Course Analysis

EI3310 Metasurfaces: Theory and Practice, PhD Course, 10.0 credits

Oscar Quevedo-Teruel
Division of Electromagnetics, EECS, KTH
June 10th, 2019

Course name: Metasurfaces: Theory and Practice

Course code, credits: PhD course: EI3310, 10.0 credits

Prerequisites /Eligibility: The course requires advance knowledge of electromagnetism, and it is desirable to have knowledge about radiofrequency technologies. Students who hold an MSc degree in Telecommunication Engineering, Electrical or Electronic Engineering or Physics should have the basis to meet the requirements of this course.
Furthermore, basic knowledge of antennas and/or microwave devices is an asset. If the student has already passed a Masters and/or PhD course on electromagnetic fields, antennas, microwaves, and optics, he/she should be in the ideal condition to follow the lectures.

Participation: 11 registered students
(9 PhD students, 2 MSc Students)

Teachers: **Oscar Quevedo-Teruel** (course responsible, giving lectures and final evaluator, KTH, Sweden).
Prof. Sailing He (KTH, Sweden).
Prof. Zvonimir Sipus (invited teacher, University of Zagreb, Croatia)
Prof. Eva Rajo-Iglesias (invited teacher, University Carlos III of Madrid, Spain)
Ass. Prof. Guido Valerio (invited teacher, Sorbonne University, France)
Ass. Prof. Raul Rodriguez-Berral (invited teacher, University of Seville, Spain)
Prof. Francisco Mesa (invited teacher, University of Seville, Spain)
Prof. Enrica Martini (invited teacher, University of Siena, Italy)

Examination:
- Students must attend the 5 weeks of lectures. Exercises and homework that are handed out during the lectures are mandatory to do and hand in.
- Each week will have a different educational leader.

- Students must attend and participate in the most of the lectures (90% of attendance is mandatory). They must complete all the exercises given to them on the lectures, deliver the required reports and respect deadlines.
- A final research project must be developed and delivered on time to the course responsible.

Examination rate

All the students who participated in the course reported and presented their homework and they delivered the research project. Therefore, the success rate was 100%.

1. Description of the course:

This course is intended for PhD students whose research topic is within or related to electromagnetic field theory, microwave propagation, antennas, metamaterials and optics.

During the course, the students will be able to acquire knowledge about an emerging research topic: metasurfaces. Metasurfaces are thin metamaterial layers that can be employed to produce unusual reflection properties of incident plane waves, or to guide surface waves. These unusual properties can be used to create innovative antennas and microwave circuits. Their main advantage with respect to conventional technology is their low cost of manufacturing and flat profile. This makes them prospectively interesting for the next generation of high rate communication antennas, high frequency filters, and radio telescopes.

The course will include an introduction to metasurfaces, a review of analytical and computational techniques to understand the operation of metasurfaces, and an overview of the present and future applications of metasurfaces with special emphasis on microwave circuits, lenses, and antennas.

The course includes talks from international experts. The students have a number of lectures, and they learn how to develop their own analytic and numerical codes to study metasurfaces. Additionally, they learn how to apply metasurfaces to real applications, and they design proofs of concept via commercial simulation software.

2. Learning outcomes:

After the course, the students should be able to:

- Describe a metasurface; explain the types of metasurfaces; and identify their limitations and properties.
- Develop analytic models to characterize canonical metasurfaces and periodic structures.
- Describe the operation of specific metasurfaces via in-house computational codes they develop.
- Choose the appropriate type of metasurface for a particular application.
- Analyze the operation of metasurfaces with commercial software.
- Design basic metasurface structures with commercial software.
- Develop an advanced microwave circuit or antenna that makes use of metasurfaces.

3. Literature

Books:

- "The Plane Wave Spectrum Representation of Electromagnetic Fields", P.C. Clemmow, IEEE Press.
- "Electromagnetic Wave Propagation, Radiation, and Scattering", Akira Ishimaru. Prentice Hall, 1991.
- "Geometry and Light: The Science of Invisibility", Ulf Leonhardt, Thomas Philbin, Dover, 1st Edition.

Most importantly, articles and notes will be provided during the lessons.

4. Implementation.

The course has approximately 75 hours of lectures and one 4-hour seminar. The implementation consisted of five intensive weeks of lectures (plus one seminar) with home assignments and a final individual research project.

About the six teaching weeks:

- Were dedicated to a specific topic in which one (or two) professors, expert in the field, led the educational process.
- Had around 15hours of lectures: 3 hours/day.
- Had home assignments, every day, which had to be delivered to the teacher in charge of the education process.

The teaching weeks were distributed as follows:

Week 1: Given by Prof. Sipus (University of Zagreb). Topics:

- Canonical metasurfaces and their use to antennas and microwave circuits.
- Spectral-domain method for analysing metasurfaces.

Week 2: Given by Ass. Prof. Valerio (Sorbonne University). Topics:

- Construction of Green's functions for multilayer structures containing metasurfaces.
- Modelling of metasurfaces using a surface admittance approach.

