Scale-Changing Technique for the Computation of the Input Impedance of Active Patch Antennas

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***Abstract*—An original and efficient numerical technique is proposed for the calculation of the input impedance of active patch antennas. Based on the partition of the discontinuity plane in planar subdomains with various scale levels this technique allows the computation of this impedance from the simple cascade of networks, each network describing the electromagnetic coupling between two scale levels. The CPU time for the calculation of the input impedance is eight times less than that of the conventional method of moment (MoM).**

***Index Terms*—Active antennas, scale-changing technique.**

I. Introduction

THE rise of the market of wireless communications generates the need for increasingly compact portable radio frequency (RF) terminals. The research is not only focused on the miniaturization of electronic components but also, on the realization of systems where these elements are integrated in the radiating structure [1]. Moreover the incorporation of active circuits in the surface of the radiating structure is particularly interesting for the design of reconfigurable networks [2], [3]. Due to the electromagnetic coupling between active elements and the radiating surface fullwave techniques are often used for the accurate electromagnetic modeling of an active patch antenna. When they are based on the spatial segmentation of the whole discontinuity plane these techniques [e.g., the method of moment (MoM), the transmission line method (TLM), or the finite-element method (FEM)] are very time-consuming. Moreover, the wide diversity of scales in the analyzed structures may generate ill-conditioned matrices [4].

An original approach for solving numerical problems linked to multiscale aspect of modern active patch antennas is proposed in this letter. Using a partition of the discontinuity plane in multiple subdomains of various scale levels the proposed approach allows the computation of this impedance from the simple cascade of networks, each network describing the electromagnetic coupling between two scale levels. This approach has been recently applied with success to the electromagnetic modeling of self-similar scatterers [5] and microelectromechanical switches in planar transmission lines [6]. In order to show that the proposed scale-changing approach is much better than the MoM in time costing the input impedance of active patch antennas is determined from these two numerical techniques and the CPU times are compared. We also discuss key advantages of the proposed technique.

Manuscript received April 18, 2005; revised June 2, 2005.
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Digital Object Identifier 10.1109/LAWP.2005.853999

II. The Scale Changing Approach

Let us consider the active patch antenna shown in Fig. 1 and reported in [2]. In the present example, the structure is composed of a rectangular patch antenna connected to an active component by mean of a quarter-wavelength microstrip line. Here, the active element is modeled by a time-harmonic transverse electromagnetic (TEM) field source E_0. The planar antenna is located on a substrate on the ground plane. A via hole [not shown in Fig. 1(a)] connects the ground plane to one port of the TEM source. The surface of the patch antenna, named the discontinuity plane, is artificially bounded by perfectly conducting sidewalls in order to facilitate the analysis through use of modal expansion of the electromagnetic field. No enclosure is present at the top of the antenna. We propose to apply the scale-changing technique for the computation of the impedance viewed by the TEM field source (input impedance calculation).

The subdomain denoted by Ω in Fig. 1(a) is first particularized: this rectangular surface includes the TEM source and the microstrip line. It presents an intermediate size (or scale) S_{middle} between the small size S_{small} of the lumped active element and the large size S_{large} of the discontinuity plane. The modal basis in the Ω-domain [bounded by the perfect electric and magnetic conditions as indicated in Fig. 1(a),] can be used to expand the electromagnetic field in this domain. Consequently, a multimodal excitation composed of the TEM source and the first N modes in the Ω-domain can be used to compute the $(N+1)$-port network that models the electromagnetic coupling between the scales S_{small} and S_{middle}. In Fig. 1(b), this network is characterized by its admittance matrix $[Y_{\text{CIRCUIT}}]$. Moreover the multimodal excitation composed of the first N modes in the Ω-domain can be used to compute the N-port network that describes the electromagnetic interaction between the half-spaces on both sides of this domain and the domain itself. In other words this second network models the electromagnetic coupling between the intermediate scale S_{middle} and the large scale S_{large}. In Fig. 1(b), this network is characterized by its admittance matrix $[Y_{\text{OUT}}]$. The two admittance matrices $[Y_{\text{CIRCUIT}}]$ and $[Y_{\text{OUT}}]$ are computed here by using a conventional Integral Equation Technique using entire domain trial function [7]. The input impedance of the active patch antenna is finally deduced by calculating the input impedance of the cascade of the two aforementioned multiport networks. Note that the number N of modes in the admittance matrices computation is such that the numerical convergence of the input impedance is reached. Before presenting the numerical results, let us point out key advantages of the proposed scale-changing technique for more complex planar structures.

