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Analysis of a 3D Microwave Imaging System

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***Abstract*—In this paper a full vectorial 3D microwave imaging system consisting of three layers is analyzed numerically. The system is capable of acquiring scattered fields in two different polarizations using modulated scattering technique. A comparison between the full system simulation and measurement data is also presented.**

I. Introduction

Microwave Tomography (MWT) is an imaging modality by which a quantitative two dimensional map of the dielectric properties of an object of interest (OI) can be obtained using high frequency electromagnetic radiations. Different experimental setups and inversion algorithms using this imaging modality have been successfully developed during the past years [1] [2] [3] [4].

To take these systems a step forward and improve their performance for real life applications, three dimensional imaging systems can be adopted. One of the approaches in doing so would be using a 2D MWT system which mechanically scans the OI to acquire data from different slices of the object. Even though the data collected using this technique is 2D, it can be inverted using a 3D inversion code such as a 3D multiplicative regularized contrast source inversion (MR-CSI) method to obtain a 3D image [3].

Another approach would be using a fully 3D scanning system such as that of [4]. This system is comprised of a transmitter and a receiver on a mechanically rotating fixture and is capable of illuminating the OI and collecting the scattered signal from different angles. The data collected from this system can be inverted using techniques such as the distorted Born iterative method incorporating the stabilized biconjugate gradient (DBIM-BCGS) [5].

The former technique is basically a 2D data acquisition system while the latter requires a very long acquisition time. To tackle such problems, multilayer data collection systems such as those described in [6] can be adopted. Although this system is capable of acquiring the scattered electromagnetic field using different transmitter-receiver combinations at different spatial locations, it uses only one polarization, thus it does not take into account all of the information available in the 3D data.

The work presented in this paper describes a three layer microwave imaging system which is capable of collecting data in two polarizations. One of the main advantages of this system is having the receiving antennas at the centre layer and using scattering probes at different layers. Such an approach reduces the cost and size of the system significantly as it requires a fewer number of receiving antennas.

II. System Description

Based on our previous 2D data collection system [2], we have developed a 3D imaging system comprising three layers of scattering probes and a single layer of 12 transceivers. Each receiver-transmitter combination can provide 10 independent field measurements at different spatial, both vertical and horizontal, locations (Fig. 1). Additionally, the imaging system is capable of collecting the scattered fields in two different polarizations which allows for more data points without the need for increasing the system's size. Using this configuration, the total data acquisition time for 1440 data points at 11 different frequeincies was less than 2.6 minutes.

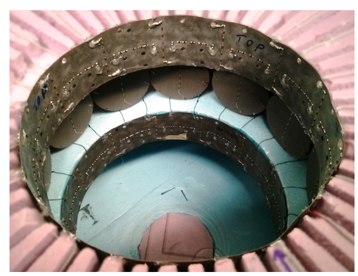


Fig. 1. Three dimensional imaging system.

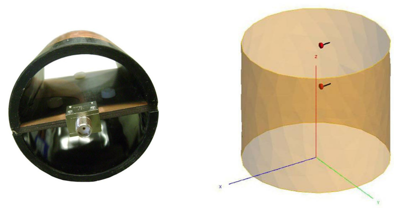
III. System Simulation

One way to evaluate the measurement performance of this system is through simulation with full-wave simulation software such as HFSS or FEKO. However, given that this system uses Double Layer Vivaldi Antennas (DLVA) each inside a PEC cavity(Fig. 2(a)), such simulations would be computationally expensive. Thus, by simplifying the antenna model to a less complex design with a similar performance, it is easier to simulate the imaging system.

The DLVA antenna excites TM_{11} and TE_{11} cylindrical modes inside its cavitiy. The two modes can also be excited by two dipole antennas with a $\lambda/4$ spacing located inside a PEC cylinder cavity as shown in Fig. 2(b). These dipoles are excited with the same amplitude but with a 90^o phase shift.