Week 3: Given by Prof. Rajo-Iglesias (Universidad Carlos III de Madrid). Topics:

- Metasurfaces to forbid the propagation of guided and surface waves and high-impedance surfaces.
- GAP waveguide technology.

Week 4: Given by Profs. Mesa and Rodriguez-Berral (Universidad de Sevilla). Topics:

- Circuit model approach to accurately analyse periodic structures and metasurfaces.

Week 5: Given by Ass. Prof. Martini (University of Siena, Italy). Topics:

- Holographic metasurfaces in two dimensional configurations.

Week 6: Given by O. Quevedo-Teruel and Prof. He (KTH). Topics:

- Introduction to lens antennas.
- Analysis and design of 2D lenses by using metasurfaces.
- Optical metasurfaces.

During the lectures, the students participated in regular discussions through the reading of papers, they developed their own analytical derivations, their own computational scripts for study metasurfaces, and they validated their results in a laboratory through the commercial software *CST Microwave Studio*. The homework was both individual and in groups, promoting the interactions between the students and enhancing their motivation. After the delivery of this homework, the teachers evaluated it.

After the lectures, the students worked in a final project, and the examination finalized with a written report of this project. These projects required two full-time weeks of work. However, since the students cannot be full time in the project, it took approximately 2-3 month (part time) to be finalised. To develop the project, the students had discussions with the examiner and (depending on the topic of the project) by e-mail/zoom with the external teachers of the course. The delivery of final report from the students was during the Period 4 (Spring 2019).

5. Evaluation:

During the course, students must attend 90% of the lessons, participate on the lectures, finalise the home-assignments, and finally they will choose a project which will be supervised by the responsible of the subject. The responsible proposed different projects, although many of the projects were proposed by the students. In all the cases, the responsible had to give the consent about the project, to ensure the quality and the difficulty of the work.

Requirements for passing the course:

- Participation in the lectures (90%).
- Delivery of the home-assignments, including exercises, development of own scripts of simulation, and the simulation labs (*CST Microwave Studio*).
- Development of an individual final project:
    - Creation of an individual written report. The report must consist of maximum 10 pages in which the student demonstrates his/her abilities to develop research on the field of metasurfaces. It must consist of (minimum):
        - A relevant introduction to the subject and interest of the topic of research. Demonstrating the understanding of the literature.
        - Individual contribution and work. The contribution must be expressed in a scientific manner.
        - Conclusions and future work (if any).

6. Personal reflection (Oscar Quevedo-Teruel):

In general aspects, I am very satisfied about this course. The students were involved in the tasks and they were highly motivated. In my opinion, they liked the general implementation of the course. They appreciated to have lectures in a PhD course, and they were really interested on having invited speakers. Two of the students claimed, for example:

> *"I think the most powerful point of the course was, utilizing a number of professors with different research interest and of course having correlation between the topics of professors. this feature helped me to learn more and*

made me more interested to go through the areas which was more interesting for me."

"I really like that we had many invited professors to teach the course. Each of these professors is an expert in the topic he was presenting. It was really good to see different teaching styles in addition to different interesting research points."

I really appreciated the fact that both students and professors enjoyed the environment during the lectures. One example of the relaxing and positive environment is the following comment:

"Believe it or not, this is the best PhD course I have ever attended in my life, sincerely."

Personally, this course was having an innovative implementation that it was based on my previous experience as teacher of PhD courses at KTH. I feel positive about the fact that the students had a great feedback about the implementation. Looking in deep to the course survey, all the key aspects are mainly evaluated by the students as excellent (5/5) with only few evaluations below 5.

I tried to match my lectures to the knowledge of the students which were quite heterogeneous, as it is the usual case in PhD courses at KTH. To get feedback, after each lecture, I approached to the students to get their informal opinion about the on-going of the course, and later on I tried to correct the lectures to the interest and needs of the students. I think that all these efforts are appreciated by the students and shown in the good evaluations of the survey. One student mentioned:

"The course is top tier, resembling more a set of state-of-the-art conferences very well explained than just a normal course. I think the in-depth study of the subject in this course is especially remarkable, as so is the good organization of it. The flexibility in the schedule to adapt to students' availability is also worth highlighting."

Personally, my skills of teaching have been increased with this course, and I have learned how to better perform in a lecture to PhD students. I learn with the different styles of the invited speakers, and I try to apply their successful techniques to my own teaching at all the levels: bachelor, master and PhD.

7. Next Steps (Long-term plan):

As mentioned, metasurfaces is becoming a trend topic, and there is a potential interest of Industry. Industrial partners, such as SAAB and Ericsson in Sweden, are interested in the establishment of this course and it is potential continuation during the next years.

Given the challenging implementation, this PhD course is not given every year. This is due to the needed volume of incoming PhD students, which is not enough for justifying the lecturing and the financial investment of bringing international professors. External speakers/professors are a desirable, and it was really appreciated by the students. The course is expected to be given every 2 years, depending on the renewal of the PhD students in the Electromagnetic department (EME).

