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# **Electromagnetic theory, CAD and experimental approach, bases of an efficient education in microwave and RF techniques**

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« *Le savoir s'organise à partir de l'action* » . Piaget

## Abstract

This paper suggests some teaching approach and gives examples to make more efficient education in microwave and RF techniques and increase the interest of students in such courses.

## Introduction

This paper is based on a twenty five year education experience in microwave and antenna theory and practice. This experience took place between 1970 and 2001 in three different french universities :

1. The « University of Lille »
2. The « Ecole Nationale Supérieure des Télécommunications de Bretagne » in Brest
3. The « Ecole polytechnique de l'université de Nantes »

In the past few years, the evolution of education in microwave and RF techniques has been connected not only to the development of the available such as computer power and a associated software but also to the fast evolution of the technical and human needs in the world of microwaves and telecommunications. If microwave techniques were formerly used for quasi confidential applications, to days various sectors of industry use these techniques. The impressive development of mobile communication is one of the best example of this evolution.

This uncommon dynamism has required a quick evolution of teaching contents and methods. In this paper, after speaking of the microwave education which was generally used in France a few years ago, we will take some examples to illustrate how it is possible to more and more motivate students to choose a microwave and RF technique course in order to meet the growing needs of engineers in this sector activity.

### ***1. The course in microwave and RF techniques and its necessary evolution***

Several years ago and even now, the microwave engineer was specialized. One who developed active circuits did not study antennas or passive circuits. In all cases , electromagnetic theory constituted the basis of teaching and the mathematical approach was very important. Therefore, a lot of students, more interested in practical aspects did not choose to study microwaves as a specialization in electronic engineering.

Unfortunately, this physical reality was not easier to master than theory in the context of experimental benches which were difficult to mount and use. A long practice of the “slotted line” was necessary to be accepted in the restricted group of microwave experimenters.

Concerning circuit theory, formalism was not a problem : it was the natural continuation of low frequency circuit theory yet, this simple approach hid a lot of traps whereas the experimental approach a more precise vision of the reality.

Microwave power generation using semiconductor devices was just beginning with IMPATT and gunn diodes and one had to like solid-state physics to work in this area. As no reliable non-linear model existed, it was hazardous to develop microwave power amplifiers or oscillators.

As microwave teaching needs to associate mathematics and solid-state physics theory with high capacity in mechanics and experimentation, few candidates were interested in a course offering such

techniques. However, because the narrowness of the job market, such situation was not actually a problem. So the teaching could retain a « French touch » with « closed » exercises following lectures and experiments being implemented just to verify the main theoretical results.

With the development of general public radio applications, the situation is very different. The need for Microwave and RF designers is growing and the course and teaching must be suited to this new situation. As a large number of students have choose a speciality in which microwave and RF techniques are present, the effort must be made towards the motivation of the students. Moreover, given the complexity of the new systems, the microwave and RF engineer must be prepared to deal with MMICs, passive and active circuits, antennas, bearing in mind that each element can be coupled to the others (EMC). Also, the designer must have a good practice of base-band circuits and signal processing. This situation coinstitutes a new challenge for the teacher and we do not claim to give an exhaustive response to this problem. In this paper we just want to suggest some examples of teaching approaches which have given good results in the motivation and training of our students.

**2. Have a more physical and comprehensive approach of the propagation phenomena in order to appreciate the students'point of view better and lead them in to the necessary mathematical approach.**

If electromagnetics remains the basis of any technical development at very high frequencies, we can now use 3D electromagnetic commercial software such as HFSS or Microwave Studio or home software allowing the observation of fields and current scattering in complex devices. Thus, it is possible to show how a specific mode is propagated in a waveguide, how is diffracted by a discontinuity or how a guided wave is transformed into radiation. The materialization of these basic phenomena is a very strong lever in the understanding of propagation. It helps to convince the students of the necessity of a precise mathematical approach.

As many applications use planar or multilayered 3D technologies, we think that it is important for the student to understand the different influences of conducting planes and dielectric materials on the propagation conditions at specific fequencies. Roughly speaking, « low frequency conditions” as the existence of cut-off frequencies are related to the relative position of the conducting planes and dielectric materials imply wave propagation at higher frequencies. For a good understanding of such phenomena, very simple experiments can be mounted such as the study of non-homogeneous cross section rectangular waveguide. Figure 1 shows the basic idea.

