DEVELOPMENT OF DIELECTRIC FILLED TEM-HORN

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INTRODUCTION

Antennas for impulse Ground Penetrating Radar (GPR) should be designed specially to radiate pulses with given properties into the ground and receive pulses scattered from subsurface objects. Due to their usage in the impulse system, the antenna should be ultra wideband with a linear phase characteristic and with a constant polarization [1]. Despite of the fact that GPR antennas operate near the ground, the antenna performance should be independent from ground properties, which also is a very important demand. One of the best known antennas for radiation of short pulses is the TEM-horn. This antenna may radiate signals over an in ultra-wide frequency band and has a linear phase characteristic over this band. However attempts to use this antenna in GPR systems for radiating into the ground were not successful when the antenna were situated close to the ground. The reason for this failure is that the basic TEM-horn is not matched to the ground and the ground reflection causes strong late time ringing. Besides the basic TEM horn antenna has large physical dimensions. To overcome these disadvantages a dielectric filled TEM horn antenna has been developed and has been measured as a single antenna and as a part of a Tx-Rx GPR system.

BASIC TEM HORN ANTENNA

The basic TEM horn antenna has been designed for radiation of short pulses with duration of about 1ns [1]. The antenna's schematic drawing is presented in Fig.1.

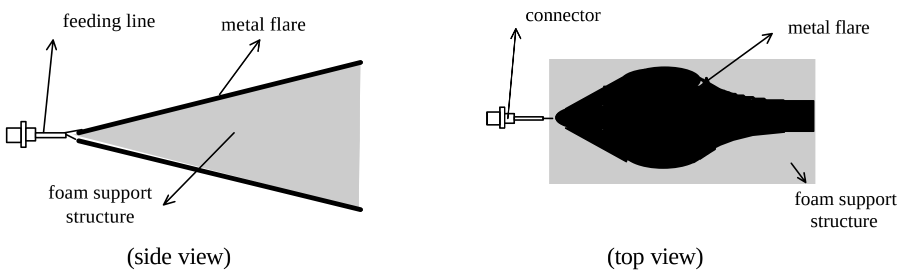


Fig. 1. Basic TEM horn antenna

The antenna has been measured in free space as well as in the GPR antenna test range [2]. Two different types of feeding pulse have been used: a monopulse with duration of about 190ps and a monocycle with duration of 0.8ns. When excited with the monopulse the TEM horn radiates a non-exact derivative of its waveform (Fig.2). The measurements have been done at three different distances from the aperture. In Fig. 2 the waveforms are shifted in time to compensate the time delay due to propagation and to achieve overlapping of the main pulses. Reflection-free time window in these measurements equals 5ns and after that (after 8ns in Fig. 2) the measured waveforms show different behavior due to reflections from surrounding objects. Although the radiated pulse has a very good waveform with short ringing, the field reflected from the antenna aperture and then from the feed point is re-radiated again (in Fig. 2 this signal is seen at a time of about 7ns). For short-range radar systems such as GPR this drawback of TEM-horns causes essential problems because the reflection from the aperture can mask a target return. To avoid this re-radiation different kinds of resistive loading schemes were proposed (see e.g. [3]). Absorbing energy of re-radiated pulse the resistive loading decreases also the antenna efficiency. Other disadvantages of air-filled TEM horns are their high sensitivity to external EMI and a strong coupling (Fig. 3) between two such antennas when they are used in a radar system with separate transmit and receive antennas. It can be observed in Fig. 3 that the coupling starts with a direct feed-to-feed air wave and continues with a direct aperture-to-aperture air wave. Ground reflection can be seen at the time 11ns. When the antenna system is placed on the ground, the coupling becomes even worse due to additional ground wave coupling. Finally large physical dimensions of the TEM-horn (typically its size equals 3 times the duration of the pulse multiplied with the velocity of light) causes additional problem in GPR systems.