It is also clear that the possibility of inviting external speakers/teachers depends on external funding. Erasmus agreements, existing research projects led by O. Quevedo-Teruel (such as STINT), and European COST Actions were used to cover the expenses for travelling. None of the teachers asked for a remuneration for the teaching. Given the present situation and the diverse amount of funding to this aim, I don't see troubles to continue with the implementation in middle-term.

8. Course evaluation (survey):

The students were asked to respond to a survey of the course. The results are here attached. In general aspects the students liked the organization of the course and they evaluated positively the teachers, and the notes. One of the comments reads:

> *"I liked that the course covered everything from theory to applied aspects of the topic. It was particularly interesting to listen to people give lectures in their topic of research.."*

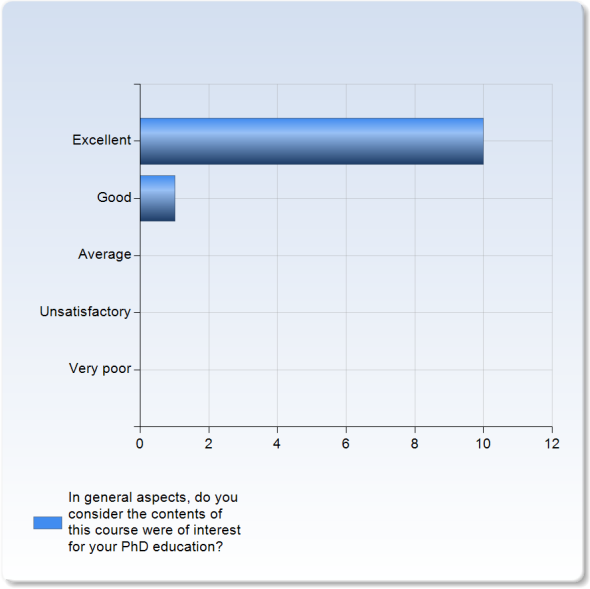
According to the comments, points which could be improved are having a more consistent notation in the lecturing slides and reading material prior to the lectures. These comments on the survey will be taken into account for future editions of the course.

Survey of EI3310 Metasurfaces, PhD Course

Respondents: 11
Answer Count: 11
Answer Frequency: 100.00 %

In general aspects, do you consider the contents of this course were of interest for your PhD education?

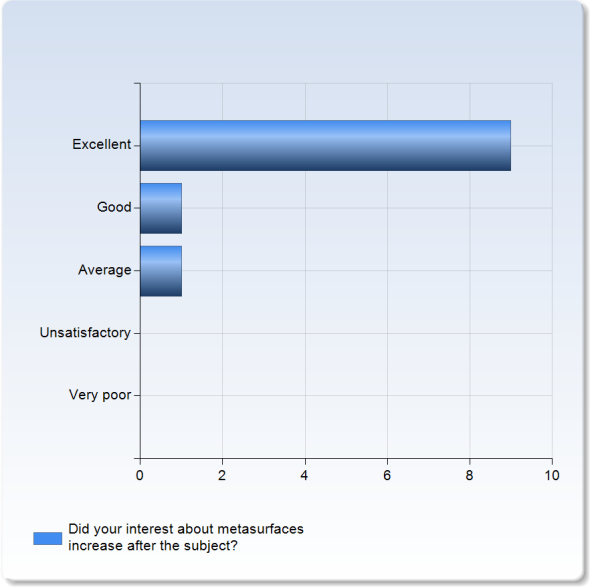
In general aspects, do you consider the contents of this course were of interest for your PhD education?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	1 (9.1%)	1 (9.1%)
Excellent	10 (90.9%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)



	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
In general aspects, do you consider the contents of this course were of interest for your PhD education?	4.9	0.3	6.1 %	4.0	5.0	5.0	5.0	5.0

Did your interest about metasurfaces increase after the subject?

Did your interest about metasurfaces increase after the subject?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	1 (9.1%)	1 (9.1%)
Good	1 (9.1%)	2 (18.2%)
Excellent	9 (81.8%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)



	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
Did your interest about metasurfaces increase after the subject?	4.7	0.6	13.7 %	3.0	5.0	5.0	5.0	5.0

How did you like the organization of the course: lectures, invited speakers, final project, and evaluation?

