Research Networking Programmes

Science Meeting – Scientific Report

***Proposal Title**: Advanced Mathematics for Antenna Analysis (EsoA Course)*

Application Reference N°: 5427

1) Summary

The objective of this course is to explain the mathematical methods used in computational antenna analysis and to provide students with mathematical background necessary for advanced antenna engineering and electromagnetic software development. This course can also serve as a mathematical introduction to other ESoA courses. The course will cover different approaches to solving wave equations, various wave representations, and mathematical theorems used to simplify the original electromagnetic problem. In this sense, the aim of this course is to help students gain a deeper understanding of which field representation is suited for a given complex electromagnetic problem.

The topics of the course are:
1. Fundamental theorems framed in the antenna analysis
2. Complex analysis
3. Construction of solutions
4. Waves: scalar wave equation
5. Fields: vector wave equation
6. Asymptotic evaluation of integrals
7. Periodic structures

As in the previous edition the course lasted for 6 days and the schedule comprised 40 hours of lectures and 10 hours of guided and self-study exercises. Lectures were held at the conference room of Hotel Uvala, while lodging was organized in the nearby Hotel Vis, both situated in the Lapad bay not far from Dubrovnik city centre.

Course Info:
Dates: 12/05/2014 – 17/05/2014
Venue: Hotel Uvala, Dubrovnik, Croatia
Organizing institutions: University of Zagreb (UNIZAG, Croatia), University of Siena (UNISI, Italy)
Course Coordinators: Prof. Zvonimir Sipus (UNIZAG), Prof. Stefano Maci (UNISI)

Organizing Committee: Prof. Zvonimir Sipus (UNIZAG), Dr. Marko Bosiljevac (UNIZAG)

Speakers:

(a) Prof. Angelo Freni (UNIFI)
(b) Prof. Stefano Maci (UNISI)
(c) Prof. Zvonimir Sipus (UNIZAG)
(d) Prof. Anja Skrivervik (EPFL)
(e) Prof. Giuseppe Vecchi (POLITO)

2) Description of the scientific content of and discussions at the event

2.1. Lectures

The lectures were held from Monday 12th May thru Saturday 17th May 2014, in the morning and in the afternoon. The morning lessons focused more on theoretical background, while the afternoon lessons looked more into practical applications. Extra assignments were handed out on Friday morning and had to be solved in small groups. Each group got a random selection of three exercises related to the three main topics covered at the course. The results were presented on Saturday afternoon as a part of the final assessment tests.

2.2 Summary of the lectures

The analysis of many types of antennas and electromagnetic structures can be simplified if some of the electromagnetic theorems are applied. Therefore, the first lecture **Fundamental theorems in antenna analysis** gives the detailed overview of theorems in electromagnetics and discusses (with examples) how to implement them in the analysis procedure. One of them, the equivalence theorem (explained in the lecture **Construction of solutions**), is of particular interest since it enables the division of a complex electromagnetic problem into a set of simpler sub-problems. Electromagnetic structures are mathematically described with partial differential equations (PDE). Since the procedures for solving PDE are usually very complex, this topic is addressed with two lectures. First, the methods for solving **scalar wave equation** are explained, and then this approach is generalized for **vector wave equation**, both for the source-free case. The presence of the sources is taken into account by the **Green's functions** approach. The Green's functions approach leads to integral equations, which can be solved either numerically (e.g. by the method of moments) or by asymptotic evaluation of integrals. The latter approach is thoroughly explained in lectures **Complex Analysis Background** and **Asymptotic Evaluation of Integrals**. Finally, in advanced antennas and electromagnetic structures it is advantageous to use periodic structures, either to obtain artificial materials (such as magnetic materials at microwave frequencies) or to obtain frequency-dependent structures. The analysis methods for periodic structures are taught in the lecture **Periodic Antenna Problems,** while possible examples (such as metamaterials or EBG - electromagnetic bandgap structures) are explained in the lecture **Advanced Periodic Structures**.

2.3 Participants

A total of 15 students attended the course: the statistics is shown in Table I. Demographic analysis with respect to the country of origin is shown in Chart 1.

Fig. 1. Photo of the course (students and teachers)

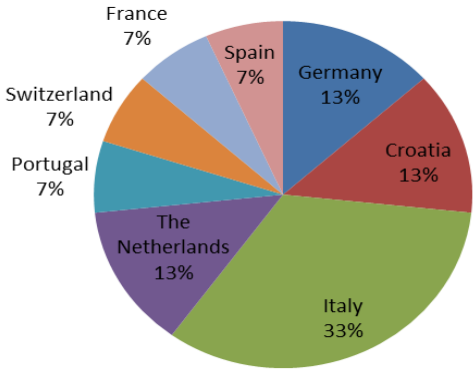

Chart 1. Distribution of students by country of origin

2.4. Logistic arrangements

Venue

The course was held at Hotel Uvala in Dubrovnik, Croatia. Hotel Uvala is a four-star hotel situated in the tourist resort of Lapad bay, not far from the city centre. The conference room of the hotel was adapted to a classroom with a projector and an A0-size notepad/board. Some photos from the lectures are shown below.

