Implementation of Project-Based Telecommunication Engineering Design Course

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Key Words:	Communication engineering education, Student experiments, Direction of arrival estimation

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Dear Editor-in-Chief, Associate Editors and Reviewers,

We wish to thank you for your valuable remarks and comments. They resulted in a considerable upgrade of the paper. The detailed modifications to the manuscript are as follow.

Best Regards,
Hadi Aliakbarian

General Comments:

1. Assessment-ABET is mentioned, but the learning objectives are not tied back to ABET learning objectives.

- ABET/EC2000 Criteria 3(a)-(k) their relation to our Program Outcomes is now mapped in Table III. Since KU Leuven programs are affiliated to the Dutch-Flanders NVAO accreditation framework, an ABET accreditation is neither in place nor sought at the moment. Despite the unavailability of a formal obligation to do so, the authors through this work attempt to relate the existing education framework in this course to the ABET2000 criteria, which is original, especially for a postgraduate-level, project-based course.

2. Figure quality-make sure all figures are readable (in black and white) and meaningful. Fig. 7 does not provide any new information beyond what is given in Table 3.

- We thank you for pointing this out to us. Fig. 7 is now removed and relevant information is combined into Table III.

- Comments from the Editor-in-Chief:

In addition to comments from reviewers and the Associate Editor, I think several issues need to be addressed:

The introduction needs to frame educational issues related to teaching telecommunications engineering. The introduction presents an overview of the P&O course, but it does not identify the needs in telecommunication engineering for such course. The opening paragraph provides generic statements about need for upgrades, but there are not enough detailed statements about needs for change in telecommunication engineering.

- We agree with this remark. The Introduction section (paras. 1, 2 and 3) has been rephrased to clarify this aspect according to input from our more experienced co-authors.

Once needs have been articulated, the authors should describe why they think the instructional approach they have chosen addresses the needs they have identified. The manuscript presents an adequate description of the course, but it does not explain why design decisions that chose specific aspects of the course were made in relationship to the needs identified.

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- We agree with the editor-in-chief's comment. The following sentences have been added into Section I, para. 3 to clarify this aspect: "These GIL educational activities, in line with KU Leuven's Strategic Plan to ensure quality engineering education based on the Dublin Descriptors (DD), are also analyzed within the context of ABET 2000 for this specific case-study, which is deemed original, especially for a graduate-level course re-defined on an annual basis. The GIL's selection for this course's implementation is based on the fact that DD is a more general framework characterizing academic education, whereas the former is an all-embracing concept based on a close relation between research and education, besides being unrestrictive to a single teaching method [8]. This property is extremely relevant to such design course, as students are expected to be autonomous in their own learning process."

The page limit is six pages. Most of the detailed descriptions of the course and timeline (Figure 1) in Section II, could be placed on a course website to allow the authors to explain their course design decisions. Similarly most of the descriptions of the system and sub-systems (Sections III and IV, Figures 4-6) could be placed on the course website to provide space to address the educational issues that should be the core of the manuscript.

- Since the project is custom-defined on an annual basis, only the course objectives and outcomes (COs) are generic and listed on the course information website. Information presented in Sections III-IV and Figs. 4-6 is only relevant to the specific year/semester where this case study was carried out. Moreover, the authors believe it is important to only provide a high-level specification description for this course, and leave detailed definition to students taking part in the course to spur creativity and innovation, besides avoiding repeated projects and reference to past project reports. The following sentence is added to section II.A to clarify this:

"The project topic is changed annually to match the availability of TAs and the number of registered students, besides avoiding the possibility for reference to past reports. Moreover, only a high-level project specification is provided to enable students to define more detailed project requirements based on their problem solving skills, besides spurring creativity to arrive with an innovative solution to the topic. For instance, the project topics for the last two years were "Through-wall detection" and "Secure RFID wireless transmission".

Assessment data about the quality and quantity of student learning will be needed. These should be in addition to the data obtained from student self-reports that are currently presented in the manuscript.

- We agree with the reviewer's suggestion. A new Fig. 6 and a discussion of the quality and quantity of student learning, gathered from their final grades is added to section V.D, as follows:

"Detailed marks for each student from the three micro-groups are depicted in Fig. 6. The macro-group performance is graded equally for all 12 students, and similarly, students from the same micro-group receive equal marks. One exception was with the Antenna micro-group, as students' performance is observed to be significantly distinct by all TAs. All 12 students passed the minimum threshold of 50%, including marginal passes by two students. As reflected in the graph, student no. 7, which posses an outstanding technical

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knowledge and eventually led the whole macro-group to achieve their objectives was awarded the highest grade in this case study."

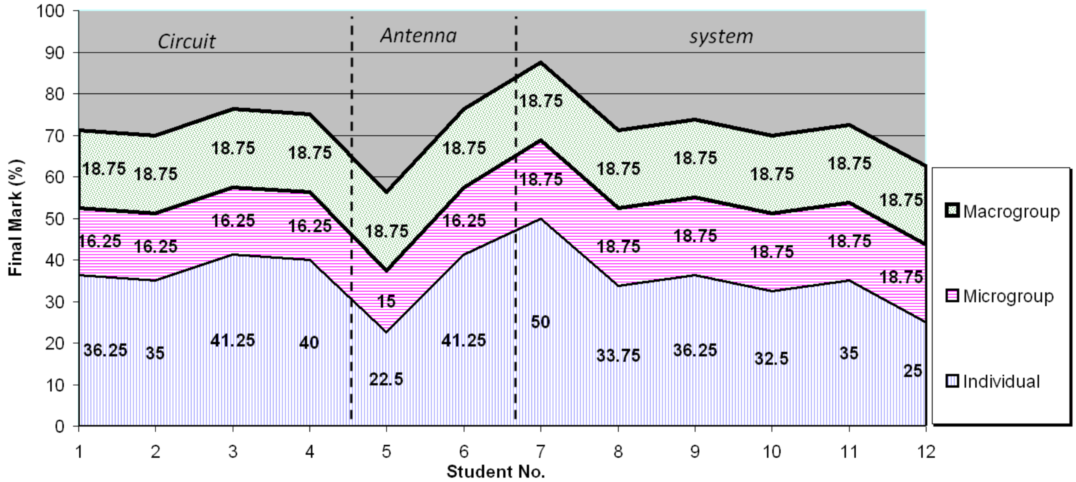

Fig. 6: Student's detailed results, individual, (micro/macro) group and final marks

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Reviewer comments to authors (from custom fields):

Reviewer: 1

1. Describe the type of course(s) to which this manuscript applies, the level of interest that this manuscript will generate in the faculty teaching this/these course(s), and the contributions that this manuscript makes to the education of engineers.: The content of the manuscript applies directly to team design project courses, or "guided independent learning" courses, offered at the senior undergraduate or masters graduate level. The content is most applicable to team project courses in radio frequency (RF) system design, although many concepts can be generalized to other types of team project courses in telecommunications, electrical engineering, and computer engineering.

- Thank you for your comment.

The manuscript is likely to be of great interest to those faculty members teaching or planning to teach a team-based project course at the senior undergraduate or masters graduate level. It provides a very good description of the authors' practical experience in developing and offering a challenging, team-based project course. The manuscript is well written and well organized and is, thus, accessible and easy to follow.

- Thank you for your comment.

While interesting and useful, the content of the manuscript is not particularly novel. While the exact form of this class in this domain may be new, the general concepts are not new. While the manuscript presents some evaluation, the assessment provided and the lack of deep, general insight provided only modestly advance the field of engineering education.

- We agree with the reviewer's comment. The following sentences have been added into paragraph 3 of Section I to clarify its novelty: "These GIL educational activities, in line with KU Leuven's Strategic Plan to ensure quality engineering education based on the -

Dublin Descriptors (DD), are also analyzed within the context of ABET 2000 for this specific case-study, which is deemed original. The GIL's selection for this course's implementation is based on the fact that DD is a more general framework characterizing academic education, whereas the former is an all-embracing concept based on a close relation between research and education, besides being unrestrictive to a single teaching method [8]. This property is extremely relevant to such design course, as students are expected to be autonomous in their own learning process."