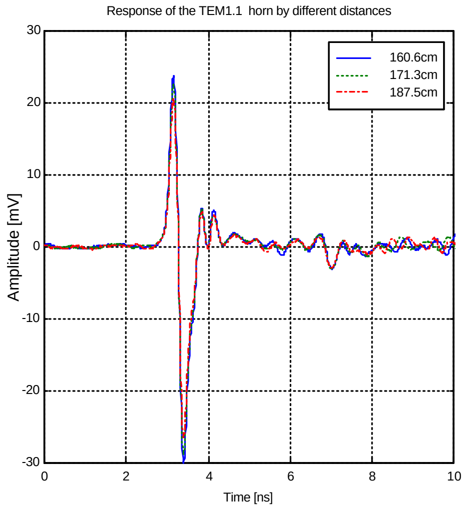


Fig. 2

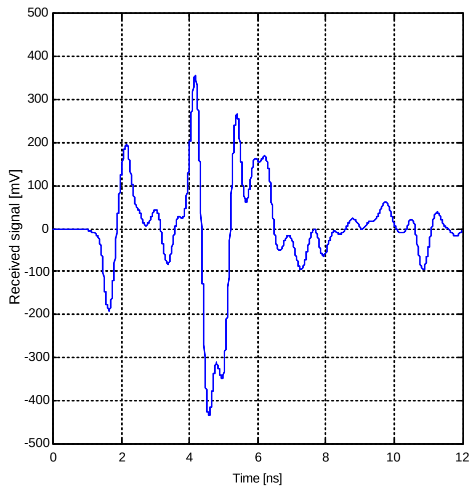


Fig. 3

Fig. 2. Transient radiation from the air filled TEM horn excited by the 190ps monopulse
Fig. 3. Coupling between two air filled TEM horns excited by the 0.8ns monocycle. Separation between antennas 10cm, antenna elevation above the ground 100cm

THE DIELECTRIC FILLED TEM HORN

In order to improve the performance of the basic TEM horn a dielectric filled TEM horn (TEM22) has been designed. This antenna is based on a dielectric wedge. Such design may reduce the sensibility of the antenna for external EMI and 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. 4). The antenna has been excited by 0.8ns monocycle. The reflection from the feed point is observed at a time of about 4ns, and the reflection from the antenna aperture is observed at a time of about 7ns. The radiated signal in the far-field is an approximate derivative of the exciting voltage (Fig. 5) and has a waveform similar to the waveform of the reflected signal.

Radiation into the ground by the air filled TEM horn and the dielectric filled TEM horn have been measured in the GPR test range. The antennas were placed directly on the ground and were excited by the 0.8ns monocycle. The probe response in the ground is presented in Fig. 6. The magnitude of the signal radiated from the dielectric filled horn is 1.48 times larger than that from the air filled horn. The waveform of the main signal is similar for both antennas, while for the dielectric filled horn the resonant part of the signal has smaller amplitudes but larger duration. The reflection from the aperture is 7.3% from the peak-to-peak value of the main signal for the air filled TEM horn and only 2.9% for the dielectric filled horn. So the relative value of the reflection is decreased in 2.5 times. This reflection takes place 3.46ns after the maximum of the main signal for the air filled TEM horn, while for the dielectric filled TEM horn the reflection is delayed to 4.25ns from the main signal.

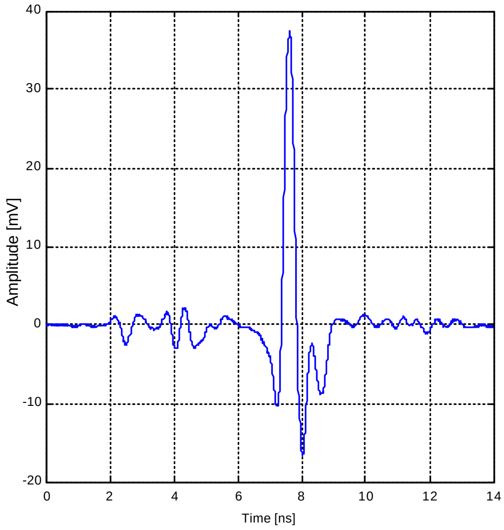


Fig. 4

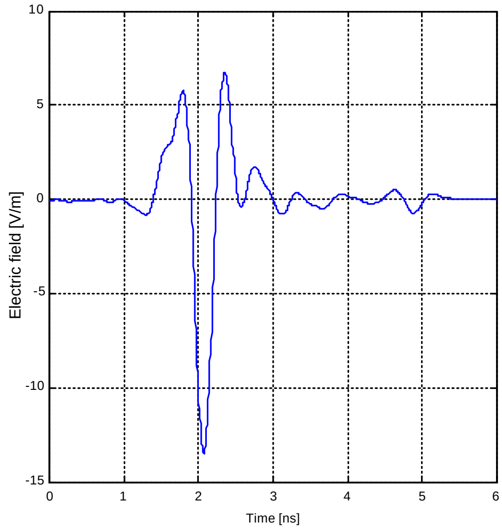


Fig. 5

Fig. 4. Reflection from the dielectric filled EM horn
Fig. 5. Transient radiation from the dielectric filled EM horn at the distance 150cm