How did you like the organization of the course: lectures, invited speakers, final project, and evaluation?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	2 (18.2%)	2 (18.2%)
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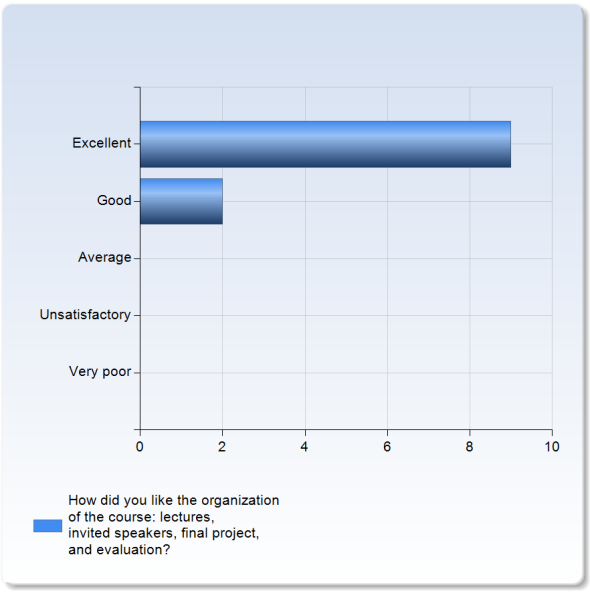
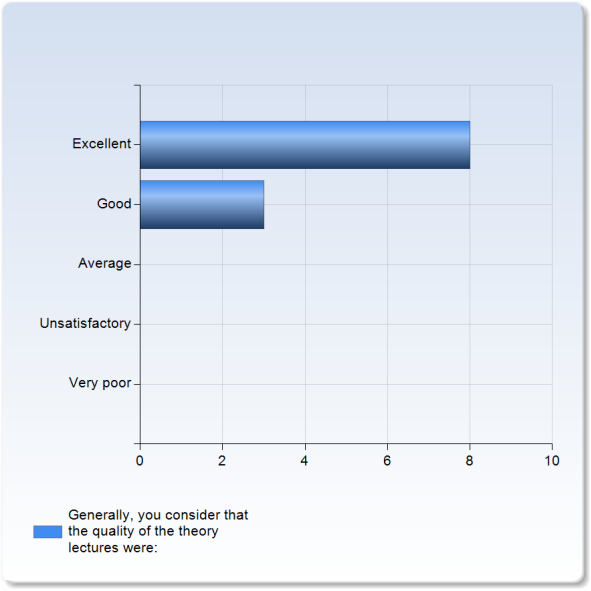


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
How did you like the organization of the course: lectures, invited speakers, final project, and evaluation?	4.8	0.4	8.4 %	4.0	5.0	5.0	5.0	5.0

Generally, you consider that the quality of the theory lectures were:

Generally, you consider that the quality of the theory lectures were:	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	3 (27.3%)	3 (27.3%)
Excellent	8 (72.7%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)



	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
Generally, you consider that the quality of the theory lectures were:	4.7	0.5	9.9 %	4.0	4.5	5.0	5.0	5.0

About the person responsible for this subject (Oscar Quevedo-Teruel):

Did you like his organisation and management of the course?

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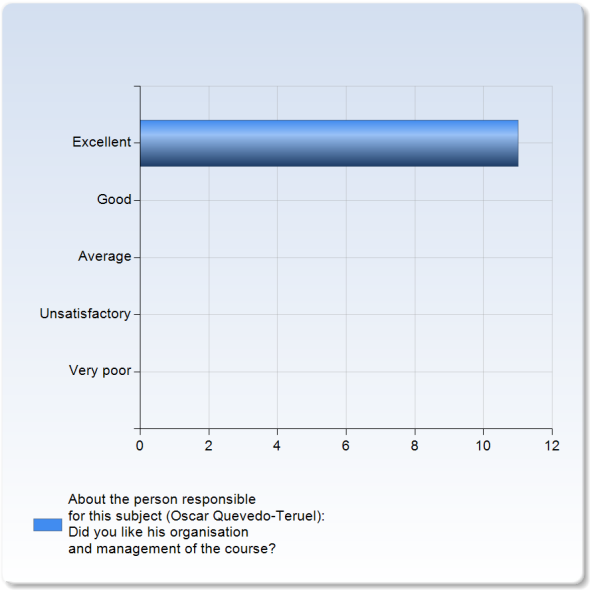

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About the person responsible for this subject (Oscar Quevedo-Teruel): Did you like his organisation and management of the course?	5.0	0.0	0.0 %	5.0	5.0	5.0	5.0	5.0

About the person responsible for this subject (Oscar Quevedo-Teruel):

Did he attended to your special requirements from you during the course?

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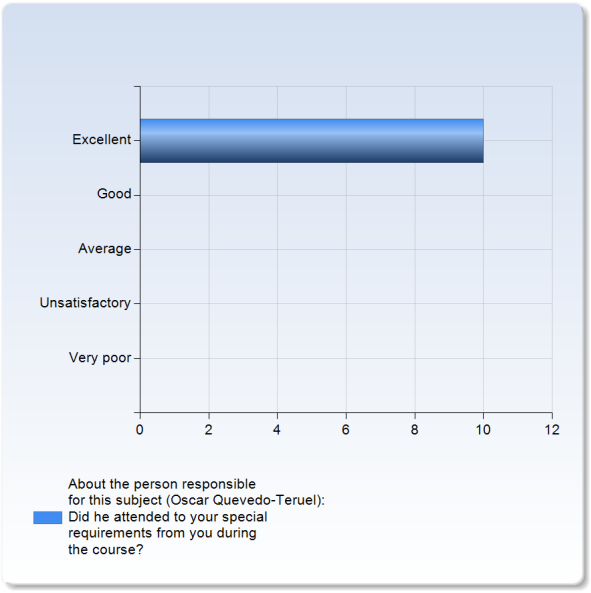

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About the person responsible for this subject (Oscar Quevedo-Teruel):