Reviewer: 2
1. Describe the type of course(s) to which this manuscript applies, the level of interest that this manuscript will generate in the faculty teaching this/these course(s), and the contributions that this manuscript makes to the education of engineers.: This manuscript would be of interest primarily to electrical or telecommunications engineering programs; or those programs containing a significant component from one of these disciplines. However, the assessment methodology would be applicable to a variety of disciplines.
-Thank you for your comment.

Reviewer: 1
2. Discuss the technical accuracy of the manuscript: The manuscript appears to be technically accurate.
-Thank you for your comment.

Reviewer: 2
2. Discuss the technical accuracy of the manuscript: The manuscript appears to be technically accurate and the authors identified and accomplished their stated primary objective. Abstract and Conclusion sections are beneficial to the overall flow of the manuscript. Grammar should be rechecked throughout as some errors were noted.
- We thank you for pointing this out to us. The manuscript has been thoroughly read and re-checked to ensure grammatical correctness.

Reviewer: 1
3. Discuss the clarity of the manuscript. Is it easy to read? Do ideas flow clearly? Will a reader in a different engineering discipline be able to follow the presentation in the manuscript: The manuscript is generally well written and organized. It is easy to read and the ideas flow clearly. A reader in a different engineering discipline might not be able to follow all aspects of the technical details of the project described as a case study, but such a reader would be able to follow most of the manuscript and, especially, the engineering education ideas that are provided.
-Thanks for the comment.

There are, however, areas for significant improvement with this manuscript.

Section IV focuses almost exclusively on technical aspects of the case study presented, with too little discussion of the educational aspects of the project. The technical presentation is fine since it is brief and at a high level. However, the manuscript could

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better describe educational aspects of this course and the case study project. For example, there is too little discussion of the context of this project course with respect to the overall curriculum for the Masters program in Electrical Engineering at K.U. Leuven. What topics are new to students and what topics are being reinforced? Is this the only such guided independent learning opportunity for the Masters students?

- Thank you for highlighting this to us, we agree with the reviewer's remark. A new paragraph in Section I, para. 4 and a new table have been added to clarify this aspect: "This P&O course is designed to take place throughout the second semester of the first academic year (of the two-year Master Program). It is worth to note that this course is the only of its kind throughout the Master Program. Due to the flexible system, the type and amount of courses attended prior to the start of the P&O course varies depending on each the student and their chosen option, either "Electronics and Integrated Circuits" or "Embedded Systems and Multimedia". In the first semester, these students are already reinforced with 6 Core Education lecture- and laboratory-based courses, which are higher in their level of instructional guidance. Another 6 courses run concurrently in the same semester as the P&O, and are mostly option-specific. Courses taken throughout the first year and their relevancy to the P&O course are listed in Table I."

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TABLE I: COURSES IN THE FIRST YEAR AND THEIR RELEVANCE TO THE P&O COURSE

Semester 1	ECTS	Relevancy	Semester 2	ECTS	Relevancy
H05A0A Analysis of Digital Communication Systems	3	3	H09L9A P&O for Electronics & Integrated Circuits	6	NA
H09J4A Building Blocks for Telecom Systems	3	5	H05K2A Antennas	3	5
H05F1A Digital Signal Processing for Communications and Information Systems	6	3	H05TQA Electromagnetic Propagation	3	5
H06A3A Analog Building Blocks for Signal Processing	6	5	H05E3A Design of Analog Integrated Circuits	6	3
H09J6A Design of Digital Platforms	6	2	H09K1A Design of Digital Integrated Circuits	3	4
H09J7A Design of Electronic Circuits	3	2	H09Q3A Technology for Microelectronics	3	2
			H05D3A Computer Architectures	3	2

The manuscript provides too little insight into shortcomings or lessons learned. For example, the failure of the students to not get audio working across the link is barely discussed. How and when was this detected? What was the response? What was learned by the students and by the GTAs and faculty team? There is a bit more discussion about areas of concern from the survey of students in Section V.B. But, little insight is provided. More details of the educational aspects of such shortcomings would improve the manuscript.

- More details and studies about the educational aspects of the course are added to different parts of Section IV-F and Section II.B, as follows respectively:

- Section IV.B:

Since the receiving antenna needs to be conformal, i.e., made from textile, whereas the transmitting antenna is designed to be mounted on a base station, identical antennas could not be designed for both purposes. During intermediate presentation, it was noticed that the both antennas were not designed to radiate with similar polarization, i.e., receiving antenna with Righ-Hand Circular Polarization (RHCP) and transmitting antenna with Left-Hand Circular Polarization (LHCP) due to a misunderstanding. This is expected to have an adverse effect on the overall system performance, but fortunately there was additional time for a re-design process to be performed. The lesson learnt here is that students should communicate more in understanding and defining specifications to ensure proper system operation.

An issue faced by the Circuits micro-group was a PLL design which did not work up to the required specification. This was detected at the integration phase, as the whole system performance was degraded upon testing. This suspected hypothesis was then confirmed when an input a signal generated using a commercial source was used to test the system, and the system was proven to be working as it was supposed to. The lesson learnt by the TAs and students was to start system integration earlier than scheduled to ensure sufficient additional time to resolve such issues. Moreover, an additional problem faced in the same group was a damaged receiver, broken after several tests, believed due excessive power. Due to damaged circuit, the root-cause was not clearly determined. However, they were replaced by additional backup boards which were fabricated simultaneously together with the original boards. Thus, besides the importance of allocating additional time for troubleshooting and integrating new components into the backup boards, the lesson learnt here is that additional budget must be allocated for backup boards to be fabricated.

On the other hand, one difficulty faced by the System micro-group was that they realized the ADC board's interface did not match the FPGA development board's interface standard. This problem was seen during the components' assembly procedure, and the solution was to bypass the board and connect the signals directly to the FPGA using wires. Although this might not be the best solution, this was practically proven to be working. From this, the students realized that different interface standards exist, and this should have been checked more thoroughly during the components' selection process. Practical problem solving and troubleshooting skills were also proven crucial in solving this issue.

- Section II.B:

“As a full cycle of system design, fabrication and measurement is needed by the end of the semester, TAs have to be able to prepare a back-up plan for the case of failure in any

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crucial part of the system with reasonable cost. For instance, if the system's phased lock loop (PLL) has a problem, a lab signal source would be employed."

The process for forming micro-groups needs to be more clearly described. How is a student's background considered when he or she is assigned to a micro-group? Do students have input on assignment to a micro-group?
- The group forming process is now more clearly explained in Section II-A: "The number of students per micro-group is pre-determined by the TAs based on the expected amount of work load. Students are given the freedom to form each micro- groups based on their interest and experience. In the event of over- or under-capacity, TAs will then need be involved in the formation process to facilitate a proper balance."

The operation of the course that is described is very people intensive. It would be good if the manuscript could discuss this matter. Is this a concern? Is it out of line with other courses in the Masters program or with predecessor project or design courses?
- Indeed, we agree with the reviewer's remark that the course implementation is very people-intensive. However, this should not be a point for concern as the topic is defined anew every year based on the number of TA available for supervision. Moreover, the requirement for each Doctoral Student (or TA) to be involved in instructing at least one course related to his/her research area a year enables a consistent availability of TAs. This is in fact one of the inherent elements of the doctoral study in KU Leuven, A rule of thumb for this P&O course is that each TA is assigned to supervise a micro-group with a maximum of c.a. 3 or 4 students to ensure the quality of the course implementation and TA supervision. As for its cohesion within the program structure, students' technical and soft skills gathered from the 6 Core Education courses in the preceding semester are thoroughly tested for the first time in the program. Moreover, the timing of this course enables them to prepare for the start of a 24 ECTS Master Thesis which runs over the next academic year, upon completion of this design course. It is also worthy to mention that this course enabled the students to discover their interest prior to the selection of their Master Thesis topic. More information can be found in Table.I.

