COMPUTER-BASED ANTENNA EDUCATION AT THE TECHNOLOGICAL EDUCATIONAL INSTITUTE OF CRETE

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ABSTRACT
In the past most electronic engineering students tended to have repulsion against subjects related to microwaves, electromagnetics and antennas, especially due to their abstract, theoretically demanding, and complex mathematics requiring nature. This paper contains a representative sample of the authors' efforts to keep students' interest at electromagnetic subjects high and to have several students specialized in such topics. At the Microwave Communications and Electromagnetic Applications Lab of the Technological Educational Institute of Crete (TEI-C) we have developed several computer-based exercises and virtual experiments to accompany all lectures and complement most laboratory exercises, respectively. Various computer tools, and especially Mathematica, have been used in order to improve electromagnetic and antenna teaching. As a result, the teaching-learning process in TEI-C has been highly upgraded and since 2000-01 students interact with the theory and they are more interested in these courses accomplishing better grades.

KEYWORDS
Antennas, electromagnetics, antenna education, microwave education, RF education, engineering education, simulation, training, multimedia, degrees, classroom methods

INTRODUCTION

Electromagnetism is a major branch of physics, describing one of the four known fundamental interactions in nature and permeating a vast variety of both theoretical and applied sciences (Georgieva and Tam, 2003). Related subjects, such as integrated circuit design, engineering electromagnetics, microwave theory and techniques, and antenna design and measurements, are of outmost importance to the modern world, as they have profound applications in electrical and electronic technologies.

As Sevgi (2003) states, electromagnetic waves play an increasingly important role in wireless communications, cellular telephony, wireless local- and personal-area networks, remote sensing, radar technology, multi-sensor integrated systems' detection and identification, microwave hardware design, bio-electromagnetics, electromagnetic compatibility, as well as in many other applications at complex natural or man-made environments. Thus electromagnetics, being the foundation of many different branches of engineering sciences and technologies, deserves a special place in synchronous electrical, electronic, and computer engineering education (Chew, 2001).

The end of the cold war era, the globalisation of industry, and the rapid emergence of wireless communications in all aspects of today's society have provided a renewed prominent role to microwave and RF sciences and technologies (Gupta, Itoh and Oliner, 2002). Microwaves and RF are no longer crucial primarily for military systems, but are also playing a very significant role in the current climax of wireless communication systems. So today, as Gupta (2000) clearly states, electromagnetics education is facing new challenges and is ready for a major shift, because of the rapid technological changes unleashed by the evolution in wireless communications and Internet technology.

Taflove (2002) concluded that the study of electromagnetics is fundamental to the advancement of electrical and computer engineering technology as we continue to push the envelope of the ultra-complex and the ultra-fast. Indeed, recent trends in the design of military and commercial electrical and electronic systems rely more heavily upon electromagnetics. More strict requirements in military defence, high-speed communications, ultra-high-speed computing, and advanced biomedicine, as well as improved performance demanded by higher frequencies, faster clock speeds, and increased circuit density, have significantly motivated the modern undergraduate study of electromagnetics (Menzel, 2003; Vardiambasis, Makris and Petrakis, 2003).

However, since most students dislike topics that are abstract, complicated theory demanding, and complex mathematics requiring, a change in the traditional presentation of antennas' and microwaves' topics is necessary to strengthen students' physical insight at electromagnetic waves behaviour and interaction with devices and systems.

ELECTROMAGNETICS AND ANTENNA EDUCATION AT TEI-C

The Technological Educational Institute of Crete, Greece (TEI-C), as any other university, is considered to have three major objectives, i.e., the education of students, the generation and assignment of competent young engineers to industries, and the evolvement of basic and applied research. Combining these roles, TEI-C's Microwave Communications and Electromagnetic Applications (MCEMA) Laboratory has comprehensive modern facilities for teaching and research activities in theoretical and computational electromagnetics, antenna analysis and design, microwave theory and applications, advanced communication and radar systems, and electromagnetic compatibility issues.

