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Education in Antennas, Wave Propagation and Microwaves

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Professional paper

The paper is focused on teaching of »applied microwaves«. Attention is turned to antennas, but the same structure of education process is possible to apply for e.g. radio-wave propagation, microwaves, EMC, and other »electromagnetic topics« in their whole. The structure of the education is based on the appropriate amount of the theory followed by the computer simulations, the theoretical and engineering design and development, the measurement and final evaluation, which acts as the feedback between the initial goals and the final results. Important role of laboratory experiments based on flexible experimental set-ups is introduced and the possibility of distant (internet) laboratory excess is mentioned.

Key words: antennas, electromagnetic field, education, modeling, teaching

1 INTRODUCTION

Deeply and well understood theory of electromagnetic field opens the gates to the other branches of electrical engineering study. What the quality of education in electromagnetics at technical research universities should be? What and how many branches to teach, what level of information to give and what level and quality of outputs we want to achieve? These are the main questions especially for research universities, where the deep theoretical background is the basement (especially for master and doctoral study stage). In the beginning of »nineties« several authors published the articles dealing with the »new possibilities of teaching electromagnetics« [1–4]. They described the possibilities of computer simulation and visualization in the »Electromagnetics Curriculum«. That time, mostly the tools written by teachers were used and the possibilities of visualization were lower. Today, mostly the professional electromagnetic simulators are used to concentrate more to pedagogical aspects without the needs to prepare the tools.

Now, the structured – bachelor, master and doctoral studies – concentrate on the quantity of students in bachelor stage, mostly without the deeper demands on knowledge of mathematical and physical reality. On the other hand now is a chance to open the new horizons of understanding to »Maxwell equation« and what is »behind them« using the software visualization, new tools of CAD, numerical methods and optimization processes. Here is the chance to open mind of students in the really beginning of their study – in the electromagnetic field theory and later, to continue in balanced

process of education – in any branch where we want to specialize students. In this concept is still a chance to keep the high standard of technical research universities education. The good physical level of understanding to electromagnetic processes based on up-to-date simulation tools is necessary to follow by the stage of design and measurement – similarly in any specialized study branch. In this way it is not too important what subjects student takes, important is to teach him »the methodology«.

The process how to continue and build »on this knowledge« is mention here. The steps are described on the example of teaching experiences in antennas at the Department of Electromagnetic Field (DEF) of the Czech Technical University (CTU) in Prague [5]. Similarly, these methods are used there in microwaves, radio-wave propagation, EMC etc. The concept generally can be easily modified for any group of subjects. The main question is, of course, the cost of such education. But here is a key chance and role of collaboration with industry, research units and centers, to link the education with other partner universities and to keep the high standard and to be attractive for students to prepare them in flexible engineering way of understanding and thinking for their future professional carrier.

2 GENERALIZED STRUCTURE OF TEACHING PROCESS

Some of the temporary problems of technical university education in electromagnetics are:

- less contact hours for theory of electromagnetic field

- complicated theory for students – difficult to imagine what is behind the equations
- there is a gap between basic studies and subjects with »applied electromagnetics«
- the structured – bachelor, master and doctoral – studies concentrate to the quantity of students in bachelor stage, mostly without the deeper mathematical and physical knowledge.

The key questions should be:

- Do all the bachelor students need the deep background of electromagnetic field theory?
- What kind of information do they need?
- What method of teaching to use?
- How to compromise between theory and applications?

Such and many other questions we can ask. It is impossible to say that there is a simple final solution that gives the universal answer. We can discuss how to use the state-of-art of modeling of electromagnetic field to simplify the understanding of the nature of the electromagnetic field. This is not only the question of students of bachelor stage but the same pedagogical aspects we need for master as well as for doctoral students. Based on the good physical level of understanding of electromagnetic processes on up-to-date tools, we can explain complicated behavior of electromagnetic structures. In this way, we can give students good basement which is easier to remember comparing with a way of »equations and formulas«. In this way it is not too important the branch of study, important is the physical matter of phenomena.

Some parts of the study can also use electronic courses accessible via Internet. It is possible to take them easy from home, but on the other hand, the information we get in this way is only »standard« and the active discussion and efficient feedback with experienced teacher are missing. It is necessary to keep the balance, not only create interesting animations, but to explain them too, describe very carefully what everything can be seen from them.

