Fractional Patch Antenna Analysis Based on the Iterative Approach

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Abstract—the aim of this paper is to profit from the advantages accorded by the rigorous iterative approach. Two important operators are required for the method operation, which determine a relation between space and spectral domains. The iterative approach performances have been used to analyze the fractal patch antenna. The Wave Concept Iterative Process (WCIP) obtained results are demonstrated by measurement, note that insightful results have been recorded.

Keywords— WCIP method; wave concept; numerical method; fast modal transform; fractal patch antenna.

I. Introduction

The technological outcome is accompanied by a real evolution in the analysis methods that allow predicting the electromagnetic and electrical behavior of the parameter's devices. The most physical problems resolution consists to find a field (scalar, vectorial or tensor) satisfying to partial differential equations that determine the problem and respecting the boundary conditions defined on the domain border of the problem definition. The most computational methods are based on the Maxwell's equations resolution or on different derived forms. The method choice to solve Maxwell's equations depends on the problem's complexity and the boundary conditions; the intended aim is to get results that are more accurate in a minimum computing time. The methods called rigorous are based on the equations system discretization. They are qualified rigorous because they solve the equations without introducing approximations. The electromagnetic problems have been solved by using analytical methods in limited cases, until the 1940s. The numerical solution of electromagnetic (EM) problems started in the mid-1960s with the availability modern high-speed digital computers [1-3].

The Wave Concept Iterative Process (WCIP) has been revealed by H. Baudrand destines to solve electromagnetic problems. It is close to the spectral methods « S.I.T. » (Spectral Iterative Technique) [3-4] developed by Bojarski [5], Ko and Mittra [6] applied for an extended range of diffractions and radiations problems. Firstly, iterative approach has been moreover explored by M. Azizi [7-8] after by R. S. N'gongo [9-10] as an instrument for the study scattering problems in-guide and planar circuits; it is used with success to calculate the current density on the surface of a conducting cylinder in free space excited by a plane wave. In [9], a full wave Fast Wave Concept Iterative technique has been developed to express the boundary conditions on the radiating surfaces in term of the waves.

Our contribution through this study is aiming to affirm the exactness and the accuracy of the iterative rigorous approach.

The investigated approach uses a wave's formulation and fast Fourier modal transformation (FMT) algorithm. These two tools minimize the computational complexity and offer a respectable computing time gain.

Validations of the numerical codes used in this study are made by comparing the computed iterative results for fractal patch antenna with measurements. Excellent agreement has been found between numerical analysis and the measured results.

The organization of this paper is summarized as follows. Section II presents the iterative approach formulation. Section III shows the results comparisons between the iterative simulation and the measurement. Section IV concludes the paper.

II. Iterative Approach Formulation

The iterative approach consists of a convergent algorithm. This proven convergence guarantees the response optimality, in dominant cases.

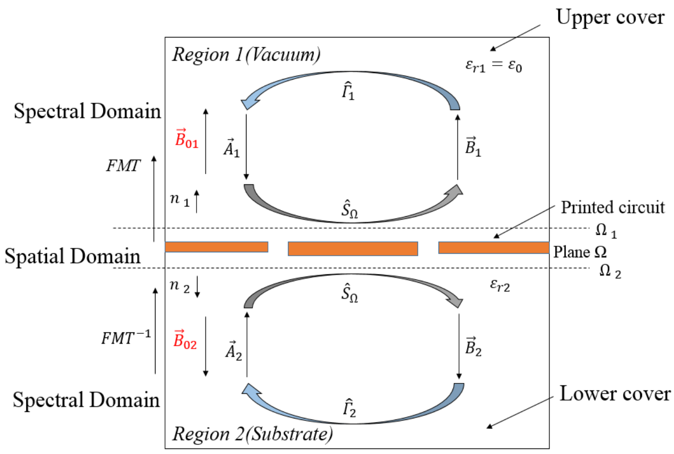


Fig. 1. Rigorous iterative approach.

Figure 1 describes the studied circuit as defined in the iterative approach. The process is introduced by excitation source, which appears in the plane Ω.

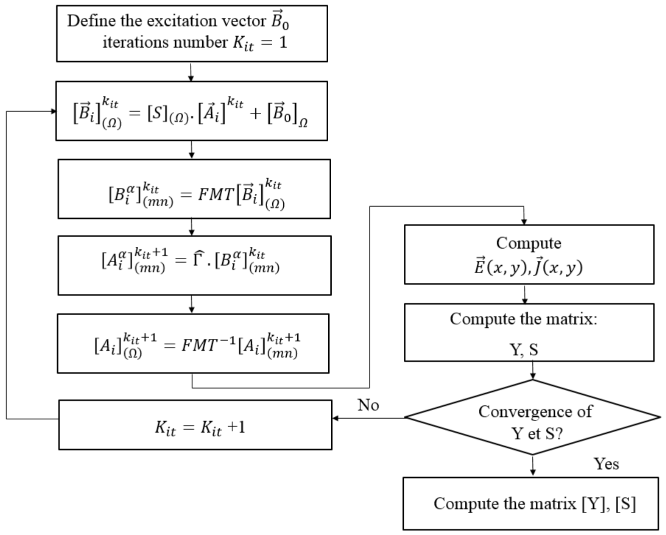


Fig. 2. Iterative approach organigram.