In this paper we will concentrate upon the antenna and wireless communications engineering education at TEI-C's Department of Electronics. Its Division of Telecommunications covers the area of electromagnetics, microwaves, and antennas. TEI-C's undergraduate curriculum in electronics includes: a) one introductory course in electromagnetic theory and applications, called "Applied Electromagnetism", at the second-year level, b) four additional telecommunications-specialty courses in transmission lines, waveguides, microwaves, antennas, radiolinks, electromagnetic wave propagation, radars, and satellite communications, called "Antennas and Electromagnetic Wave Propagation", "Radars and Radio Accessories", "Microwaves and Applications", and "Mobile and Satellite Communications", at the third- and fourth-year level, and c) six advanced elective courses in antenna arrays, signal processing, RF and wireless technologies, electronic warfare systems, electromagnetic compatibility, and computational electromagnetics, called "Smart Antennas and Wireless Communications", "Electromagnetic Compatibility", "Measurements of Electromagnetic Fields", "Computational Electromagnetics", "Microwave and Satellite Technologies", and "Scattering, Propagation and Radiation of Electromagnetic Waves". All these courses are fully supported by the MCEMA Lab, with many lab exercises and experiments using antennas, microwave benches, and computer simulations, while most of the lectures are supported mainly by text books written by the corresponding professors, and also by a number of well-recognized international books.

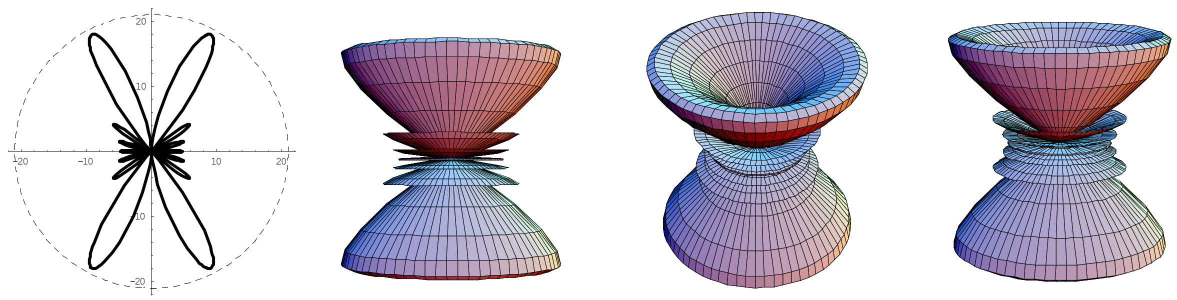
In the past many students tended to have repulsion against subjects related to microwaves, electromagnetics and antennas, especially due to their abstract, theoretically demanding, and complex mathematics requiring nature, but also due to the increased interest in informatics. Students were facing major difficulties, especially when teaching was taking place with oral explanations, static-chalk drawings on the blackboard and simple experimental presentations. But as Staecker (2002) asserts, the outlook for the microwave industry is rich with opportunity, but *the skill set of the entry-level practising microwave engineer is woefully lacking and being neglected by both academia and industry. In the field of microwaves, what took weeks of analysis 10-15 years ago is available by a keyboard click today. The obvious caveat is that it must be an informed keyboard click.* To ensure this, we highly motivate our students by the modern methods of computational electromagnetics we have used and the computer simulation tools we have implemented. These complement traditional theory and laboratory material, in order to have substantial improvement of the teaching-learning process and strong and continuous interest in all electromagnetic courses.

Various computer tools (Mathematica, Maple, Mathcad, Java, Matlab, Mefisto, VRML) have been used by many universities and authors in order to improve electromagnetic teaching. Of all these tools, Mathematica has been chosen to develop several computer-based exercises and experiments (Vardiambasis, 2004; Vardiambasis, 2005) at our MCEMA Lab. This paper reports on the authors' efforts to support antenna education and teaching in TEI-C by virtual laboratories and simulation exercises and animations. The introduction of interactive computer tools has enhanced the students' ability to conceive basic antenna principles by visualizing 2D and 3D antenna radiation patterns, resulting in an enthusiastic student feedback about electromagnetic field topics.

ANTENNA ANALYSIS SIMULATIONS

This section contains a representative sample of the authors' efforts to solve, visualise, and animate antenna radiation problems by computer programs developed in Mathematica. Nowadays classroom activities in TEI-C include the use of a powerful PC running the appropriate interactive simulation programs and projecting the rich output graphics on a screen along with the respective explanations, in order to accompany the standard theory lectures presented on the blackboard.

As linear wire antennas are some of the oldest, simplest, cheapest, and most versatile radiating elements for many applications, our first antenna simulation, which is based upon equation (4-64) of (Balanis, 1997), refers to far-field radiation characteristics of thin dipoles with arbitrary length L and sinusoidal current distribution.



