MULTISCALE APPROACH FOR MICROWAVE CIRCUIT STUDY

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ABSTRACT

In this poster presentation, a new approach for complex circuits is exposed. It consists in considering a large grid and to study the no-uniform pixels (i.e. the pixels that contain metal and substrate) alone with a finer grid. Then, when these pixels are characterised, they are inserted in the general grid by their transverse S-matrix. Firstly, the theoretical justification and its validity domain are presented. Then some applications are investigated. This approach has two major applications: the study of classical circuit with a large grid in order to reduce the computational time and the study of multiscale circuit.

1 - INTRODUCTION

For many years, microwave circuits have become more complex with a smaller size. These two characteristics imply in most cases the presence inside the same circuit of different scales of length. Traditional numerical methods have two major disadvantages to solve this type of problem. They are the need of large memory resources and a long calculation time due to the smallness of the grid.

To solve this problem of numerical methods, works have been published to present multigrid or multiscale approaches. In the time domain, a very interesting approach is the Multi-Resolution Time-Domain (MRTD) Scheme (Krumpholz and Katehi [1]), which is based on the wavelet-use. Recently, Carat [2] presents the application of this approach to study microstrip circuits so as to use a different grid in function of the width of the microstrip line. For the moment method, the Adaptative Multi-Scale Moment Method (AMMM) - which had been introduced in 1998 by Su and Sarkar [3] - had been applied to large scattering structures containing small size inclusions like cavities [4].

Another approach and the one which is the subject of this abstract is the use of "sub-pixels" [5] in the iterative method WCIP (Wave Concept Iterative Method) [6]. The principle of this approach is to use for describing the structure a large grid. But with this grid, some pixels can contain metallic parts and insulator (dielectric) parts. Then these pixels are discretised with a finer grid and they are studied separately. Finally, they are replaced in the large grid by surface impedance. This approach is based on the hypothesis that the coupling between two pixels of the largest grid is realised only by the fundamental modes of these pixels.

In the first part of this abstract, we present the theoretical justification and investigate the validity limit of this hypothesis. This study will be made in considering the coupling between the modes of two pixels of a circuit. In order to simplify the exposition of the theory, we limited it to 1D circuit. Then, in the second part, we will apply this approach to a stop-band filter with a stub and to a patch antenna. In these two cases, it allows a reduction of computation time without a worse accuracy.

2 - THEORETICAL APPROACH FOR A 1D CIRCUIT

As we said in the introduction, the use of "sub-pixels" is based on the hypothesis that the coupling between two pixels is only due to the fundamental modes. In this part, we are going to expose the theoretical investigation in order to determine the coupling between modes of two arbitrary chosen pixels in a 1D circuit.

So, let us consider a structure (see fig. 1) of length "a" composed of smaller parts of length "c" (where a/c is an integer noted N). The whole structure has an eigenmode basis noted $(f_n)_n$, whereas each subdomain has a basis noted $(g_p)_p$.

In order to calculate the matrix, which represents the couplings between the modes of two pixels, we begin with the determination of the wave incident on a pixel M_2 when a wave is emitted from a pixel M_1.

Let us consider a wave emitted by the pixel M_1. This wave B_{M1} can be decomposed on the eigenvector basis of P_1:

$$B_{M_1} = \sum_p b_p^{M_1} \left| g_p^{M_1} \right\rangle \tag{1}$$

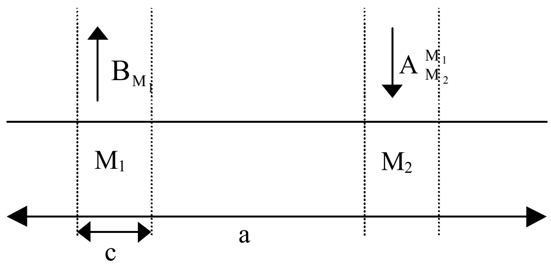

Fig. 1. One-dimensional structure of length "a" with two pixels of length "c"

The created wave is reflected by the circuit environment (which can be a short-circuit at length "l", an open-circuit, ...) via a reflection operator. Its eigenmodes are those of the whole structure $(f_n)_n$. So, we obtain an incident wave on the whole circuit. But, we are interested only in the part of this wave incident on the pixel P_2. Thus, we take the restriction of the incident wave on the spatial domain corresponding to P_2. Finally, we obtain the wave on the pixel P_2 due to the excitation by the pixel P_1:

$$A_{M_1}^{M_2} = \sum_q \sum_p \sum_n b_p^{M_1} \Gamma_n \left\langle f_n, g_p^{M_1} \right\rangle \left\langle g_q^{M_2}, f_n \right\rangle \left| g_q^{M_2} \right\rangle \quad (2)$$

