INTRODUCING CAD TOOLS FOR ELECTRONIC DESIGN USING A COMPETITION BASED EVALUATION METHOD

I. Adin[1], G. Bistué[1], I. Gutierrez[1], J. Mendizabal[1], R. Berenguer[1]

[1] *Electronic and Communication Department. CEIT and TECNUN - University of Navarra. Spain.*

iadin@tecnun.es, gbistue@tecnun.es, ingutierrez@tecnun.es, jmendizabal@tecnun.es, rberenguer@tecnun.es

This paper presents the course of Laboratory of Electronic Circuit Design offered by TECNUN (Escuela de Ingenieros de San Sebastian – Universidad de Navarra). The aim of this course is to bring the student closer to the professional electronic circuit design world .The methodology of this practical course is innovative. The educational resources used consist of a professional CAD tool for electronic design (Cadence), the use of English as the "official language" of the course, 8 practical cases, 3 competitive challenges among the students and Figure Of Merits (FOM) for the evaluation of these milestones. The course is laid out following a progressive learning curve, after which the students are highly prepared to link the theoretical trends to real circuits, and combine basic blocks to build complex circuits such as Operational Amplifiers. The good results obtained by the students in the final year exams, in front of designers' panels or even in the polls conducted at the end of the term are the best guarantee of the success of the methodology here presented.

Keywords: laboratory, Electronic design, Professional CAD tool, competition.

1. Introduction

It is widely accepted nowadays that the key to the success of an engineering training programme is the balanced combination of theoretical and practical courses. The former must provide the appropriate background to fully understand the physical processes involved in each subject, as well as developing the analytical tools and methods needed to calculate different magnitudes. Obviously, the aim of the practical courses should be the application of the concepts previously introduced to real case situations. However, on many occasions it is extremely difficult to reproduce a true industrial environment inside the walls of a lecturing room.

In the field of electronic circuit design, the recent evolution of CAD tools offers new possibilities to training courses. Not so many years ago, CAD software required expensive workstations and computer networks. Today a simple network of PCs is powerful enough to run last generation professional tools. Therefore, time has come to innovate the methodology of practical courses, trying to add a professional edge in order to bridge the gap between the academic world and the real application of knowledge.

In this paper, the course of Laboratory of Electronic Circuit Design (4,5 credits) is presented. The course is included in the Telecommunications degree offered by TECNUN (Escuela de Ingenieros de San Sebastián – Universidad de Navarra). This course takes place during the second year of the career, in the spring semester. The students have previously completed the course titled "Electronic Circuit Design",

during the autumn semester (4,5 credits) of the second year, which aims to develop the ability of the student to analyze and design discrete and integrated electronic circuits, from basics of the transistors to basics building blocks and techniques.

In Section 2, main course aims are described. Next section is dedicated to the explanation of the activities carried out at the laboratory throughout the course. Section 4 shows the evaluation method, in fact one of the innovations hereby presented. Finally, conclusions are enunciated in the last point with the recommended bibliography [1-5].

2. Course Aims

Evidently, the aims of the laboratory have to go one step beyond on the technical field, but also on the practical skills of the students. The main concepts of the theoretical course are reviewed, but the use of professional CAD tools for electronic circuits design brings major improvements to the understanding of the ideas. This is the clue of the real world design: taking control of the basics as the origin, the students are highly capable to build really complex compositions by their own. This learning is provided through the teacher's lessons and advices but also thanks to the comparison and kind competition with their classmates, as will be explained in the *working methodology* and *evaluation* sections.

The intermediate aims pursued by this course are:
- They have to be able to use the CAD tool without limits.
- They have to be capable to simulate any block and obtain the most common output characteristics.
- They have to understand all the concepts of the basic blocks and have to be able to link these blocks to form more complex circuits (as in a real market product).
- They have to know how to achieve the proposed results for any circuit, thanks to the variation of the parameters of the elements of the circuit.
- They need to make sure they have understood their own design process and have to express the steps as well in the reports as orally to their classmates and teachers.

Moreover, this course tries to change the mindset of its attendees, i.e. they have to change the way they face other courses. Up to this point, they have worked following the, let's say, classical academic problem-solution flow. You have a problem, you are given all the input data; and you apply a calculation method in order to find some particular parameter.

This method does not always work and it is part of our course work to ensure they change they mindset and thought process. In a true working environment, we need to view things not as a problem but as goals to achieve. These goals are usually handed as specifications, and can be as diverse as the value of gain, power consumption, cost or even a particular technology. And we must find an appropriate circuit that fulfils the expectations.