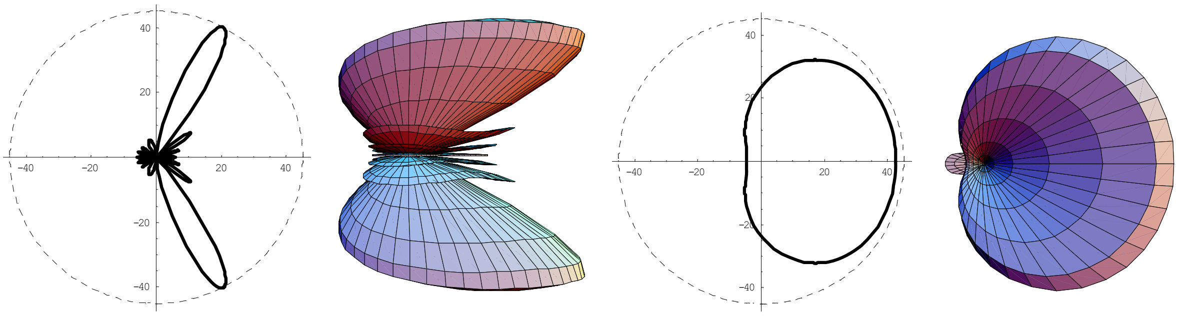
(a) (b) (c) (d)

Figure 1. 2D and 3D radiation patterns for a thin dipole of length L=3.5λ, placed along z-axis in free space. (a) Elevation plane (θ) pattern for φ=0, (b) the corresponding 3D pattern, (c)-(d) 3D patterns from different viewpoints.

As the dipole's length increases, the beam becomes narrower, while the directivity and the number of lobes increase. In case of a single dipole (centre-fed by I_1) radiating in an unbounded medium, the radiation pattern is omni-directional in the horizontal plane, as shown in Figure 1. This behaviour can be strongly affected by the placement of a second thin dipole (centre-fed by I_2) parallel to and in the vicinity of the first.

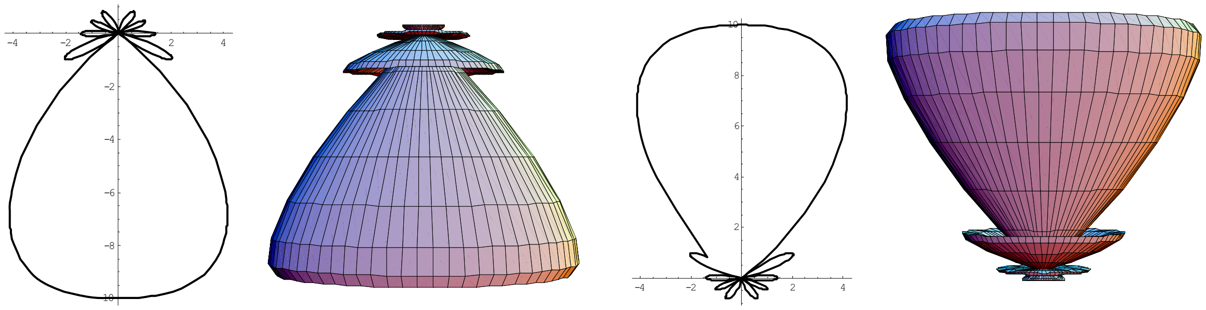
As Figure 2 reveals, the presence of an obstacle, especially when it is near the radiating element, can significantly alter the overall radiation properties of any antenna system. Visualizing radiation patterns, while the position, the length, the currents, and/or the dipole distance are changed, provides to students comprehension of electromagnetic wave propagation and interaction with the environment.

However specific radiation pattern requirements, especially in long distance communications, usually cannot be achieved by single antenna elements due to their low directivity values. New antenna systems, called arrays, are formed as assemblies of radiating elements in various electrical and geometrical configurations. Arrays are the most versatile antennas, since they can synthesize any desired radiation pattern or scan electronically any region with their main lobe. The simplest and most practical arrays are formed by placing the N elements along a line. Such an array of identical elements with excitation currents of identical magnitude and a β progressive phase, is referred to as a uniform linear array with array factor given by equation (6-10) of (Balanis, 1997). This simulation illustrates in Figure 3 the array factor and the far-field radiation patterns of an end-fire array with 10 dipoles of uniform amplitude and λ/2 length.