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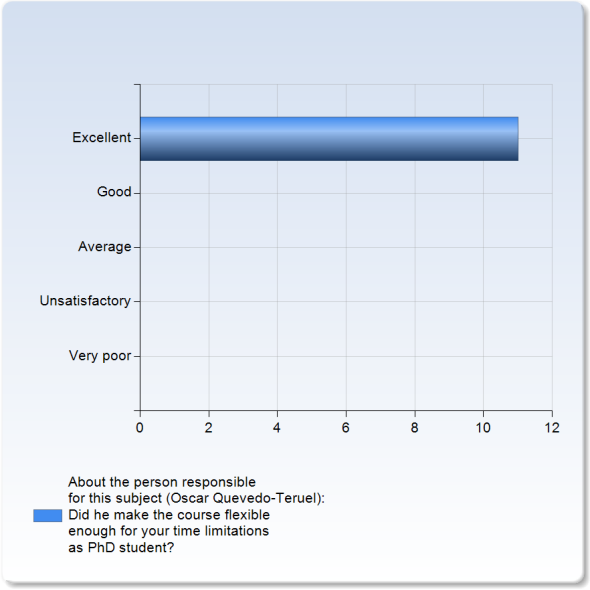

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About the person responsible for this subject (Oscar Quevedo-Teruel): Did he make the course flexible enough for your time limitations as PhD student?	5.0	0.0	0.0 %	5.0	5.0	5.0	5.0	5.0

About the person responsible for this subject (Oscar Quevedo-Teruel).

During his lectures. Did he explained the concepts so that they were easy to understand?

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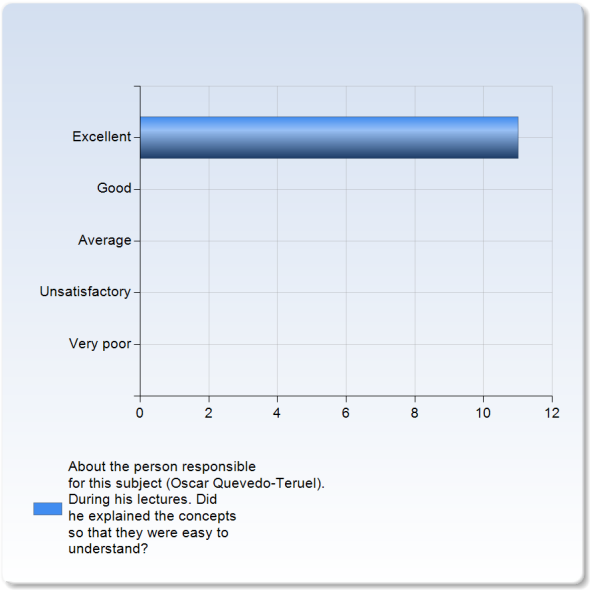

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About the lectures given by O. Quevedo-Teruel:

How do you evaluate his teaching?

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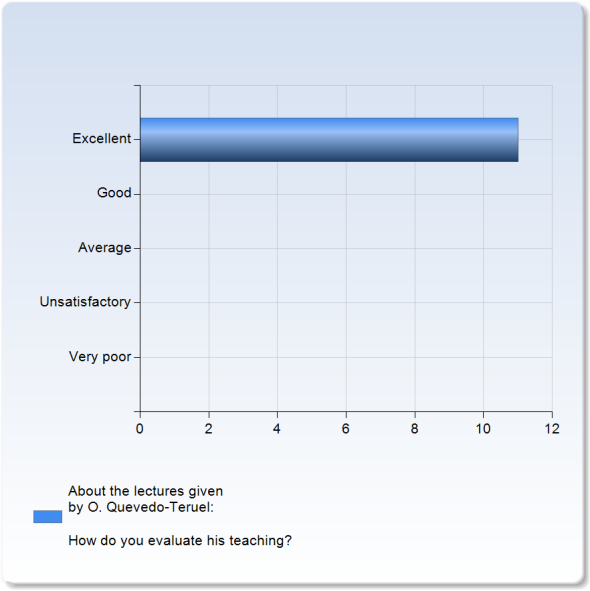

	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the lectures given by O. Quevedo-Teruel: How do you evaluate his teaching?	5.0	0.0	0.0 %	5.0	5.0	5.0	5.0	5.0

About the invited speakers: Do you think that the format of the course including invited speakers was...