The process of education of »applied electromagnetics« is based on the mutually balanced structure consisted from four steps with the final goal to improve the understanding of the physical matter of electromagnetic phenomena. The structured and balanced process consists of:

- A. theory, basic equations, philosophy of the mathematical description
- B. modeling, computer simulations using different software tools (professional and/or written by students)
- C. engineering design and development, CAD
- D. measurement and evaluation.

Each of these steps has a local feedback loop between the local results and previous goals as well as the final evaluation which really waited the optimum in the whole complexity including not only electrical parameters but also the material science, economy, fabrication and final cost.

3 EDUCATION IN ANTENNAS – EXAMPLE OF METHODOLOGY

The education in antennas (as well as in other branches mentioned above) is structured in two parts. The first is a concept of antenna »background«. It includes several well structured items:

- guided and radiated waves, general concept of radiation, superposition, reciprocity, duality etc., and basic antenna parameters
- concept of individual sources
 - ▶ radiation of wire structures
 - ▶ radiation of apertures
- concept of arrays
- measurement and evaluation.

Then, in the second part, the more engineering attitude is applied. This is concentrated more on application and practice, but still keeping the theoretical background. Explanation of antenna theory is supported by calculations of distribution of radiating elements (e.g. elements of current) and then using basic antenna parameters. It is important that students at first are able to calculate the current distribution using their own written programs (e.g. based on any software tool background, e.g. MathCad, Maple, MathLab etc.) and then to compare their results with the analytical ones (if possible to use them) as well as with the result of the professional simulation software. Students are able to believe much more in their own abilities, and later they use professional software tools more carefully. Then, they do not overestimate the possibilities of software tools, and they are able to find the best criteria for optimization techniques of the design.

It is necessary to create a very good description including many details. Experienced teachers' comments are necessary, analytical descriptions and their solutions are options used depending on the level and position of the subject in frame of the study. On the level of »basic study« mostly »ready made« examples are used. Independent projects of students are used in the followed »specialized« subjects.

3.1 Theory

The good »old fashion« standard of the theory is used e.g. [6] together with modernly written books [7]. Attention is devoted to those things,

which are usually hidden for students in textbooks, e.g. to principles and questions like:

- behavior of any object from a point of view of electromagnetism is only the question of distribution of electromagnetic sources (currents, charges) given by:
 - ▶ object geometry (shape, volume)
 - ▶ material parameters (complex permittivity, permeability) of the object and surrounding media
- radiation pattern is a complex question of amplitude, phase, and polarization properties
- there is always relationship between an impedance and radiation characteristic of the antenna.

3.2 Software tools, CAD, and modeling

Any mathematical software, where students are »familiar with« can be used. Students prepare step by step a parametric calculation of current distribution e.g. for linear wire antenna using method of moments to study the results of wire of different

length, thickness, shape etc. They can see, that they are able obtain good results with quite simple process. Then students can use professional software tools for modeling of more complicated structures. They see that the complexity is only the problem of shape and feeding position. This process is very efficient and student have chance to understand more to the numerical results compare with the case where directly the »ready made« software tools and calculations are used.

Simple examples, starting e.g. from monopole resonant frequency, array factor of simple patch array [8], to more sophisticated relations as improved transmission line model of the patch antenna [9] has been implemented to demonstrate basic antenna properties.

Software for 3D modeling of array radiation pattern has been developed to show the influence of spatial and source (amplitude, phase) distribution.

Figures 1a, 1b, 1c, 1d show the radiation and final design of the Yagi-Uda antenna structure.



