COMPUTATIONALLY EFFICIENT ANALYSIS AND DESIGN OF PRINTED STRUCTURES

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Abstract

An efficient and rigorous technique, based on the spatial-domain MoM in conjunction with the closed-form Green's functions, is presented for the analysis and the design of printed geometries in a multilayer environment. The derivation of the closed-form Green's functions and the analytical evaluation of the MoM matrix entries have alleviated the most of the computational burden of the spatial-domain MoM. In addition, with the use of the order recursive Gaussian elimination in the solution of the MoM matrix equation, when the original geometry is modified, the computational efficiency of the spatial-domain MoM is further improved. The assessment of this improvement is demonstrated here, in the characterization of a series-fed microstrip array and an inset-fed microstrip antenna.

1 Introduction

Since printed geometries in layered media are widely used in the applications of microstrip antennas and monolithic milimeterwave and microwave integrated circuits, efficient and accurate modeling of such structures has gained a lot of interest. There are basically two approaches for the modeling of printed geometries; i) using a simple equivalent model such as transmission line model, cavity model in the analysis of microstrip antennas, and quasi-TEM, quasi-static approaches for the characterization of interconnects, transmission line discontinuities, ii)using a full-wave method like the method of moments, the finite difference time domain method and finite element method. Since the equivalent models are numerically efficient, they might be prefered in the computer-aided-design procedures involving optimization, but they often lack accuracy and are valid for specific geometries. In the case of microstrip antennas, for example, when stubs, parasitic elements or discontinuities are introduced, a full-wave analysis method has to be employed. Therefore, one need to improve the numerical efficiency of these rigorous techniques without sacrificing the accuracy. After a series of studies, the spatial-domain MoM has become a computationally efficient method which can be used in CAD applications. These studies involve casting the spatial-domain Green's functions into closed forms[1, 2] and analytically evaluating the MoM matrix elements[3]. Consequently, the elimination of the numerical integrals, involved in the traditional spatial-domain MoM, results in a significant improvement in the matrix fill-time.

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In this study, a rectangular region is divided into subregions (cells) and the corresponding spatial-domain MoM matrix is filled by using roof-top basis and testing functions, then the calculated matrix is stored. The geometry to be analyzed is printed onto this region and the corresponding matrix entries are selected from the stored matrix. As a result, the analysis of any structure printed on this region requires only a solution of a matrix equation whose computation time increases with the dimension of the matrix (usually $O(N^3)$). In interactive design or optimization, the whole geometry is not changed at each iteration but some part of it is deleted or added, so at each step some few rows and columns are added to or deleted from the previous matrix. For this type of applications, order recursive Gaussian elimination method[5], developed to improve the computational efficiency of solving matrix equations for modified geometries, can be utilized very efficiently. This method provides the solution of the modified matrix with the use of the solution in the previous iteration, hence eliminates the repeated solution of the whole matrix equation. Since the computation time is reduced significantly, the real time assessment of the results, due to small changes in the geometry, becomes possible. The numerically efficient procedure presented in this paper is employed to analyze two different geometries and their results are presented in Section 2.

2 Results and Discussions

In this section, two rectangular patch antennas connected in series as shown in Fig.1a are analyzed. The permittivity and the thickness of the substrate are 2.55 and 1.59 mm, respectively and the operation frequency is 2.275GHz. A region of 17.688cm × 4.02cm, which is chosen to be large enough to incorporate the largest possible circuit that we would like to investigate, is divided into subregions and the corresponding MoM matrix is obtained. Out of this area, a square patch antenna with dimensions 4.02cm × 4.02cm is chosen and its normalized (with respect to 50Ω) input impedance is calculated as 6.78+j0.0. Since the main goal is to investigate the characteristics of a series-fed array of two elements, the second antenna can easily be printed on the original area for which the corresponding MoM matrix elements have already been calculated. As series-fed antennas are generally used for broadside operation, the length of the transmission line connecting the two patches is adjusted to $\lambda/2$(4.623cm) by inserting or deleting some cells between the antennas. The current distribution of the geometry shown in Fig.1a, is given in Fig.2a and the input impedances of antenna # 1 and # 2 in this configuration are given in Table 1. These results show that the mutual coupling between the antennas shifts the resonant frequencies of the patches. Moreover, the input impedance of the patch #1 is changed due to the loading of the patch #2. The coupling and loading effects are observed for different transmission line lengths and the results are also given in Table 1. It is observed that the mutual coupling decreases with increasing the length of the transmission line and the input impedance of the antenna #2 approaches to that of the resonance condition. On the other hand, when the length of the transmission line is different from $\lambda/2$, antenna #1 is loaded by different complex loads, consequently the resonance condition of the array can be achieved by readjusting the length of the first antenna. This behavior should be taken into consideration when designing series-fed phased arrays.

