A Practical Approach for an Introductory Control Engineering Course

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Abstract – **A methodology of the organization of practical classes of Control Systems course is presented in this paper. There are several voices in the community of educators and researchers over the benefits of using software simulation tools comparing the classical ones for implementing laboratory classes in engineering education curriculum. The aim of this approach is to make the students see the relation between theoretical concepts, MATLAB representations and physical circuits that can be used to implement compensators.**

Keywords – Control System, transfer function, laboratory board, experimental exercices, improving classroom teaching

I. INTRODUCTION

In most of educational engineering programs, it is included the course Control Systems or Process Control. There is no much difference in this aspect in educational programs in Europe, USA, Asia, etc. as stated in [1]. Nevertheless, the Control System course falls in the category of difficult courses that are present in any engineering curriculum [2]. The problem with this course is that it requires mathematical knowledge that is not intuitive. To cover this information requires a lot of time. As a consequence, the time allocated to the practical aspects is diminished. There are several commercial solutions developed by specialized companies like Lukas-Nuelle, Alecop, Feedbackplc, etc. that could help cover the experimental applications. Usually these products are not cheap.

At present time there are several discussions among researchers and teachers over the methodology of teaching in engineering education programs[3].

There are several voices that mention the advantages of software simulations over hand-on laboratories [4,5].

At the University of Pitesti, this course is taught in the 3rd year, first semester of engineering studies. This is structured as two parts.

The 1st part of the course, which is an introduction in System Theory, covers:

- System representation through transfer function and state space concepts
- Time and frequency analysis
- Stability

The 2nd part of the course, which is concerned on System Analysis and Controllers Design, covers:

- System analysis methods
- Design algorithms for different types of controllers

In the study plan of Electrical Engineering specialty given at the University of Pitesti, through this course it is intended that the students acquire several competencies:

- Capabilities of understanding the real engineers' life systems. In this sense, an Electrical Engineer should be able to represent real systems using world wide representations (differential equations, block schematics) and dedicated software (MATLAB, SCILAB, etc.)
- Capabilities of understanding the design methodologies using Control System Theory concepts (root locus, frequency, state space methodologies)

II. TOOLS FOR IMPLEMENTATION

A. *Software tools for simulation*

One of the main software tools used in Control System course is MATLAB [4], and in certain measure the Open Source equivalent SCILAB[5]. MATLAB is a very used software tool used by many teachers, engineers and scientists that need to focus on dynamic analysis of complex systems. One of the issues, that the authors are confronted is that somehow students loose the connection between software tools and the reality they try to analyze. Many times the laboratory classes are resumed at simulating some system representation through block schematics without connection to real life situations. The author arrived at the conclusion that simulations only should not be the purpose of these classes. This opinion is shared by several other authors[6,7].

B. *Hardware tools for simulation*

The solution to this problem could approached by several methods: real life system analysis, software both online or offline simulations[8] using different dedicated tools or hardware simulation using/adapting dedicated laboratory tools for this purpose[6].

For the purpose of implementing this laboratory, the authors used the Texas Instruments' Analog System Lab Kit Pro. The purpose of this tool is the study of Analog Circuits and analog signal processing[11].

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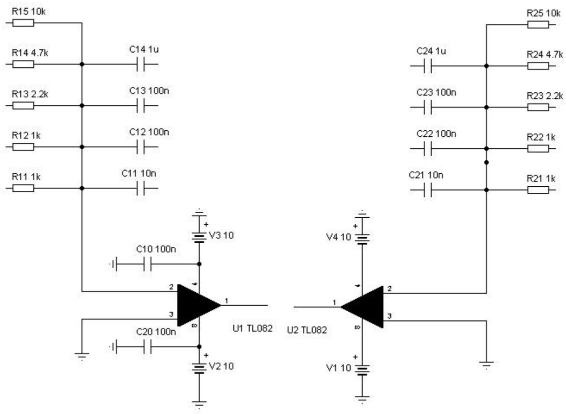