Fig. 1a Yagi-Uda antenna – surface current. in time domain (animation)

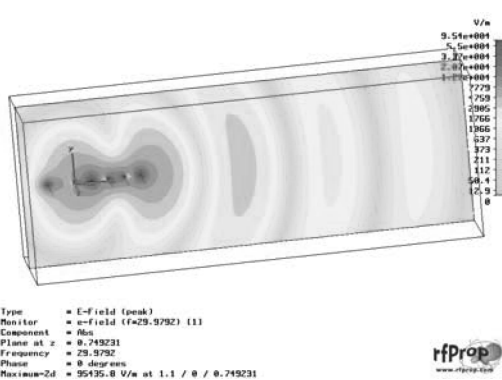


Fig.1b Yagi-Uda antenna – mechanism of radiation (animation)

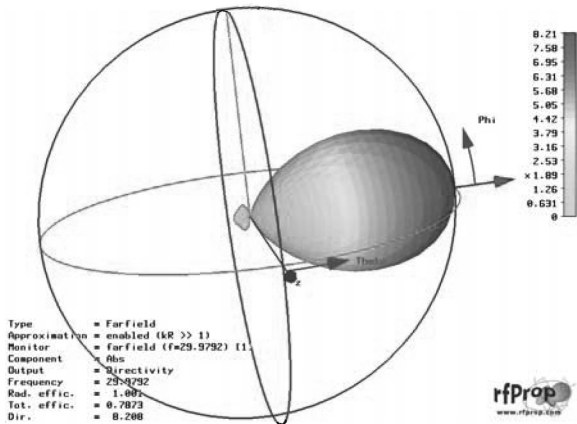


Fig.1c Radiation pattern of the Yagi-Uda structure

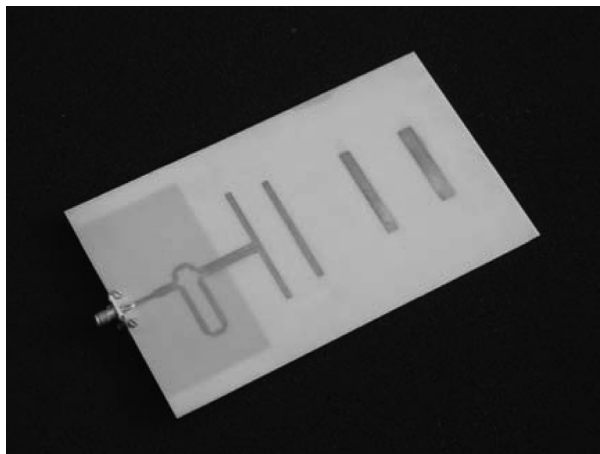


Fig. 1d Design planar structure of the Yagi-Uda antenna

Functions of elements above the resonance (inductive = reflectors) and below the resonance (capacitive = directors) are explained. The analysis of the current distribution shows the dynamic function and mutual coupling between elements (active as well as passive). Directive behavior of such structure is shown.

Radiation and diffraction, reflections, sources of radiation (primary as well as secondary), results from the full wave analysis and the geometric optics and their differences can be explained from Figures 2a, 2b. Different phase velocity with the distance from the radiating element can be seen from the animations.

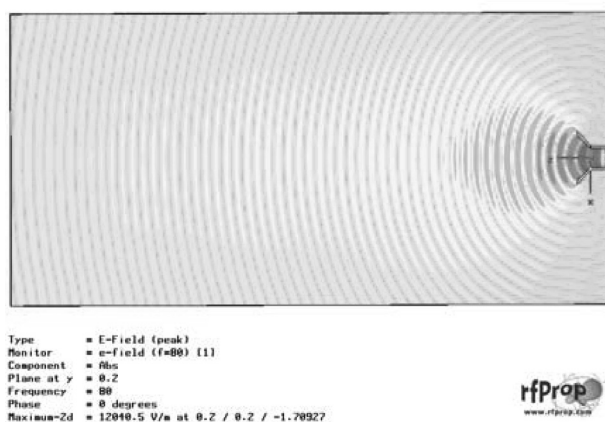


Fig. 2a Radiation of the horn antenna into a free space

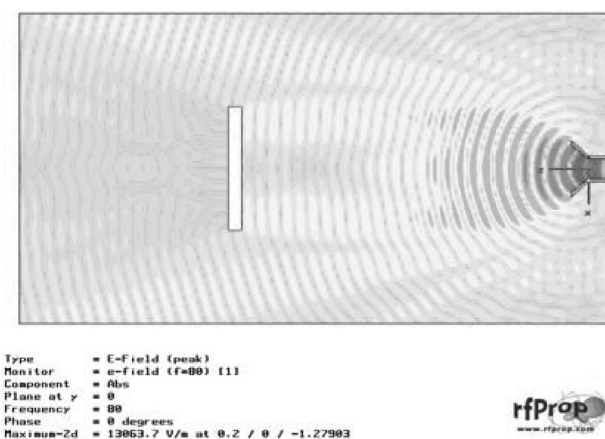


Fig. 2b Diffraction on the metallic obstacle (animation)

