

## **Design and technologies of 2D and 3D antennas from L band up to V band.**

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### **1. Introduction**

To day complex radiating structures need more accurate electromagnetic tools for either 2D or 3D planar or conformal printed antennas but also fast response if possible; in addition to the EM analysis, optimization procedures are also of great importance to choose properly the dimensions of antennas which are often defined with a large number of parameters (for sources first but also for arrays). Among the various available full wave methods (Integral equation, FDTD...) the FDTD is very powerful to analyze arbitrary shaped antennas even if the computer time is rather large. One way to reduce the computational time is to use large computers or to combine FDTD with simple models when it is possible. Simple ideas are also necessary as a first step for an array design with a shaped pattern ; Moreover to optimize these radiating structures the genetic algorithm is also well suited because it does not need any a priori knowledge of the behavior of the cost function.

As mentioned above the first problem is the computational time which can be large; different approaches have been considered to reduce this time for the designer:

- use of parallel computers
- use of derived simple models for the initial and short time designs with an acceptable accuracy.

The second aspect is the technology which has been developed for the various frequency bands and specially for the millimeter wave band or for the design of complex antenna shape (multilayer structures, 3D antennas...).

### **2. FDTD for 2D , 3D problems and arrays**

#### **2.1. Complex radiating structures**

FDTD codes are powerful tools which allow to analyze antennas of any shape, with several conducting surfaces and wires (multifunction antennas), dielectric substrates and coaxial probe, line or coupling feeding.

Complicated surfaces with large and small dimensions need small meshes for good precision ; but with the powerful calculations and parallel machines it is not a real problem.

It is easy to take into account the coupling between the different parts of a multifunction antenna fed by several generators [1].

#### **2.2. Connection with other time domain codes, or circuit models**

When many wires are associated to surfaces in a complex antenna, it is efficient to treat the wires using a time domain integral equations code and the surfaces using a FDTD code. The coupling between the two codes is made at each time step.

When an antenna is placed on a large support, a car for example, the FDTD code used to study the antenna is coupled with a GTD code in time domain to take into account the car, particularly at high frequencies, with no large computational memory and time.

Furthermore, antennas are sometime associated to linear or non linear circuit elements. As the FDTD code is in the time domain, it can, easily coupled to a circuit code like SPICE [2].

### 2.3. Arrays

It is not possible, today, to study with FDTD an array with many elements. A sub-array of no more than 4x4 elements can be analyzed by the FDTD code taking into account the line circuit feeding which is generally coupled to the elements. Then the communication between all the sub-arrays is analyzed by the classical circuit models [3].

### 2.4. Photonic bandgap material antennas

Recently a high gain (fig. 1), directive antenna has been designed using a PGB reflector. The FDTD has efficiently analyzed this antenna. The material is introduced in the code using a surface impedance model [4].

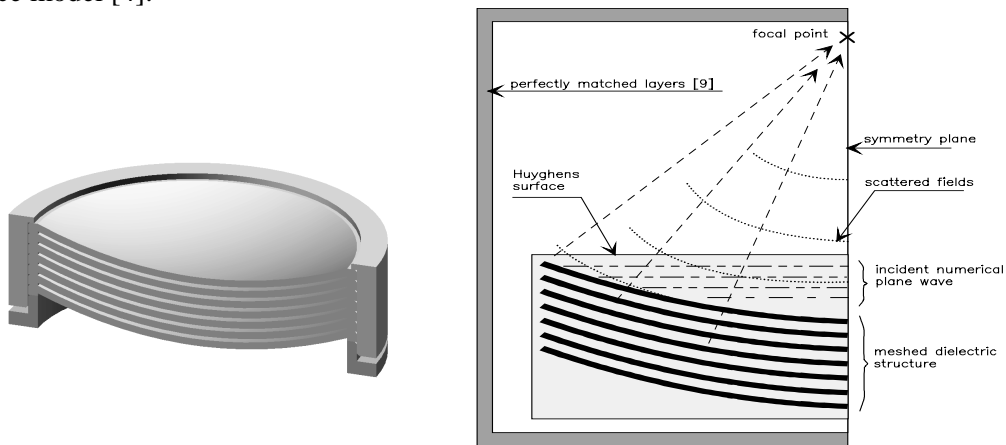


Figure 1 : PBG reflector composed of 7 dielectric dishes

## 3. Circuit models for various shapes and arrays

Electric circuit models are attractive because they can be easily implemented in circuit simulators for various shapes including the presence of electronics components, and also because they can be combined with optimization tools such as genetic algorithm which offers the possibility to synthesize and/or develop new structures taking into account many parameters during the optimization process. Various electric circuit models have been proposed during these last ten years for different kind of printed radiating structures (slots, dipoles, patches with various excitations and shapes,...) and some typical structures were developed using these models in combination with genetic algorithm. Some unexpected solutions were obtained through this process. Comparisons with experience and/or full wave results give a good idea on the accuracy and limits of this approach.

### 3.1. examples of models (transmission line and cavity model for various feeding)

All the analysis consider the antenna as an electric circuit (from initial physical considerations) where the radiation appears as extra losses added to the dielectric and metallic losses. For the transmission line model of dipoles and slots the radiation losses are “distributed” along the equivalent line through an  $\alpha$  attenuation coefficient which is calculated from the radiated power of analytically known distribution of currents (electric or magnetic) [5,6]. This method has been developed for both printed slots and dipoles of various shapes; some examples of monopoles will be presented in the conference.