The analytical expression of the iterative process comprises a two equations system, the first one in the spatial domain characterizing the structure studied geometry. The second is expressed in the modal domain following the modes independence. The passage between the two domains is carried out via a fast modal transform FMT and its inverse (FMT^{-1}).

The iterative algorithm is expressed in detail by the figure 2 organogram.

$$\begin{bmatrix} B_{1\,x,y} \\ B_{2\,x,y} \end{bmatrix}^{(k_{it})} = [\hat{S}_{\Omega}] \cdot \begin{bmatrix} A_{1\,x,y} \\ A_{2\,x,y} \end{bmatrix}^{(k_{it})} + \begin{bmatrix} B_{01} \\ B_{02} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} A_{1m,n} \\ A_{2m,n} \end{bmatrix}^{(k_{it}+1)} = \begin{bmatrix} \hat{\Gamma}_1 & 0 \\ 0 & \hat{\Gamma}_2 \end{bmatrix} \cdot \begin{bmatrix} B_{1\,m,n} \\ B_{2\,m,n} \end{bmatrix}^{(k_{it})} \quad (2)$$

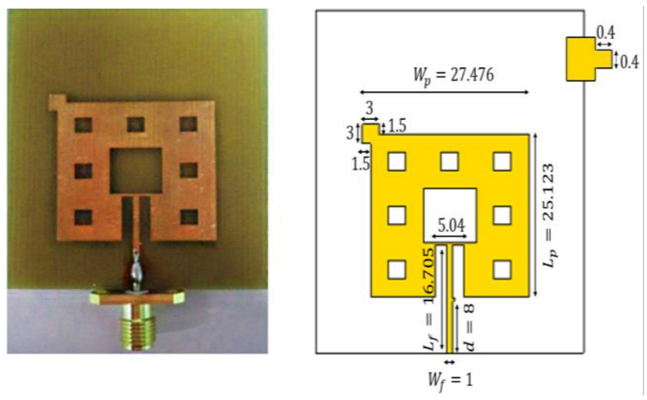
The equations (1) and (2) describe the wave concept on the plane Ω. The first equation is defined in spatial domain, the second in spectral. More iterative approach details have been presented in [11].

III. RESULTS AND DISCUSSIONS

To confirm the WCIP robustness for fractal patch antennas, an application example, which has been proposed in [12], is examined. The simulations are performed using an Intel (R) Core (TM), 64 bit i7-3632QM CPU@2.20GHz with 6 Go RAM memory on the same computer, without simulation parallelization and hardware acceleration.

Figure 3 (a) presents the fabricated prototype of the antenna; its detailed dimensions are shown in figure 3 (b). The considered antenna is printed on the FR4 substrate with thickness h=1.58 mm, relative permittivity $\varepsilon_r = 4.7$ and a loss tangent of 0.025.

The measurement results have been carried out using an Agilent Network Analyzer, N5230A.



(a) (b)

Fig 3. (a) Fabricated prototype reported in [12]. (b) Dimensions of fractal patch antenna.

In order to efficiently analyze the fractal patch antenna performance, a discretization of 128×128 ($M \times N$) pixels is exploited.

A pixel is a surface rectangle, which is defined as (Δx Δy), with ($\Delta x = a/M$) and ($\Delta y = b/N$). The elementary dimensions are defined as: $\Delta x = 0.4143\ mm$ and $\Delta y = 0.3646\ mm$. Note that $a \times b$ is the rectangular box dimensions, which packages the studied circuit.

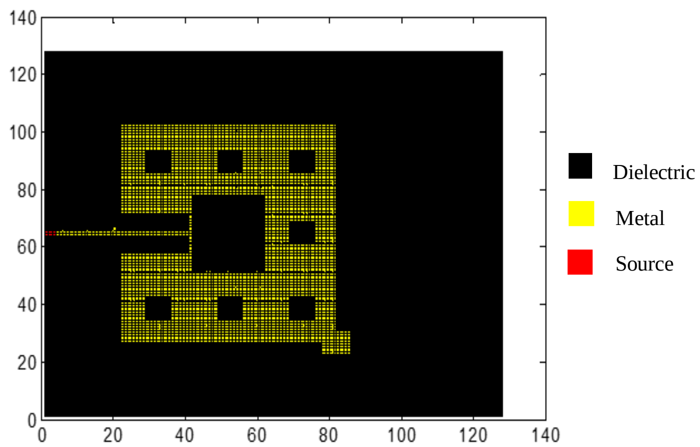


Fig.4. Fractal patch antenna scheme discretized with 128×128 pixels.

