TEACHING MICROSTRIP PATCH ANTENNAS TO UNDERGRADUATE STUDENTS

Custódio Peixeiro

Instituto Superior Técnico
Technical University of Lisbon
Av. Rovisco Pais 1, 1096 Lisboa Codex, Portugal

Abstract
A program on microstrip patch antennas which has been taught to the electrical engineering degree undergraduate students of the Technical University of Lisbon is presented. It covers analysis, design, fabrication and test. Course objectives, course content, software, experimental facilities and some evaluation projects are described.

1. Introduction

An optional advanced course in antennas has been offered to the fourth and fifth year students of the five-year electrical engineering degree at the Instituto Superior Técnico, Technical University of Lisbon. This course covers the main topics of aperture antennas theory, slots, horns, reflectors and microstrip patch antennas. The enrolling students have a good background in electromagnetics as they have to attend before compulsory basic courses in electromagnetic waves, antennas and microwave engineering. The course lasts for a whole semester of 15 weeks with 6 hours of lectures (theoretical, problem solving and laboratories) per week. The subject of the present paper, the teaching of microstrip patch antennas, takes about 36 hours which means a little bit more than a third of the whole advanced course on antennas.

2. Course Objectives

Microstrip patch antennas are probably the most rapidly developing topic of the antenna field in the last twenty years. Microstrip patch antennas have been used in many applications, mainly in telecommunications but also in other areas. The last push arrived with the mobile wireless communications revolution [1]. In the second generation mobile communication systems microstrip patches are mainly used in the base station antennas but in the near future they are expected to play an even more important role also in the handset mass product market.
The success of microstrip patch antennas is due to some well known advantages such as small size, lightweight, low profile, planar and conformal geometries, easy to integrate active elements, easy to fabricate, and low cost. However they also have some drawbacks, the most important being narrow band. Intensive research has been carried out to found solutions for this and other disadvantages, and to present new configurations.

0-7803-4478-2/98/$10.00 (c) 1998 IEEE

Therefore the topic of microstrip patch antennas is interesting for university people both from the research and teaching points of view. It is important to provide to the future generations of electrical engineers some basic knowledge of this new type of antennas. The most recent reference books on antennas [2-4] already include a chapter on microstip patch antennas.
The objectives of this course chapter is to provide general knowledge of the fundamental principles and concepts related with microstrip patch antennas and circuits. Analysis, design, fabrication and test are addressed. There is a strong emphasis on computer-aided design (CAD) techniques and "hands-on" laboratory work including fabrication and measurement. This approach is possible because few students enrol each year.

3. Course Content
The outline of the course chapter on microstrip antennas is given below.

1. Introduction
   1.1 Printed Structures
   1.2 Waves in Microstrip Structures
   1.3 Microstrip Transmission Lines
   1.4 Microstrip Patch Antenna Geometries
   1.5 Feeding Techniques
   1.6 Typical Characteristics
   1.7 Applications
   1.8 Examples
2. Methods of Analysis
   2.1 Radiation Mechanism
   2.2 The Transmission Line Model
   2.3 The Cavity Model
   2.4 Integral Equation Formulations
   2.5 Moment Method Solution of the Mixed Potential Integral Equation
   2.6 Green's Functions
3. Design Procedures
   3.1 Substrates
   3.2 Substrate Trade-Offs
   3.3 Simple Design Equations
   3.4 Techniques to Increase Bandwidth
   3.5 Circular Polarization
   3.6 Planar Arrays
   3.7 Design of Array Feeding Systems
4. Fabrication and Measurement Techniques
   4.1 Photolithography Printing Circuit Technology
   4.2 Tolerances
   4.3 Assembling
   4.4 Input Impedance Measurement
   4.5 Radiation Pattern Measurement

4. Laboratories

As stated above there is a strong emphasis on “hands-on” work both CAD techniques and laboratory practice on fabrication and measurement. CAD of planar microstrip patch antennas and transmission lines is based on the ENSEMBLE software tool [5]. ENSEMBLE uses a mixed potential integral equation rigorous formulation and the method of moments to analyse planar arbitrary shaped multilayer structures. A conventional photolithography printing circuit facility is used to fabricate the prototypes. Microwave and millimeter wave vector network analyzers are available to measure impedance and S matrix parameters. An anechoic chamber equipped with control and acquisition instrumentation is used to measure the far field radiation pattern. Absolute gain is calculated by comparison with calibrated horn antennas.