In order to find the optimum location of the dipoles inside the PEC cylinder, a parametric study was conducted. The configuration with the best match between the patterns of the

DLVA antennas and the simplified model were found. A plot of the co-pol. and cross pol. of the two antennas in two different planes is provided in Fig. 3.



(a) (b)

Fig. 2. DLVA (a) and the dipole fed cylinderical cavity (DFCC)(b).

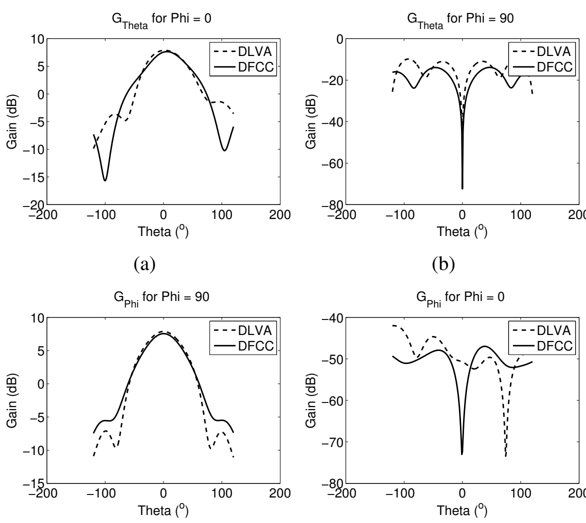


Fig. 3. Co-pol and X-pol radiation patterns for (a) ϕ = 0 and (b) ϕ = 90 at 4 GHz.

IV. System Results and Conclusion

Having the numerical model of the antenna with a close performance to that of the true cavity enclosed DLVAs, the full system was modeled and simulated in FEKO (Fig. 4) and the magnitude and phase of the electric field at the location of all the probes was found.

The simulation results were then compared with a set of measured data from the experimental setup as shown in Figs. 5. As can be seen from the results, the phases in simulated and the measured results are close to each other while there are some variations in the magnitude of the electric fields. The magnitude variations are mostly due to modelling error; that is, many of the features of the real system were not taken into account, such as the biasing wires for each probe as well as the styrofoam and the absorbing layer surrounding the chamber. Work is ongoing to refine the model. Some preliminary imaging results using the collected data from this system are presented in [7].

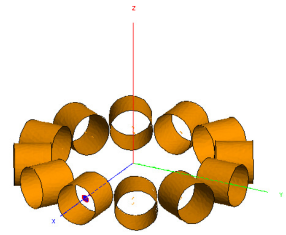


Fig. 4. 3D system model in FEKO.

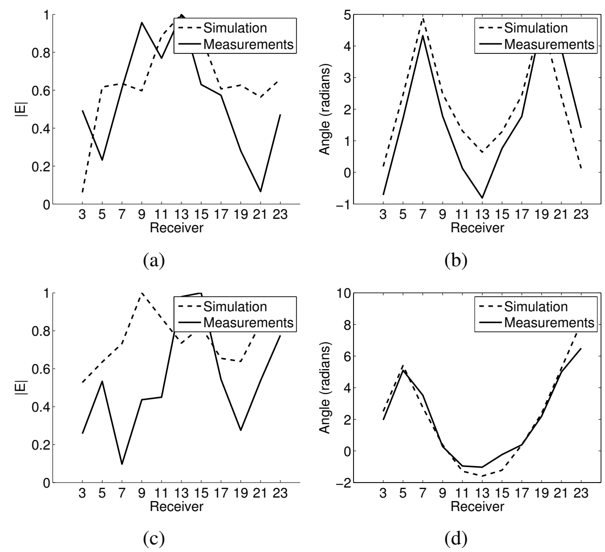


Fig. 5. Normalized magnitude and phase of the (a) E_{ϕ} of incident field (middle row probes) (b) E_z of PEC cylinder scattered field (top row probes) at 4 GHz.

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