is achieved when the feedpoint-first slot distance is 9cm and the first slot width is 1.8mm. The response of the tapered bow-tie with this feedpoint-first slot distance fed by the 0.8-ns monocycle is shown in Fig. 11. As a reference the response of the conventional bow-tie is presented as well. It can be seen that the capacitive loading changes the waveform of the radiated pulse and increases its duration. However, the magnitude of the main pulse is increased as well - in this case with 4dB. The capacitive loading drastically decreases late time ringing. The portion of the energy that would be radiated at the end of the bow-tie is now distributed at the slots, resulting in minor radiation from each slot and can be effectively suppressed by covering the slots with merely low-cost absorbers. This gives a late-time ringing level of lower than −40 dB after less than 2ns from the beginning of the pulse. Absorbers drop the maximum amplitude only slightly (0.7dB with respect to the antenna without absorber). It is furthermore observed that the absorbers should be placed only on the upper side of the bow-tie, because the ground (on the surface of which the antenna will be placed during operation) works as an absorber itself.

Performance of the antenna in frequency domain can be described by its sensitivity [8]. Sensitivity of the capacitively-loaded antenna and of the usual bow-tie is presented in Fig. 12. Substantial increase of the antenna bandwidth and 5dB improvement of its sensitivity in the frequency band from 1GHz till 3GHz is clearly seen.

CONCLUSION

Different GPR applications demand different antennas. Three new types of GPR antennas have been developed and measured in IRCTR. Capacitively-loaded bow-tie provides very small ringing and can be used for deep subsurface sounding at low frequencies. The dielectric embedded dipole can be used in high resolution GPR systems providing excellent isolation from external EMI, low-level Tx-Rx coupling and wide antenna patterns in the ground. The dielectric filled TEM horn with its stable performance by different elevation, small footprint in the ground and good matching to both air and the ground can be successfully used in specialized GPR systems, e.g. for landmine detection.

ACKNOWLEDGMENTS

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The dielectric filled TEM horn and the dielectric embedded dipole have been developed in collaboration with and manufactured by SATIS, Russia.

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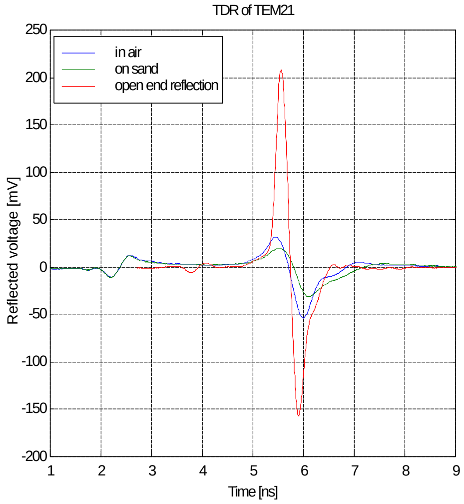

Fig. 1. Reflection from the dielectric filled TEM horn

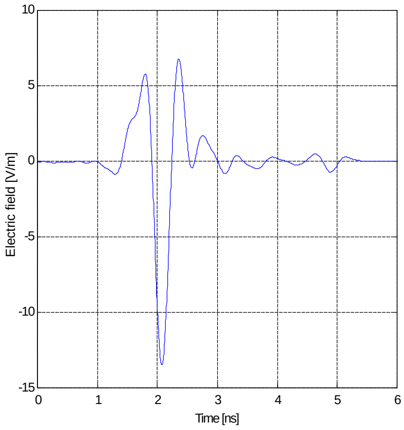

Fig. 2. Transient radiation from the dielectric filled TEM horn at the distance 150cm