5. Evaluation Project Examples

As part of the evaluation procedure students are required to design, fabricate and test a microstrip patch antenna prototype fulfilling a set of realistic specifications. Last year C band has been chosen and the specifications emphasise some important features of microstrip patch antennas namely large bandwidth, dual frequency band and dual polarization behaviours, and circular polarization. The corresponding prototypes are shown in figure 1.

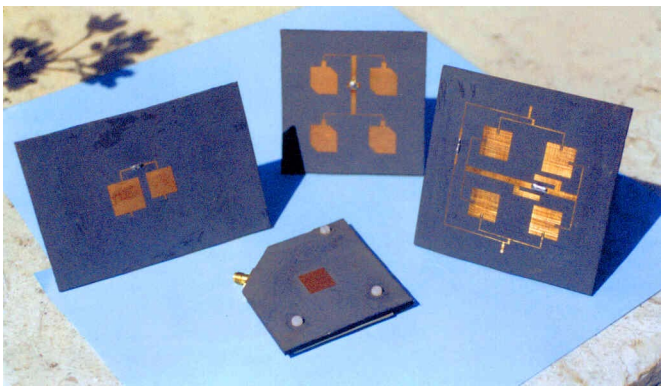

Figure 1: Photograph of the microstrip patch antenna prototypes.

As an example of the problems that the students can solve, the following main requirements were specified for an evaluation project.

- Frequency range: 5.8 - 6.2 GHz
- Input impedance: 50 Ohm with input return loss ≤ - 10 dB
- Gain: 12 dBi
- Vertical and horizontal planes half-power beamwidths: 45 degree
- Circular polarization
- Axial ratio: ≤ 3 dB
- Side-lobe level: ≤ -20 dB

To fulfil the specifications a student has designed, fabricated and tested the array prototype of four square patches with truncated corners shown in figure 1.

A good agreement between simulations and experimental results has been obtained. The main antenna characteristics are summarised in table 1.

	Frequency [GHz]		
	5.8	6.0	6.2
Input return loss [dB]	-16.7	-17.4	-19.6
Gain [dBi]	11.8	12.2	12.1
E plane half-power beamwidth [Degree]	46	46	42
H plane half-power beamwidth [Degree]	44	43	41
Broadside axial ratio [dB]	3.3	1.9	5.4
Side lobe level [dB]	-17.5	-15.3	-12.6

Table 1: Evaluation project experimental characteristics.

Input return loss, referred to 50 Ohm, was below - 10 dB in the frequency range 5.63-6.40 GHz. Except for the axial ratio at 6.2 GHz and the side-lobe level which was too optimistic all the other specifications were fulfilled.

6. Conclusions

Microstrip patch antennas is nowadays an important topic in the antenna field, therefore justifying its inclusion in the teaching programs even at undergraduate levels. The chapter on microstrip patch antennas which has been taught to the electrical engineering degree undergraduate students of the Technical University of Lisbon as part of an optional advanced course on antennas has been presented. It covers analysis, design, fabrication and test. There is a strong emphasis on computer-aided design techniques and "hands-on" laboratory work including fabrication and measurement. Course objectives, course content, software, experimental facilities and some evaluation projects have been described.

References

1. Sainati, R. A., *CAD of Microstrip Antennas for Wireless Applications*, Artech House, Boston, 1996.
2. Balanis, C. A., *Antenna Theory, Analysis and Design*, second edition, John Wiley & Sons, New York, 1997.
3. Drabowitch, S., A. Papiernik, H. Griffiths, J. Encinas, and B. L. Smith, *Modern Antennas*, Chapman & Hall, London, 1998.
4. Stutzman, W. L., and G. A. Thiele, *Antenna Theory and Design*, second edition, John Wiley & Sons, New York, 1998.
5. *ENSEMBLE, Design & Review User's Guide*, Version 4.0, Boulder Microwave Technologies, Inc., February 1996.