- Section II.B
"The project topic normally varies each year, depending on the number of TAs available for project supervision due to the people-intensive nature of this course. However, the students signing up for the course also varies from year to year, and the main objective is to maintain a maximum one-to-four TA-to-student ratio."

The manuscript does not discuss any involvement of industry. Is there any, for example for project review, student mentoring, or consultation for faculty?
- For this case study, the involvement of industry/industrial partners is yet to be implemented. This is mainly due to the limited local antenna/microwave hardware industry in the university's vicinity. Industry involvements are limited to students' interaction and contact made with multi-national companies to obtain student licenses for simulators or requesting samples for selected ICs and substrates. Nonetheless, the authors highly appreciate this remark, and this aspect will be definitely taken into account for the next run.

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The role of ABET is very unclear. There is discussion of ABET criteria and assessment frameworks, but it is not clear how ABET relates to the course described in the manuscript. Is the Master of Electrical Engineering program at K.U. Leuven ABET accredited or is it seeking ABET accreditation? It is also noted that the manuscript does not show a close alignment of program objectives to ABET criteria, such as the so-called "a-k" criteria. This should be addressed, perhaps in Section V.A.

- EC2000 Criteria 3(a)-(k) their relation to our Program Outcomes are now mapped in Table III. Since K.U. Leuven programs are affiliated to the Dublin Descriptors and the EUR-ACE framework, an ABET accreditation is neither in place nor sought at the moment. Despite the unavailability of a formal obligation to do so, the authors through this work attempts to relate the existing education framework in this course to the ABET2000 criteria, which is original, especially for a postgraduate-level, project-based course.

Also, based on Table V, it seems that achievement of Course Outcomes is not consistent across all micro-groups. In particularly, only the Circuits Micro-Group achieves Course Outcomes 3 and 4. Is this the case? What Course Outcomes are achieved by all through macro-group activities? Do all students achieve the Course Outcomes and, if so, how? Do all students achieve the Program Learning Outcomes and, if so, how?

- We thank you for pointing this out. This is actually a minor mistake due to a misunderstanding, and this is deeply regretted. Table V actually lists down micro-group activities within the first three weeks of the course performed by each TA (and consequently each micro-group), which are closely-guided sessions. These activities are also intended to provide an initial understanding of the high-level project requirements and basic technical knowledge, i.e. the achievement of COs 1 and 2. Although this might vary according to students, COs 3, 4 and 5 are intentionally left to be achieved later in the course duration, when students actually start to implement or troubleshoot their designs/hardware. Activity B3 and B4 in the Table have been corrected to reflect this.

Is the budget of $1500 for each micro-group or for the macro-group? This is not clear.

- The following sentence is modified for better clarity: “However, they are also responsible in managing their bill of materials (BoM) using a $1500 macro-group project budget.”

There were 12 students in the class, but only 9 responses for the survey. Why were three responses missing? Did students stop participating in the class? Also, nine is a very small number of responses, in general. This limitation should be discussed.

-The three missing responses were from students refraining from participating in the on-line survey. Due to the blind and voluntary nature of the conducted survey, no follow-up process was possible in tracking these three students. We agree that the sample size is small due to the limited and unpredictable number of students participating in this course every year, and thus affecting the worth of this study in terms of statistical power and Type II error. Nonetheless, different student exit surveys from each year could be

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combined to perform a meta-analysis which could enable a better validity of such surveys.

The task names in Figure 1 are hard to read.
- The Gantt chart has been updated in a more compact and readable form.

Figure 2 includes color. Will color be available if this manuscript is published? Some of the text in Figure 2 is hard to read due to low contrast (such as white on maroon and black on dark blue).
- This figure is now replaced for better clarity.

A similar concern with colors exists for Figure 3.
- This figure is now replaced for better clarity.

The text in Figure 4 is nearly impossible to read. The figure is simply too small.
- The figure is now magnified and larger texts are provided.

Figures 5 and 6 are similar. Just one of these could be used, probably Figure 6, without detracting from the manuscript.
- Both two figures are now combined into a single figure (Fig.5).

Figure 1 (Gantt chart) is somewhat useful, but detail could be reduced or it could be removed if space is needed for expansion of the discussion.
- The Gantt chart has been updated in a more compact form.

Reviewer: 2
3. Discuss the clarity of the manuscript. Is it easy to read? Do ideas flow clearly? Will a reader in a different engineering discipline be able to follow the presentation in the manuscript: The manuscript is well written and organized; its flow could be improved by correcting some grammatical inconsistencies?
- We thank you for pointing this out to us. The manuscript has been thoroughly read and re-checked to ensure grammatical correctness.

Reviewer: 1
4. Discuss the relationship of the manuscript to related literature (text books, reference books, archival journals, and conference papers). Are the proper references cited? Are the cited references adequate: As noted previously in this review, this manuscript is not particularly novel with respect to its contribution to engineering education? The manuscript does not attempt to show novelty in the broad area of design projects for engineering education.
- We agree that the novelty of this work was not well highlighted in our previous version. Thus we have added the following sentences in Section I, para. 3 to clarify this aspect: "These GIL educational activities, in line with KU Leuven's Strategic Plan to ensure quality engineering education based on the Dublin Descriptors (DD), are also analyzed within the context of ABET 2000 for this specific case-study, which is deemed original,

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especially for a graduate-level course re-defined on an annual basis. The GIL's selection for this course's implementation is based on the fact that DD is a more general framework characterizing academic education, whereas the former is an all-embracing concept based on a close relation between research and education, besides being unrestrictive to a single teaching method [8]. This property is extremely relevant to such design course, as students are expected to be autonomous in their own learning process."

The manuscript provides sufficient discussion of related literature on other team-based project courses in RF systems design.
- Thank you for your remarks.

There are numerous typing errors in the list of references, such as the lack of spaces after terms such as "vol." and "no.," inconsistent abbreviation of journal names, and inconsistent formatting of dates. These should be fixed.
- We apologize for the typing errors. They have been improved accordingly.

Reference [8] is out of date. There is an updated version that should be cited.
- The new version of this document is now updated as reference [8].

Reviewer: 2
4. Discuss the relationship of the manuscript to related literature (text books, reference books, archival journals, and conference papers). Are the proper references cited? Are the cited references adequate: References are abundant, cited well, and are adequate? The authors did an excellent job at incorporating relevant literature to the topic.
- Thank you for your comment.

Reviewer: 1
5. Other Comments to the Author(s): There are numerous grammatical and typographic errors that should be fixed if this manuscript is to be acceptable for publication. The manuscript should be carefully copy edited by a proficient writer of English. Here are some examples of problems. These are just some examples. There are numerous other problems throughout the manuscript.
- We thank you for pointing this out to us. The manuscript has been thoroughly read and re-checked to ensure grammatical correctness.

The title would be clearer as "Implementation of a Project-Based Telecommunication Engineering Design Course." Note the insertion of "a."
- This has been corrected as per the reviewer’s suggestion.

In first sentence of the abstract, the meaning of the word "work" is not clear. Perhaps it should be "paper."
- This has been corrected as per the reviewer’s suggestion.

Later in the abstract, the sentence should be "... graduate-level GIL activities which are unique ..."
- This has been corrected as per the reviewer’s suggestion.

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In the same sentence, the meaning of the phrase "unique to the project title, both at the system and sub-systems level" is not clear.
- The sentence is separated into two sentences for better clarity, as follows: “Its main implementation challenge is the need for instructors to define graduate-level GIL activities which are unique for the project objectives and scope. This process is required at both the system and sub-system levels.”

Later in the abstract, the term "course commencement" is awkward.
- The word ‘initiation’ is used instead.

Later in the abstract, the terms "detailed out" and "detailing" probably would be better written as "described" and "describing," respectively.
- This has been corrected as per the reviewer’s suggestion.

Section V.B refers to Table II when it should be Table IV.
- We apologize for the error, this is now corrected.

Section V.B refers to Q4 about specifications and requirements, but this should probably be in reference to Q5 and/or Q6.
- We apologize for the error, this is now corrected.