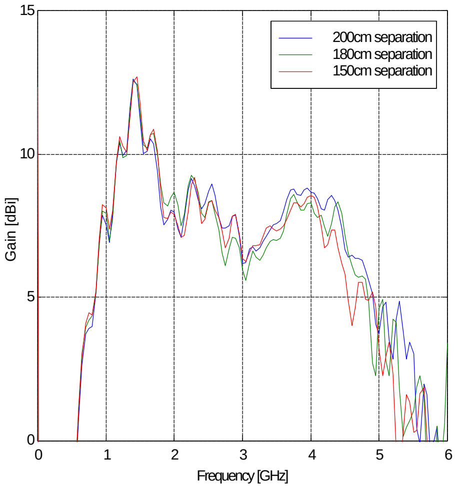

Fig. 3. Gain of the dielectric filled TEM horn

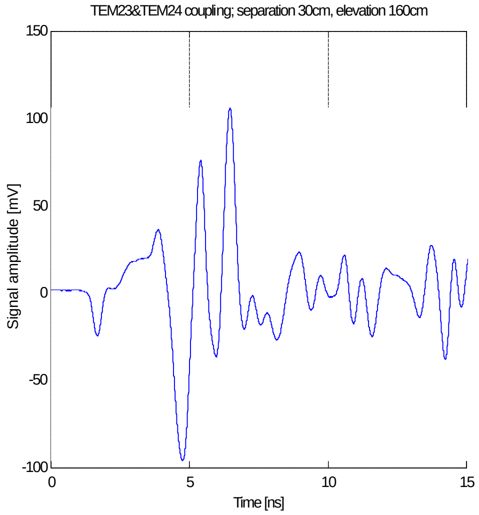

Fig. 4. Coupling between Tx and Rx TEM horns

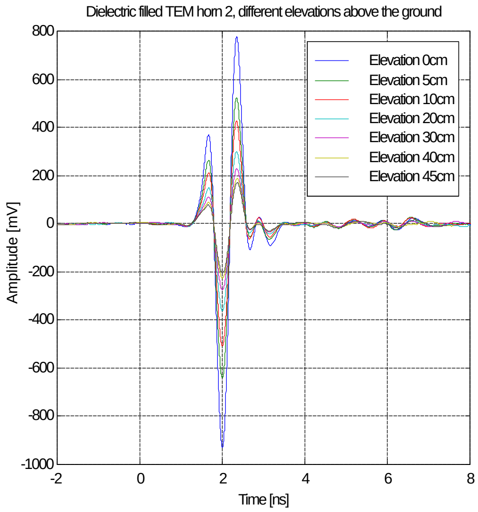

Fig. 5. Comparison of signatures by different elevations

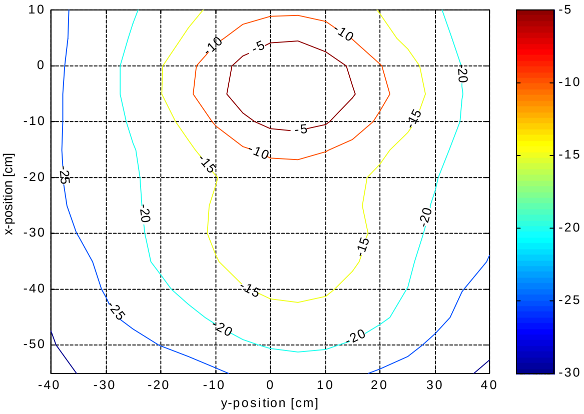

Fig. 6. Normalized footprint (in dB) of the dielectric filled TEM horn at the depth 17.5cm in the sand

