A Teamwork-based Education Strategy for Teaching Lab of Analog Integrated Circuits Design

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***Abstract*— This paper describes the education activities carried out to motivate students enrolled in a laboratory course focused on the design of analog CMOS integrated circuits. Instead of using the traditional method based on doing practical exercises, a teamwork methodology was followed that consisted on a chip design project implemented by a group of students, each one playing a different role in the design team and being in charge of different tasks. A short training period at the beginning of the course was used for a preliminary assessment of students in order to assign their task and role in the design project. One of the students was selected as the project manager, while teachers acted as project reviewers. A set of control mechanisms, including internet-based videoconferences and chats, was established. These tools allowed students to coordinate their activities and also were used by professors to check the work in progress during the course – apart from those review sessions taking place on-site in classroom. As a result of all these initiatives, students become more encouraged to do the practical exercises required to fulfill the course objectives and – at the same time – they developed and improved other complementary competencies, like the ability to work in a team and to defend their work by means of oral presentations.**

Keywords: teamwork-based education; learning with case studies.

I. INTRODUCTION

Nowadays the use of information and communication technologies is extended to a large and growing part of the world population. The increasingly number of consumer electronic devices is transforming the lifestyle of billions of people all over the world and this trend is set to continue. However, in spite of living in a very technological society, the interest for engineering studies is continuously decreasing, especially in western and rich countries. The high living standards – that make it easier to get well-paid jobs – together with the lack of motivation in young people for studying technical contents that involve an extra effort, are behind the reasons for the loss of interest for engineering studies [1].

This situation represents a challenge for the university community in general, and particularly for engineering professors, who have the responsibility, on the one hand, to teach technical skills, and on the other hand, to make their courses attractive for students. From this perspective, teaching engineering should be focused not only on training in technical theoretical contents – which of course are important and essential – but also in other complementary skills which are also critical in a professional engineering career, like social skills, management, leadership, teamwork, etc. An interesting approach to achieve all these learning objectives is the so-called project-based education, in which students are grouped in teams and trained to work together to fulfill the course objectives presented in form of an engineering project [2], [3].

The work in this paper contributes to this topic and presents the author experiences in the last years on applying a teamwork-based methodology to teach lab courses of analog CMOS integrated circuit design. The course contents consist of a set of lab exercises focused on the design of basic and advanced CMOS analog and mixed-signal building blocks. These contents are structured around a set of specific objectives, which are linked to tasks and work packages, given to the students as an engineering project. To this end, a work plan – synchronized with the four-month course period – is defined by the teacher, who plays the role of the project reviewer, and one of the students – selected according to a previous assessment – acts as the project leader.

Different circuits and systems, including signal conditioning, filtering and data conversion, have been designed over the years in order to put the proposed methodology in practice. In all cases, students are encouraged to be an active part of the course by applying the knowledge learned in previous (theoretical) courses, and working together towards the com- mon objective of designing some case-study circuits – from specifications to layout. To this end, on-site lab sessions are combined with web-based coordination mechanisms available in the e-learning WebCT (“Web Course Tools”) platform [4]. The assessment of the course has three components: the daily monitoring of students activity, the evaluation of a design report written by all students and an oral presentation of their work. The latter is also used to evaluate the contribution of each student separately.

The lesson learnt from the presented education experience is that students become more motivated and satisfied than following a traditional lab course, what translates in higher grades in the majority of students.

II. COURSE STRUCTURE AND OBJECTIVES

The teamwork-based education methodology presented in this paper has been implemented in an undergraduate lab course named Laboratory of Advanced Microelectronic Cir-

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cuits (LabAMC), which forms part of the final year syllabus in an Electrical and Electronics Engineering bachelor degree. The course is given in a 15-week class period, taking 3 hours a week, which corresponds to 4.5 European Credit Transfer System (ECTS) practical credits.

