AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electronics and Communications Engineering Department

IMPACT OF PROPAGATION ON ANTENNAS DESIGN FOR GROUND PENETRATING RADAR (GPR)

A Thesis

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Electronics and Communications Engineering

Submitted By

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For the P.H.D. thesis with title

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STATEMENT

This Thesis is submitted to Ain Shams University for the degree of Doctor of Philosophy in Electronics and Communications Engineering.

The work included in this thesis was carried out by the author at the Electronics and Communication Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt in collaboration with the Microstrip Department at Electronics Research Institute and National Research Institute of Astronomy and Geophysics.

No part of this thesis was submitted for a degree or a qualification at any other university or other scientific entity.

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ABSTRACT

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Impact of Propagation on Antennas Design for Ground Penetrating Radar (GPR),

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In this thesis, a study for the impact of propagation on antennas for Ground Penetrating Radar (GPR) is done, a novel Ultra-wideband Willis-Sinha Tapered Slot antenna for landmine detection using Ground Penetrating Radar (GPR) system with enhanced gain and directivity is presented. The structure is constructed on FR4 dielectric substrate which is low cost material. The antenna is fed by novel tapered coplanar waveguide (CPW) to coplanar strips (CPS) transition feed. The antenna's impedance bandwidth is extended by adding an antenna arm constructing parabola shape with the antenna element. The antenna has a corrugated structure along the antenna outer edges to improve radiation efficiency and get higher directivity. Also, mushroom like circular EBG structure is used in the lower side of the antenna arm to reduce interference and enhance front-to-back ratio (F/B ratio). A partially substrate removal like circular cylinders inside the substrate are aligned with the antenna tapered profile to obtain better radiation efficiency and enhance antenna gain.

Secondly, A novel Ultra-wideband CPW to CPS transition for TSA in landmine detection in GPR system is proposed. EBG structures of coplanar circular patches exist near the transition open slot and aligned with the outer edge of the CPW ground. To characterize this transition, the equivalent - circuit model of back-to-back transition that consists of non-uniform transmission lines is established using ABCD parameters by MATLAB program. The design verification is done by comparing the calculated and converted S-parameters and simulated one using FDTD simulation (CST Studio Ver 15). The results based on equivalent-circuit model, FDTD simulation, and measurements are compared and good agreements were found between numerical and experimental results.

Finally, modeling and simulation of the GPR propagation medium using ready-made electromagnetic software packages and MATLAB program have been achieved using stretched coordinates. In addition, the clutter reduction method using appropriate techniques for buried objects detection/imaging has been achieved by MATLAB program which is constructed to do these analyses.

Key words: Ground Penetrating Radar (GPR) - Tapered Slot Antenna (TSA) - ABCD parameters - Coplanar Waveguide (CPW) - Coplanar Strips (CPS) - CPW to CPS transition - Electromagnetic Band Gap (EBG).

SUMMARY

Ground Penetrating Radar (GPR) systems are widely adopted as non-destructive techniques for detection of underground objects. The basic configuration of GPR is transmitting unit, a receiving unit and a signal processing unit. The transmitting signal frequency content determines the class of targets which can be detected; depends on the resolution and on the penetration depth to be obtained, lower or higher bands are needed: (0.01–2 GHz) in architecture and archaeology, (0.5–3 GHz) in military, (1–10 GHz) in medicine. The Federal Communications Commission (FCC) of the United States on February 14, 2002, approved the first report and allowed commercial exploitation of GPR (UWB) technology according to the frequencies mentioned above with equivalent isotropically radiated power (EIRP) for GPR signals was regulated to -65 dBm/MHz.

GPR is used in various applications such as borehole inspection, archaeological investigations, building condition assessment, bridge deck analysis, detection of landmines (anti-personnel and anti-tank), and evaluation of reinforced concrete, geophysical investigations, pipes and cable detection.

In a certain GPR system, the antennas (transmitting or receiving antennas) are one of the most important components in this system. For a fine resolution and good penetration depth for a portable GPR, the antenna must have desired features such as ultra wide bandwidth, good impedance matching, unidirectional radiation pattern, accepted front to back ratio and high gain, in addition to small or compact size.