3.3 Design, development, fabrication

The problem of an antenna design is generally much more coupled with other engineering branches – students need to choose the materials not only from a point of view of its electrical parameters

but they have to choose it from a point of view of mechanical and environmental properties as well. The other thing is to compare different ways of design from a point of view of economy (reproducibility, needs of individual tuning etc.) and, of course, from a point of view of its final cost. Chosen quality of fabrication depends on the complexity of construction and final needs. Some of the planar structures are processed by quite simple laser (photo-plotter) and etching technology up to 20/30 GHz directly at the DEF.

3.4 Measurement, evaluation, feedback

To keep the balance between theoretical and design parts of the education, the measurement with samples designed and directly fabricated or ready made modular antenna prototypes is used. Such an approach has been chosen to support the education process in playful form. Most of the measurement is performed in the antenna anechoic chamber (Figure 3) of DEF CTU in Prague which enables the limited far field as well as compact range (CATR) and near field (planar scanner) methods of measurement. Student have a chance to measure radiation pattern and the other parameters of the same antenna using different methods and then to compare them. Of course, such antenna measurements are expensive because of the cost of the lab and all the equipment and small amount of students who

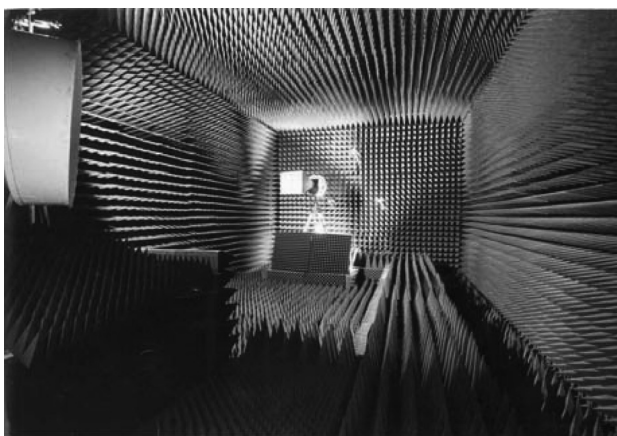


Fig. 3 Antenna anechoic chamber of Department of Electromagnetic Field CTU in Prague

can experimentally work together. Therefore also an internet set of tasks with active distant access to the laboratory measurement was prepared as a pilot pedagogical project (LabLink) [10].

System of experimental set up antennas has been designed and realized to enable fast and simple modification between individual spatial and electrical configurations of prototypes during time limited

measurement. Resulting changes in impedance and radiation properties of antennas are measured and evaluated by students in relation with theory (analytical approach) and simulation (numerical approach) of radiating sources distribution.

Laboratory tasks have been prepared. The guidelines for measurement is necessary prepare very carefully with many comments to give students chance to broad their horizons and to grow their flexibility and creativity – to give them a possibility to rearrange the measurement, to think what and how to measure and to describe the results and give final solution for changes of design etc.

Modular structure of basic types of antennas to create the experimental set-up to demonstrate influences of individual parameters of the structure was used. Different modular antenna prototypes – e.g. wire monopole, microstrip patch, simple four elements patch array and more sophisticated electronically controlled phased array has been designed and realized to provide fast and simple modification between individual geometrical and electrical configurations. For each parameter which is measured, the theoretical part, basic description and computer simulations were prepared too.

4 MODULAR ANTENNA PROTOTYPES

Several modular antenna prototypes were prepared to demonstrate the basic properties of radiating structures.