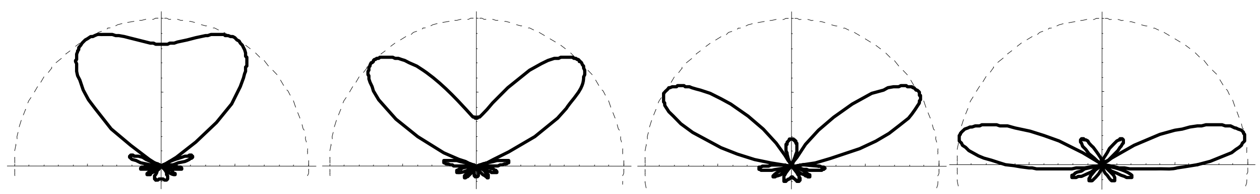
(a) (b) (c) (d)

Figure 2. 2D and 3D radiation patterns for a couple of parallel thin dipoles of length L=3.5λ, placed along z-axis in free space with distance d=0.5λ. (a) Elevation plane (θ) pattern for φ=0, and (b) the corresponding 3D-pattern, (c) Horizontal plane (φ) pattern for θ=π/6, and (d) the corresponding 3D-pattern.



(a) (b) (c) (d)

Figure 3. Array factor and 3D radiation patterns of an N-element uniform amplitude *end-fire* linear array of λ/2 dipoles parallel to and positioned along the z-axis, with N=10, d=λ/4, and (a)-(b) β= kd. (c)-(d) β= -kd.

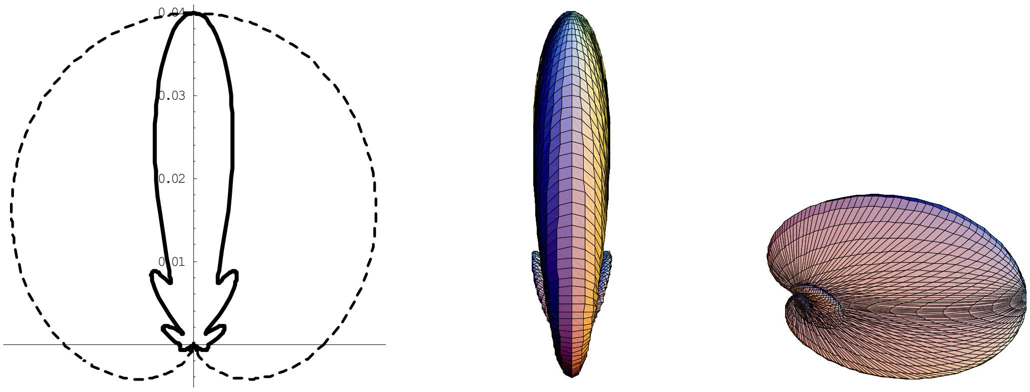


(a) (b) (c) (d)

Figure 4. Array factor patterns of an N-element uniform amplitude scanning linear array of λ/2 dipoles parallel to and positioned along the z-axis, with N=10, d=λ/4, β= -kdcos(θ_0). (a) θ_0=π/6. (b) θ_0=π/4. (c) θ_0=π/3. (d) θ_0=7π/16.

In Figure 3 it is shown how to control the phase excitation between the 10 elements of a uniform amplitude linear array, in order to direct its major radiation along its axis. However by properly selecting the current phase excitation ($\beta = -kd\cos(\theta_0)$), the maximum radiation can be oriented in any direction θ_0, forming a scanning array like the one whose array factor is depicted in Figure 4.