In many instances, the specs don't determine the entire solution, and during the process we must incorporate design choices. With this approach we can achieve many solutions, depending on our design process. For example, we can obtain the cheapest solution, or the circuit with the highest gain… but we could also end up with a completely useless circuit, a total waste of time and money. This learning aim can be achieved using an appropriate evaluation method, in which creativity, working group capabilities and other features are integrated as part of the final mark. The language used during the entire course is English, which is also an asset for the education of the students for the future real working environment.

3. Labs Description

The course is composed of 8 practical cases with a rising complexity between 3 milestones. This progressive learning, shown in Figure 1 has an effect on the students, as it gives the idea that any final product is built of several basic blocks correctly interconnected for a common aim. The participants in the course have previously acquired the capability of simple circuit analytic calculation, and here they are guided to tackle more complex designs. The apparent complexity of dealing with circuits with several transistors disappears as the building *block* concept is developed. This also helps to focus their attention on higher aims, as the self-confidence is a key point in any design activity. Table 1 presents the content of each practical case.

Table 1. Laboratory of Electronic Circuit Design programme

	Description
LAB 1: MOS TRANSISTOR	Analysis of NMOS transistor. Extraction of main characteristics (transconductance and output resistance)
LAB 2: CURRENT SOURCES	Study of different topologies of current mirrors, Wilson Scheme
LAB 3: COMMON-SOURCE AMPLIFIER	Main characteristics of a common-source stage, selection of an appropriate DC operation point and its implementation in the circuit, DC, AC and TRAN analyses: advantages and limitations, procedures for the determination of the gain of the circuit
LAB 4: COMMON-SOURCE STAGE OPTIMIZATION	Cascode configuration, Mid frequency optimization, Active charge, Narrowband amplification, LC tank
LAB 5: COMMON-DRAIN STAGE	Characteristics and optimization of the common-drain stage, design of a multistage amplifier
LAB 6: NON LINEAR AMPLIFIER CHARACTERIZATION	Methods to calculate 1-dB compression point and output spectrum, improve the gain and linearity of an amplifier
LAB 7: DIFFERENTIAL AMPLIFIER	Optimization of the differential amplifier, simulation of circuits with differential signals
LAB 8: MULTISTAGE AMPLIFIER OPTIMISATION	Application of the rest of labs to the design and optimization of multistage amplifiers – Operational Amplifier

As said in the aims of the course, the students have to prove that they have caught all the concepts of the basic blocks, and they compete among each others trying to achieve the aims set by the teachers for the 3 challenges of the course: the 3 main complete designs: "the real current source", "the Low Noise Amplifier" and "the Operational Amplifier". These 3 milestones of the course represent a competition among the students, which pushes them to a real understanding of the schemes in order to reach the better figures. The two results of this kind competitive ambient are the stimulation of the optimization of each single block and the use of alternatives for any single part of the real and complex circuit. This is, furthermore, highly recommended to distinguish themselves in comparison to their classmates.
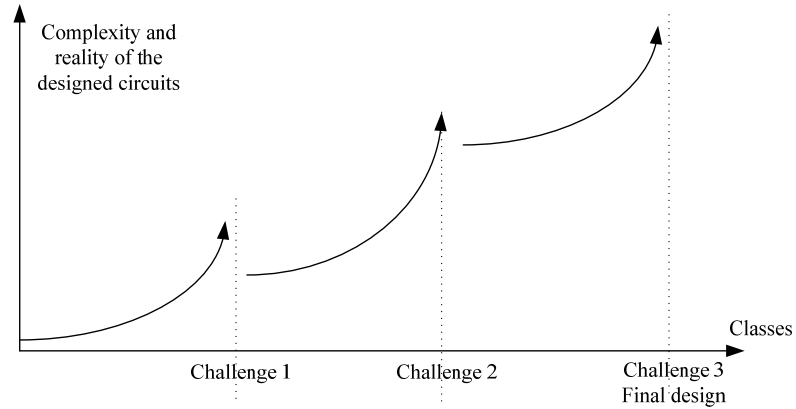
Figure 1: Progressive learning during the course