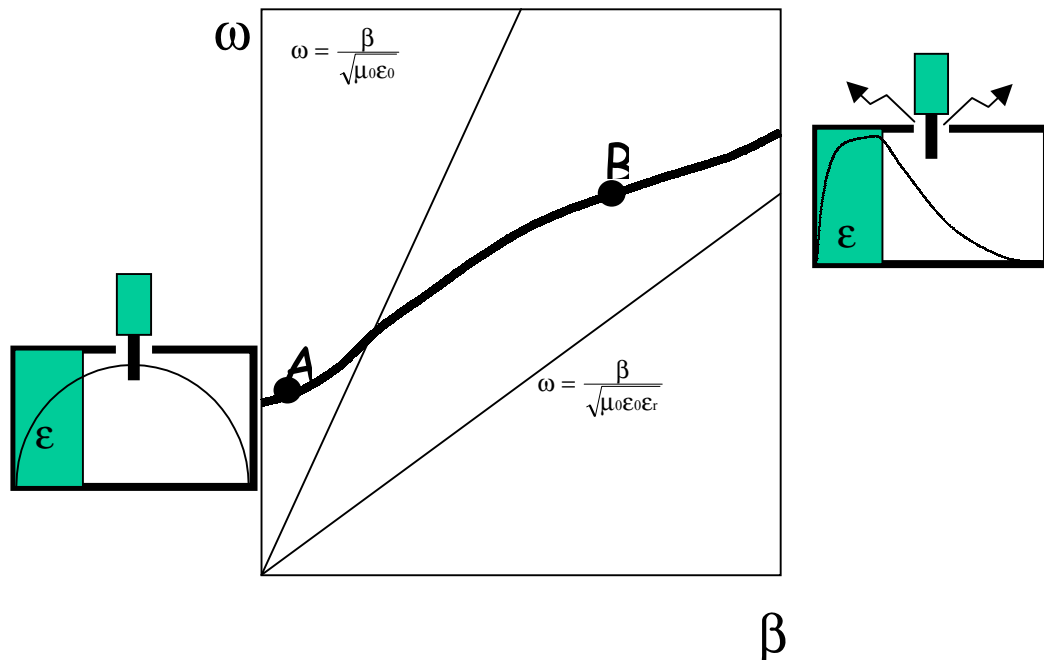


Figure 1 : Experimental study of non-homogeneous cross section rectangular waveguide

The slotted line, used for V.S.W.R or wavelength measurement, can also be used to set off the thinking of the students. For that, a dielectric slab is put along one of the vertical walls of the waveguide. Near, the cut-off frequency of the fundamental mode (point A), the scattering of the fields is slightly disturbed by the presence of the dielectric slab and it is easy to make a wavelength measurement to define the cut-off frequency for instance. When frequency is growing, the electromagnetic fields are concentrated in the dielectric material. It is more difficult to make measurements because of the weakness of the fields at the center of the guide and of the radiation of the slot (cf figure 1). By using home software it is possible to determine the field scattering and the  $\omega$ - $\beta$  diagram at each frequency at which the experiment is carried out and to explain all these odd phenomena. As the students must precisely explain their observations, they understand the concept of dispersion in waveguides more quickly. It is then easier to introduce dispersive models of planar waveguides as Getsinger model for the microstrip line or Cohn model for the microslot line, models which are used when millimetric hybrid integrated circuits are designed.

**3. Do not to make of microwaves a subject separated from electronics but rather show their common points and the differences.**

As the future microwave and RF engineers generally have a good knowledge of electronics and electrical engineering, we must use this basis to correctly understand the problems related to the concepts of lumped, quasi-lumped and distributed components. The study of microstrip low-pass filters gives us the possibility to illustrate these concepts simply and to show how it is possible to combine lumped elements and distributed elements in the same circuit in order to improve its performances. To implement this approach, we need a basic CAD software program such as PUFF (freeware by Caltech) and reasonably large circuits in order to modify them by using auto-adhesive copper sheets. The filter synthesis theory is generally well known by students and it is easy for them to determine all the elements (inductances and capacitances) of the filter when the template is fixed. A simulation of this lumped element filter is done by PUFF then, the inductances and capacitances are determined by using transmission line sections of respectively high and low characteristic impedance.