From this theoretical expression and via the introduction of a vector (G_{M2}) corresponding to the excitation and a vector (B^{M1}) corresponding to the eigenmodes of P_2, it is possible to define a matrix (C_{M1}^{M2}), which corresponds to the coupling matrix between pixels P_1 and P_2. The expression of the general term contains a series of inner product between the modes of the macrostructure and the modes of the two pixels:

$$\left(C_{M1}^{M2}\right)_{pq} = \sum_n \Gamma_n \left\langle f_n g_p^{M_1} \right\rangle \left\langle g_q^{M_2} f_n \right\rangle \quad (3)$$

From this last expression, we can numerically calculate the coupling values.
The first simulations correspond to the convergence study of the coupling values versus the number of modes in the whole structure, because, from a numerical point of view, the series must be replaced by a finite sum. This first study allows us to determine the minimum number of modes in order to reach the convergence.
Then, we simulate the coupling matrix versus the value of k_0a (where k_0 is the wave number in vacuum). The coupling between two modes will be neglected if it is lesser than a tenth of the maximum coupling (i.e. a difference of 20dB). Simulations are realised for values of k_0a between 0.01 and 10. They show that the maximum coupling corresponds to the fundamental modes coupling. But when k_0a is greater than 5, the second maximum coupling is greater than a tenth of the fundamental modes coupling (see Fig. 2).

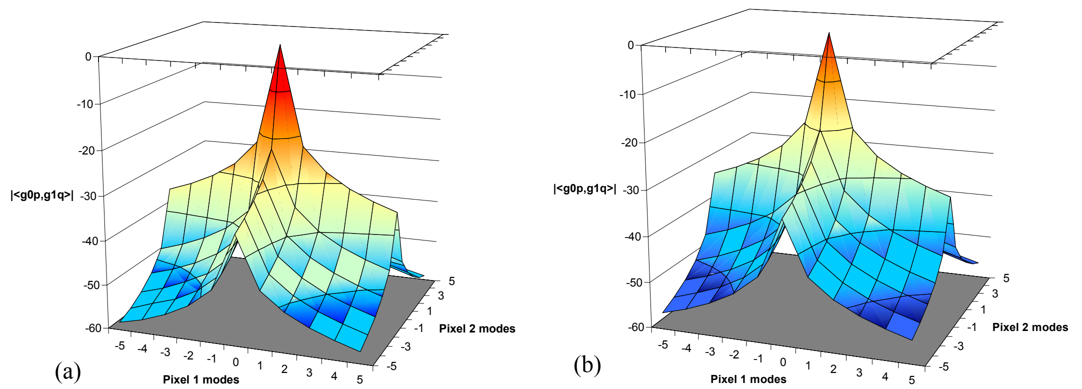

Fig. 2. Couplings between modes of two adjacent pixels for (a) k_0a=1 and (b) k_0a=5

In conclusion, this theoretical study allows us to justify the multiscale approach presented in the introduction (and which will be applied below) and to obtain its validity limit.

3 - CLASSICAL CIRCUIT STUDY BY THE "SUB-PIXELS" APPROACH

When a circuit is discretised with a grid too wide, it can be possible that some pixels cover metallic parts and dielectric parts. Instead of using a thinner grid, which would need more memory and calculation time, we replace those pixels with another grid in order to study them separately. Then, they will be replaced in the first grid via equivalent surface impedance. This approach has two main applications: the multiscale circuits and classical circuits. In the later case, it allows to use a larger grid in order to reduce the calculation time. The two circuits studied here are in the second kind of applications.

3-1 Stop-band filter with a stub

The first studied structure is very simple. Let us consider a microstrip line with a stub so as to reject one frequency. Its value is related to the stub length. So in order to have a good numerical prediction of the rejected frequency, it is necessary to use a grid that traduce the physical length of the stub. But, such a grid can imply large computation time. Another solution is to use a larger grid, so as to reduce the computation time, but the accuracy of the simulation decreases. So, we apply the "sub-pixels" approach. With this approach, the circuit can be described with a large grid, whereas the end of the stub is represented by sub-pixels.
For this circuit, we make three simulations: one with a grid of 32x32 pixels (and so the stub length is not well represented), one with a grid of 32x32 pixels with sub-pixels at the end of the stub and one with a grid of 64x64 pixels (in this case the grid can traduce the physical length of the stub). We notice that the grid of 32x32 pixels with sub-pixels give the same result for the rejected frequency value that the 64x64 pixels but with the computation time of a 32x32 pixels grid (cf. fig. 3).