Not only the CAD design tool is taken from the professional design world (CADENCE in this case), but also are the aim levels of the complex circuits designed. Each Challenge is set out with an output Figure of Merit (FOM) taken from the up-to-date state of the art. This helps in the comparison of the results among the groups because the diversity is normally high. But this is also part of a major lesson for the students: The electronic design is a constant trade-off among the output parameters.
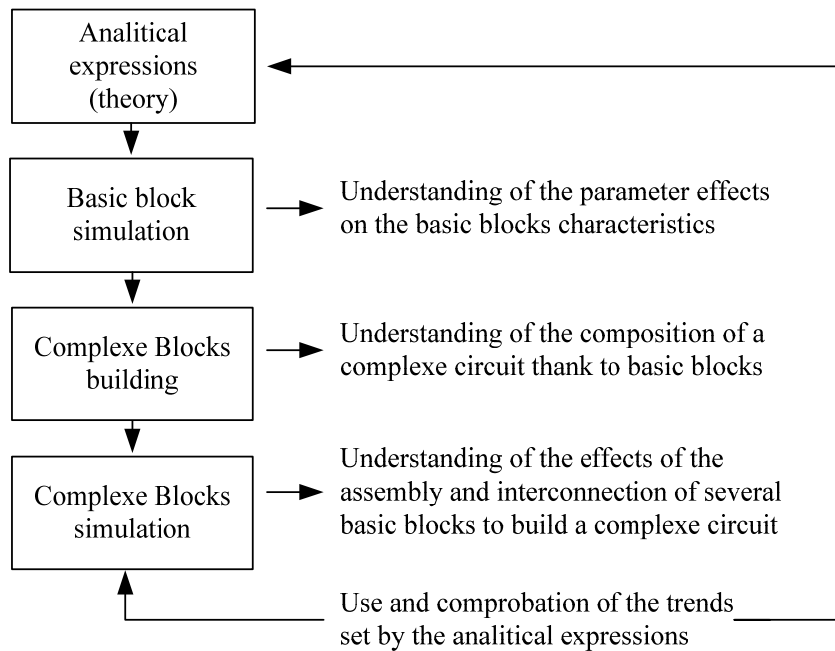
For instance, for integrated Low Noise Amplifiers, the most common output parameters are Gain (in dB or converted to an absolute figure), Noise Figure (in dB or also as an absolute figure), 1dB Compression point for the Linearity (in dBm or converted to mW), Power consumption (in mW) and working Bandwidth (in MHz). It is clear that the relationship among these parameters can not follow the pursued win-win strategy, since, for instance, a higher gain is normally followed by a higher power consumption, or a higher 1dB Compression point normally produces a gain decrease for the same power consumption. The expression used in this case is the following one:

$$FOM_{LNA} = \frac{Gain(abs) * 1dBComp(mW) * Bandwidth(MHz)}{(NF(abs) - 1) * PowerConsumption(mW)} \tag{1}$$

The trade-offs are needed and the students have to assesss the efforts used for each field, which is also a time-effort trade-off.

4. Design practical cases description

Each practical case, the 3 challenges and the other common ones, has the same composition. The steps and the partial aims are presented in Figure 2.

```
┌──────────────┐
│  Analitical  │◄──────────────────────────────────┐
│  expressions │                                    │
│   (theory)   │                                    │
└──────┬───────┘                                    │
       ▼                                            │
┌──────────────┐                                    │
│  Basic block │──►  Understanding of the parameter effects
│  simulation  │     on the basic blocks characteristics
└──────┬───────┘                                    │
       ▼                                            │
┌──────────────┐                                    │
│Complexe Blocks│──► Understanding of the composition of a
│   building   │     complexe circuit thank to basic blocks
└──────┬───────┘                                    │
       ▼                                            │
┌──────────────┐     Understanding of the effects of the
│Complexe Blocks│──► assembly and interconnection of several
│  simulation  │     basic blocks to build a complexe circuit
└──────▲───────┘
       │             Use and comprobation of the trends
       └─────────────set by the analitical expressions───┘
```

Figure 2: Practical case flow

As it has been explained in the previous section, the CAD tools are really useful for the student as they permit the student to check the theoretical expressions and they illustrate graphically their considerations and their suppositions. The basic building blocks may be easily understood, because the number of elements is usually low. But what happens when we have to deal with several blocks interconnected among them? Are they behaving as they did when analyzed and simulated by their own? The professional tools work with the real models for any element of the circuit (normally diodes, transistors, resistors, capacitors and inductors) and hence provide the most accurate results. It is really useful to go one step beyond and face the circuits far away from any simplification.

