The Effect of Substrate Dispersion on the Operation of Square Microstrip Antennas

Konstantinos P. Prokopidis and Theodoros D. Tsiboukis
Dept of Electrical and Computer Engineering, Aristotle University of Thessaloniki
GR 54124 Thessaloniki, Greece
E-mail: kprokop@faraday.ee.auth.gr, tsibukis@auth.gr

Abstract—The significance of the substrate dispersive properties of microstrip antennas is evaluated with an extension of the finite-difference time-domain (FDTD) method. It is shown that the inclusion of the material dispersion in FDTD simulations results in accurate estimation of the resonant frequencies, operation bandwidth and input impedance of microstrip patches.

I. INTRODUCTION

Since the first fabrication of microstrip antennas, extensive research and experimentation of patches and arrays have led to structures with great variation and different operation. Microstrip antennas exhibit numerous advantages such as light weight, low cost, robustness, conformability to planar and non-planar surfaces and versatility in terms of resonant frequency, polarization, radiation patterns and input impedance.

Both the rectangular and circular patches, fed conventionally, radiate mainly linearly polarized waves. However, circular polarization operations can be obtained by embedding slots (such as a cross-slot of unequal arm lengths), inserting slits of different length at the edges or truncating the patch corners [1]-[3]. Furthermore, by loading slots in the patch, dual frequency operation can be achieved where the resonant frequencies can be tuned by the length of the slots. Dielectric anisotropy and dispersion of the substrates and complicated feeding techniques render analysis and design of such structures difficult or even impossible through analytical methods. Therefore, several numerical techniques, including the finite-difference time-domain (FDTD) method [4] have been formulated to model such antennas. In this paper, a rectangular microstrip antenna with slits and truncated corners is examined and the effect of the substrate dispersion is analyzed. Specifically, the return loss and the input impedance of the proposed antenna are evaluated taking into account the Debye dispersion of the substrate.

II. ANTENNA DESCRIPTION AND CALCULATIONS

The choice of the substrate material is one of the crucial issues in designing microstrip antennas. Generally, the dielectric properties depend on the excitation frequency, the operation temperature, the ageing, the water absorption and even the ultraviolet radiation exposure [1]. It is surely very difficult to model all these parameters in a simulation, but the effect of the material dispersion upon the antenna operation is usually attainable.

The operation bandwidth of the microstrip antennas is small (usually up to 150 MHz) and the dielectric properties of the substrate material remain practically unchanged in this frequency region. Nevertheless, in modern dual-frequency antennas, the two operating modes are quite far from each other in the frequency spectrum (sometimes 2.5 GHz). It is obvious that in such a frequency region dielectric properties can vary seriously. Suitable values of the relative permittivity and loss tangent at one frequency mode are not valid in the other mode, rendering the numerical analysis cumbersome and inexact. In the majority of the materials used in practice, the dielectric constant and the loss tangent change little with frequency. But there are materials, often used as microstrip substrates, whose complex permittivity obeys the first-order (Debye) dispersion and assuming $\varepsilon_r(\omega) = \varepsilon_r(\infty) + \frac{\varepsilon_r(0) - \varepsilon_r(\infty)}{1 + j\omega\tau}$

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\end{equation}

where $\varepsilon_r(0) = \varepsilon_r(\infty)$, and $\tau$ is the Debye relaxation time constant. In the following, we assume an epoxy substrate with parameters: $\varepsilon_r(0) = 4.45$, $\varepsilon_r(\infty) = 4.27$, and $\tau = 1.1 \times 10^{-10}$ sec.
As referring to the antenna geometry in Fig. 1, two pairs of narrow slits are embedded in a rectangular patch with two truncated corners. In order to perform an exact modeling of the antenna, we use an extension of the FDTD technique to dispersive media [5]. To illustrate the effect of the dispersive substrate upon the operation of the antenna we calculate the return loss and the input impedance for the antenna under consideration. The simulation region is $60 \times 60 \times 20$ cells in the $x$, $y$, and $z$-directions, respectively, and the cell sizes are $\Delta x = \Delta y = 0.07$ cm and $\Delta z = 0.04$ cm. We also perform an FDTD simulation with constant $\varepsilon_r = 4.4$ (this value corresponds to 900 MHz in the Debye model) for comparison. It is obvious from Fig. 2 that the exact resonant frequencies are higher than the computed with the lossless case. This can be attributed to the fact that the resonant frequency of a patch is inversely proportional to the square root of the relative permittivity of the substrate $\varepsilon_r$. In Fig. 3, we notice that the input resistance for the first mode is calculated nearly 50 Ohms with the Debye model and more than 80 Ohms with the lossless model. This is due to the fact that the last model does not account for the dielectric losses of the substrate and it is also observed in [6]. Therefore, the accurate prediction of the input impedance permits the matching with a coax cable. The differences in value can be great in frequencies where the constant $\varepsilon_r$ differs seriously from the real part of complex permittivity at that frequency as it is observed near 5 GHz in Figs. 2 and 3. From Fig. 4 it is also demonstrated that circular polarized operation can achieved for two frequencies.

III. CONCLUSIONS

The effect of the substrate dispersion upon the resonant frequencies and the input impedance is examined for a rectangular microstrip antenna. As a rule of thumb, the calculated input impedances are larger than the exact ones and the resonant frequencies are shifted if a simple constant $\varepsilon_r$ model is applied in the simulations. Since for real-life applications (like WLANs) the resonant frequencies and the operation bandwidth must be precisely estimated, the substrate dispersion should be taken into account in the antenna design.

REFERENCES