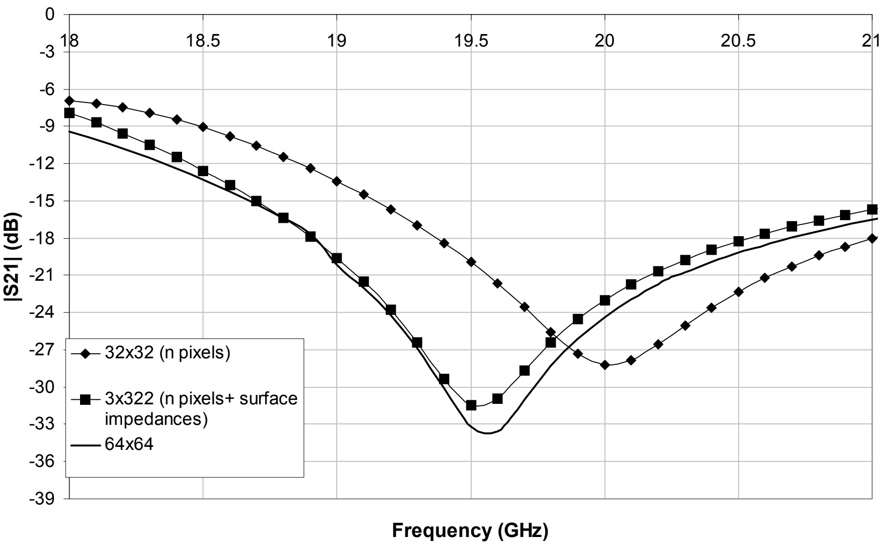

Fig. 3. Frequency response of a stop-band filter with a stub with and without a multiscale approach.

3-2 Rectangular patch antenna

In this second case, the problematic is similar to the previous case, that is to say the difficulty to precisely describe the length of the patch (see Fig.4) with a large grid. We investigated a patch antenna with a resonance frequency of 1.3GHz, printed on a substrate with a dielectric constant of 2.2 and a height of 0.5mm. Like in the paragraph 3-1, we choose a grid of 32x32 pixels with sub-pixels. The numerical results for the resonance frequency are compared with experimental ones and show a good agreement (cf. Fig.5). In this case and without a multiscale approach, the dimensions of the patch and the excitation line would imply a grid with at least 128x128 pixels. (In the example presented here the patch has stubs in order to have a good impedance match and so with a large grid it is very difficult to traduce numerically this geometry on the $|S_{11}|$. But with the multiscale approach, we can see on Fig.5., that, not only the frequency value is closed to measurement but also the $|S_{11}|$ at the resonance).

4 - CONCLUSION

In this abstract, we have presented the theoretical justification and two applications of a multiscale approach of microwave circuits. We have chosen to work with a recent iterative method for convenience. But, the same principle can be adapted to other numerical method. We have shown that this technique allows the reduction of the grid size (and so the computation time and the memory resources) with a good accuracy.

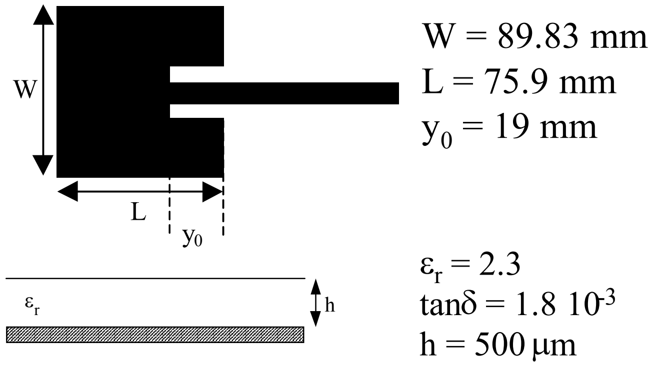

Fig. 4. Patch structure

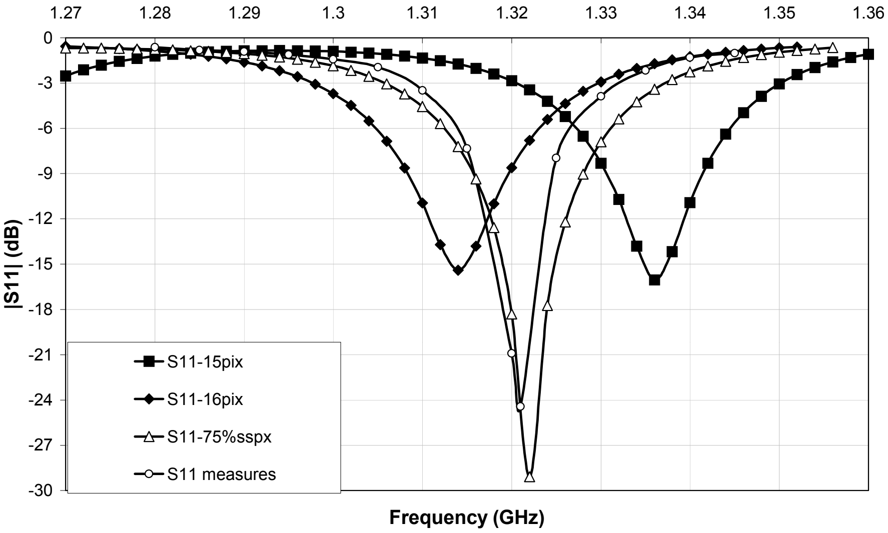

Fig. 5. $|S_{11}|$ of the patch antenna. Comparison between measured and simulated results.

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