Consequently, the students who work with these CAD tools can check what would be the output parameters of the most complex circuits only by playing with the properties of the elements. The chance here given creates a favourable atmosphere for the design, for a positive nerve for investigate and, which is the main aim of the University. Some unforeseen alternatives have been tried successfully by the students during the challenges, which is the biggest pride for a teacher.

Each practical case is guided during the basic block simulation in order to set what are the parameters that influence the output characteristics. This gives the student the idea of how to play individually to reach the later proposed aim. This is permanently linked to the basic working theory of each single block, remembered by the teacher.

Then, with the most complex composition built in the third step, the students have to be able to simulate the complete circuit and to know how to tune the diodes and transistors' parameters and the values of the passive elements to achieve the aims set.

The final reports gather solutions and considerations for the 4 steps:
- The development of the theoretical expressions of the blocks studied in the practical case.
- Tables with output characteristics depending on the guided combinations for the elements' parameters. This culminates in the written conclusions of the effect of the parameters on the output.

- The final circuit scheme to check the blocks' interconnections.
- The final results in comparison to the aims set, and the steps followed by the designer to reach these figures.

In the case of the challenges, as said in the previous section, there is, moreover, an extra step which is the competition among all the groups.

5. Evaluation Method

According to the general aims of the course, the evaluation of the work is carried out combining several exercises, in order to assess the progress of the students on different levels: Personal understanding of fundamentals, joint work capabilities or efficient time management. The use and understanding of English is taken for granted as they are future engineers.

Three main exercise categories are used throughout the term: Labs reports, Challenges and Final Exam.

5.1. Lab reports

After each practical case has been completed (usually 2 or three sessions), students must fill a pre-defined form with several questions about the design and optimisation of the circuit. The form has two parts: In the first one, questions cover the theoretical and analytical approach to the circuit under study. The second part is dedicated to the description of the practical work carried out with the CAD tools. The aim of these questions is to provoke students to find the relation between theoretical and practical work, and also to fully understand the raw data provided by the simulations. Ultimately, these forms contain the basic material needed to prepare the rest of evaluation tests.

5.2. Challenges

In these exercises the students must face a real case design scenario, within a limited time frame. Work is carried out in pairs. Usually, the same set of specs is given to all the groups. Depending on the circuit, a set of FOMs (Figure Of Merit) is also defined. Once the design exercise is completed, each group must present the design flow and the obtained results to the rest of the class and to a special panel of designers. During these presentations, the designs are evaluated and the best design is awarded an extra point.

5.3 Final Exam

At the end of the course, an individual exam is carried out. The aim of this exercise is to validate the rest of the tests performed throughout the course. This exam consists of a reduced design case and a short question type test. It is mandatory to obtain more than 5 points out of 10 in each part in order to pass the course.

6. Conclusions

The inclusion of competitive tests has proven to be an effective resource to improve students' interest in the course. Compared to the traditional exam, the Challenges are powerful methods to assess the overall performance of the attendees. However, a special care must be taken into account in order to define a workload consistent with the time slot allocated for the test. The technical content of the exercise

must be also adapted to the learning curve. If the design goals are too complicated, then students may get frustrated. Realistic goals within an appropriate time frame are the key to success.

Based on the comparison with previous years, the number of students not passing the final exam has been dramatically reduced. Polls conducted at the end of the term show a high level of satisfaction among participants.

Another educational tool proposed successfully at this course is the use of English as the official language. Most of the time it's the first time the students work in a foreign language, which is the "professional world language" and their interest and their efforts are constant and satisfactory.

The methodology introduced is also worthy for other engineering activities, and as a result of the experience and new skills learned, students effectively open their minds to new ways of solving problems.

References

[1] A.S. Sedra y K.C. Smith. Microelectronics Circuits. Ed. Oxford University press. 1998.
     P.R. Gray y R.G. Meyer. Analysis and design of analog integrated circuits. Ed. John Wiley -Sons. 1984.
[2] R.L. Geiger, P.E. Allen y N.R. Strader. VLSI Design techniques for analog and digital circuits. Ed. McGraw-Hill 1990.
[3] D.L. Feucht. Handbook of Analog Circuit Design. Ed. Academic Press. 1990.
[4] R.J. Baker, H.W. Li y D.E. Boyce. CMOS Circuit Design, Layout and Simulation. Ed. IEEE Press. 1998.
[5] A.P. Malvino Principios de Electrónica. Ed. McGraw-Hill. 1993.