4.1 Wire monopole antenna

Wire monopole prototype (Figure 4) has been designed to demonstrate frequency detuning depending on monopole length and capacitive disk loading at the top of the monopole. Further impedance mismatch can be seen with decreasing

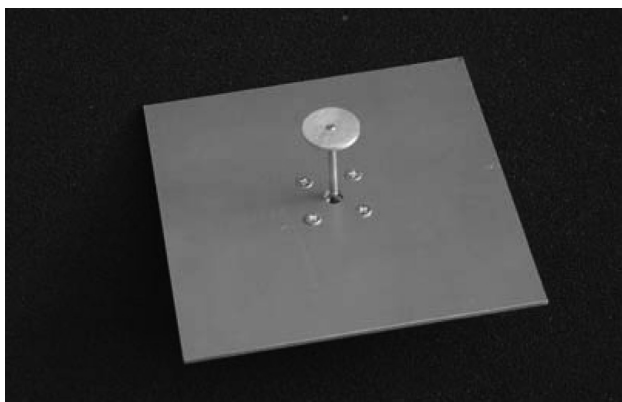


Fig. 4 Modular monopole wire antenna with capacitive disk loading

of ground plane size. Antenna prototype consists of ground plane (two elements of different size: 125 mm × 125 mm and 250 mm × 250 mm, what is approx. λ_0 at 2.4 GHz and 1.2 GHz), three wire monopoles with different lengths (30 mm, 100 mm, and 150 mm) and three capacitive disks with different diameters (20 mm, 50 mm, and 100 mm). Changing of electrical length either by the length of λ_0 monopoles or by different capacitive disks results in frequency detuning and can be demonstrated with above mentioned components.

4.2 Patch antenna

Microstrip patch radiator has been designed to demonstrate frequency detuning depending on patch size, changes of impedance bandwidth depending on the height of patch over ground plane, and impedance matching depending on the proper feed point position. Patch prototype consists of two different patches ($\lambda_0/2$ resonance approx. at 1.8 GHz and 2.4 GHz), ground plane (for comparison the same as in the case of monopole wire antenna) and feed probes with different size (from 5 mm to 34 mm, it is approx. from $0.03 \lambda_0$ to $0.2 \lambda_0$ at 1.8 GHz). Each patch radiator has possibility to change feed location using several holes for fixing the probe using screw (see Figure 5).

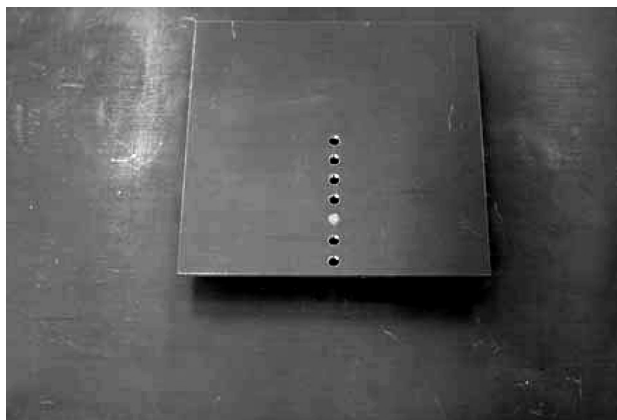


Fig. 5 Microstrip patch radiator setup

4.3 Patch array antenna

Patch array for 1.8 GHz band has been designed to demonstrate basic properties of antenna array factor (the same type of elements are used). Array enables to change element separation (from 0.6 to $1.0 \lambda_0$ with $0.1 \lambda_0$ step), and feeding current distribution in amplitude (uniform 1-1-1-1 and nearly optimal 1-1.7-1.7-1) and phase. (Figures 6 a, b.) The array consists of four patches, two types of power dividers, set of coaxial cables of different length (for different phase shift) and mechanical mounting for element and power divider handling.



Fig. 6.a Patch array antenna – top view and all setup

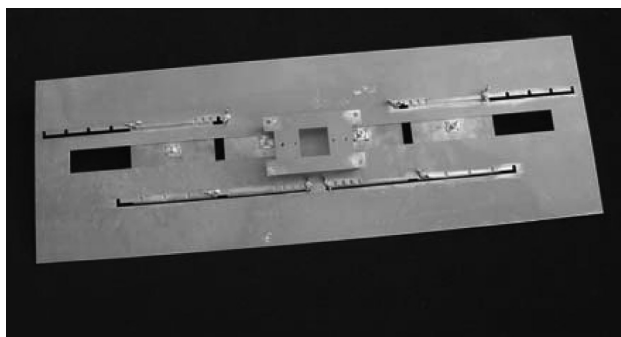


Fig. 6.b Patch array antenna – bottom (feeding part)

4.4 Phased antenna array

Electronically controlled phased four element array is designed as multifunctional prototype that is able to demonstrate the influence of current amplitude and phase distribution (changes), element separation (achieved by frequency change of equidistantly placed elements) and element type on the array properties. The prototypes consist of synthesized generator, board with feed network and quadrature modulators (Analog Device AD8346 working in the frequency band 0.8–2.5 GHz) for amplitude and phase shifting and different removable radiators (monopole, spiral and patch).

