Analysis of Microstrip Patch Antennas on Nanostructured Ceramic Substrate by an Iterative Method Based on Transversal Wave Concept

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***Abstract*—A new utilization of the Wave Concept Iterative Procedure (WCIP) on microwave printed antenna on nanostructured materials is proposed. The WCIP method is based on a transverse waves formulation. This method is proposed to analyze a rectangular patch antenna on a ceramic substrate. Significant computation time and used memory savings are obtained using the FFT algorithm to define a fast modal Fourier transform. WCIP results are compared to HFSS simulation data and measured data. A good agreement is verified.**

***Index Terms*—Iterative methods, modal analysis, microstrip antennas, high K dielectric materials, nanostructured materials.**

I. Introduction

The Wave Concept Iterative Procedure is a full wave formulation that uses the transversal wave concept to solve the electromagnetic problem. The WCIP is an iterative and integral method that proposes a general and efficient solution for antennas based circuits [1]-[3]. The WCIP characterization for a rectangular patch antenna on a substrate with high permittivity is considered.

Nanomaterials are being identified worldwide as the key for the discovery of a new generation of devices with many different revolutionary properties and functionalities. Also dielectric ceramics are materials that are being considered for the miniaturization of microwave devices, antennas, and equipments [4].

The purpose of this work is focused on investigation a new type of ceramic, *ZPT*, characterized by having high permittivity dielectrics, of approximately 16, and commonly used to decrease the dimensions of the substrates, besides being applicable for using microstrip antenna in the microwave and wireless communications range.

II. The WCIP Formulation

WCIP is a full wave formulation based on the use of concepts of wave to solve the electromagnetic problem. The principle of the WCIP is to describe the incident $\vec{A}$ and reflected $\vec{B}$ waves at the boundaries interfaces as a function of the tangential electric and magnetic fields. The relationships between these incident and reflected waves are given in (1) and (2).

$$\vec{A} = \frac{1}{2\sqrt{Z_0}}\left(\vec{E}_T + Z_0\vec{J}_T\right) \quad (1)$$

$$\vec{B} = \frac{1}{2\sqrt{Z_0}}\left(\vec{E}_T - Z_0\vec{J}_T\right) \quad (2)$$

where Z_0 is the intrinsic impedance of the medium, $\vec{E}_T$ is the electric field tangential component to the surface and $\hat{n}$ is the normal vector to the surface. The transverse current density is defined in terms of tangential magnetic field by $\vec{J}_T = \vec{H} \times \hat{n}$.

The iterative process initializes by a wave generated by an electrical source (current or voltage), it is to determine a recurrence relation between the incident waves and the reflected waves. This process is described by two fundamental equations, one in the spatial domain (3) and the other in the modal domain (4),

$$\vec{A} = \hat{S}\vec{B} + \vec{A}_0 \quad (3)$$

$$\vec{B} = \hat{\Gamma}\vec{A} \quad (4)$$

where $\hat{S}$ is the scattering operator, defined on the interface containing the circuit that takes into account the boundary conditions in the space domain, and $\hat{\Gamma}$ is the scattering operator that takes into account the reaction of the medium in the spectral domain.

The incident wave created by the source in the space field, $\vec{A}_0$, is described as a function of the total electric field $\vec{E}_0$ produced by the excitation source. The link between the two domains is given by the Modal Fourier Transform (FMT) and Inverse Modal Fourier Transform (FMT^{-1}) [3].

III. Fabrication of Ceramic Substrate

To obtain powder $Zn_{0,8}Pb_{0,2}TiO_3$ initially is prepared a mixture of stoichiometric composition calculated according to the propellant chemical. In this work used to combustion synthesis to obtain the powder $Zn_{(1-x)}Pb_xTiO_3$, where x had a value equal to 0.2. According [5], this type of synthesis combustion is one of the most efficient techniques for obtaining nanoparticles, and ceramic oxide nanocomposites. This synthesis is characterized by being a redox reaction of a mixture containing the metallic ions used in this characterization, represented by nitrates as being oxidants agents and urea as the a fuel. According to the amount of reactants, was generated the following equation to obtain 8 grams of the final product:

$$0.8Zn(NO_3)_2 + 0.2Pb(NO_3)_2 + TiO_2 + 3.67\mathrm{CO(NH_2)_2} \rightarrow Zn_{0.8}Pb_{0.2}TiO_3 + gases \quad (5)$$