The meaning of "their final report" in Section V.D is not clear. Whose final report?
- We apologize for the vagueness. This is actually a combined full written report based on each micro-group's sub-report. The sentence is now modified as follows: "The conclusion is based on the TA’s observations, the Professors’ remarks on the three presentations and a final written report submitted by the macro-group at the end of the semester."

Reviewer: 2
5. Other Comments to the Author(s): Figure 1 is difficult to read even in high resolution, it needs reformatting
Left justify line #36-37 on page #6, proportional spacing makes it difficult to read.
- We apologize for the formatting error, this is now corrected.

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Implementation of a Project-Based Telecommunication Engineering Design Course

Hadi Aliakbarian, *Member, IEEE*, Ping Jack Soh, *Student Member, IEEE*, Saeed Farsi, *Student Member, IEEE*, Hantao Xu, *Student Member, IEEE*, Emmanuel Van Lil, *Senior Member, IEEE*, Bart Nauwelaers *Senior Member, IEEE*, Guy A.E. Vandenbosch, *Fellow, IEEE*, Dominique M. M.-P. Schreurs, *Fellow, IEEE*

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***Abstract*— This paper describes and discusses the implementation of a project-based graduate design course in Telecommunication Engineering. This course, which requires a combination of technical and softskills for its completion, enables guided independent learning (GIL) and application of technical knowledge acquired from classroom learning. Its main implementation challenge is the need for instructors to define graduate-level GIL activities which are unique for the project objectives and scope. This process is required at both the system and sub-system levels. These activities must also satisfy each Program Learning Outcomes and Course Outcomes (PLO and CO). The course initiation, implementation and management from the instructor's perspective are first described. Technical specifications and outcomes from a recently-implemented project entitled "A Human Inspired Telecommunication System" is taken as a case study. Besides explaining students and course evaluation methodology, an empirical assessment of PLOs and COs versus the associated educational activities is also presented. The students' exit survey, with each instrument mapped to specific COs indicated a good satisfaction level, besides accomplishing the intended course objectives.**

***Index Terms*— Communication engineering education, Student experiments, Direction of arrival estimation, Biomimetics.**

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I. INTRODUCTION

The dynamism and ever changing industry requirements demand innovative educational methods in telecommunications and electromagnetics [1-2]. Besides constantly upgrading the content of the program and courses, it is also important that methods used are attractive. One of such means is through the integration of practical elements into the courses, enabling potential engineers to independently assess and decide for an optimal system design and solution in a way that interests them. Skills such as applying computer-aided design (CAD) [3] to analyze system requirements, conducting a trade-off analysis and choosing suitable components through the use of documentations will be put into practice, to complement technical knowledge already acquired through classroom learning.

In this work, a one-semester GIL activity in the Department of Electrical Engineering, K.U Leuven is presented and discussed. It involves a telecommunication system design project carried out by a group of graduate students using the bottoms-up approach, through the H05I3A course (Problem Solving and Design in Telecommunications and Telematics). This course, referred hereafter as "P&O", is implemented as a pre-requisite for every Master student in Electrical Engineering prior to their thesis year. The scope of the project, which covers both hardware and software design and development, is one of the most attractive features of this course. The prospect of completing a full hands-on implementation cycle of a Telecommunication system i.e., from design and simulation to components' selection, fabrication and measurements in a team environment has proven to be very attractive for them. Moreover, the timing of this P&O course is ideal to complement the well-known laboratory-based courses [4-5], considered insufficient to provide essential theoretical and practical skills for a postgraduate level thesis. Besides facilitating an independent learning environment due to the lower amount of guidance [6-7], this course also evaluates the accomplishment of

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soft-skills-related PLOs, e.g. team work, progress reporting, communication skills and presentations.

To enable GIL, all students taking up the P&O course (referred to as the macro-group) are assigned into a smaller group of two or three (known as a micro-group). The micro-groups are each assigned to pursue a more specified goal for project completion. These GIL educational activities, in line with KU Leuven's Strategic Plan to ensure quality engineering education based on the Dublin Descriptors (DD), are also analyzed within the context of ABET 2000 for this specific case-study, which is deemed original, especially for a graduate-level course. Moreover, the need to re-define them on an annual basis is also challenging and unique. The GIL's selection for this course's implementation is based on the fact that DD is a more general framework characterizing academic education, whereas the former is an all-embracing concept based on a close relation between research and education, besides being unrestrictive to a single teaching method [8]. This property is extremely relevant to such design course, as students are expected to be autonomous in their own learning process

This P&O course is designed to take place throughout the second semester of the first academic year (of the two-year Master Program). It is worth to note that this course is the only of its kind throughout the Master Program. Due to the flexible system, the type and amount of courses attended prior to the start of the P&O course varies depending on the student and the chosen option, either "Electronics and Integrated Circuits" or "Embedded Systems and Multimedia". In the first semester, these students are already reinforced with 6 Core Education lecture- and laboratory-based courses, which are higher in their level of instructional guidance. Another 6 courses run concurrently in the same semester as the P&O, and are mostly option-specific. Courses taken throughout the first year and their relevancy to the P&O course are listed in Table I

This paper is organized as follows. The next section describes the initiation, project management and implementation of this course, while section III details the technical specifications and

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expectations at both macro- and micro-group levels. Next, section IV discusses the technical outcomes of sub-system, and the bottom-up integration into a complete working system. An empirical assessment is performed in section V to assess the achievement of each program learning outcomes and course outcomes (PLO and CO), based on ABET 2000's criteria [9]. Besides that, Teaching Assistants' (TAs) educational activities for respective micro-groups in achieving each COs are also specified, prior to our concluding remarks.

TABLE I: COURSES IN THE FIRST YEAR AND THEIR RELEVANCE TO THE P&O COURSE

Semester 1	ECTS	Relevancy	Semester 2	ECTS	Relevancy
H05A0A Analysis of Digital Communication Systems	3	3	H09L9A P&O for Electronics & Integrated Circuits	6	NA
H09J4A Building Blocks for Telecom Systems	3	5	H05K2A Antennas	3	5
H05F1A Digital Signal Processing for Communications and Information Systems	6	3	H05TQA Electromagnetic Propagation	3	5
H06A3A Analog Building Blocks for Signal Processing	6	5	H05E3A Design of Analog Integrated Circuits	6	3
H09J6A Design of Digital Platforms	6	2	H09K1A Design of Digital Integrated Circuits	3	4
H09J7A Design of Electronic Circuits	3	2	H09Q3A Technology for Microelectronics	3	2
			H05D3A Computer Architectures	3	2

II. PROJECT REQUIREMENTS AND MANAGEMENT

A. Course Overview

The P&O course is a six-credit course designed for postgraduate (master) students. The project topic is changed annually to match the availability of TAs and the number of registered students, besides avoiding the possibility for reference to past reports. Moreover, only a high-level project specification is provided to enable students to define more detailed project requirements based on their problem solving skills, besides spurring creativity to arrive with innovative solutions to the topic. For instance, the project topics for the last two years were "Through-wall detection" and "Secure RFID wireless transmission.

In general, the course is held on a weekly basis, during 13 weeks, 5 hours per session. Guided-learning sessions are initially held for the first 4 weeks. To complete the course, 120 working hours are required: the scheduled contact hours are estimated to be 65 hours, and the remainder is reserved for independent work. In these sessions, Teaching Assistants (TAs) are assigned to smaller micro-groups, each undertaking a different assigned part of the project. Therefore, each TA is assigned to four students, on average.

Courses listed in Table I are explained in a more practical manner to suit the context of the project. Certain courses are attended concurrently during the P&O's active semester. For the remaining eight sessions in the semester, students are then required to work in their respective assigned micro-groups, while being in communication with other micro-groups as a team. The number of students per micro-group is pre-determined by the TAs based on the expected amount of work load. Students are given the freedom to form the micro- groups based on their interest and experience. In the event of over- or under-capacity, TAs will then need be involved in the formation process to facilitate a proper balance.