The contents of the course are structured around a set of practical lab exercises and organized in the following parts:

- *Part I: CAD tools*, where students do a set of tutorial exercises to learn how to use essential design CAD tools, including electrical SPICE-like simulators, layout edition and verification (DRC and LVS) tools, etc.
- *Part II: Basic building blocks,* covering the design from specifications to layout of fundamental building blocks like operational amplifiers, transconductors, biasing circuits, switches, comparators, etc.
- *Part III: Advanced analog circuits and systems,* that cover the design of more complex analog and mixed-signal circuits such as analog-to-digital converters, filters, etc. which are based on the building blocks designed in Part II.

The aforementioned contents can be taught following a conventional methodology based on doing lab exercises, which cover the contents of the different parts of the course. Instead of that, the approach in this work aims at teaching students the same contents and practical design issues, but structured around a practical case study, where students can put their theoretical knowledge into practice by solving the different design problems involved in a real project.

Therefore, the main objective is to transmit students the practical contents by means of facing up a real, practical situation in which they may find themselves while engaging in their future professional activity. The case study involves the design – from system-level to layout – of a circuit, just as if the students were a team of engineers working on an industrial project. The teacher will provide the functional specifications for the chip, will allocate tasks to each student and will review the work progress in order to be carried out during the term. These specifications and the corresponding project work plan cover the LabAMC course contents and learning objectives.

The idea is thus to encourage teamwork as a real, effective means of executing engineering projects in the field of Microelectronics. The activity will also push students to make greater use, in both physical and virtual environments, of advanced CAD tools for the design of analog and mixed- signal integrated circuits and to exploit telematic computing and laboratory resources. The aim is to make full use of all the potential of Information and Communication Technologies (ICTs) to provide key knowledge of the core content in each subject being studied and to develop transversal skills in those subjects.

The fulfillment of the aforementioned objectives will be complemented by the following partial objectives:

- *To encourage active student participation and coordination using the tools available in the WebCT e-learning platform*, such as chats, virtual tutorials, etc. As the proposed educational approach involves working on small (4-month term) engineering projects, it becomes necessary to schedule the tasks associated to these projects and synchronize them with the classroom syllabus being followed during the academic year. Moreover, control sessions must also be programmed in which students progress in these tasks can be monitored, both in class (through oral presentations) and in virtual forums.
- *Creation and updating of didactic material on the course WebCT platform,* at different levels. This includes transparencies of all the material presented in classroom, computer simulation results, technical documentation and progress reports written by students, links to related web sites, etc.
- *Use of bibliographical databases related to the Electronic Engineering degree course,* especially the IEEE Xplore. The objective here is twofold. The first aim is to familiarize students with using an updated bibliography which will keep them informed about the latest developments affecting their professional activity, and the second is to encourage students actively to participate in the subject by using their own initiative to choose those papers, technical-scientific documents, standards, etc. they need to further their knowledge of the tasks they have been assigned as part of the circuit design project.
- *Encouragement of bilingualism,* mainly by using didactic and bibliographic material in English and communicating in English in the debate fora mentioned above.

All these objectives can be satisfied by following an appropriate teaching methodology as described in the following section.

III. Specific Goals and Methodology Approach

The working methodology proposed in this work is fueled by the following lines of teaching improvement:

- *Study and experience of new teaching methodologies.* This is one of the priority concerns in this work, because the proposal is to change traditional teaching methodology, based on laboratory procedures for an experience comparable with a real project – in this case the design and layout implementation of an integrated circuit – involving all the students in a working group.
- *Methodological change geared towards the acquisition and evaluation of general skills,* which are complementary to subject-specific skills. In this teaching initiative, the students learning experience is improved through the development of transversal, complementary skills, such as analysis, synthesis, organization and planning, a solid professional grounding, the ability to analyze data from different sources, decision-taking, team-work, interpersonal

skills, the capacity to apply theory to practical situations, research skills, quality awareness, etc.

- *Use of active teaching methodologies* (case methods, problem-focused learning, learning through projects, etc). The work carried out in this education experience is in fact based on the study of a practical case as a method of learning. It helps students learn about analog and mixed signal CMOS integrated circuit design (one of the main objectives in the LabAMC course) via the real execution of an Electronic Engineering project, which involves working together as a team to design a chip.
- *Design of new, practical teaching activities, which will encourage an interdisciplinary approach.* The subjects covered in this educational experiment are eminently practical. They are aimed at helping students not only to put their theoretical knowledge into practice but also to develop complementary skills which will enable them to perform their professional tasks correctly in the future. In particular, students are encouraged to work as part of a team, assume their responsibility for specific tasks, present their work in class and participate in virtual forums to discuss the topics that have to be covered.