Fig. 1. Laboratory board inverting configuration

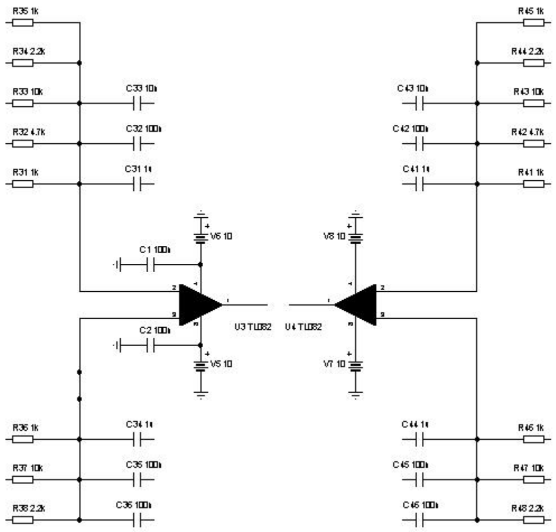

Fig. 2. Laboratory board full configuration

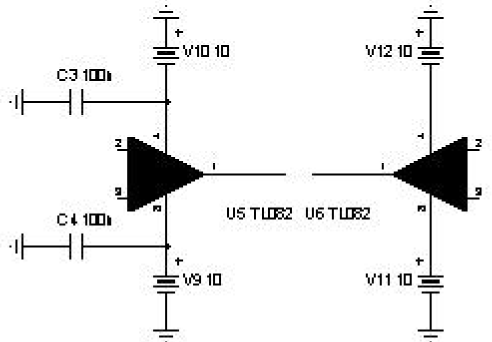

Fig. 3. Laboratory board open configuration

It is a dedicated laboratory board with different development areas:

- Three TL082 OP-Amp ICs
- Three analog multipliers
- There are two digital-to-analog converters (DAC)
- A wide-input non-synchronous DC/DC buck
- Two transistor sockets on the board
- A specialized LDO regulator IC
- Two 1kX trimmers (potentiometer)
- Two diode sockets on the board

For the purpose of implementing laboratory applications for the Control System course, the authors used the OP-Amp ICs structures in order to implement different circuit configurations.

III. PROPOSED APPLICATIONS

A. Analyzed circuit

The transfer function of a given complex circuit is derived from the basic equations that describe it's function. Very often in Control Systems courses, there are indicated transfer functions of 'systems' and many times it is not an easy task for students to link the mathematical representation with a physical system.

The first exercise chosen to be emphasized here has the purpose to help students make the transformation from a physical circuit to the transfer function representation. The structure of the circuit is indicated in figure 4:

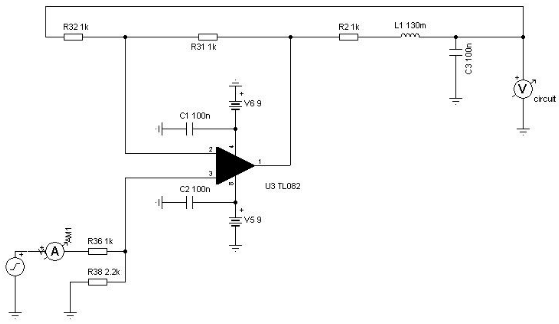

Fig. 4. Determination of transfer function from physical system

The equations that describe the function of figure 4 circuit are:

$$\begin{cases} V_e = \dfrac{(R_{32}+R_{31})\cdot R_{38}}{(R_{36}+R_{38})\cdot R_{32}}\cdot V_G - \dfrac{R_{31}}{R_{32}}\cdot V_O \\ G(s) = \dfrac{V_O}{V_e} = \dfrac{1/L_1\cdot C_3}{s^2 + s\cdot R_2/C_3 + 1/L_1\cdot C_3} \end{cases} \quad (1)$$

where:

R_{3k} - resistor network of the OA

R_2, L_1, C_3 - target circuit parameters

The equivalent block diagram of the circuit from figure 1 is indicated in figure 5.