Each of these micro-groups, consisting of two to six students are responsible for a part of the project which covers either antennas, passive and active microwave circuits, digital and analogue circuits, propagation or signal and data processing. This course is offered every winter semester, and is capable of accommodating between 10 and 20 first-year master students. The course is supervised and evaluated by all the four TAs and another four Professors, which also function as the jury members.

B. Project Definition

The project topic normally varies each year, depending on the number of TAs available for project

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supervision due to the people-intensive nature of this course. However, the number of students signing up for the course also varies from year to year, and the main objective is to maintain a maximum one-to-four TA-to-students ratio. To decide a suitable topic, a brainstorming session involving the course coordinators and the TAs is carried out in early January. Project titles and scopes are proposed based on recent telecommunication trends, its novelty, and involvement of the telecommunication expertise and facilities within the research group. A final decision is made based on the following considerations: scope, completion feasibility, available equipment, and allocated budget. As a full cycle of system design, fabrication and measurement is needed by the end of the semester, TAs have to be able to prepare a back-up plan for the case of failure in any crucial part of the system with reasonable cost. For instance, if the system's phased lock loop (PLL) has a problem, a lab signal source would be employed. In the recent semester, the chosen topic is "A Human-Inspired Telecommunication System", which was inspired by a work described in [10], published only a year earlier. The technical details of this project will follow in Section III.

C. Planning and Timeline

Mid-February, an info session dedicated to describe the project scope, specifications and details is organized. Students are also divided into micro-groups in this session to work together for the following 13 weeks. The Gantt Chart in Fig. 1 details the timeline and further activities involved.

In Week 5, the students working in the assigned micro-group under respective TA's guidance are required to present their proposal to their peers and the jury members. Based on the Gantt Chart, they are required to be familiar with the system overview, the tools used for system modeling, and be able to propose an initial design prior to an intermediate presentation in Week 5. In the next four working weeks, they are expected to finalize and validate their designs. This is due to the fabrication process, which is scheduled to commence during the two-week Easter break. This will ensure ample time is available for design evaluations and troubleshooting prior to a second intermediate presentation scheduled in Week 9. From hereon, every micro-group will gradually

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integrate their separate component blocks into the whole system after the successful validation of their respective blocks. After three weeks of integration work, a final report and project demonstration is expected for evaluation in Week 13.

To put a strong emphasis on teamwork, the project is designed intentionally such that any inability of the micro-groups to complete their respective assigned design will surely hinder the overall system functionality. Thus, every micro-group is expected to stick strictly to the planned schedule, with only two weeks of allowable time attrition for troubleshooting. This situation would compel each micro-group to offer assistance to another to avoid any latency. In other words, groups must also be concerned about other groups' progress as this cooperation will determine the achievement of the overall objective, which is also significantly evaluated. TAs' are responsible to guide and to ensure that each micro-group has at least one alternative solution in the event of any components or design failures. This way, failure risk is significantly reduced, as each TA is a postgraduate-level expert within the micro-group's work scope. Since the timing of this P&O course matches the IEEE Antennas and Propagation Society (AP-S) Student Design Challenge, the proposal was also submitted for contest participation. The final evaluation of the course was two days before the contest final submission deadline. The potential of their work being recognized internationally through this participation has motivated the students to thrust towards a quality and timely project completion.

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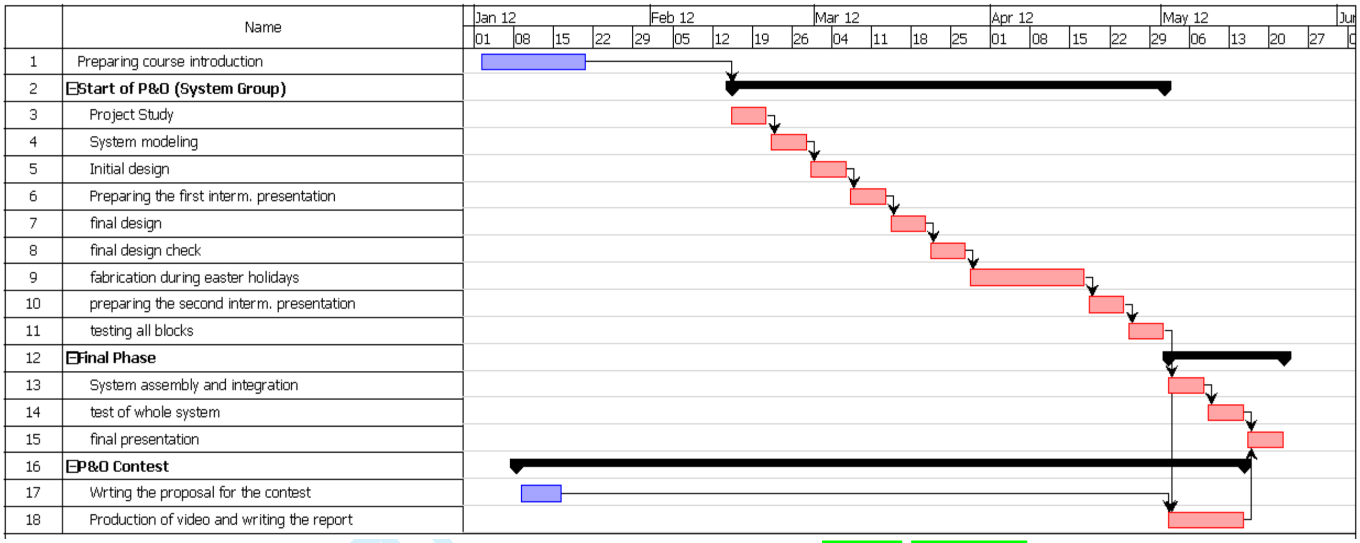

Fig.1. Project Gantt chart in 2012. (figure updated)

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III. System Overview

A. Project Proposal

The project objective is to design and implement a simple, efficient and low-cost communication system inspired by the human communication mechanism. A combination of mechanical and electronic beam-steering is proposed to enable communication between a 1x2 receiving array (resembling a pair of ears) and a transmitter (resembling a speaking human voice).

Upon signal reception, the pair of human ears utilizes a Direction of Arrival (DoA) estimation concept to locate the direction of the signal source. The human head and consequently, its ears (i.e. radiation beam) are steered towards it. A similar model is used in our system, utilizing uni-directional antennas and mechanical steering to improve communication quality. The two elements in the array, working in the 2.45 GHz Industrial, Scientific and Medical (ISM) band, are located more than a half-wavelength apart. DoA is estimated using both amplitude and phase information, similar to a human acoustic hearing system at frequencies above 3 kHz [10]. Besides determining front/back source's origin via the ears' directional pattern, further communication quality improvement is achieved by the head mechanical rotation towards the source. Moreover, this combination is capable of finding more than one signal source working at the same frequency using combined mechanical and electronic steering, despite being composed of only two elements.

This proposed system can easily be integrated onto a helmet, worn visual display and other on-body locations for search and rescue, emergency response, or medical monitoring applications. The proposed design for the electromagnetic "mouth" and "ears" is shown in Fig. 2. Although a similar idea has been implemented in [11], this system offers several additional advantages over the former work:

1. The addition of tracking and communication capabilities, besides the developed direction finding mechanism.
2. The addition of mechanical and electronic steering capabilities, instead of using an electronics direction finding system.
3. A joint solution, combining array factor and element pattern, to achieve long range transmission.

B. Equipments and Facilities

To accomplish the aforementioned goal, the students are given access to different antenna and microwave lab facilities under the supervision of the TAs. In addition, they are also provided access to in-house electrical and mechanical workshop services. For antenna measurements, an anechoic chamber and a vector network analyzer are available for use, while for RF circuits evaluation, an RF sweep generator, spectrum analyzer, function generator, and various RF adapters and circuits are made available. Moreover, access to electrical and mechanical facilities for soldering and assembly is also authorized.