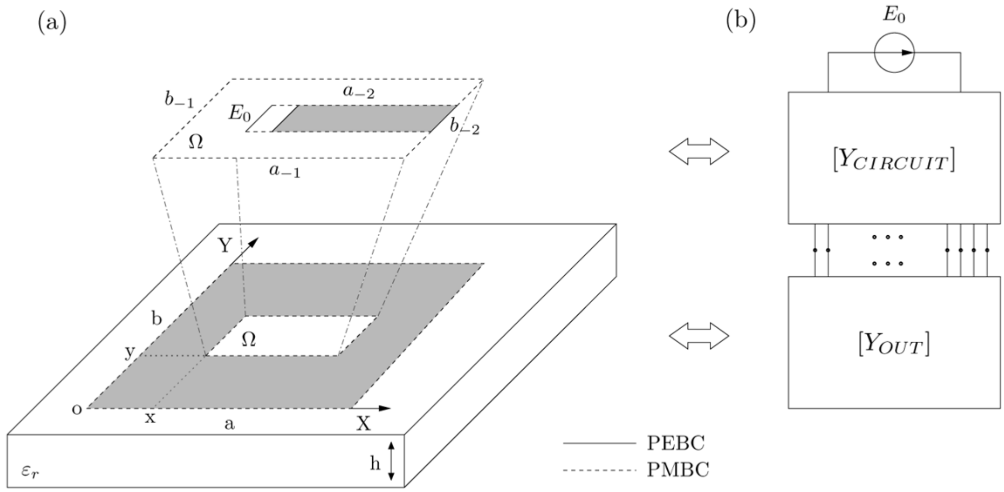

Fig. 1. (a) Active patch antenna under consideration and (b) its equivalent network. PEBC and PMBC stand for perfect electric and magnetic boundary condition, respectively. The time-harmonic TEM field source E_0 models the active element. Dimensions are: $a = 34.7$, $b = 42.3$, $a_{-1} = 25$, $b_{-1} = 10$, $a_{-2} = 13.7$, $b_{-2} = 5$, and $h = 1.576$ mm [$\varepsilon_r = 2.55(1 - j0.0019)$].

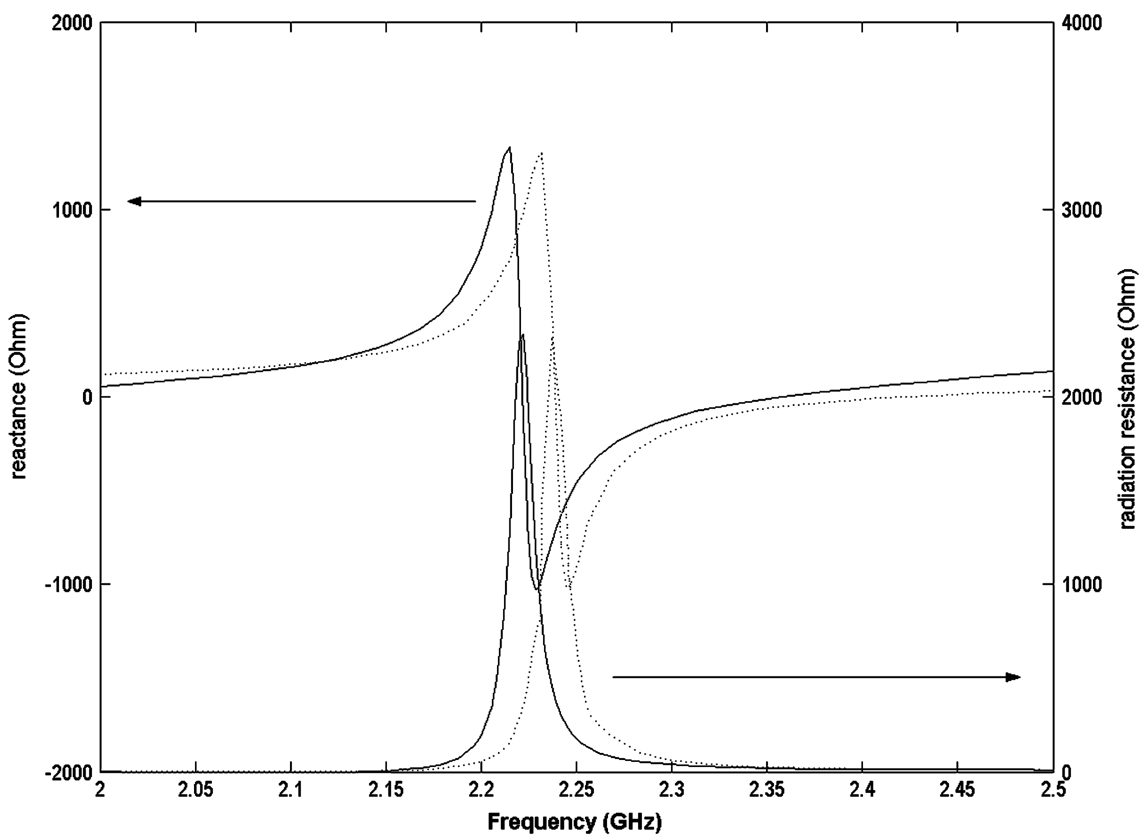

Fig. 2. Reactance (imaginary part of the input impedance) and radiation resistance (real part of the input impedance) versus frequency of the active patch antenna shown in Fig. 1(a): (——) Scale-changing technique; and (—) MoM.

