Design and Analysis of TEM Horn Antenna for GPR Applications

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Abstract- Ground penetrating radar (GPR) is a technique used to probe the ground. This technique is positioned top among all existing geophysical techniques. Applications of GPR are enormous and are ranging from planetary exploration to the detection of buried mines. In GPR to get high resolution and to get the wave traveled through deeper distance inside the earth, the transmitting antenna (Tx) must transmit the narrow width pulse signal into the ground where objects are hidden. This thesis presents the work on the design of TEM horn antenna. For this application A Compact Double-Ridged Horn Antenna from the family of horn antennas with an ultra-wide band (0.827-4.5) GHz is designed & simulated. Both the time domain and frequency domain requirements are satisfied by this antenna. This antenna is simulated using Computer simulation technology (CST) microwave studio. This antenna is test simulated in time domain solver with feeding via 50 SMA and also tested in both thermal solver & mechanical solver to check for its malfunction. The variation of characteristic impedance across the antenna structure is gradually varied from 50 to 377 .In this thesis we will go through the steps how the lower range frequencies can be achieved with TEM horn & in what way the Linear TEM horn is transformed to Compact Double-Ridged Horn Antenna. This thesis also includes an explanatory part on both theoretical & simulated version of Linear TEM horn antenna, double ridged horn antenna, Compact Double-Ridged Horn Antenna & Double-Ridged Horn Antenna in GPR scenario along with the simulation results.
Keyword: GPR, TEM, CST

I. INTRODUCTION

Ground penetrating radar techniques are increasingly being used to detect and find location of buried objects and structures remotely that are hidden beneath the earth's surface. Ground penetrating radar technique is also known as Ground probing radar, subsurface radar, and surface penetrating radar (SPR).The first use of electromagnetic signals to determine the presence of remote terrestrial metal objects is generally attributed to Hiilsmeyer in 1904, but the first description of their use for location of buried objects appeared six years later in a German patent by Leimbach and Low Their technique consisted of burying dipole antennas in an array of vertical boreholes and comparing the magnitude of signals received when successive pairs were used to transmit and receive.

In this way, a crude image could be formed of any region. These authors described an alternative technique, which used separate, surface-mounted antennas to detect the reflection from a sub-surface interface. An extension of the technique led to an indication of the depth of a buried interface, through an examination of the interference between the reflected wave and that which leaked directly between the antennas over the ground surface. The main feature of this work is continuous wave (CW) operation.

The work of Hiilsenbeck in 1926 appears to be the first use of pulsed techniques to determine the structure of buried features. He noted that any dielectric variation, not necessarily involving conductivity, would also produce reflections and that the technique, through the easier realization of directional sources, had advantages over seismic methods. Renewed interest in the subject was generated in the early 1970s when lunar investigations and landings were in progress. For these applications, one of the advantages of ground penetrating radar over seismic techniques was exploited, namely the ability to use remote, no contacting transducers of the radiated energy, rather than the ground contacting types needed for seismic investigations.

II. PREVIOUS WORK

A. S. Turk; D. A. Sahinkaya M. Sezgin H. Nazli [2020] this paper proposes the planar and 3-dimensional ultra-wide band (UWB) antenna types suitable for hand-held and vehicle mounted impulse GPR systems. On this scope, bow-tie, spiral, TEM horn, dielectric-loaded Vivaldi, multi-sensor adaptive and array model antenna configurations are designed, simulated and measured. The numerical and experimental results are presented with performance comparisons.

A. Turk and B. Sen [2019] This paper deals with ultra-wide band (UWB) TEM horn antenna types, which are suitable for hand-held and vehicle mounted impulse GPR systems. On this scope, conventional, dielectric loaded, Vivaldi form, multi-sensor adaptive and array configurations of the TEM horn structure are designed, simulated and measured. Vivaldi shaped TEM horn fed ridged horn and parabolic reflector antenna prototypes are proposed to reach hyper-wide band impulse radiation performances from 300 MHz up to 20 GHz for multi-band GPR operation that can provide high resolution imaging. The gain and input reflection performances are demonstrated with measurement results.