The self-ignition of the combustion reaction occurred around 260ºC. The combustion synthesis was accurate and efficient. According to the propellant chemical, the energy released during the combustion, made the liquid mixture to acquire the initial state of the ceramic oxide after being subjected to an elevated temperature. The power went through a uniaxial pressure to 41.6 MPa, were used 2.8 grams powder for sample. The ceramics were prepared using a steel die with a diameter of 29 mm. The samples were sintered at a temperature of 1100°C.

The process of characterization of the dielectric substrate, as well as the simulation, construction and measurement of a microstrip antenna are presented. The simulation procedure is performed through WCIP formulation. The Ansoft HFSS commercial software based in the finite-element method is used to compare with the theoretical simulation data and a good agreement is verified.

IV. Results and Discussions

Fig. 1 shows the antenna structure considered in this paper. The antenna patch length, L_{patch}, and width, W_{patch}, are 14.5 mm and 13.6 mm respectively. The antenna is fed by a microstrip line with length, L_{line}, and width, W_{line}, equal to 7.79 mm and = 1.71 mm respectively. The antenna substrate is composed of a cylindrical nanostructured ceramic layer with electric permittivity, ε_r, 16, substrate height, h, 1.65 mm, base radius, R, 13.73 mm, and dielectric loss tangent 0.01.

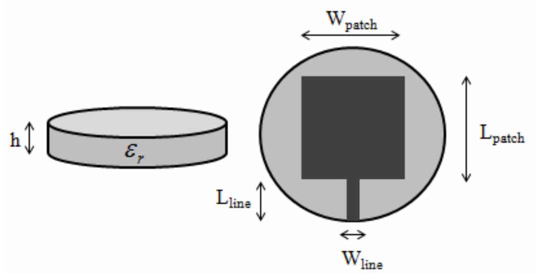

Fig. 1. Micostrip patch antenna geometry.

Fig. 2 depicts the insertion loss of the considered antenna in this work. The antenna measured resonant frequency value is 7.32 GHz, with s_{11} = -23.6 dB. The WCIP analysis indicates a resonant frequency value equal to 7.28 GHz, with an error equal to 0.5 %, compared to the measured one. The HFSS simulation indicates a resonant frequency value equal to 7.43 GHz, with an error equal to 1.5 %, which is three times the obtained WCIP error. Table I summarizes the measured and simulated results for this antenna.

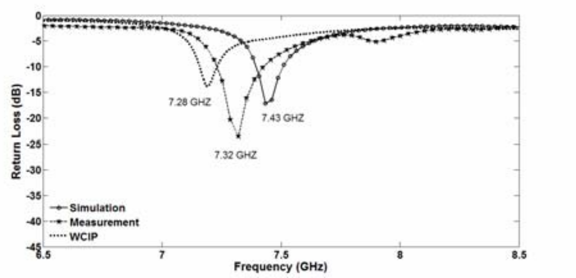

Fig. 1. Return loss results for the patch antenna on a ceramic substrate.

TABLE I
FREQUENCY RESPONSES OF THE CONSIDERED ANTENNA

Parameters	Simulated	Measured	WCIP
Resonant Frequency	7.43 GHz	7.32 GHz	7.28 GHz
Return Loss	-17.2 dB	-23.6 dB	-14.8 dB

A good agreement between simulated and measured results was obtained as shown in Table I. In addition we observed that the WCIP method provided accurate results (compared to measured ones) with a very good running time. The HFSS simulation was used to validate the WCIP formulation results and the antenna measurement to verify its accuracy.

V. Conclusions

An efficient method for the analysis of the microstrip patch antennas was presented. The results demonstrated a good agreement among HFSS and WCIP simulated results as well as measured ones. The WCIP iterative method provided faster convergence because there is no need of matrix inversion and of large amount of memory space. In addition the use of a FFT algorithm has improved the required computing time. Furthermore the use of ceramic substrate allows a reduction of the antenna dimensions. The analysis of other microwave circuits on ceramic substrates by WCIP formulation will be considered in future works.

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