For planar patches both transmission and cavity model have been used [7]. In this case the radiation effects are inserted either through localized resistance at the discontinuities positions (for the transmission model) or distributed and included in an equivalent  $\text{tg}\delta$  dielectric coefficient. Various patches structures have been tested.

The slot fed patch is an interesting example which have been widely studied and three examples of extended source have been designed: slot fed and slot loaded patch exhibit a two or three resonant frequency [8] while keeping a good matching, the electronic frequency tuning is obtained for a slot coupled patch loaded with varactors [9] and the slot fed patch with two steps change allows very significant size reduction while keeping a good matching too [10].

### **3.2. connection with optimization (genetic algorithm)**

Genetic Algorithms are well suited to solve the time-consuming combinatorial problems that arise in the electromagnetic analysis of geometries of "elementary" antennas. All the complex electromagnetic interaction between different parts of the antenna can be fully taken into account, although in many cases this still leads to problems that are difficult to handle.

Simplified theories or approximate models are used, which provide an acceptable accuracy without excessive requirements for memory and computation time. The solutions can then be refined using more sophisticated codes and optimization processes [11]. The problem of finding an optimal geometry of a printed antenna in order to satisfy simultaneously various criterias such as a matching condition (with or without the characteristic impedance reference), large bandwidth, low cross polarization, etc ... is three fold. First, the electromagnetic analysis should give accurate results for all characteristics such as impedances, patterns without needing a huge amount of computer time. The main reason for this demand is related to the genetic algorithm itself, which operates on a population (typically between 50 and 200 or more) and requires the computation of each element. The second aspect is related to the genetic algorithm and the definition of the fitness function, which should include different terms such as: the return loss, the isolation between two input ports for dual polarized antenna (in the whole frequency band, or at some points) and the radiation pattern (for the copolar and the crosspolar over the whole or partial angular domain). The third aspect concerns the number and the limits of variation of the different parameters, which correctly describe the structure. It is also interesting to mention that the solution (or the group of solutions) depends on the choice of the limits for the parameters.

## **4. Technology and applications**

The printed technology is very attractive since it gives some flexibility for the design of either flat or conformal array antennas and is competitive for low cost production. This is true from L band to V band although with specific technical problems occur at high frequencies such as small thickness of substrate and lack of rigidity with polymers. One of the main activity at the University of Rennes 1 with the assistance of some French research centre and SME (CNET- France Télécom, Avi & Peschard and Antennes Process), is the development and the characterisation of the new technologies based on the metal deposit technique on polymers and foams.

### **4.1 Polymers**

The metal deposit process concern the polypropylene and polymethyl-pentene [12] ( $\epsilon_r \approx 2.2$ ,  $\text{tg}\delta \approx 10^{-3}$  valid up to 60 GHz). In this case the fabrication process is a simple procedure. Two types of board are considered :

- double-sided printed circuit : Cu-polymer-Cu
- thick metal backing substrate : thick metal base (Al or Cu)-polymer-Cu

Polymers are manufactured by heating polypropylene and polymethyl-pentene granules or foil to the melting point ( $170^\circ$  for polypropylene and  $250^\circ$  for polymethyl-pentene) and pressing them.

It is important to note that this technique is compatible with the report of components (MMIC). Many interesting results from L-band to V-band have been obtained (integration of amplifiers, mixers...).

### **4.2 Foams**

It is still interesting to design and built 2D antennas. However 3D antennas appear as a new challenge especially if low cost is considered. The idea is to use foams in order to reduce the effect of surface waves ( $\epsilon_r \approx 1.2$ ,  $\text{tg}\delta \approx 10^{-3}$  valid up to 60 GHz) and the weight of antennas. The technology is based on the chemical deposit metal on the foam support, patented by the University of Rennes I in France [13].

First of all, the foam form is built mechanically or by milling (thermoforming can be done by heating foam in specific mould). Next, a thin layer of chemically deposit copper (or other metal) is applied, and after that, the desired full copper thickness is obtained by the electrolyses copper.

One of the most interesting point of this process, is the possibility to deposit graphite for waveguide matched load, and also, the possibility to built metallic holes.

Examples of very low cost and efficient planar or 3D antennas (V dipoles (fig. 2), slot-array waveguide antennas...) from L-band to K-band will be presented.

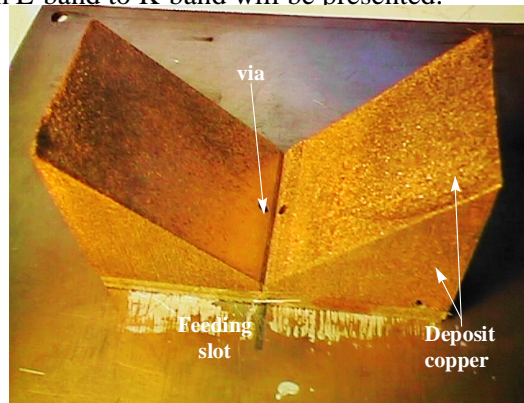


Figure 2 : V-dipole

## 5. Conclusions

This paper concern the analysis, optimization, design of different antennas and printed arrays architectures, from L-band to V-band. Two technological aspects for 2D and 3D antennas are developed. Several examples and applications will be discussed during the presentation.

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