Overview of a Design Project Developed to Meet 0.5 Credits of Design Content in an Introductory Electronics Course

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Abstract—After a revision leading to restructure the curriculum design content, 0.5 credits of design were allocated to an introductory electronics course. What follows is an overview of one of the open ended design projects developed to meet these requirements. Completion of the project involved hand calculations, computer simulation, written documentation and demonstration of a working prototype. The introductory nature of the course in addition to the fact that some students were learning to use the required software for their first time, imposed some limitations on the scope of the project. Team work was emphasized, student response through out the project was evaluated and used to draw some conclusions regarding the overall merits and drawbacks of our approach. Those portions of the project involving design, as currently being defined in the literature, and those involving analysis are clearly pointed out

I. Introduction

The project to be reported is a multistage transistor amplifier design subject to several constraints. The course is introductory in nature, feedback and frequency response are postponed for a second quarter, therefore the complexity of the design exercise is limited, however, its value as a design experience [1] and teaching tool remains unmatched. There have been reports in the literature regarding this type of projects but at a level that already includes feedback and frequency response. Proposing a basic design project at an early stage prepares the student to address further design issues at a second course.

A list of constraints, as usually happens in the real word, is presented to the students, further, they have to design in order to meet a set of given specifications or in other words, to provide a desired performance, Despite this design constraints the project is carefully kept open ended, each team is expected to produce a distinctive original design. Not only component values should be different, but also their amplifier topology is expected to show some differences. Design decisions by the student will be emphasized, the pseudo design or "backward analysis" portions of the project will also be pointed out.

Spice, usually Design Center student version for Windows, is used by the students to perform a preliminary test of their design. Fine tuning of the design is also possible at this stage. MathCad is recommended for the design and analysis portion of their work even though any spreadsheet could be used to this end. The design and analysis procedure, developed by the student, when written in MathCad can perform automatic calculations, answer "what if" type of questions and facilitates any trial and error needed for fine tuning. There are also some drawbacks as we shall see later. Many students have used Spice at their introductory circuit analysis course, however, few of them have used MathCad. Despite some complains at having to learn yet another software package, all of them do learn MathCad. A walk through the computer center, at the end of the quarter, invariably shows students taking advantage of their newly acquired skills, for completing projects and laboratories in other areas as well.

II. THE DESIGN PROJECT

Since frequency response is not covered in this introductory course, capacitors values are suggested to the student. At this point the student will be designing without much regard for the amplifier bandwidth, however, a frequency response analysis will be carried out using Spice and the design will be tested at midband. The student is therefore exposed to some frequency response concepts in preparation for a detailed study in a second course,

A maximum input signal is specified and no distortion is allowed at the output. The specified gain together with the maximum expected input are such that small signal analysis approximations can be applied. Usually, gain and bias stability are required. Voltage gain is usually specified and in some projects a variable gain range is required. Other specifications or constraints could be the output impedance, input impedance, power gain, power consumption, minimization of cost, maximization of battery life, overall number of parts, weight and the like, Writing down a list of specifications, to solve a proposed problem, is also and important part of the design process. The student should be exposed to this task in future projects.

A typical specification sheet for the analog amplifier design would look like this:

1- Voltage amplification of 25 times is required.
2- The amplifier will be driving a 150 ohms load.
3- An input resistance in the range of 1 kohms to 3 kohms is acceptable.
4- Both, bias (de) and gain (at) stability are required.
5- Maximum voltage amplitude expected for the input signals is 0.04 V.
6- The available DC supplies are 1.5V, 3V, 6V, 9V, and 12V.
7- No distortion of the output signal is allowed.
8- Select transistor models which are available within the Pspice student version.
10- Try to use commercially available resistors.

Remarks:

i) Turn in a formal report and documentation.
ii) Justify all your design decisions such as number of stages, gain of each stage, type of transistor, type of stage, battery selection and Q point placement.
iii) Explain everything you do. Your design and analysis equations should be derived in the theory section of your report.
iv) Output wave forms for each stage are required.
v) Q point coordinates, transistor characteristic curves (generated using Spice), and a sketch of dc and ac load lines, including Q point, are required for each stage.
vi) After the design has been completed calculate your current gain, power gain and power consumption. (By hand and using Spice).
vi) Voltage gain obtained, input impedance, current gain, power gain, output impedance, power consumption and any other relevant data concerning your completed amplifier should be included in a summary. Desired and obtained values should be compared in a table.