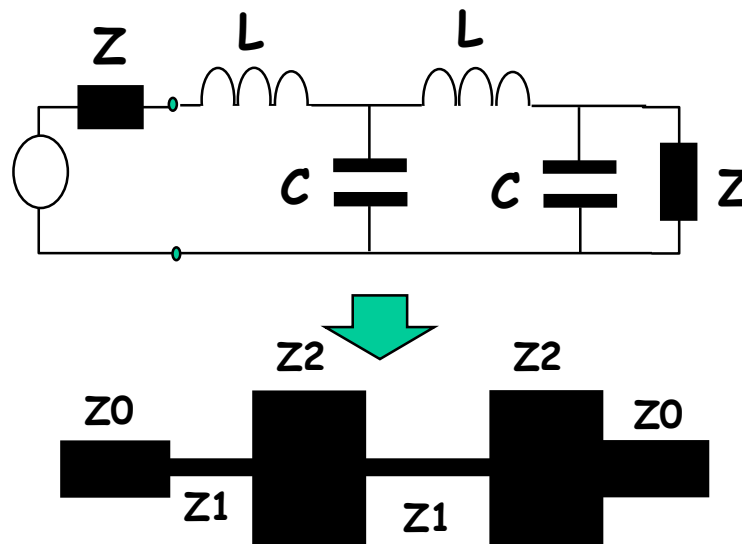


Figure 2 : Design of a low pass microstrip line filter

It is then easy to show what the main limitations of such an approach are by a very large frequency band simulation. It is also possible to introduce the effect of impedance discontinuities and to discuss the possibilities of correcting the length of the transmission line sections to obtain better results near the cut-off frequency. As the circuits are large, students can easily modify their dimensions and show that their hypotheses

are verified. This modus operandi generally arouses the students curiosity and increases their motivation. So, it is very interesting to develop this experimental approach to autonomy. We develop this aspect in the last example that we propose.

#### ***4. The practical discovery of autonomy can enhance the interest in theoretical lectures.***

To improve the efficiency of lectures it is necessary to arouse the interest of the students. One possibility among many is to propose lab. projects with a possibility of a delayed supervision by the teacher. To be efficient, such an approach must use very simple concepts and very simple elements. The discovery of microstrip antennas can be used as an example of such an approach.

Microstrip patch antennas are open resonators easy to build using auto-adhesive copper sheets. If we make a substrate with a coaxial feed line as presented in figure 3, the first experiment consists in search the matching point on the patch antenna. Making the hypothesis of a field scattering under the patch, it is relatively easy to determine its place. In a first step, the coaxial feeder is put on one of the two radiating discontinuities of the open resonator and the equivalent impedance is determined by using a network analyzer. Then, a second measurement is taken putting the coaxial feeder in the median plane, between the center and the end of the patch. The realistic hypothesis made on the field scattering allows to find the perfect matching point precisely and to verify this fact experimentally. So the gain, the efficiency and the radiating pattern can be experimentally determined and a simple model of the patch (like for instance the transmission line model) can be verified. Starting from this basis, it is possible to imagine a lot of variations : develop a wideband antenna using parasitic resonators on each side of the patch, develop dual band antenna by cutting slots into the auto-adhesive copper sheets etc... In these cases, the use of 2.5D electromagnetic CAD software can be introduced in order to compare the hypotheses made by students with the simulation. Such a comparison is very interesting to develop the physical awareness of the students.

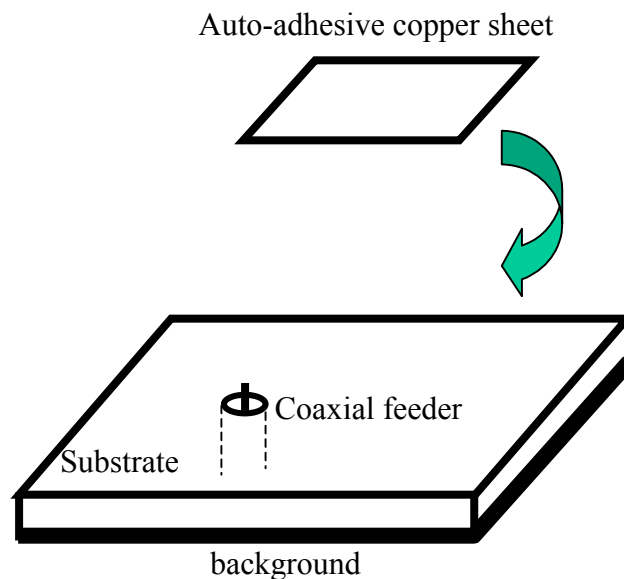


Figure 4 : The study of patch antennas

Another aspect of such an experience is in the necessity for the teacher to supervise the work of each student in order to synthesize the questions that crop up during this training in autonomy. In this respect, the practice of groupware can bring some interesting solutions. Then, in the following lecturers, the teacher can concentrate on the points presenting some difficulties for the students.

These teaching approaches have been used successfully in several cases . However, they do not constitute a panacea and we are interested in discussing other teaching experiences to develop student motivation and improve the efficiency of education in microwave and RF techniques.