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Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	3 (27.3%)	3 (27.3%)
Excellent	8 (72.7%)	11 (100.0%)
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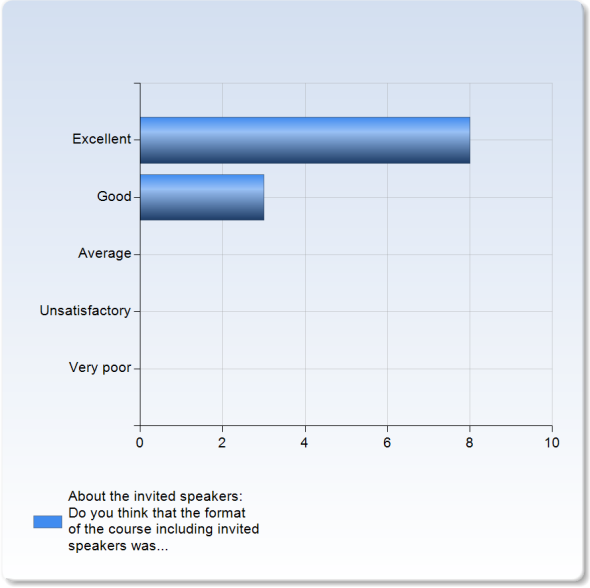

	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited speakers: Do you think that the format of the course including invited speakers was...	4.7	0.5	9.9 %	4.0	4.5	5.0	5.0	5.0

About the invited lectures given by Prof. Sipus:

How do you evaluate his teaching?

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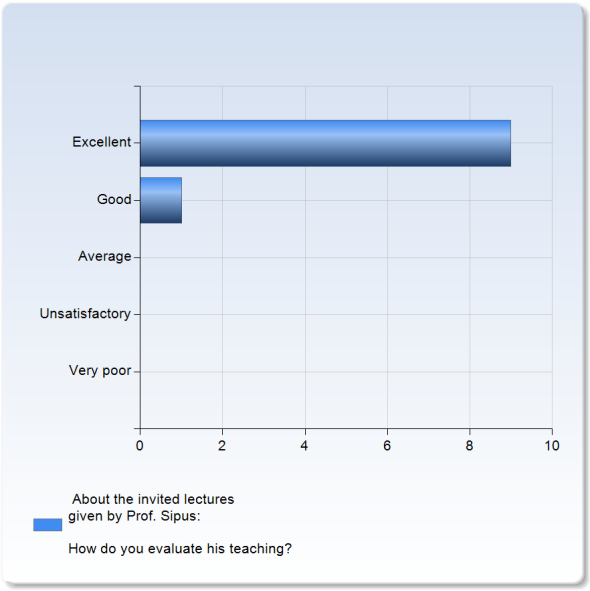
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	1 (10.0%)	1 (10.0%)
Excellent	9 (90.0%)	10 (100.0%)
Total	10 (100.0%)	10 (100.0%)

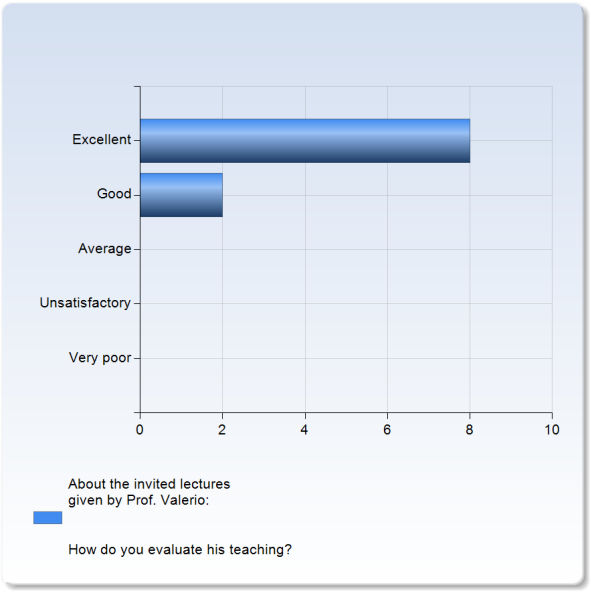


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Sipus: How do you evaluate his teaching?	4.9	0.3	6.5 %	4.0	5.0	5.0	5.0	5.0

About the invited lectures given by Prof. Valerio:

How do you evaluate his teaching?

About the invited lectures given by Prof. Valerio: How do you evaluate his teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	2 (20.0%)	2 (20.0%)
Excellent	8 (80.0%)	10 (100.0%)
Total	10 (100.0%)	10 (100.0%)

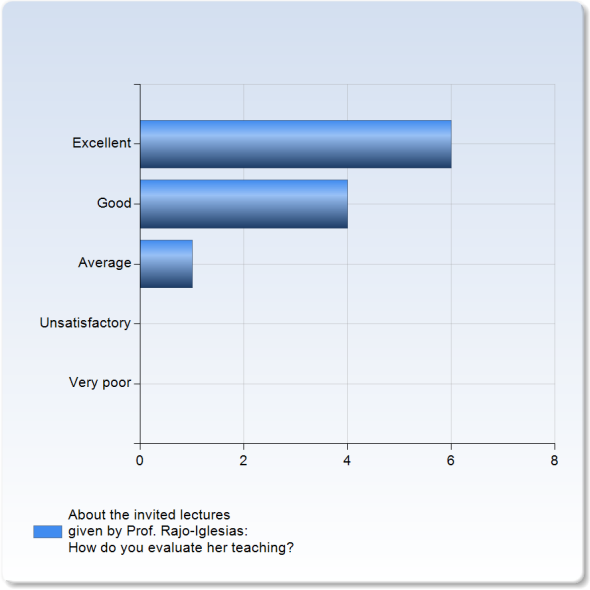


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Valerio: How do you evaluate his teaching?	4.8	0.4	8.8 %	4.0	5.0	5.0	5.0	5.0

About the invited lectures given by Prof. Rajo-Iglesias:

How do you evaluate her teaching?

