A New TEM Double-ridged Horn Antenna for Ground Penetrating Radar Applications

A. Teggatz, A. Jöstingmeier and A. S. Omar

Institute for Electronics, Signal Processing and Communications, FEIT
Otto-von-Guericke-University of Magdeburg, PF 4120, 39016 Magdeburg, Germany
alexander.teggatz@et.uni-magdeburg.de, http://iesk.et.uni-magdeburg.de/hf/

Abstract — Within this contribution we will present two major modifications of the standard design of the TEM double-ridged horn antenna, that increase its performance. By filling the space between the ridges partially with dielectric material it is possible to extend the frequency range to the lower end while maintaining the size of the original setup. In addition an absorber structure has been introduced in order to decrease the antennas return loss. The suggested concept has been applied to subsurface radar applications in both, 3d field simulations and various measurement experiments. The ability of this modified TEM horn antenna with respect to the detection of non-metallic objects inside the soil will be verified.

I. INTRODUCTION

The detection of buried objects such as landmines or unexploded ordnance by means of ground penetrating radar (GPR) is an intensely investigated field of research. In the past a variety of antennas has been used in GPR [1], such as Vivaldi antenna, resistively loaded dipoles, bow-tie antenna, spiral antenna and TEM double-ridged horn antenna [2]. The latter one has been used very successfully in GPR. It fulfills the basic requirements of such a system, namely, a low return loss, a wide frequency band and a reasonable gain.

In this contribution we suggest two modifications of the standard TEM double-ridged horn antenna that further improve its performance. Our design goals which are not met by the standard structure are a return loss of less than –15 dB and single main lobe operation in the frequency range from 2 GHz to 10 GHz. Fig. 1 shows the suggested structure. The design goals are achieved basically by two modifications, namely, an integrated wave absorber and a dielectric which partially fills the gap between the ridges.

Two prototypes of the new antenna design have been manufactured and the electromagnetic parameters of both structures have been measured in an anechoic chamber. The experimental results will demonstrate that the desired design parameter have been achieved successfully.

The ability of the suggested antenna structure to detect buried objects inside the soil will be proven by simulations and experiments. For the GPR simulations the same 3d field simulation tool (Microwave Studio) has been used as for the optimization of the antenna in free space. It allows for simulating the complete real world GPR environment including the antenna, the soil and different buried objects [3].

Nevertheless, real experimental data will also be presented that demonstrate the possibility to detect buried objects by means of subsurface radar with outstanding resolution.

II. TEM HORN ANTENNA DESIGN

There are basically two major differences between the suggested design and the standard TEM double-ridged horn antenna like it has been investigated in [4] and [5]. Firstly, the space between the ridges is partially filled with dielectric. This is done in order to decrease the lower frequency limit and by doing so increasing the frequency range of the antenna. At the coaxial feeding line the dielectric homogeneously fills up the gap between the ridges, whereas it has the shape of a wedge at the aperture of the antenna as shown in Fig. 2.

Thus the dielectric filling has maximum effect where it is needed most, namely, at the feeding of the TEM horn antenna. At this place the dimensions of the housing are small leading to a quite large lower frequency limit. This constraint is than relaxed by the dielectric. At the aperture, however, a smooth transition between free space and the antenna is required in order to keep the overall return loss small. This is guaranteed by the wedge shape of the dielectric filling inside the double-ridged TEM horn antenna. The best trade-off between a
reasonable average return loss and the maximum extension of the operating frequency down to the low frequency end has been obtained for dielectric materials with a moderate permittivity like that of PTFE, which is close to 2.

Secondly, the suggested TEM horn antenna has an integrated wave absorber where standard TEM horns have a short circuit. From 3d field simulations it has turned out that it cannot be avoided that a small portion of the energy is transmitted to the waveguide in the back direction of the antenna. This effect might occur for frequencies higher than 4 GHz where this waveguide starts to support wave propagation. Although the amount of energy transmitted in this direction is quite small it really has a bad impact on the return loss of the antenna. Hence an integrated wave absorber has been suggested in order to get rid of thus unwanted reflection. The absorber consists of a double wedge of absorbing foam located in a short-circuited waveguide section as it is shown in Fig. 3.

The suggested modifications of the usual TEM horn antenna design do not affect the radiation characteristic significantly. The single main lobe in the horn axis remains stable up to 10 GHz. At higher frequencies the it starts to split into several side lobes pointing in off-axis directions with a dip of up to 6 dB between them along the main axis, exactly like it has been predicted before by simulation in [4] and [5].