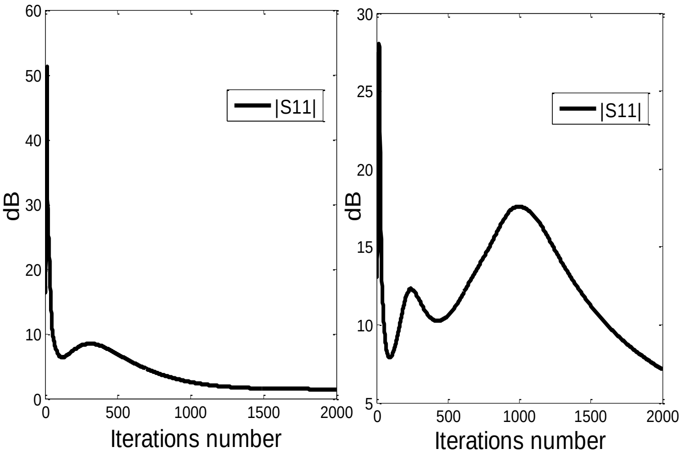
The electrical circuit simulation presents an indispensable stage. It allows predicting the electromagnetic and electrical parameters behavior of the studied circuits.

Each an electrical circuit must present a stable state during its simulation. The rigorous iterative approach verifies the stability by studying the electrical parameters convergence of as a function of the number of iterations.

Figure 5 shows the return losses convergence as a function of the iterations number. The study is carried out at the resonance frequency point and outside the resonant frequency, so two cases are presented.

The figure 5(a) curve shows that the return loss S_{11} convergence is reached at 1500 iterations, with a computation time of two minutes. The fractal patch antenna has required an iterations high number to ensure the stability. The increased iteration number is due to the antenna design complexity.

According to figure 5 (b), the convergence study at the resonance frequency didn't reach and the antenna requires more than 2000 iterations to ensure the stability.



(a) (b)

Fig.5. Convergence study of S_{11} parameters.
(a) at a deferent frequency,
(b) at the resonance frequency.

After certitude that the antenna converges, the frequency study of the electrical parameters will be presented.

The S_{11} parameters results obtained by iterative analysis and measurement published by IKA Shrestha et al. [12] in the frequency band [2-5 GHz] are presented in the figure 6.

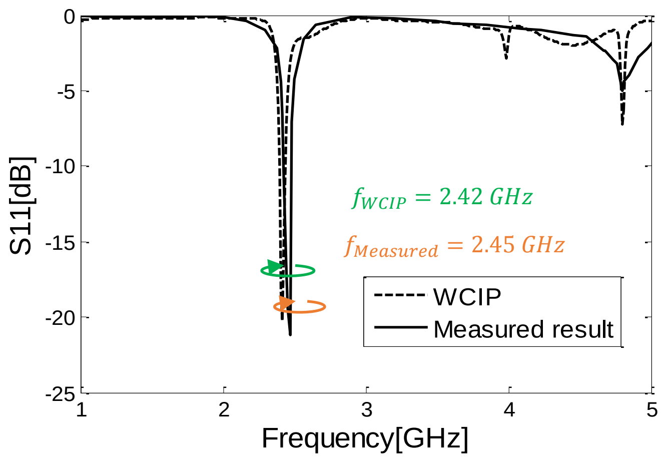


Fig. 6. Measured and simulated return loss S_{11} of fractal patch antenna in the frequency band [1-5 GHz].

The iterative analysis of the return loss S_{11} is in excellent agreement with the measurement result obtained by IKA Shrestha et al. [12] in the frequency band [1-5 GHz]. The theoretical WCIP simulation provides a resonant frequency at 2.42 GHz with a peak of -20.26 dB. However, the measurement result gives a peak of -21.2 dB at the frequency 2.45 GHz.

The VSWR characteristics of the fractal patch antenna are presented in figure 7. A good agreement is observed between the WCIP and the measured result [12]. The VSWR levels are close to unity, confirming the antenna adaptation and the WCIP precision.