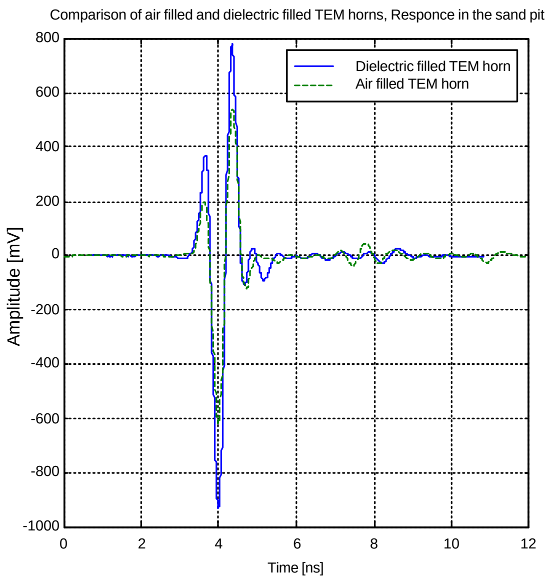


Fig. 6

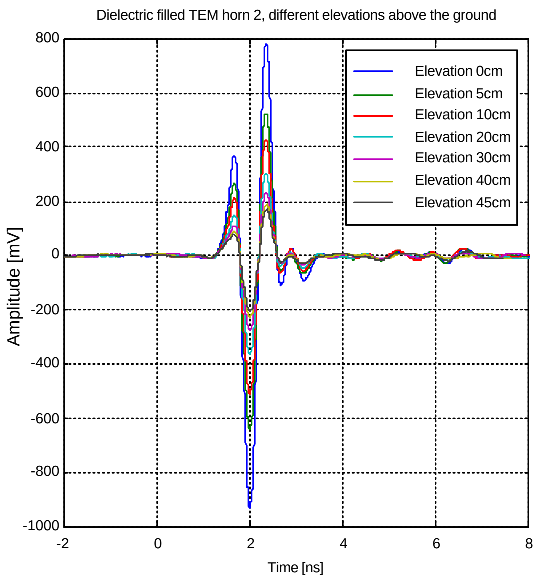
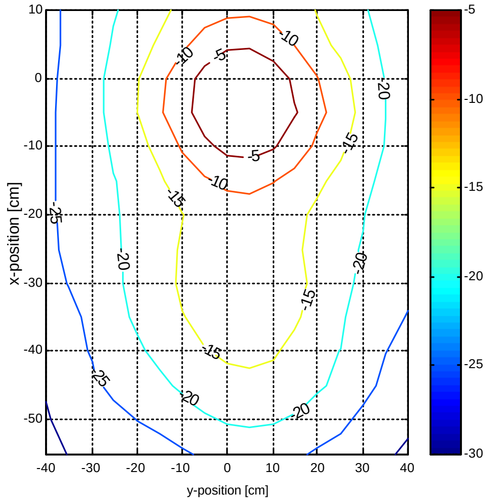


Fig.7

Fig. 6. Comparison of signatures of the TEM22 and TEM11 antennas
Fig. 7. Comparison of signatures by different elevations

Signatures of the dielectric filled TEM horn by different elevation above the ground are presented in Fig. 7. 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 resonant part of it remains stable by antenna elevation. This proves the stability of antenna performance in different environmental conditions, which is a very important feature for GPR antenna. The footprint of the TEM22 antenna on the depth 17.5cm in the sand by the antenna elevation 1cm above the sand has a slightly elliptic structure with main axis 26cm and 36cm on 10dB level (Fig. 8).



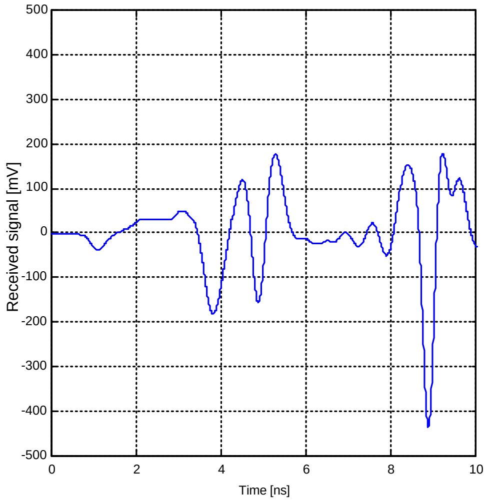


Fig. 8 Fig. 9

Fig. 8. Normalized footprint (in dB) of the dielectric filled TEM horn at the depth 17.5cm in the sand
Fig. 9. Coupling between two dielectric filled TEM horns excited by 0.8ns monocycle. Separation between antennas is 35cm, antenna's elevation above the ground is 88cm

As was expected in advance, the dielectric filling has decreased the antenna sensitivity to external EMI and has decreased coupling between similar antennas (Fig. 9). Due to a smaller antenna elevation above the ground, the time window in Fig. 9 is smaller than that in Fig. 3 and the time scale is also different. Ground reflection is observed in Fig. 9 at 9ns. Duration of the coupling between two dielectric filled TEM horns is the same as for air filled ones. However the magnitude of the coupling is 2.2 times smaller.

CONCLUSIONS

We have designed a first prototype of a dielectric filled TEM horn antenna for application in a GPR system. This prototype radiates 2.2 times more energy into the sandy halfspace, is less sensitive to external EMI and provides 5 times smaller (in power) coupling in the antenna system, and finally is approximately two times smaller than the air-filled TEM horn (designed for radiation of same pulses in free space). The dielectric filled TEM horn possesses 2.5 times smaller magnitude of the re-radiated reflection from the aperture and has shown a stable performance by different elevations above the ground.

ACKNOWLEDGEMENTS

This research is supported by the Technology Foundation STW, applied science division of NWO and the technology program of the Ministry of Economic Affairs of the Netherlands.

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