III. ANTENNA CHARACTERISTICS

The electromagnetic characteristics of the suggested TEM double-ridged horn antenna design has been verified by both, simulation techniques and different measurement experiments.

A. Return Loss

The measured and simulated return loss of the TEM horn are presented in Fig. 4. There is a good agreement up to 5 GHz. For higher frequencies a discrepancy between the measured and simulated results occurs, that might result from losses, or inaccuracies in the fabrication. However, the measured return loss is even better than the simulated one.

B. Radiation Pattern

The measured E- and H-plane radiation pattern are presented in Fig. 5. For both planes a minimum beam size is observed between 3 GHz and 4 GHz as it has been predicted by the simulation of the suggested antenna design. In the H-plane the shape of the beam is almost frequency independent between 2 GHz and 5 GHz.

Furthermore the simulations show that the directivity of the simulated TEM double-ridged horn antenna is almost constant between 2 GHz and 6 GHz. However, the single main lobe starts to split up into different side lobes at higher frequencies. Thus the overall antenna performance is significantly degraded for frequencies above 10 GHz (Fig. 6).
IV. SIMULATION OF A GPR-ENVIRONMENT

The applicability of the suggested TEM horn antenna for GPR has also been investigated. Figs. 7 and 8 show the quasi-monostatic GPR simulation setup. For the simulation of the electromagnetic field the 3d field simulator Microwave Studio has been used. It is possible to automate the process of the antenna movement above the considered ground section by using an ActiveX connection which allows for changing parameter of the field simulation from another application [3].

Both antennas are moved in a fixed distance, in steps of 1 cm at a height of 20 cm above the surface of the soil. The cylindrical test object with a diameter of 10 cm, a height of 3 cm and a permittivity of 1 has been placed in a depth of 7 cm below the surface of the homogeneous soil with a depth of 30 cm and a permittivity of 3. Figs. 9 and 10 show the corresponding results of such a GPR simulation setup.
The simulation has been done in the frequency range between 1 GHz and 5 GHz. For every considered antenna position either the reflection coefficient for one of the antennas namely, $S_{11}$ or $S_{22}$, or the transmission coefficients $S_{21}$ and $S_{12}$ are taken into account to generate a cross-section image (B-scan) with the different antenna positions on the x-axis and the depth on the y-axis. As the permittivity of the soil is known the depth information is corresponding directly to the time domain results. Though no further processing has been applied to the results of the simulation the position of the cylindrical object in the soil can clearly be identified.

The buried target can clearly be identified using the transmission signal as it is shown in Fig. 9. However, the true cross section of the target can be determined with a better accuracy using the resulting reflection signal $S_{22}$ as it is shown in Fig. 10. Obviously the reflection signal of a single antenna yields better results with respect to the actual size of the target because of the smaller footprint size of a single antenna.

V. GPR MEASUREMENTS

To verify the subsurface radar ability of the modified TEM double-ridged horn antenna experimentally it has been used for measurements in a GPR environment. The reflection coefficients and the transmission coefficients have been measured by connecting the horn antennas to the two ports of a network analyzer to perform a stepped frequency continuous wave (SFCW) measurement. In this quasi-monostatic setup as it is shown in Fig. 11 the two antennas are moved together in a fixed distance of 18 cm in steps of 1 cm at a height of 30 cm above the surface of the soil. The position and orientation of the 3 test objects inside the soil is illustrated in Fig. 12.

Both, the metal cylinder and the two emptied anti-personal landmines (APM) have been placed in a depth of 7 cm below the surface of the soil. The scattering parameter for 48 different antenna positions with a step width of 1 cm have been measured.
been taken into account to form the B-Scan image across the metal cylinder and one of the anti-personal mines which is shown in Fig. 13. The reflections of the metal body are much stronger than the reflections that occur due to the APM. However, a further processing could increase the contrast and reveal the correct size and position for both objects.

Fig. 13. B-scan measurement above two object in the soil.

VI. CONCLUSION

Within this contribution an improved design of the TEM double-ridged horn antenna has been presented. The design goals have been achieved by two modifications, namely, an integrated wave absorber and a dielectric wedge between the ridges. The characteristics of the suggested antenna have been investigated by field simulations and experiments. The GPR applicability of the suggested antenna structure and the detection of different buried metallic and non-metallic objects with an outstanding resolution have been proven successfully by various simulations and measurements.