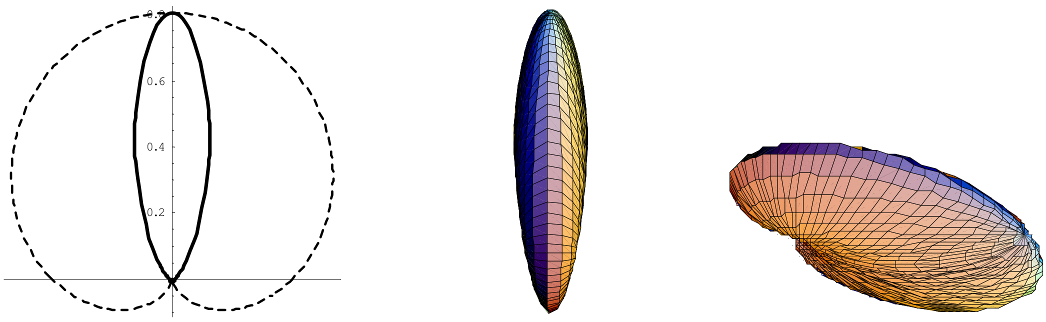
On the other hand horns are simple, easily constructed and excited, versatile antennas with large gain and excellent overall performance. They are widely used as feed elements for reflectors and lenses, elements for phased arrays, and lab standards for gain measurements and calibration purposes. A horn is a hollow metal pipe of variable cross section, tapered to a larger opening. The type, direction, and size of the taper can have a profound effect on the overall performance of the horn antenna. Using the following simulations students study the E-plane, the H-plane, and the pyramidal horns, in order to understand better their design, operation, and applications.



(a) (b) (c)

Figure 5. 2D amplitude and 3D far-field patterns of an E-plane sectoral horn, when $\rho_1=6\lambda$, $b_1=2.75\lambda$, $a=0.5\lambda$, $r=21\lambda$. (a) E-plane ($\varphi=\pi/2$) [with solid line] and H-plane ($\varphi=0$) [with dashed line] amplitude patterns. (b)-(c) 3D field pattern from different viewpoints.

In order to better understand the radiation performance of the E-plane sectoral horn, 2D and 3D far-field patterns have been plotted in Figure 5 utilizing equation (13-11) of (Balanis, 1997). Because this horn has larger dimension in the E-plane direction, the E-plane pattern is much narrower than the H-plane. Of course, the dyadic behaviour with narrow pattern characteristics in the H-plane, is expected from the H-plane sectoral horn, whose 2D and 3D far-field patterns have been plotted in Figure 6 utilizing equation (13-30) of (Balanis, 1997).



(a) (b) (c)

Figure 6. 2D amplitude and 3D field patterns of an H-plane sectoral horn, when $\rho_2=6\lambda$, $a_1=5.5\lambda$, $b=0.25\lambda$, $r=8\lambda$. (a) E-plane ($\varphi=\pi/2$) [with dashed line] and H-plane ($\varphi=0$) [with solid line] amplitude patterns. (b)-(c) 3D field patterns from different viewpoints.

The fields radiated by a pyramidal horn, as given by equation (13-48) of (Balanis, 1997), are plotted in Figure 7. The radiation characteristics of the pyramidal horn, which is flared in both directions, are a combination of those of the E- and H-plane sectoral horns, as the E-plane and H-plane patterns of a pyramidal horn are identical to the E-plane pattern of an E-plane horn and the H-plane pattern of an H-plane horn, respectively. As illustrated clearly in Figure 7, the maximum radiation of a pyramidal horn is not necessarily directed along its axis, because the rays emanating from the different parts of the aperture toward the axis are not in phase.