5 CONCLUSIONS

Up-to-date attitude to the teaching of electromagnetics used at the Department of Electromagnetic Field, Czech Technical University in Prague was described.

The general structure of a theoretically and experimentally balanced education (theory, modeling, design, measurement, evaluation) was introduced on the example of teaching antennas. Such courses are used in all different levels of structured study and in different subjects, including microwaves, EMC, radiowave propagation etc. The courses and especially the animations are attractive for students. On the other hand such attitude is always a question of teaching economy due to the time consuming measurement compare to the mass courses based only on software tools and modeling.

6 ACKNOWLEDGEMENT

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REFERENCES

- [1] X. Cui, J. Wang, H. Shao, **The Teaching of Numerical Techniques in Computational Electromagnetics**. IEEE Transaction on Education, Vol. 36, No. 2, pp. 261–265, May 1993.
- [2] L. Broschat, J. B. Schneider, F. D. Hastings, M. W. Steeds, **Interactive Software for Undergraduate Electromagnetics**. IEEE Transaction on Education, Vol. 36, No. 1, pp. 123–126, February 1993.
- [3] A. A. Read, **Computers and Computer Graphics in the Teaching of Field Phenomena**. IEEE Transaction on Education, Vol. 33, No. 1, pp. 95–103, February 1990.
- [4] J. R. Whinnery, **The Teaching of Electromagnetics**. IEEE Transaction on Education, Vol. 33, No. 1, pp. 3–7, February 1990.
- [5] ..., www.elmag.org, www.rfspin.com, Department of electrical engineering, CTU Prague, accessed 10 July 2006.
- [6] J. D. Kraus, **Antennas**. McGraw-Hill, Inc. Boston 1988.
- [7] C. A. Balanis, **Antenna Theory**. John Wiley & Sons Inc., New York, 1997.
- [8] ..., http://www.elmag.org/k317/projekty/frvs_rada/index.html, 5th May, 2005.
- [9] ..., http://www.elmag.org/k317/projekty/frvs_anteny/index.html, 5th May, 2005.
- [10] M. Mazanek, R. Catthoor, **Lablink Pilot Project**. Proc. IEEE symposium on EMC, Istanbul 2003.
- [11] P. Valtr, P. Pechac, **Diffraction Calculations and Measurements in Millimeter Frequency Band**. Radioengineering. 2004, Vol. 13, No. 3, p. 18–21. ISSN 1210-2512.
- [12] P. Pechac, **Electromagnetic Wave Propagation Modeling Using the ANT Colony Optimization Algorithm**. Radioengineering. 2002, Vol. 11, No. 3, p. 1–6. ISSN 1210-2512.
- [13] ..., www.antennasvce.org

Obrazovanje na području antena, rasprostiranja valova i mikrovalova. Rad je usredotočen na učenje »primijenjenih mikrovalova«. Pozornost je okrenuta antenama, ali se ista struktura obrazovnog procesa može primijeniti na rasprostiranje radijskih valova, mikrovalove, elektromagnetsku kompatibilnost i druge elektromagnetske sadržaje. Struktura obrazovanja osniva se na odgovarajućoj teoriji popraćenoj simulacijama na računalu, teorijskom i inženjerskim proračunima i razvoju, mjerenjima i konačnoj provjeri, koja djeluje kao povratna veza između početnih ciljeva i konačnih rezultata. Utvrđena je važna uloga laboratorijskih eksperimenata temeljenih na fleksibilnim eksperimentalnim modelima i spomenuta mogućnost učenja na daljinu.

Ključne riječi: antene, elektromagnetsko polje, obrazovanje, modeliranje, učenje

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