D.A. Kolokotronis; Y. Huang; J.T. Zhang [2019] As it is well known, TEM horns are antennas that can achieve wideband characteristics over multiple decades. This special characteristic of these antennas makes them really attractive for wideband radar/communication systems, where short time-domain pulses of a very wide frequency range are employed. Although these antennas have been investigated by a number of researchers over the last 25 years, as far as we known, there is very limited analysis and design guidelines available. In this paper, the TEM horn antenna has been investigated using the multiple quarter-wavelength transformer technique, which can be served as a design guideline. Antennas have been designed, made and tested. Good measurement results have demonstrated the usefulness of this technique.

Ahmet Serdar Turk; Ahmet Kenan Keskin [2017] This paper deals with ultra-wide band (UWB) TEM horn antenna types, which are suitable for hand-held and vehicle mounted impulse GPR systems. On this scope, conventional, dielectric loaded, Vivaldi form, multi-sensor adaptive and array configurations of the TEM horn structure are designed, simulated and measured. Vivaldi shaped TEM horn fed ridged horn and parabolic reflector antenna prototypes are proposed to reach hyper-wide band impulse radiation performances from 300 MHz up to 20 GHz for multi-band GPR operation that can provide high resolution imaging. The gain and input reflection performances are demonstrated with measurement results.

Ahmet Kenan Keskin [2016] This paper deals with ultra-wide band (UWB) TEM horn antenna types, which are suitable for hand-held and vehicle mounted impulse GPR systems. On this scope, conventional, dielectric loaded, Vivaldi form, multi-sensor adaptive and array configurations of the TEM horn structure are designed, simulated and measured. Vivaldi shaped TEM horn fed ridged horn and parabolic reflector antenna prototypes are proposed to reach hyper-wide band impulse radiation performances from 300 MHz up to 20 GHz for multi-band GPR operation that can provide high resolution imaging. The gain and input reflection performances are demonstrated with measurement results.

III. METHODOLOGY

A TEM horn antenna can be considered to be a transformer from the impedance of a transmission line to the impedance of the free space and the variation of characteristic impedance is usually designed to be between 50 ohms and 376.7 ohms. The first step is obtaining the variation of characteristic impedance along the conductor plate. A smooth variation of impedance can keep the reaction from antenna as small as possible. Hecken had derived a function of near-optimum matching section that could provide a smooth impedance variance. Impedance variance can be calculated by the following formulas. The second step is calculating the length of conductor plate. Given the lowest operation frequency and an expected reaction coefficient, the length of conductor plate can be determined.

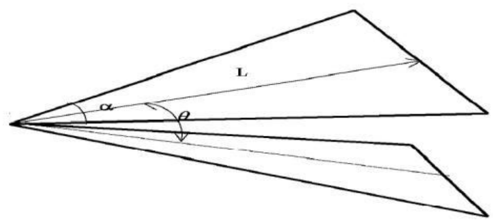

Figure 1: TEM Triangular Antenna

The third step is estimating the distance between two conductor plates. There are two main factors in considering the distance between two plates. One is to determine how long the distance between two conductor plates at the feeding point. For the linear taper TEM horn, after the distance of two plates at feed point is determined, next stage is to decide they are angle between the two conductor plates. The final step is obtaining the width of conductor plate. After obtaining the distance between two conductor plates, the width of conductor plate can be estimated by the parallel micro strip line equations since the variance of characteristic impedance is already known by the first Step. The design equations needed to calculate the dimensions are given by the equations. A variety of profiles for the cross section of wideband TEM horns, employing an optimal impedance function or exponential taper can be introduced in order to minimize reflection losses. Figure shows the performance of TEM Horn with elliptical profile. Based on the tapering how we designed, the performance of the designed TEM horn antenna matching with impedance of 200 Ω may be better than that with free space impedance of 376.7 Ω.