In order to put the proposed learning methodology into practice, the class period is structured as follows:

1) *Training period.* During the first three or four weeks, students do simple lab exercises and tutorials of those CAD tools that will be used in the course, including electrical simulators, layout editors and verification tools. For each exercise, students must write a brief report including an introduction, procedure, results and discussions.

2) *Selection of project leaders and teams*. At the end of the training period, students make a short (10-15 min.) oral presentation about their individual work and teachers may ask questions about the procedure followed and the problems found. Based on this presentation, the quality of written reports and the daily monitoring, those students who will play the role of project leaders will be selected and the rest of students can be grouped in teams of less than 5 students each one.

3) *Presentation of project topics and tasks assignment.* Once the students have been grouped in project teams and the project leaders have been selected, teachers make a presentation in class about the different topics and projects to be carried out during the course, defining the objectives and work plan according to the course schedule. After this presentation, projects are assigned to the different teams according to the preferences shown by those students acting as project leaders, who have previously agreed with their respective teams. Project tasks are assigned to every student. This is an initial assignment suggested by teachers and discussed with project leaders and students. However, this is something that can be modified during the course whenever it is necessary.

4) *Control sessions.* Every three weeks, a control session takes place in classroom in order to check the work progress of every project. To this end, every project team makes a presentation of their activities in the last three-week period, their milestones, results and problems. All students must present the results of the tasks they are in charge, while those students acting as project leaders must make the overall presentation, summary of main results, planning issues, etc. In each control session, students report to the teacher how far they have got with the work, what problems they have encountered at each stage of the same and how they plan to complete the task. They also have the opportunity to ask questions and clarify any doubts, and to conduct (global or partial) collaborative sessions to coordinate the different tasks needed to complete the project.

5) *Internet-based control sessions.* Apart from these control sessions held in classroom, a daily monitoring of the work in progress is carried out during all the course. In addition, other telematic control mechanisms can be eventually used, like chats, videoconference over the Internet using the WebCT platform or other specific software for that purpose. Of course, these media are also used by students during the course to hold project internal meetings. Those students acting as project leaders are in charge of organizing and coordinating these activities as well as keeping teachers informed.

6) *Final evaluation.* At the end of the course period, a final project report must be written for every project and a final review session is held in order to evaluate the results obtained. All students must participate in the oral presentation and they must answer the questions made by teachers. The final individual assessment consists of three components: the daily monitoring of each student, the final project report, the overall final (and control-session) presentations and the individual contribution of each student to the oral presentations. Those students acting as project leaders may increase their marks up to 2 points out of 10, depending on how they managed the coordination activities in their teams.

IV. EXAMPLES AND RESULTS

A number of different projects have been carried out by students in the last academic years, including analog front-ends for telecom systems, signal conditioning circuits, analog-to-digital converters, etc. As an illustration, Fig. 1 shows the schematic of an active-RC filter with a programmable bandwidth, which was designed and implemented in a 0.35μm CMOS technology during the academic course 2009-2010. Fig. 2(a) shows the extracted layout of the operational amplifier used in Fig. 1 and Fig. 2(b) shows the entire layout including bonding pads. The circuit was completely designed and verified within a 10-week class term, and considered the effect of circuit parasitics and technology process variations.

In addition to the circuits designed by the students within the framework of the project-based learning approach, the activities carried out as part of this educational research experience have also contributed to improve the *virtualization* of the LabACM course, giving rise to a significant increase of the materials and resources available on the WebCT. This way, the learning material incorporated in the WebCT includes the following sections:

- *Learning modules,* which comprise different thematic blocks grouped by the topics covered in the course and containing both teaching material (notes, seminars, audio-visual presentations, bibliographic references, database links, etc.) and learning material (self-correction questionnaires, distance learning theory classes, tutorial exercises, etc.).
- *Seminars:* Apart from theoretical seminars, practical seminars are also included in the WebCT of the course as part of the training resources provided to students. These seminars are geared towards explaining the use of the CAD tools used in the course, which go from system-level (behavioral) simulators to electrical simulators to layout editors and DRC/LVS verification tools, etc.
- *Simulation examples* in order to help and guide students, particularly during the training period.