Consider an active patch antenna combining multiple scale levels $S_i (i = 1, 2, \ldots, I)$ with $S_1 < S_2 < \ldots < S_I$. The computation of the input impedance from the scale-changing technique consists in: 1) computing separately the network that models the electromagnetic coupling between two successive scales S_i and S_{i+1}, and 2) determining the input impedance by cascading all the networks. By a proper partition of the discontinuity plane the successive scale levels S_i and S_{i+1} can be chosen in order to avoid critical aspect ratios and consequently, for eliminating numerical problems related to the treatment of ill-conditioned matrices. Moreover, at each scale level S_i, the electromagnetic field can be described as precisely as wished by taking an appropriate number of modes in the corresponding subdomain. Finally, since the computation of all the networks can be performed separately a modification of the antenna geometry at scale S_i requires the recalculation of two networks

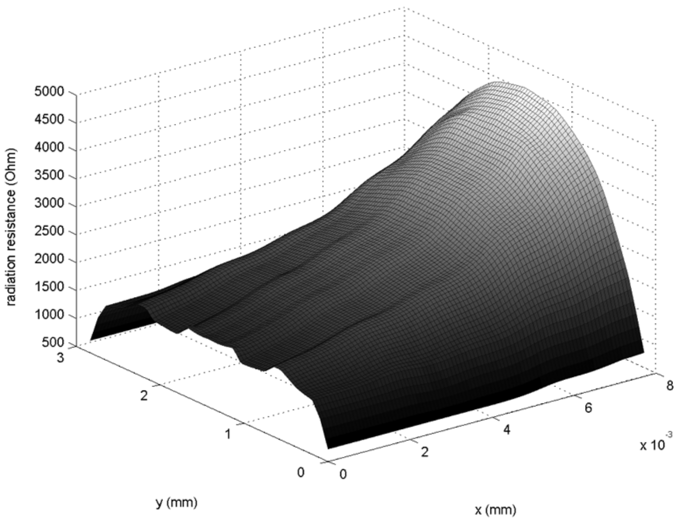

Fig. 3. Radiation resistance at the resonant frequency of the active patch antenna shown in Fig. 1(a) as a function of the active element location inside the patch.

only. In other words, the partition of the discontinuity plane in multiple subdomains makes the approach very flexible and modular.

III. Numerical Results

We proceed to the calculation of the input impedance of the active planar antenna shown in Fig. 1(a) with dimensions given in [2]. Fig. 2 displays the radiation resistance and the reactance versus the frequency in the range 2–2.5 GHz. In order to reach the convergence of the numerical results 6400 modes are taken in the large size $S_{\rm large}$ of the discontinuity plane while $N = 625$ modes are adopted at the intermediate scale $S_{\rm middle}$ (see the previous section for the definition of $S_{\rm large}$ and $S_{\rm middle}$). The results obtained from a commercial software [8] based on the method of moment (MoM) are given for the reference solution. A very good agreement is observed: the difference between the resonant frequencies given by these two methods is less than 0.7%. However the cost time in calculating the input impedance from the scale-changing technique is about eight times less than that of the MoM.

Fig. 3 displays the radiation resistance at the resonant frequency as a function of the active element location inside the patch antenna. For each location, the resonant frequency is numerically deduced from the cancellation of the antenna reactance (we have observed that the resonant frequency takes value between 2.1 and 2.4 GHz when the active element location is varied). The scale-changing technique tends to increase the proportion of numerical expressions that are independent of frequency and position in the calculation of the impedance. These

TABLE I
CPU Time Assessment for the Calculation of the Input Impedance of the Active Patch Antenna Shown in Fig. 1(a)

	CPU Time (in second)	Percentage
Calculation of expressions independent of frequency AND position	33.04	47.54%
Calculation of expessions independent of the position	0.656	0.943%
Calculation of expressions independent of frequency AND position	35.79	51.49%
Total time costing	69.5	100%

expressions, that are evaluated just once, represent 47% of the total cost time (see Table I). Moreover, the dimensions of the Ω-domain—that is, the rectangular surface including the TEM source and the microstrip line—are unchanged. Consequently, when the location of the Ω-domain is varied, the scale-changing technique requires only the recalculation of the admittance matrix $[Y_{\rm OUT}]$. By using the scale-changing technique the CPU time for obtaining the results displayed in Fig. 3 is 16 times less than that of the conventional MoM.

IV. Conclusion

The scale-changing technique has been applied to the calculation of the input impedance of active patch antenna. The validity and the advantage in term of CPU time of the proposed approach have been numerically confirmed.

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