Lodging

Lodging was organized at Hotel Vis (***) only 50 m away from Hotel Uvala where classes were held. Almost all students and teachers stayed at Hotel Vis in single and double rooms with private bathrooms (only several students were staying at a hotel next to Hotel Vis due to late travel arrangements). Everyone staying close to each other proved to be excellent because it enabled stronger social interaction among students as well as between students and teachers.

Coffee breaks and social events
Two coffee breaks with coffee, tea, juices and different snacks were prepared daily: one between two morning lessons and the other between two afternoon lessons. The coffee breaks were held on the terrace of Hotel Uvala overlooking Lapad bay. The official course dinner was organized on Wednesday 14th May at restaurant "Kopun" in the old town center.

Course Material
All students were given the handouts of all the lectures at the beginning of the course on Monday. At the end of the course, all participants were also given CDs with all lectures in PDF format, as well as exercises and questions from the final exam. A selection of photos taken during the course by both students and organizers was also included.

Fig. 2. Several photos taken during the lectures and during exercises.

3) Assessment of the results and impact of the event on the future directions of the field

3.1. Credits and Exams
In view of the overall number of hours of lectures and exercises, the course has been valued **3 ECTS credits** for all students who followed and successfully passed the final exam. The students who attended the course but were not able to take the final exam or decided not to take it were attributed **2 ECTS credits.** The exam exercises were composed by the course teachers and included three exercises for each major course topic (fundamental theorems, construction of solutions, Green's functions/asymptotic evaluation). Students were divided in groups and had to solve two exercises from each topic. The exercises were distributed on Friday and the solutions were presented during the last lesson on Saturday. Photos of students working on the exam in the classroom and the hotel lobby are shown below.

Fig. 4. Students solving the exam in groups.

3.2. Evaluation of the course from the students

On the last day of the course, the students were given the standard ESoA Evaluation Form and one additional questionnaire, which separates the notes for each teacher and for each lesson, in order to provide more detailed feedback on the quality and balance between the lessons. The rating system was from 1 to 5, with 1 being the worst note and 5 being the best. The average scores are reported in Tables below.

Table 1.a Teachers Evaluation – Average Scores

	Prof. Angelo Freni	Prof. Stefano Maci	Prof. Zvonimir Šipuš	Prof. Anja Skrivervik	Prof. Giuseppe Vecchi
Instructor is knowledgeable about the subject	4.93	4.93	4.93	4.93	5.00
Instructor is prepared	4.93	4.53	4.93	4.93	4.93
Instructor encourages participation	4.40	3.93	4.40	4.79	4.27
Instructor answers students' questions	4.73	4.60	4.93	5.00	4.93
Instructor is enthusiastic about teaching	4.47	3.93	4.80	4.93	4.87
Instructor's fluency in English	4.33	4.20	4.53	5.00	5.00
Interest of material	4.67	4.20	4.53	4.64	4.60
Relevance of material	4.80	4.60	4.73	4.29	4.47
Using teaching aids (overheads, videos, handouts)	4.47	4.27	4.40	4.43	4.27
How pertinent were the course objectives to the target audience?	4.80	4.60	4.80	4.71	4.80
How well do you feel the course objectives were met?	4.47	4.00	4.67	4.64	4.60
How do you feel about the level of detail of the course documents?	4.53	4.47	4.60	4.50	4.47
Average note for the teacher	4.63	4.36	4.69	4.73	4.68

Table 1.b Logistical Support – Average Scores

Invitation letter about the course	4.73
Support before coming to the course (travel information, accomodation, visa)	4.87
Registration / Check-in	4.87
Support during the course (materials, handouts, ...)	4.87
Accomodation	4.67
Classroom is comfortable and inviting	4.73
Desks and tables provide adequate working space	4.73
Quality and variety of the meals served	4.40
Overall Average	4.87

The course was in general rated very positively. The choice and the order of lectures were found satisfactory, and teachers and most lectures had very high average notes. Most students pointed out the Fundamental Theorems in Antenna Analysis and the Green's Functions as the most important lessons in the course, and the general opinion is that the course is very good, but still in some parts hard to follow. The hardest lessons to follow, according to students, were the lessons on Green's functions and Asymptotic evaluation of integrals, given by Prof. Maci.