IV. RESULTS AND ANALYSIS

Till now all the simulations are done in CST MW studio in ideal conditions only. Ideal conditions indicate Constant temperature across the body & constant temperature in surrounding part of antenna. Ideal conditions also indicate that the mechanical properties of the antenna body also do not affect the body shape. But what happens if there is a temperature variation both across the body & in surrounding air. What happens if there is mutual temperature exchange in between the antenna body & surrounding. If the temperature variations exist in reality what happens to the structure of the antenna, whether any structural deformation takes place across the structure or it will not show any deformation. To answer all the questions above the designed antenna is simulated in Thermal solver & Mechanical using CST Multi physics studio and there by concluded that the designed antenna is not prone to thermal & mechanical effects. Figures below shows that S11 result with & without analysis. The scaling factor variation gives the whole system an increase or decrease in the Thermal & mechanical effects to the antenna body.

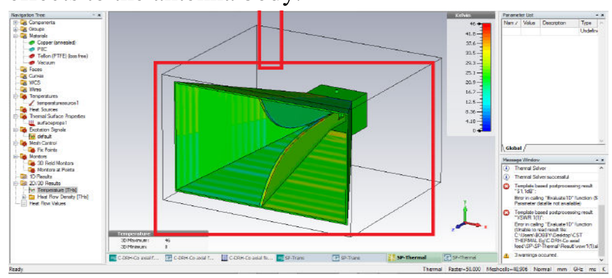

Figure 2: Temperature Variation across the Antenna Body

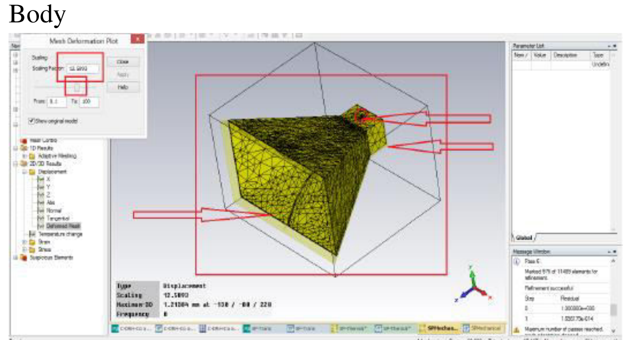

Figure 3: Temperature and Mechanical Effect on the Antenna Body

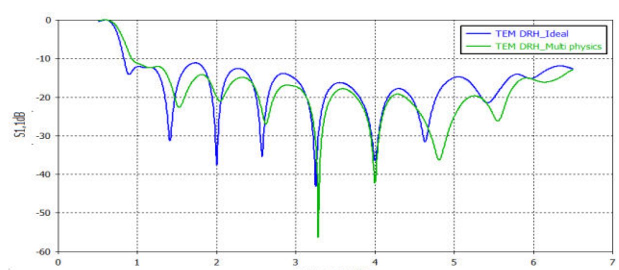

Figure 4: Thermal and Mechanical Solver Analysis on TEM DRH Antenna

V. CONCLUSIONS

The compact TEM Double ridged horn antenna is appropriate for ground-plane based measurements. The stub design and resistive taper design are important for proper impedance matching, and each design is unique to the antenna, although standardization is possible. Pattern measurements and design modifications have been simulated in a finite element modeling CST microwave studio environment and have provided insight into measurements and pattern behavior. Finally, various applications were presented showing how these antennas are used in GPR measurements. Because of the favorable characteristics of these types of antennas, we are able to measure in a wide variety of measurement environments.

Designing an antenna suitable for coupling the signal into air is not the goal for GPR antenna. GPR antenna must couple the whole signal completely into ground but not into air. So designing antenna suitable for wireless communication, for Air borne Radar is not the same way in designing an antenna suitable for GPR application. Specific GPR application needs to couple the signal into specific dielectric medium bodies. the S11 result produced by the Compact TEM DRH antenna in GPR scenario. This S11 result is deviating from its original. The lower frequencies of operation are affected when its surrounding resembles reality. So the antenna should be designed specifically for a particular application. By using resistive loading techniques the effect on the antenna at lower frequencies can be reduced further. Using CST MW studio itself performance analysis of antenna in GPR scenario can be carried out. By including the resistive loading technique reactions at antenna aperture can be further minimized.

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