length of the transmission line	input impedance of patch #1	input impedance of patch #2
4.623 cm	4.15+j1.58	7.65+j1.36
5.434 cm	0.33-j0.66	7.53+j0.78
6.238 cm	0.12+j0.11	6.98+j0.73

Table 1: Variation of the input impedances with the length of the transmission line

An other geometry, analyzed by using the method proposed in this paper, is the inset-fed patch antenna shown in Fig.1b. For typical patch widths ($\approx \lambda/2$), the input impedance of the antenna is so high that it is required to feed the antenna with a very narrow transmission line to decrease the mismatch between the antenna and the feed network. To eliminate this problem, the antenna feed point should be shifted towards the center of the patch by inserting notches. The depth of the notch changes both the real and imaginary parts of the input impedance and this variation is given in Table 2. In obtaining the results, the width of the notch is chosen to be equal to the width of the 50Ω feed line which is 0.4467cm. When the inset-fed configuration is used, it is desired to retune the antenna. This tuning can be achieved either by changing the length of the patch or by adding stubs to proper locations. In this study changing the length of the patch is prefered and the results are given in Table 3. The current distribution corresponding to the antenna with a notch depth of 0.8388cm is shown in Fig.2b. These results show that the input impedance of the patch antenna can be decreased and adjusted to a desired value by increasing the depth of the notch. However, the depth of the notch can not be chosen arbitrarily large since it degrades the radiation pattern[4].

depth of the notch	input impedance of the antenna
0. cm	6.78+j0.0
0.201 cm	1.36+j2.73
0.402 cm	0.42+j1.61

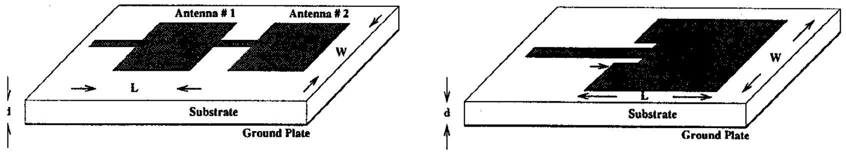
Table 2: Variation of the input impedance with the notch depth

length of the patch	depth of the notch	input impedance of the antenna
4.132cm	0.4132 cm	5.57+j0.0
4.194cm	0.8388 cm	3.49+j0.0

Table 3: Input impedance of tuned antennas for different notch depths

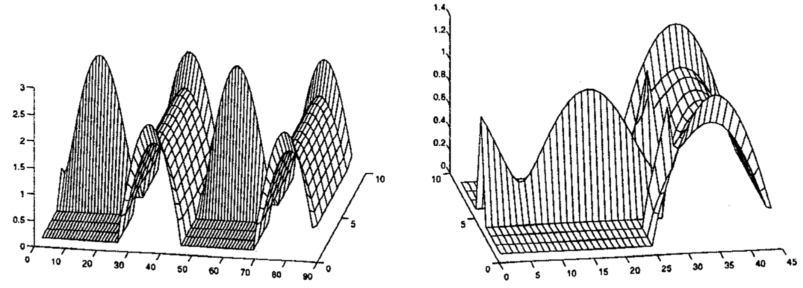
3 Conclusion

An efficient and accurate numerical modeling of printed structures is presented and employed in the characterization of a microstrip array consisting of two elements, and an inset-fed microstrip antenna. It is observed that the use of the order recursive Gaussian elimination in addition to the closed-form Green's functions has improved the computational efficiency of the spatial-domain MoM when used in an optimization problem.



(a) (b)

Figure 1: (a) Series-fed antenna array; (b) Inset-fed patch antenna



(a) (b)

Figure 2: Current distributions for (a) series-fed array; (b) inset-fed patch

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