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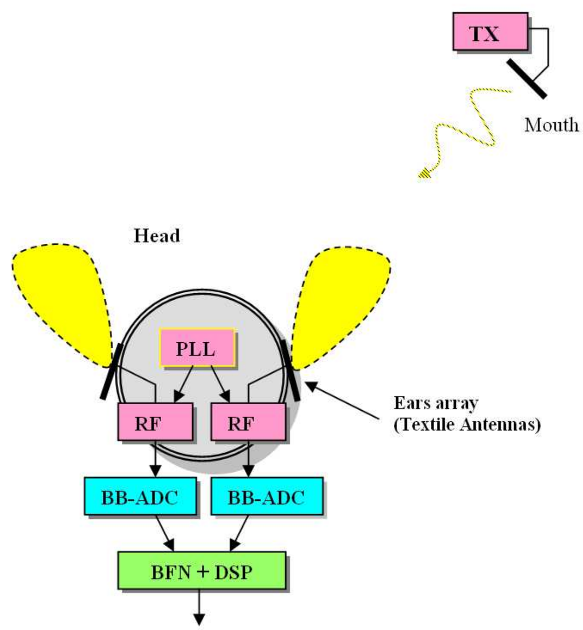

Fig.2. Block diagram of the human-inspired communication system (figure updated)

C. Components access

Students are expected to find and select their required components themselves. Nevertheless, the selection is supervised by the TAs to avoid mistakes. They are given the option to source components from electronic vendors such as Farnell and RS-components. However, they are also responsible in managing their bill of materials (BoM) using a $1500 macro-group project budget. The orders are placed with TAs' assistance, while students are responsible for ordering free components by themselves.

IV. Sub-systems and Technical Outcomes

The system is split into three sub-sections, assigned to three micro-groups with separate functions, namely, Antennas, Circuits, and Systems. The number of students assigned to each micro-group is proportional to their assigned work load and estimated man-hours, as shown in Table II. Therefore, two, four and six students were assigned to Antennas, Circuits, and System micro-groups, respectively. In this section, the sub-system specification and tasks required to achieve each micro-group's objectives are explained, followed by their evaluation procedures.

A. Antennas Micro-group

1) Receiving (Rx) Antenna (Ears)

The group utilizes flexible, conductive and non-conductive textile materials to fabricate the antenna. A square-shaped radiator with chamfered edges is chosen to enable circular polarization. Textiles provide ease of integration onto clothing, mobility and users comfort. This also guarantees conformity when being attached to any type of scatterers, while providing consistent radiation properties.

2) Transmitting (Tx) Antenna (Mouth)

A circularly-polarized (CP) aperture coupled microstrip antenna is proposed as the antenna for the mouth. Similar to Rx antennas, the Tx antenna has been designed to work within the 2.45 GHz ISM band. It has been fabricated using conventional Rogers 4003 dielectric substrate with a thickness of 1.575 mm.

3) Scatterer

The scatterer is a 80 mm diameter, water-tight plexi-glass cylinder filled with a commercial liquid, representative of a human body. The effect of the cylinder on the received signals at the antennas, and consequently, the whole system reception performance are investigated.

4) Link Budget

To ensure every micro-group is aligned to a standard specification set, the worst case receive power level is calculated based on the estimated antennas' gains and transmit power. To determine this, the antenna group is responsible to estimate the overall link budget based on the project requirements and constraints.

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B. Circuits Micro-group

1) Receiver boards

The receiver board receives signal from the antenna and filter, amplifies and downconverts it to an Intermediate Frequency (IF). Its output is then connected to the Analog-to-Digital Converter (ADC) input. The receiver board must comply with the specifications imposed by the ADC board, especially in terms of output power level and frequency. Based on the received power level from the antennas, the board should amplify the signal to a specified level. The downconversion to IF is performed by a mixer connected to the PLL output. Other components such as filters, programmable amplifiers and regulators are also used on the board. Two identical receiver boards are required for each receiving antenna.

TABLE II: MICRO-GROUPS AND THEIR TASKS DESCRIPTION

Group Name	No. students		Assigned Tasks
Antennas	2		Tx and Rx Antenna, Scatterer, Link Budget
Circuits	4		Transmitter and Receiver (RF & baseband), PLL
Systems	6	2	FPGA, digital processing, and ADC
		2	PC interface and Processing
		2	Mechanical tracking and calibration

2) Transmitter board

The transmitter board features an RFIC transmitter module. Other ICs like regulators, a crystal oscillator, a controller and amplifiers, along with some passive components are used in the transmitter. The initial goal is to send audio data via the transmitter board, and to detect it at the receiver. However, this goal has not been fully achieved by the end of the semester, and instead, a simple CW source has been used as the transmitter.

3) Phase-Locked Loop (PLL)board

A PLL is used as the local oscillator (LO) to provide sine waves for the down-converting mixer in the receiver board. It generates a CW waveform at 2.45 GHz and is controlled by the FPGA board via a data interface.

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C. Systems Micro-group

The system micro-group designs the digital platform that handles the analog, digital and mechanical system blocks.

1) FPGA and Digital Processing

In FPGA platform, the concept of hardware/software co-design is utilized. The digitized input is first calibrated since mismatches between the analog down-converting paths of the two antennas are expected to exist. It contains the complete digital demodulation path for data communication, which utilizes high-speed, parallel programmable components, as "hardware". This includes the digital waveform synthesis, digital quadrature mixer and polyphase decimation filter. Along with the demodulation path, small, independent digital hardware components are built and hooked onto the system bus, forming the digital platforms. For example, the step rotor control signal generator and PLL programmer are implemented in this configuration as peripherals to the embedded platform. The digital platform is mastered by an embedded core, which parameters are generated by the software running inside and configured through the system bus. Buffers are inserted into the digital platform, allowing investigation of intermediate results or passing necessary info to the DoA software in the PC.

2) Mechanical Tracking

A mechanical rotation block is built to direct the array towards the signal source once its direction is successfully determined. The antenna array with scatterer is placed on top of a metallic horizontal plate which is rotated by a step motor. A simple circuit board with rotor driver IC is developed to translate the rotor control signals from the FPGA into currents and voltages to drive the step motor.

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3) Signal Processing and Software

On the PC platform, a program with a Graphical User Interface (GUI) is developed for system monitoring. Besides that, this GUI also allows the demonstration of the signal tracking process via the direction finding 'engine' running in the background. The PC program takes fractions of down converted signals from the two antennas as inputs, and passes them through the MUSIC algorithm [12] to compute initial DoA estimates. Due to the existence of the $\lambda/2$ element spacing between the two antennas, ambiguity i.e. spatial aliasing effect, comes into the picture. To eliminate this ambiguity, amplitudes from the two elements are compared, enabling the actual DoA to be determined among initial estimates. The antenna element which receives the larger amplitude is more likely to have the signal source originating from its proximity due to the existence of a line-of-sight (LoS) path. The presence of the scatterer thus avoids the LoS existence for the other antenna element.

Once the signal source direction is determined, the software will command the step rotor via the embedded system to rotate towards it. The mechanism of signal capture, analysis and info feedback to the rotor resembles a close control loop. The loop is stabilized when the system has reached its optimal point. This level is constantly monitored, and the process of maximizing SNR via the system rotation towards the signal source occurs again once a variation is detected.

D. Inter-micro-group Cooperation

For proper project completion, constant communication between all micro-groups is crucial. This inter-relation is presented in Fig. 3. For instance, the programmed direction finding algorithm must be based on the measured 1x2 receiving antenna array's radiation pattern. Moreover, the receiver boards must be compatible with the receiving antennas in terms of physical realization (mounting, connection, etc.). At the same time, the receiver boards must also fulfill the requirements of the ADC board (unilateral or differential digitization, voltage swing, etc).