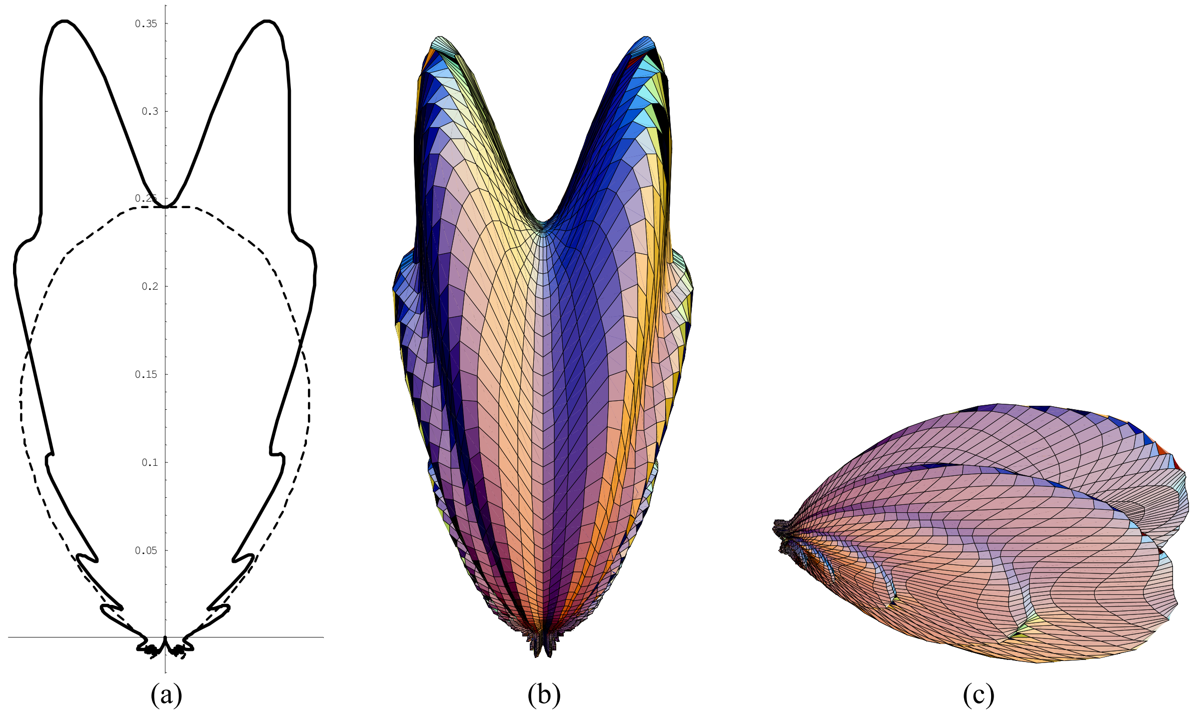


Figure 7. 2D amplitude and 3D field patterns of a pyramidal horn with maximum not on axis, when $\rho_1=\rho_2=6\lambda$, $a_1=12\lambda$, $b_1=6\lambda$, $a=0.5\lambda$, $b=0.25\lambda$, $r=21\lambda$. (a) E-plane ($\varphi=\pi/2$) [with solid line] and H-plane ($\varphi=0$) [with dashed line] amplitude patterns. (b)-(c) 3D field pattern from different viewpoints.

Visualizations like those in Figures 1-7, offer to students, knowledge of antenna radiation principles, understanding of radiolink characteristics and comprehension of electromagnetic wave propagation and interaction with the environment.

The introduction of novel teaching tools in electromagnetic courses, like the aforementioned antenna radiation simulations, has already upgraded the teaching-learning process in TEI-C. Students now obtain a deeper physical insight into the field behaviour and wave mechanisms that cause the propagation, radiation and scattering characteristics of structures, due to the visualization of electromagnetic waves and their interaction with the figures illustrating the theory. As a result, the assessment of students' annual survey and accomplished grades show that students' interest, satisfaction and learning profit have been improved by about 45% compared to those in the starting year 2000-01.

Nevertheless the benefits of introducing TEI-C's students to microwave modelling and computer simulations are more than academic, as our future graduates are now adequately trained to fulfil industry's need in this area.

Introducing novel teaching tools in antenna education, like the aforementioned simulations, has already upgraded the teaching-learning process in TEI-C. Students now interact with the figures illustrating the theory and as a result, they are more interested in these courses and accomplish better grades.

CONCLUSIONS

Students' renewed interest in microwave engineering courses in TEI-C is a fact. The explanation for this promising attitude is mainly threefold: a) the recognition of the necessity of electromagnetics' understanding for many areas in electrical, electronic, and computer engineering, b) the increased public concern about biological and environmental effects of electromagnetic waves, and c) the introduction of novel teaching tools in electromagnetic courses and computerized solutions in microwave problems. As Wiesbeck (1990) suggests, teaching electromagnetics has to be more streamlined in the future, presenting solutions after basic understanding of the possible applications and the use of existing software simulations, in order to make electromagnetic theory accessible to a wider number of future engineers.

ACKNOWLEDGMENTS

This work was co-funded by the European Social Fund (EKT) with 75% and National Resources (Greek Ministry of National Education and Religious Affairs) with 25%, under the ΕΠΕΑΕΚ project "Archimedes – Support of Research Groups in TEI of Crete – Smart antenna study and design using techniques of computational electromagnetics and pilot development and operation of a digital audio broadcasting station at Chania (SMART-DAB)".

Also, the authors would like to thank Prof. John L. Tsalamengas and Ass.Prof. George Fikioris, of the National Technical University of Athens, for their helpful discussions and insightful comments.

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