Observations:

a) When using approximate formulas, make sure you are monitoring the compliance with the conditions that make the approximation valid.

b) All your design and analysis equations are to be implemented using MathCad.
c) Simulations in Spice are required as a part of the design and validation process.
d) Make sure your are monitoring compliance with manufacturer specifications, such as power rating for each transistor.

Note I: Frequency Response and Feedback are not covered within this introductory course, however, you should use the ac instruction in Spice to check the frequency response of your amplifier. Test your amplifier at midband.

Note II: Building and testing a working prototype is required. A demonstration in the lab, using appropriate instrumentation, is mandatory. Prototype performance, comparison with your theoretical design, and changes made, if any, must appear in the report.

The use of Spice can give some problems in terms of matching hand calculation with simulation results. This has been reported extensively in the literature [4,5]. In a basic project like this a judicious selection of transistor parameters usually yields good agreement between hand calculations and simulation results.

III. WHAT IS DESIGN AND WHAT IS NOT

In order to complete their projects the students must make several design decisions. At that point, most designs are likely to become different, however, all of them should meet specifications. In a more complex second course amplifier project, the opportunity to keep the project open ended is even greater. Some of the design decisions the students have to make and justify are:

1- Type of transistor to be used
2- Number of stages.
3- Gain of each stage.
4- Operating point at each stage.
5- Type of configuration in the stage, such as common emitter or common collector.
6- Impedance matching at the amplifier input and at the amplifier output and among stages.
7-DC battery voltage.
8- Power consumption.
9- Output swing.
10- Coupling.

After these design decisions have been made, component values have to be calculated. When a certain transistor stage has been thoroughly specified by the design constraints and the design decisions (operating point, dc battery, gain, type of stage, load, output impedance, input impedance and the like), the simultaneous set of equations that govern the stage allows us to calculate the rest of the components values through a "backward" analysis procedure. In other words, when all degrees or liberty are lost, this backward analysis should produce a single result for each component value and therefore is not design but just another form of analysis. This portion of the work, usually mistaken by the student as design, can be taught in class and can be found explained in several texts[6,7] or can be readily worked out by the student alone. All previous design decisions become the "data" for this "backward" analysis part of the project. These equations can be implemented in MathCad, therefore, when any design change is made, component values can be recalculated automatically. Furthermore, this allows the student to monitor the behavior of other amplifier characteristics.

IV. Student response

Individual and team work were tried, however, due to time constraints and the introductory nature of this course, small teams of two or three students were preferred. In general the students liked this introduction to team work. The project, by the other hand, had enough material and a tight deadline within the quarter to justify the team approach.

There were some complains at having to learn yet another software package. A growing number of students, however, are entering this course with previous exposure to Spice and Matlab or MathCad. In all cases the students realize the benefits of learning additional, main stream, engineering software packages.

We have noticed that the students sometimes forget to justify their design decisions, loosing points in the way. This is in part due to the instant feedback that they obtain from the “backward” analysis portion of their project. Let say that they do not know how to specify dc battery voltage or a sound operating point for a given stage. They make a decision by chance and if they have any problems, such as distortion, they try again. The combination of spreadsheet and simulation packages makes much more attractive this trial and error approach. They are told that this is acceptable only for fine tuning, and should not be used as a substitute for understanding. We realize, however, that this capabilities can be used for exploration and for posing “what if’ kind of question, in other words, as an aid in the educational process.

The prototype construction and laboratory demonstration is one of the highlights. It was not part of the original design project since it was assumed that a computer simulation would be educationally equivalent. One really don’t know how many educational opportunities are being lost, until this requirement is actually enforced, The troubleshooting stage of the prototypes is particularly helpful. The dc levels are checked and then the input signal is traced from the amplifier input to the amplifier output. We have found all kinds of problems, including a final oscillating stage which was introducing a “mysterious” distortion. When the students noticed that even with the signal generator off there was an output, they were really intrigued. These are all opportunities for teaching and previewing future topics.

V. Conclusions

We have presented a design experience, in a basic introductory electronics course, worth 0.5 credits of design. The experience is focused in the design of electronics circuitry following a set of specifications. Completion of the project involves hand calculations, computer simulation, appropriate documentation and demonstration of a working prototype. The project is open ended, each design is expected to have different component values and topology, All of them, however, should meet the proposed specifications. The development of overall system specifications, to solve a specific problem, should be addressed in future projects. The result of this approach has been a tighter commitment of the students to the course, a deeper understanding of the concepts and an introduction to design within a team. Equally important is the boost in student confidence when monitoring an electronic device work within specifications using their own calculated component values and topology.

References

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