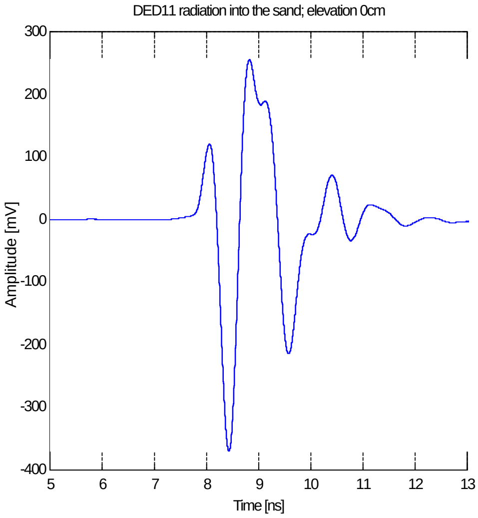

Fig. 7. DED11 radiation into the sand

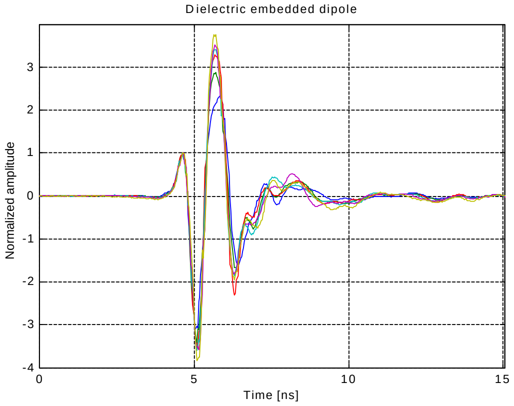

Fig. 8. Comparison of DED signatures by different elevations

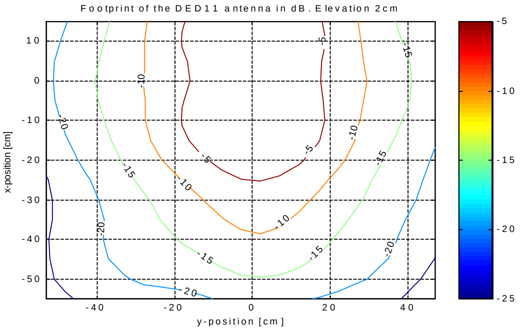

Fig.9. DED11 footprint in the sand

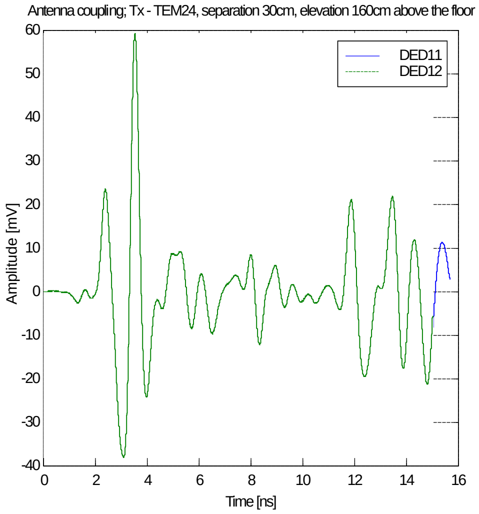

Fig. 10. Coupling between DTEM horn (Tx) and DED (Rx) antennas

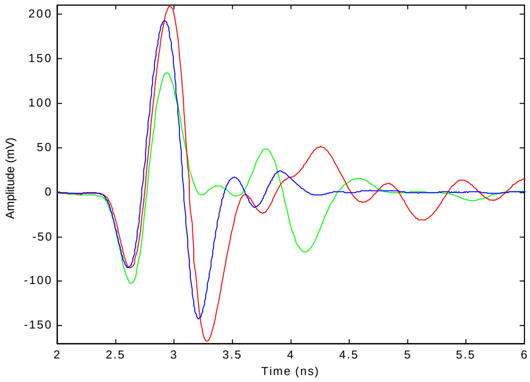

Fig. 11. Time-domain response of the tapered bowtie antenna without absorbers (red line), with absorbers (blue line), and the conventional bowtie (green line)

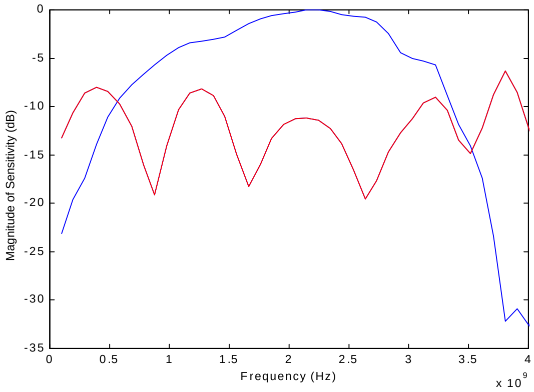

Fig. 12. Receiving sensitivity of the tapered bowtie with absorbers (blue line) and the conventional bowtie (red line)