CONCLUSIONS

An educational approach based on the combination of teamwork methodology and project-based collaborative learning has been presented. The proposed method can be used as an alternative to teach and learn lab courses, which have been traditionally structured around a set of lab exercises. As a case study, the approach described in this work has been applied to an undergraduate course named Lab of Advanced Microelectronic Circuits, which forms part of the Electrical and Electronic Engineering degree syllabus at the University of Seville. According to the author's experience, students attending this course became widely satisfied and motivated with the proposed learning experience and got good grades.

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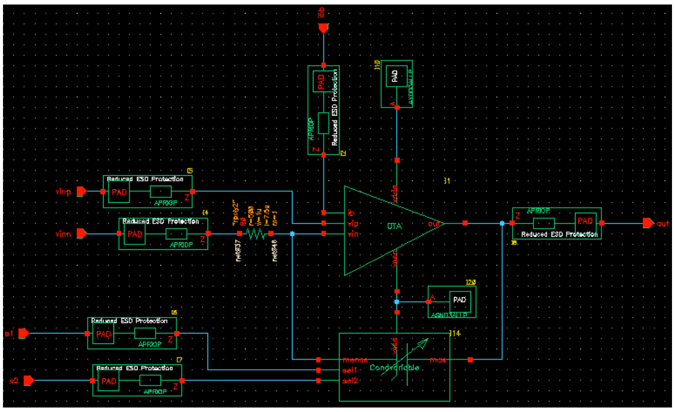
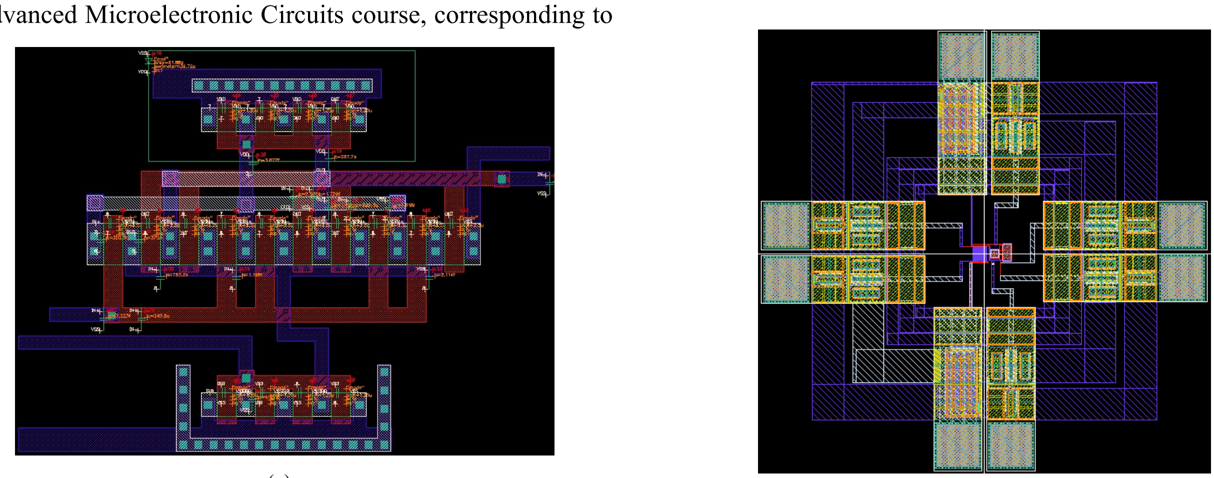


Figure 1. Schematic of a 0.35μm CMOS active-RC integrator designed by the students in classroom.



(a) (b)

Figure 2. Examples of layout designed by students in classroom. (a) Operational amplifier. (b) Active-RC integrator with bonding pads.