About the invited lectures given by Prof. Rajo-Iglesias: How do you evaluate her teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	1 (9.1%)	1 (9.1%)
Good	4 (36.4%)	5 (45.5%)
Excellent	6 (54.5%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)

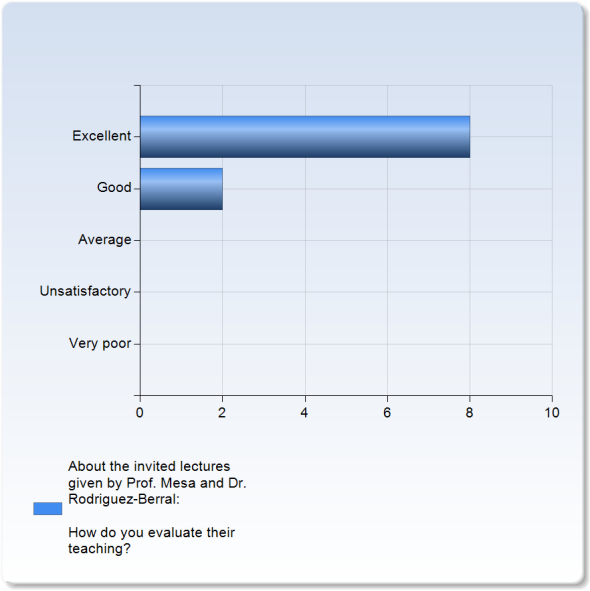


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Rajo-Iglesias: How do you evaluate her teaching?	4.5	0.7	15.4 %	3.0	4.0	5.0	5.0	5.0

About the invited lectures given by Prof. Mesa and Dr. Rodriguez-Berral:

How do you evaluate their teaching?

About the invited lectures given by Prof. Mesa and Dr. Rodriguez-Berral: How do you evaluate their teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	0 (0.0%)
Good	2 (20.0%)	2 (20.0%)
Excellent	8 (80.0%)	10 (100.0%)
Total	10 (100.0%)	10 (100.0%)

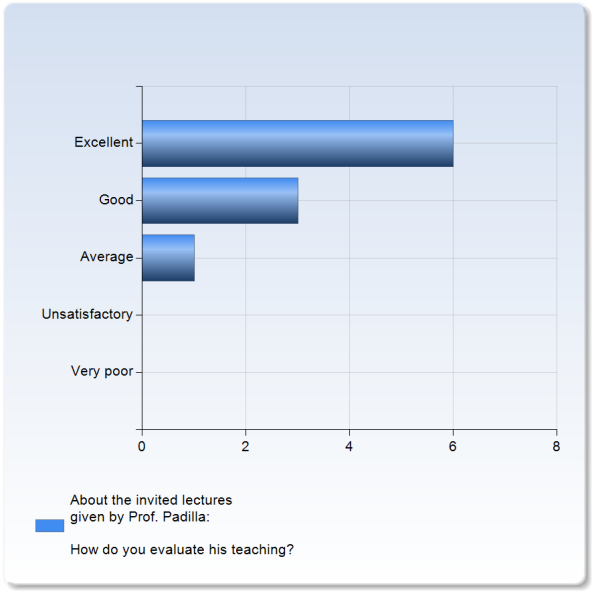


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Mesa and Dr. Rodriguez-Berral:								
How do you evaluate their teaching?	4.8	0.4	8.8 %	4.0	5.0	5.0	5.0	5.0

About the invited lectures given by Prof. Padilla:

How do you evaluate his teaching?

About the invited lectures given by Prof. Padilla: How do you evaluate his teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	0 (0.0%)	0 (0.0%)
Average	1 (10.0%)	1 (10.0%)
Good	3 (30.0%)	4 (40.0%)
Excellent	6 (60.0%)	10 (100.0%)
Total	10 (100.0%)	10 (100.0%)

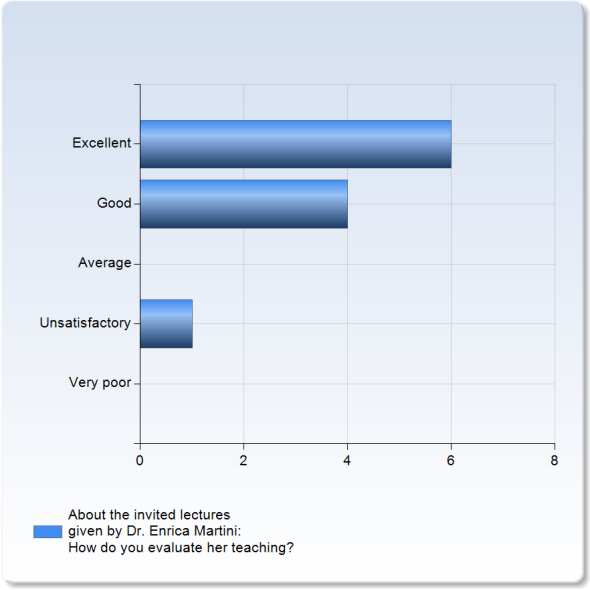


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Padilla:								
How do you evaluate his teaching?	4.5	0.7	15.7 %	3.0	4.0	5.0	5.0	5.0

About the invited lectures given by Dr. Enrica Martini:

How do you evaluate her teaching?

