using an unconditionally stable methodology, Radio Sci 38 (2003), 1048.
12. Y. Shi and J.M. Jin, Marching-on-in-degree solution of volume integral equations for analysis of transient electromagnetic scattering by inhomogeneous dielectric bodies with conduction loss, Microwave Opt Technol Lett 53 (2011), 1104–1109.
13. Y. Shi and J.M. Jin, A time-domain volume integral equation and its marching-on-in-degree solution for analysis of dispersive dielectric objects, IEEE Trans Antennas Propag 59 (2011), 969–978.
14. B. Stupfel and M. Mognot, A domain decomposition method for the vector wave equation, IEEE Trans Antennas Propag 48 (2000), 653–660.
15. Y.-J. Li and J.-M. Jin, A new dual-primal domain decomposition approach for finite element simulation of 3-D large-scale electromagnetic problems, IEEE Trans Antennas Propag 55 (2007), 2803–2810.
16. Z. Peng, X.C. Wang, and J.F. Lee, Integral equation based domain decomposition method for solving electromagnetic wave scattering from nonpenetrable objects, IEEE Trans Antennas Propag 59 (2011), 3328–3338.
17. M.-K. Li and W.C. Chew, Wave-field interaction with complex structures using equivalence principle algorithm, IEEE Trans Antennas Propag 55 (2007), 130–138.
18. M.-K. Li and W.C. Chew, Multiscale simulation of complex structures using equivalence principle algorithm with high-order field point sampling scheme, IEEE Trans Antennas Propag 56 (2007), 2389–2397.
19. P. Yla-Oijala and M. Taskinen, Electromagnetic scattering by large and complex structures with surface, Waves Random Complex Media 19 (2009), 10–125.

EFFICIENT FULL-WAVE ANALYSIS OF INVERTED CIRCULAR MICROSTRIP ANTENNA

Sami Bedra,[1] Randa Bedra,[1] Siham Benkouda,[2] and Tarek Fortaki[1]
[1] Electronics Department, University of Batna, Batna, 05000, Algeria; Corresponding author: bedra_sami@hotmail.fr
[2] Electronics Department, University of Constantine 1, Constantine, 25000, Algeria

Received 8 February 2014

ABSTRACT: *In this article, a rigorous full-wave analysis for determining the resonant frequency and half-power bandwidth of inverted circular microstrip patch antenna is presented. Green's functions of the structure are determined in Hankel transform domain. Galerkin's is used in the resolution of the electric field integral equation. The TM set modes issued from the cavity model theory are used to expand to unknown current on the patch. The validity of the results is tested by comparing results with the experimental data. Also, numerical results for the variation of the resonant characteristics of the structure for high-order mode, and for several values of substrates thickness are presented.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:2422–2425, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28618

Key words: *inverted patch antenna; spectral domain formulation; Hankel transform domain; Green's functions*

1. INTRODUCTION

Microstrip antennas have become increasingly popular for microwave and millimeter wave applications [1], because they offer several distinct advantages over conventional microwave antennas. These advantages include small size, easy to fabricate, lightweight, and conformability with the hosting surfaces of vehicles, aircraft, missiles, and direct integration with the deriving electronics [2, 3].

The inverted configuration of microstrip antenna is shown in Figure 1, where the patch is printed below the substrate and separated by an air gap from the ground plane [4]. The advantage of the inverted microstrip geometry is mainly caused by the air dielectric existing in between the inverted patch and the ground plane [5]. This allows easy integration of active devices with patch and also easy optimization of the feed location in a probe-fed design without any degradation of the medium [5–7]. Thus, the antenna should offer improved bandwidth (BW) without degrading radiation patterns or radiation patterns or radiation efficiency [7, 8].

Several methods using different levels of approximation are available in the literature to determine the resonant characteristics of circular microstrip antenna, however, the accuracy of these approximate models is limited and only suitable for analyzing simple, regularly shaped antenna, or thin substrates [9]. An alternative is to use a more sophisticated technique, such as the full-wave method of moments (MOM), which is versatile and accurate, although highly computer intensive [10].

The inverted patch antenna is a special type of a superstrate patch antenna. In the previous literature, several researches have studied the characteristics of circular micrstrip patch antenna [11–16]. Among them [5] theoretically and experimentally studied the resonant frequency of inverted circular patch antenna, but the half-power BW of inverted circular microstrip patch antenna was not investigated previously by using spectral domain approach. Effects of the air dielectric below the patch on the resonant characteristics are first presented in this study by using spectral domain approach formulations. A comparison of the results with experimental and theoretical values available from the literature shows that an extra improvement is obtained on the results of the previous models, especially for higher order modes and thicker gaps; also numerical results for circular microstrip antenna on single substrate are theoretically investigated.

The article is presented as follows. In Section 2, the authors provide details of the application of the Galerkin's method in the Fourier transform domain to the analysis of inverted circular microstrip antenna. In Section 3, the validity of the solution is tested by comparing the computed results with theoretical and experimental data available in the literature. Numerical results for the air dielectric existing in between the inverted patch and the ground plane effect on the operating frequency and half-power BW are also presented. Finally, concluding remarks are summarized in Section 4.

2. THEORY

The geometry under consideration is illustrated in Figure 1. The circular patch having radius a, is printed on a substrate having dielectric constant ε_r and thickness d_2, the cross sectional view of the inverted configuration shows the region below the substrate and the ground plane as air with an air gap higher d_1. All the dielectric materials are assumed to be nonmagnetic with permeability μ_0. All fields and currents are time harmonic with the $e^{j\omega t}$ time dependence suppressed.

The transverse fields inside the substrate region can be obtained via the inverse vector Hankel transforms (VHTs) as [2, 16, 17]

$$E(\rho,\varphi,z)=\begin{bmatrix} E_\rho(\rho,\varphi,z) \\ E_\varphi(\rho,\varphi,z) \end{bmatrix}=\sum_{n=-\infty}^{n=+\infty} e^{in\varphi}\int_0^\infty k_\rho dk_\rho \bar{H}_n(\rho k_\rho).e_n(k_\rho,z) \tag{1}$$

$$H(\rho,\varphi,z)=\begin{bmatrix} H_\varphi(\rho,\varphi,z) \\ -H_\rho(\rho,\varphi,z) \end{bmatrix}=\sum_{n=-\infty}^{n=+\infty} e^{in\varphi}\int_0^\infty k_\rho dk_\rho \bar{H}_n(\rho k_\rho).h_n(k_\rho,z) \tag{2}$$