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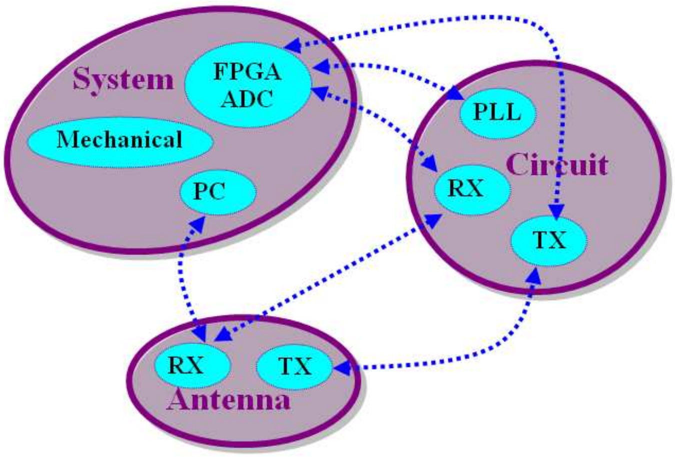

Fig.3. Micro-group inter-relation diagram (Figure updated)

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E. System Measurement and Evaluation

There exists two measurement phases within this project. The first is carried out after components (circuits or antennas) fabrication, while the second phase commences once the system integration process starts. During the first phase, which takes place in Week 7, individual components such as the Rx-Tx antennas, PLL boards, Rx-Tx boards, VHDL code, and the PC interface are tested separately. Once completed, micros-groups will then evaluate the fully-integrated system, through the use of the developed GUI shown in Fig. 4. The two received waveforms from the two Rx antennas are shown on the left side of the screen, while the corresponding DoA is found on the circle on the right. Fig. 5 (a) shows the layout of the integrated receiver system, which comprises of the Rx antenna array mounted on the cylinder, two Rx boards, PLL, power module, ADC board, and the FPGA board. As the final evaluation at the system level, students are required to demonstrate the working system to a panel of internal jury members, besides recording and publishing a YouTube video [13] to be evaluated by contest judges. Fig. 5 (b) shows a snapshot of the demo video, where the receiver system is successfully rotating towards a handheld transmitter.

F. Lessons Learnt

Since the receiving antenna needs to be conformal, i.e., made from textile, whereas the transmitting antenna is designed to be mounted on a base station, identical antennas could not be designed for both purposes. During intermediate presentation, it was noticed that both antennas were not designed to radiate with similar polarization, i.e., receiving antenna with Righ-Hand Circular Polarization (RHCP) and transmitting antenna with Left-Hand Circular Polarization (LHCP) due to a misunderstanding. This is expected to have an adverse effect on the overall system performance, but fortunately there was additional time for a re-design process to be performed. The lesson learnt here is that students should communicate more in understanding and defining specifications to ensure proper system operation.

An issue faced by the Circuits micro-group was a PLL design which did not work up to the required specification. This was detected at the integration phase, as the whole system performance was degraded upon testing. This suspected hypothesis was then confirmed when an input signal generated using a commercial source was used to test the system, and the system was proven to be working as it was supposed to. The lesson learnt by the TAs and students was to start system integration earlier than scheduled to ensure sufficient additional time to resolve such issues. Moreover, an additional problem faced in the same group was a damaged receiver, broken after several tests, believed due to excessive power. Due to the damaged circuit, the root-cause was not clearly determined. However, they were replaced by additional backup boards which were fabricated simultaneously together with the original boards. Thus, besides the importance of allocating additional time for troubleshooting and integrating new components into the backup boards, the lesson learnt here is that additional budget must be allocated for backup boards to be fabricated.

On the other hand, one difficulty faced by the System micro-group was that they realized the ADC board's interface did not match the FPGA development board's interface standard. This problem

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was seen during the components' assembly procedure, and the solution was to bypass the board and connect the signals directly to the FPGA using wires. Although this might not be the best solution, this has practically proven to be working. From this, the students realized that different interface standards exist, and this should have been checked more thoroughly during the components' selection process. Practical problem solving and troubleshooting skills were also proven crucial in solving this issue.

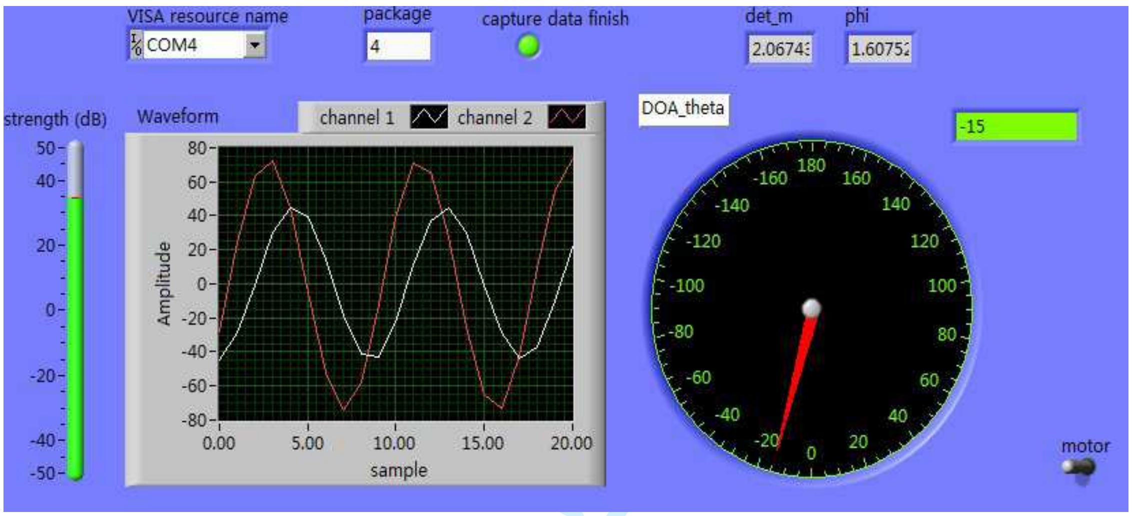

Fig. 4. Screen shot of the Labview interface. (Figure updated)

Fig.5. (a) complete receiver system setup (b) integrated system under test in a real environment

V. Empirical Assessment

A. *Course Learning Objectives*

One of the most well-known technical education frameworks is the ABET2000 criteria [9]. They have been combined to suit KU Leuven's Guided Independent Learning (GIL) [8,14] objectives, resulting in a set of specific CO for this P&O course. At the end of the course, students are expected to be able:

1. to analyze the basic tasks using given specifications
2. to perform further simulations and analysis which lead to suitable component selection and schematic design
3. to physically realize the designed components/blocks/schematic through the use of their own-designed or commercial components
4. to integrate and test the overall designed system
5. to analyze, report and document results and findings.

All these COs are in accordance with the Program Learning Outcomes (PLO) for Master of Electrical Engineering at KU Leuven, as listed in Table III.

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TABLE III: PROGRAM LEARNING OUTCOMES: MASTER OF ELECTRICAL ENGINEERING AND THEIR RELATION TO ABET2000 CRITERIA 3

No.	PLO	From ABET	Addressed by CO
1	Ability to independently acquire and apply knowledge in a creative and innovative way in the process of problem solving.	(a) (e)	2, 3, 4
2	Ability to understand technological aspects and possibilities for application implementations	(e) (h) (j)	1
3	Ability to select, for various types of applications, the most suitable electronic platform (hardware/software), and is able to implement the application.	(b) (c)	2,3
4	Ability to design building blocks and systems for telecommunication	(b) (c) (k)	2,3
5	Ability to understand, reformulate and evaluate applications with regards to optimal implementation and performance	(e) (k)	2, 3, 4
6	Ability to communicate and work efficiently in a team	(d) (f) (g)	4, 5

B. Students' Assessment

The students' course evaluation is categorized into two sections gathered through an online blind survey form. In the first section (Q1 to Q7), shown in Table IV, students are asked questions related to their personal opinions and experiences. The second part, i.e., Q8 to Q13, is focused on assessing the course effectiveness in terms of program and course outcomes. The five possible answers are rated from 1 to 5: strongly disagree, disagree, undecided, agree, and strongly agree. The process of assessment was blind and voluntary. In total 9 out of 12 students participated in the process. Table IV shows a mean rating above 3 (agree) and an overall average of 3.64 (agreeing more than being undecided), from the nine responses gathered. Moreover as can be seen in Fig. 7, most of the answers are confined around 4 (agree) which shows a confined opinion distribution among students.