About the invited lectures given by Dr. Enrica Martini: How do you evaluate her teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	1 (9.1%)	1 (9.1%)
Average	0 (0.0%)	1 (9.1%)
Good	4 (36.4%)	5 (45.5%)
Excellent	6 (54.5%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)

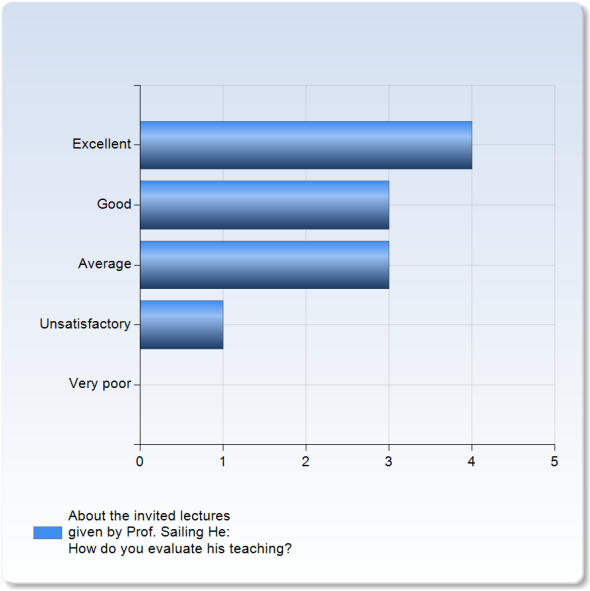


	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Dr. Enrica Martini: How do you evaluate her teaching?	4.4	0.9	21.2 %	2.0	4.0	5.0	5.0	5.0

About the invited lectures given by Prof. Sailing He:

How do you evaluate his teaching?

About the invited lectures given by Prof. Sailing He: How do you evaluate his teaching?	Number of Responses	Cumulated Responses
Very poor	0 (0.0%)	0 (0.0%)
Unsatisfactory	1 (9.1%)	1 (9.1%)
Average	3 (27.3%)	4 (36.4%)
Good	3 (27.3%)	7 (63.6%)
Excellent	4 (36.4%)	11 (100.0%)
Total	11 (100.0%)	11 (100.0%)



	Mean	Standard Deviation	Coefficient of Variation	Min	Lower Quartile	Median	Upper Quartile	Max
About the invited lectures given by Prof. Sailing He:								
How do you evaluate his teaching?	3.9	1.0	26.7 %	2.0	3.0	4.0	5.0	5.0

Any point that you would like to improve in the course?

Any point that you would like to improve in the course?
1) Consistent notation in the lecturing slides. 2) A list of reading material to be handed out before the start of course, by a good time period. I believe that will help the student follow the lectures more closely, and gain more out of the course. Especially Prof. Valerio's lectures.
I think Eva could try make her lectures a bit more difficult. Maybe go through some deeper concepts or applications, especially considering that the course is given at KTH where almost everyone knows about gap waveguides.
Maybe more exercises.
No. Believe it or not, this is the best phd course I have ever attended in my life, sinserely.

Any point that you consider was especially remarkable in the course?

Any point that you consider was especially remarkable in the course?
All of it. It was an amazing mixture of theory, numerical modelling, simulation tasks, and exposure to new concepts. The professors were very approachable. Prof. Oscar's lectures were spectacular.
The presence of some of the most prominent researchers in the field of metastructures
I really like that we had many invited professors to teach the course. Each of these professors is an expert in the topic he was presenting. It was really good to see different teaching styles in addition to different interesting research points.
The course is top tier, ressembling more a set of state of the art conferences very well explained than just a normal course. I think the in-depth study of the subject in this course is especially remarkable, as so is the good organization of it. The flexibility in the schedule to adapt to students' availability is also worth highlighting.
I think the most powerfull point of the course was, utilizing a number of professors with different research interest and of course having correlation between the topics of professors. this feature helped me to learn more and made me more interested to go through the areas which was more interesting for me.
Very good combination between theory and practice: - Without the the matlab exercises included, students would easily forget what they learn from the lecture. Luckily, we have plenty of such exercises. - From the practical point of view, I always believe the best way to evaluate a thoery or method is to apply it to practical analysis or design.
I liked that the course covered everything from theory to applied aspects of the topic. It was particularly interesting to listen to people give lectures in their topic of research. I feel like after the course, I have an overview of which different lines of research one can pursue in metasurfaces.

Any other comments?

Any other comments?
It will be really cool to have more exposure to transformation optics within the course!
What about promoting this course to ESoA?
To me, this was the best PhD course I have attended so far.