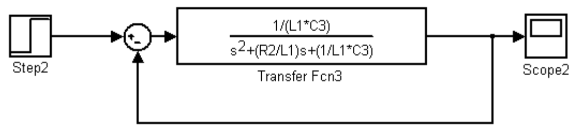

Fig. 5. Block diagram for circuit of figure 5

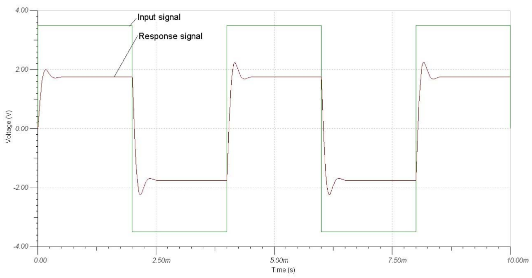

Fig. 6. Output waveforms of the analyzed circuit

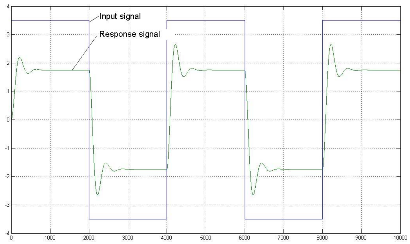

Fig. 7. Simulated output waveforms for the circuit in figure 5

The second exercise chosen to be emphasized has the purpose of get students used to the transformation from the indicated transfer function to the real physical circuit. It is indicated the following block diagram:

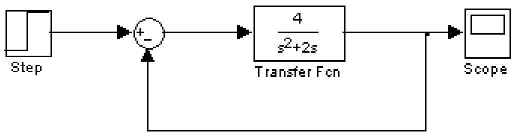

Fig. 8. Determination of physical system from transfer function

One way of simplifying the circuit from figure 8 is the equivalent block schematic. The schematic from figure 8 could be simplified by the schematic block from figure 9:

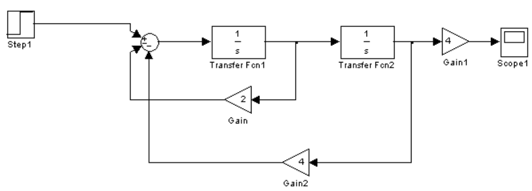

Figure 9. Simplified equivalent block schematic

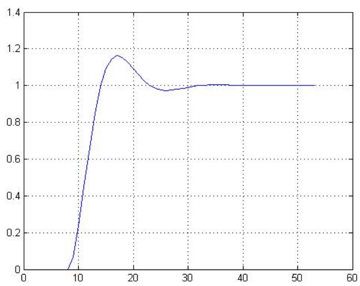

Figure 10. Simulation of the second proposed practice

Once the simplification of the initial system transfer function is done, the students could move forward for the next stage of their lesson. This is to implement the block representation using the OpAmp structures provided by the TI's laboratory board.

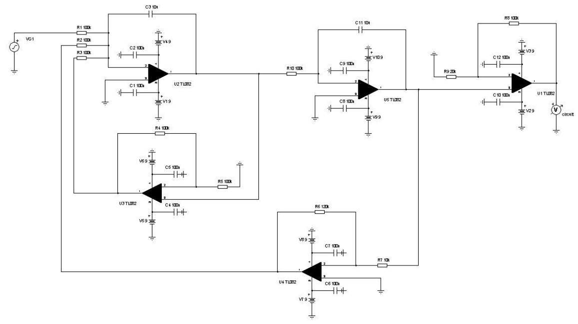

Fig. 11. Electronic schematic implementation of transfer function

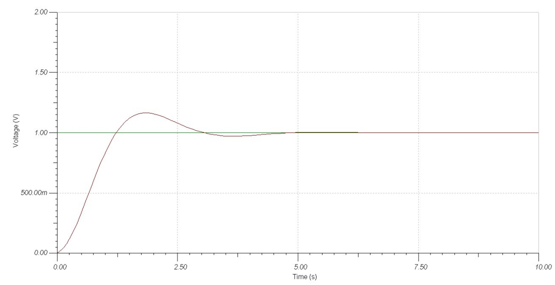

Fig. 12. Wave forms of the electronic schematic

In figure 11 it is implemented with electronic components the transfer function indicated in the figure 8, that is:

$$G(s) = \frac{4}{s^2 + 2 \cdot s + 4} \qquad (2)$$

By doing these types of applications, students could realize the equivalence of mathematical and symbolic representation and electronic circuit. Also they could understand how SIMULINK/MATLAB symbols are implemented in real world using electronic ICs.