However, from the first part of the survey, it can be observed that the TA's supervision quality can be further improved (Q6 in Table IV). Moreover, the lack of students' understanding regarding the project specifications and requirements at the initial stage (Q5) requires the improvement of the info session in future semesters. The varying opinions is most likely to be caused by a general evaluation across all TAs rather than individual assessments of each TA. On the contrary, the limitation of having a personalized TA evaluation will almost certainly decrease the level of anonymity due to the small number of students supervised by each TA. This, in turn will then hinder students from responding to the survey. From the second part, responses to Q9 and Q11 indicated that some students are still not so confident in designing and realizing a simple system, on both the block level and system levels. This is due to the fact that students in each macro-group are usually overshadowed by a more skilled one, a drawback on which TAs must be cautious about.

C. Micro-Group Tasks

Besides overall course outcomes, the TAs have also designed their respective macro-group syllabus for the first three weeks of activities. The outcomes listed in these activities are carried out to enable the achievement of the overall course outcomes, besides introducing the more specific technical skills required, and to facilitate students in carrying out their more specialized tasks. These activities are shown in Table V.

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D. Assessment Procedure

All students are evaluated based on three qualitative criteria, personal performance, micro-group achievement and group achievements, each of which has 50%, 25%, and 25% of the total grade respectively. The decision on grades is finalized in an evaluation meeting during examination period. The conclusion is based on the TA's observations, the Professors' remarks on the three presentations and a final written report submitted by the macro-group at the end of the semester.

TABLE IV: COURSE ASSESSMENT CRITERIA/INSTRUMENTS

Symbol	Question	Score/5
Q1	The project topic was interesting.	4.11
Q2	This course was interesting	3.77
Q3	The available time and man power were suitable for the project size.	3.55
Q4	The lab facilities were sufficient to carry out the project	3.55
Q5	The course information provided in the beginning of the semester was satisfactory.	3.00
Q6	The TA's supervision during the project was sufficient.	3.11
Q7	I will recommend this course to other students.	3.55
Q8	I have a better understanding of functions of each telecommunication building block and the whole system in general.	4.33
Q9	I have a better understanding of design constraints, trade-offs between telecommunication building blocks through the use of simulators and other aids	3.44
Q10	From the block's design constraints, I am able to select components to satisfactorily realize a telecommunication block's requirement/specification.	3.66
Q11	Using the most suitable components, I am able to realize and evaluate the designed block's performance.	3.33
Q12	I am able to analyze and technically report (orally and in written form) results that have been gathered through this project.	3.89
Q13	I am more confident in communicating and working in a team of engineers in the future.	3.89
Avg.		3.64

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Student's personal performance assessment is carried out on a two-fold basis. Firstly, marks are given based on the TAs' personal experience related to attendance, pro-activeness, technical and team-work ability, working flexibility and responsibility. Secondly, their personal performance is also judged by Professors based on each student's contribution during presentations and system demonstrations.

TABLE V: MICRO-GROUP TASKS/ACTIVITIES FACILITATING THE ACHIEVEMENT OF THE COURSE OUTCOMES FOR THE FIRST THREE GUIDED SESSIONS

No.	Micro-group tasks/activities	Related COs
A	Antenna Micro-Group	
A1	A review of the antenna parameters (reflection coefficient, gain, bandwidth, efficiency, radiation pattern), the Friis equation, and safety/regulatory specifications	1
A2	A microstrip antenna design using CST Microwave Studio	2
A3	Decide and design on the best transmitting/receiving antenna polarizations for the system	2
B	Circuits Micro-Group	
B1	System-level verification of the RF part: determining the best RF architecture, determining the best RF/IF frequencies	1
B2	Interpreting components' datasheets and specification considerations, balancing performance and price	2
B3	RF PCB layout and its considerations	2
C	Systems Micro-Group	
C1	A study of Direction of Arrival (DoA) estimation basics	1
C2	Embedded system design: Designing a hardware arithmetic calculator in VHDL	2
C3	Generation of two sine waves in MATLAB with different phase and displaying it	2
C4	Comparison and phase difference calculation of the generated MATLAB waves using LabView	2
C5	Understanding and investigation of advanced DoA estimation algorithm (e.g. MUSIC)	2

For the second evaluation, every micro-group is evaluated based on their success in accomplishing their respective task. Besides, inter- and intra-micros-group collaboration are also assessed based on TA's personal observations and the Professors evaluation of each micro-group final report and presentations. It is not compulsory that all micros-group members must receive a similar grade for this evaluation.

The final part of the assessment is to judge the entire group's achievement in realizing the whole system as initially planned. Besides judging based on a 'yes' or 'no' basis, the complexity of the defined project is also considered. The final results are rounded to the nearest integer, with a maximum of 20 points.

Detailed marks for each student from the three micro-groups are depicted in Fig. 6. The macro-group performance is graded equally for all 12 students, and similarly, students from the same micro-group receive equal marks. One exception was with the Antenna micro-group, as students' performance was observed to be significantly distinct by all TAs. All 12 students passed the minimum threshold of 50%, including marginal passes by two students. As reflected in the graph, student no. 7, who possesses an outstanding technical knowledge and eventually led the whole macro-group to achieve their objectives, was awarded the highest grade in this case study.

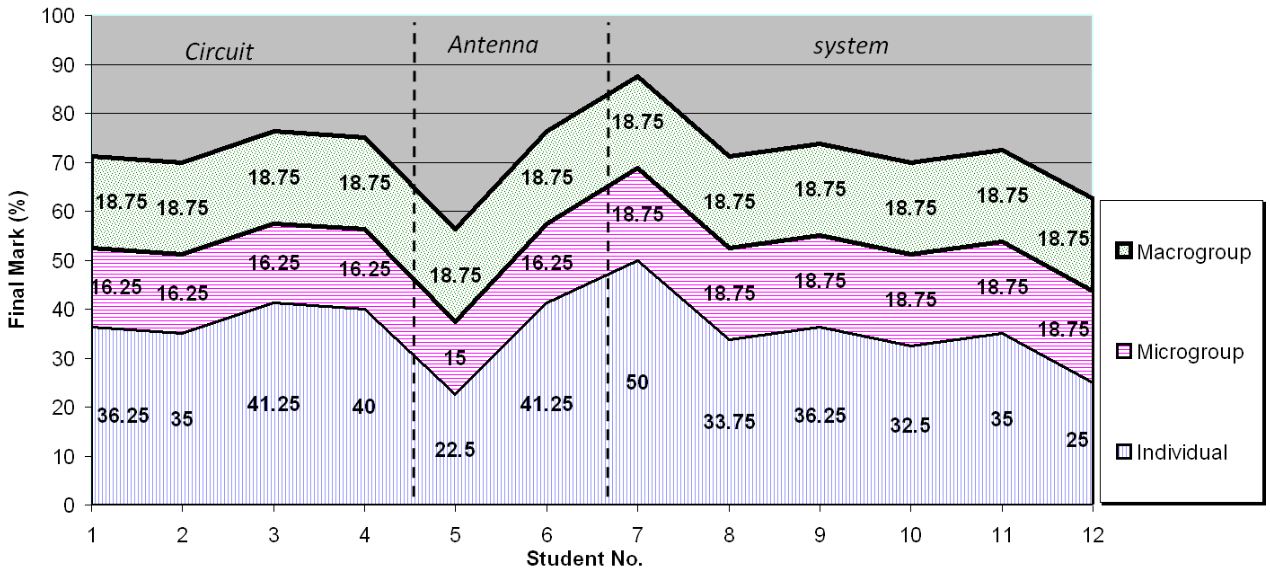

Fig. 6: Student's detailed results, individual, (micro/macro) group and final marks

VI. Conclusion

This work presented a successful implementation of a project-based graduate design course in Telecommunication Engineering. A combination of technical and soft-skills within this course enabled effective GIL, complemented by technical knowledge application which was acquired from classroom learning. From the empirical course assessments and students' exit survey, the implemented educational activities, both at the micro-group and macro-group level satisfied the intended Program Learning Outcomes and Course Outcomes.

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