For, the commercial GPRs there are many problems during detection process which is related to the wave propagation and antenna part; these problems can be grouped under the term “Clutter”, one can describe it as follows:

1) The reflections from subsurface discontinuities (buried objects) are not the only signals recorded on a radar trace. The first arrives from transmit antenna and the second arrives directly by reflection from the ground surface. The other comes from the objects exist in the surrounding environment.
2) The soil roughness and inherent heterogeneities yielding diffuse scattering.

Therefore, there is a need to design an antenna or develop appropriate techniques for clutter reduction and buried objects detection/imaging; this is a quite challenging task due

to the complexity of the EM scattering phenomenon occurring in the priori unknown antenna–air–soil–mine system. Although many detection techniques based on different signal processing approaches have been developed, but unfortunately, still there is a need to develop an easier way to remove the soil–air interface reflection and soil roughness.

In this thesis, a novel Ultra-wideband Willis-Sinha Tapered Slot antenna for landmine detection using Ground Penetrating Radar (GPR) system with enhanced gain and directivity is presented. The structure is constructed on a 235 x270 mm^2 FR4 dielectric substrate. The antenna is fed by novel tapered coplanar waveguide (CPW) to coplanar strips (CPS) transition feed. The antenna's impedance bandwidth is extended by adding an antenna arm constructing parabola shape with the antenna element. The antenna has a corrugated structure along the antenna outer edges to improve radiation efficiency and get higher directivity. Also, mushroom like circular EBG structure is used in the lower side of the antenna arm to reduce interference and enhance front-to-back ratio (F/B ratio). A partially substrate removal like circular cylinders inside the substrate are aligned with the antenna tapered profile to obtain better radiation efficiency and enhance antenna gain. The operational bandwidth of this antenna extends from 0.18 GHz to 6.2 GHz. The minimum return loss reaches 60 dB. The average directivity reaches 12.2 dBi while the gain and radiation efficiency are 11.8 dBi and 92%, respectively with gain enhancement of 195% during design procedures and the using of corrugated structure and air cavities, this ratio is around 75% compared to the published papers. The front-to-back ratio (F/B ratio) is 23 dB. Also, a size reduction of 48% is achieved due to the use of extended arm. The antenna performance was simulated and fabricated using thin film technology and photolithography. The performance was measured. Good agreement was found between numerical and experimental results.

Secondly, a novel Ultra-wideband CPW to CPS transition for TSA in landmine detection in GPR system is proposed. The structure is constructed on a 140 x140 mm^2 FR4 dielectric substrate. It is composed of 2 sections, the first one is non-uniform tapered asymmetric coplanar wave-guide (TACPW) and the second section is non-uniform Tapered Asymmetric Coplanar Strips (TACPS). EBG structure of coplanar circular patches exists near the transition open slot and aligned with the outer edge of the CPW ground. The design of the proposed transition is given in very simple four design steps. The CPW to CPS transition is analyzed theoretically and experimentally. To characterize this transition, back to back transition is constructed besides the equivalent- circuit model

that consists of non-uniform transmission lines is established. The equivalent circuit is constructed by dividing both sections TACPW and TACPS into 35 sub-sections and using ABCD parameters to characterize each sub-section and conversion to S-parameters is done using MATLAB Program. The selection criterion of the sub-section length is to maintain a linear change in the characteristic impedance with the distance. The design verification is done by comparing the calculated and converted S-parameters and simulated one using FDTD simulation (CST Studio Ver 15). The results based on equivalent-circuit model, FDTD simulation, and measurements are compared.

Several parameters are studied through simulations and experiments which are used to derive some design guidelines. The operational bandwidth for the CPW to CPS transition covers from 0 (DC) to almost 10 GHz with minimum return loss reaches 50 dB. For the GPR application (landmine detection) which extends from 0.4 to 3 GHz, the insertion loss of the proposed transition reaches almost 0.5 dB which satisfies the design requirements. The back to back transition performance was simulated and measured. Good agreement is found between numerical and experimental results especially for the GPR ranges of frequencies.

Finally A GPR System Modeling and Analysis has been achieved to study the principal factors affecting the design of a GPR system. A modeling and simulation of the GPR propagation medium model has been done using both ready-made electromagnetic software packages CST ver. 15 and MATLAB program and Experimental Work has been done to verify the simulation results. Besides, the clutter reduction method using developed appropriate techniques for clutter reduction and buried objects detection/imaging is proposed; this is a quite challenging task due to the complexity of the EM scattering phenomenon occurring in the priori unknown antenna–air–soil–mine system.

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