B. *Controller design*

A step further to cover in the course is the design of the controller. This topic is approached in the second part of the course. In class there are presented all design methods: root-locus, frequency analysis and state-space.

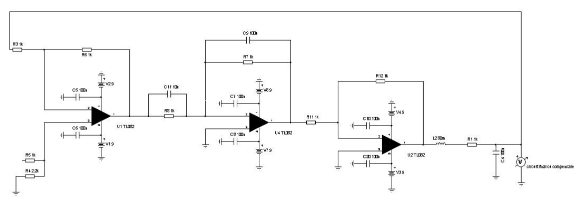

Fig. 13. Compensated electronic circuit

The circuit in figure 1 could be compensated in order to reduce the over-shoot using either one of the classical methods presented in Control Systems literature [12,13].

The compensated circuit is indicated in figure 14:

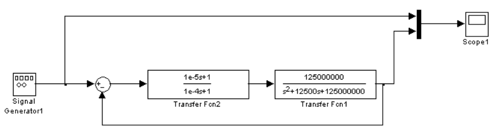

Fig. 14. Schematic diagrams for the compensated circuit

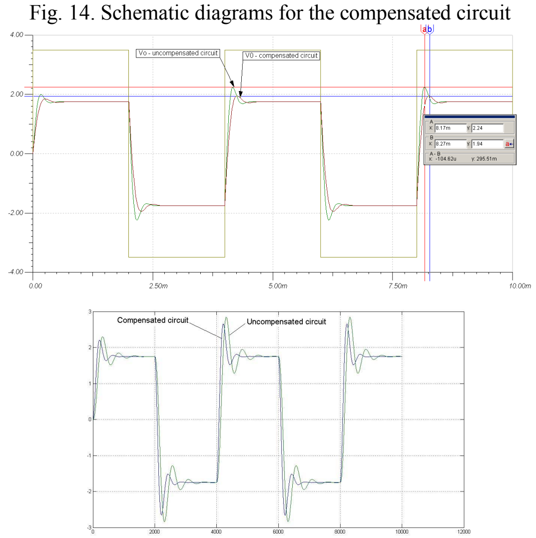

Fig. 15. Compensated circuit: schematic and wave-forms

IV. CONCLUSIONS

A methodology of the organization of practical classes of Control Systems course was presented in this paper. The aim of this approach was to make the students see the relation between theoretical concepts, MATLAB representations and physical circuits that can be used to implement compensators.

As previously mentioned, in the community of educators and teachers in engineering educational systems there is a debate over the advantages of simulation approach for practical laboratories over the ‘hand-on” classical one.

The economical aspect of setting-up, using and maintaining of such laboratories is a heavy argument. Nevertheless, the author’s opinion is that the engineer student should not prepare himself only with simulation tools. As much as this is possible, the author appreciates that the classical, hand-on approach should be adopted.

Most of Control Systems courses are given (at least as far as the author is aware of) using dedicated simulation software (MATLAB, SCILAB) or similar ones. This paper presents a methodology of using real life circuits and components to construct experiments based on the specific theory.

The main advantage of this approach is that after there are done all calculations and all the mathematical representation, the students can implement the results of their theoretical development. One important improvement of this method is that by doing mathematical algorithms and after putting them into practice will help students to better understand the link between theory and practice.

Most of the students (92%) appreciate that this course is useful and very useful for their preparation as Electrical Engineers. While the majority (85%) appreciate that the course structure is appropriate, many of them (60%) appreciate the difficulty of the concepts as being high and very high.

The author expectation is that by using this tool and a more practical tool for laboratories classes, the students could be able to better understand and retain the basic knowledge of this course.

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