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

Annex 4a: Programme of the meeting

Monday: FUNDAMENTAL THEOREMS FRAMED IN THE ANTENNA ANALYSIS		
Z. Sipus (UNIZAG)	9.30-10.00	• The European School of Antennas • Introduction to the course
A. Freni (UNIFI)	10.00-13.00	**Fundamental theorems (1)** • Uniqueness • Energy
	Lunch break	
	15.30 19.30	**Fundamental theorems (2)** • Equivalence and induction theorems • Integral equation and Computational Electromagnetics (CEM) • HF approximations for scattering and diffraction • Examples and exercises

Tuesday: FUNDAMENTAL THEOREMS SCALAR AND VECTOR WAVE EQUATION IN ABSENCE OF SOURCES		
A. Freni (UNIFI)	9.00-13.00	**Fundamental theorems (3)** • Reciprocity Theorem • Implication of reciprocity in IE-MoM and application in CEM

	Lunch break	
	15.30 17.30	**Fundamental theorems** • Examples and exercises
Z. Sipus (UNIZAG)	17.30 19.30	**Scalar wave equation** • Introduction to waves • Definition of scalar wave equations; basic properties • Solving scalar wave equation using separation of variables

Wednesday: SCALAR AND VECTOR WAVE EQUATION IN ABSENCE OF SOURCES AND COMPLEX ANALYSIS		
Z. Sipus (UNIZAG)	9.00 13.00	**Scalar wave equation** • Solving scalar wave equation using separation of variables • Eigenvectors, eigenmodes and completeness relations • Examples and exercises **Vector wave equation** • Helmholtz' and Deby' potentials • Open and closed domains • Green's identities • Examples and exercises
	Lunch break	
	15.30 17.30	**Examples, open discussion and exercises** • Scalar and vector wave equation
S. Maci (UNISI)	17.30 19.30	**Complex analysis fundamentals** • Complex transformations • Transformation of complex variables
Thursday: GREEN's FUNCTION		
S. Maci (UNISI)	9.00 13.00	**Green's functions** • Generalities • Scalar and Dyadic GF Scalar GF representation • 1D, 2D and 3D GF for the wave eqs.- GF in cylindrical spectral coordinates open-domain • ρ-Tx line and z-Tx line GF in closed –domains • Waveguides and cavities
	Lunch break	
	15.30 19.30	**Examples and Exercises:** • Parallel plate waveguide • Horizontal dipole in stratified media, • Dipoles close to cylindrical multistrates • Dipoles close to a wedge

Friday: ASYMPTOTIC EVALUATION OF INTEGRALS		
S. Maci (UNISI)	9.00 13.00	**Basics of asymptotic evaluation of integrals:** • Typical integral representation • Saddle points and SDP • Examples and exercises
	Lunch break	
	15.30 19.30	**Non Uniform and Uniform asymptotics:** • Saddle-point – pole interaction (wedge problem) • Saddle-point – complex pole (evanescent wave diffraction, slab Green's function) • End-point – saddle-point (PO-diffraction, Shadow boundary diffraction)

Saturday: PERIODIC STRUCTURES		
G. Vecchi (POLITO)	9.00 13.00	**Periodic structures:** • Floquet Theorem • Green's functions for periodic structures in space domain • Green's functions for periodic structures in spectral domain • Convergence problems
	Lunch break	
A. Skrivervik (EPFL))	15.30 18.30	**Periodic structures – advanced topics:** • Finite period structures and quasi periodic structures • Acceleration of calculation of Green's functions (summation by parts, Shanks' transform, Ewald's transform,....)
	18.30 19.30	**Final assessment tests**

Annex 4b: Full list of speakers and participants

NAME	INSTITUTION	COUNTRY	ROLE
Tomás Bernabeu Jiménez	UPV	Spain	student
Mina Bjelogrlic	EPFL	Switzerland	student
Beatriz Blazquez	TU Delft	The Netherlands	student
Dario Bojanjac	UNIZAG	Croatia	student
Simone Ciccia	POLITO	Italy	student
Santi Concetto Pavone	UNISI	Italy	student
Mario Alberto Echeverri Bautista	POLITO	Italy	student
Francesco Foglia Manzillo	IETR Rennes	France	student
Alessandro Garufo	TU Delft	The Netherlands	student
Eduardo Lima	Instituto Superior Técnico	Portugal	student
Mario Mencagli	UNISI	Italy	student
Benjamin Motz	CST, Darmstadt	Germany	student
Adam Tankielun	Rohde & Schwarz	Germany	student
Mladen Vukomanović	UNIZAG	Croatia	student
Muhammad Zubair	POLITO	Italy	student
Stefano Maci	UNISI	Italy	teacher
Zvonimir Sipus	UNIZAG	Croatia	teacher
Angelo Freni	UNIFI	Italy	teacher
Anja Skrivervik	EPFL	Switzerland	teacher
Giuseppe Vecchi	POLITO	Italy	teacher
Marko Bosiljevac	UNIZAG	Croatia	organizer