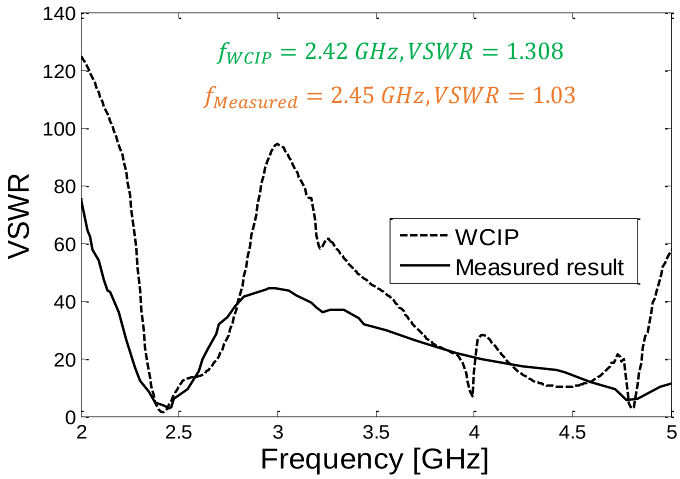


Fig. 7. Measured and simulated VSWR of the fractal patch antenna in the frequency band [2-5 GHz].

Figures 8 and 9 show the simulated and measured impedance results in function the frequency band. The impedance (Z) real component is nearly equal to 50 Ω and the imaginary around 0. Noted that, a very good coherence has observed.

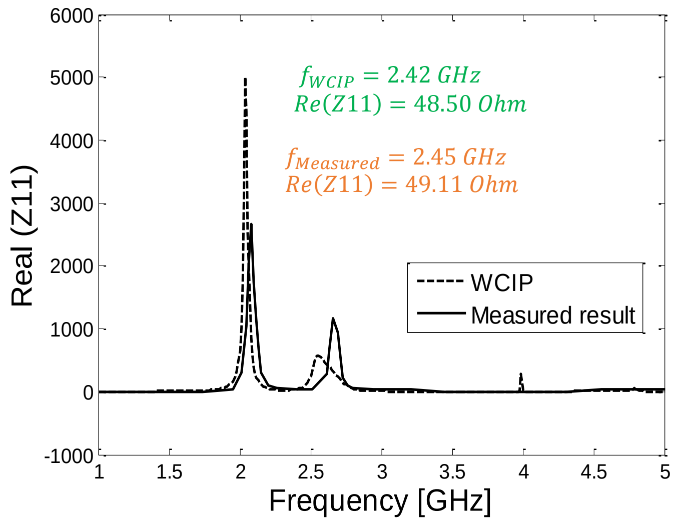


Fig. 8. Measured and simulated impedance real part of the fractal patch antenna in the frequency band [1-5 GHz].

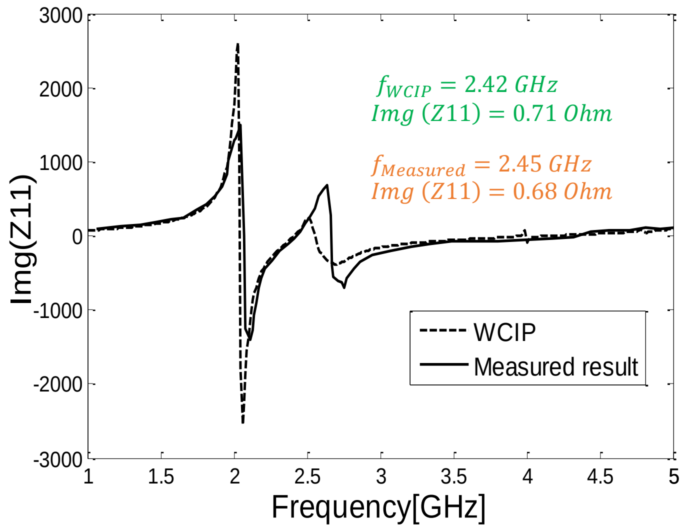


Fig. 9. Measured and simulated impedance imaginary part of the fractal patch antenna in the frequency band [1-5 GHz].

In order to highlight the advantages of the rigorous iterative approach, a performance comparison is provided in table 1.

The deviations observed between the iterative simulated and the measured results are minor and can be attributed to environmental effects and antenna manufacturing inaccuracies process.

TABLE I. COMPARISON BETWEEN WCIP THE APPROACH AND THE MEASUREMENT.

	Fractal patch antenna		
	WCIP	***Measurement[12]***	***Shift (%)***
Resonance frequency Peak [dB] (at … GHz)	-20.26 dB (à 2.42 GHz)	-21.2 dB (à 2.45 GHz)	1.23 %
VSWR	1.308	1.03	23.78 %
Re (Z_{11})	49.11 Ω	48.50 Ω	1.24 %
Img (Z_{11})	0.71 Ω	0.68 Ω	4.31 %

IV. CONCLUSION

In this paper, the fractal patch antenna analysis using the iterative approach is performed. The return loss S_{11}, VSWR, the impedances (real and imaginary part) are determined. To valid the iterative simulation results, a comparison with the measurement has been presented. An excellent agreement has been shown, confirming that the WCIP results have been obtained with reasonable accuracy.

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