A Control-Systems FPAA Based Tutorial

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Abstract: - In electrical engineering graduate schools, control systems are usually taught through lectures, tutorials, projects and practical works. Obviously, it is during projects and practical works that students acquire the most of their know-how in this field. Therefore, nowadays, because of the real systems cost, students implement more and more often virtual systems. The objective of this paper is to suggest the use of Field Programmable Analog Array to assist teachers in their teaching task. With this programmable analog components, students are able to implement classical systems and extract from it real measurements.

Key-Words: - Control Systems, practical works, FPAA

1- Introduction

For many years, the control systems and microelectronic department of the Polytech'Montpellier University Engineering Graduate School has offered a wide range of lectures, laboratory works and project surveys particularly in control systems [1]. Practical woks take a significant place in a student's curriculum. To this end, in three years, future engineers get about a 180-hour period to carry out a maximum amount of know-how in control system sciences. Therefore, in our laboratory class, because of the expensive cost of real systems, we get no more than 6 actual systems. Hence, to enhance student's skill in the domain, teachers tendency is to implement systems by the use of simulation tools such as Matlab and Simulink [2]. The original idea proposed in this paper, is located between the two approaches, the real system and the abstracted one. Indeed, with our methodology, students can implement theoretical systems learned in lectures and perform real measurement.

The paper is organized as follows. In section 2, we expose the skills enlighten by this tutorial. Section 3 is devoted to the Field Programmable Analog Array. The fourth section presents the laboratory we propose. Finally, we conclude in section 5.

2- Tutorial Skills overview

This tutorial occurs early on student's curriculum. So, the main purpose is to introduce first and second order linear systems. With the first order system students will study the feedback effects on the system response. The second order system will be employed to highlight system's instability. A progressive approach will be use by students to compensate the system and consequently reach to a stability improvement.

Likewise, because of the duality of our student's curriculum (i.e. in control systems and in general purpose of electronics), the use of an innovative programmable analog device enhances their know-how in basic electronics.

3- The Field Programmable Analog Array

A FPAA is an analog programmable integrated circuit. The FPAAs brings to analog what FPGAs brought to digital; extremely rapid production and prototype circuit realization with field re-programmability. For this laboratory work we propose to use a FPAA from Anadigm [3]. This family circuits are built on a switched-capacitor architecture [4]. The core of the FPAA is an array of identical configurable analog blocks (CABs) relied by a configurable network of interconnection (see Figure 1). A very flexible switching infrastructure surrounds the capacitor banks, enabling users to create complex configurations. This allows the FPAA to implement an almost infinite range of analog signal processing functions.

The firmware-configured operation of the FPAA allows Anadigm to offer a library of ready-to-use circuits for common analog requirements. There are a numerous "IPmodule" functions available including for example amplifiers, summing amplifiers, differentiators, integrators, comparators, filters, etc.

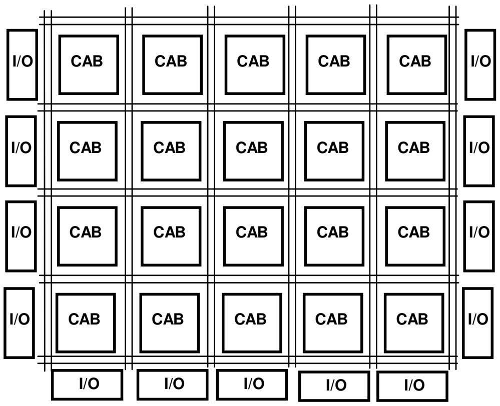


Figure 1 : Anadigm FPAA architecture

The AnadigmDesigner® software design tool provides the user an intuitive drag and drop GUI in which you simply select several of the Ipmodule functions from the library, drop them onto a graphical representation of the chip, fill in some parametric information about Ipmodule, wire up the internal and I/O connections, and hit a button to generate the bit stream.

4- Laboratory

The circuit use in this tutorial is the AN10E40. This FPAA chip is included in a development board : AN10DS40. This development board provides all the feature required to simplify host and system and I/O connection for evaluation, debug and test. In addition, the PCB incorporates a microcontroller which can dynamically modify FPAA functionality by loading a new configuration file.

The laboratory we propose has a duration of height hours. Students needs one Personal Computer implemented by the AnadigmDesigner® software and PSPICE, a square signal generator, an oscilloscope and the Anadigm AN10DS40 development board. AnalogDesigner® design tool can be free download from the Anadigm website [3].

The lab is splited in two sessions. First session has a duration of two hours and the second one of six hours. To guarantee a didactic progressive approach, in the first session students work with a simply first order system and in the second one students implement a second order system. This kind of systems are very important to the control-system engineer. Indeed, this type of system characterizes the dynamics of many control-system applications found in the field of servomechanisms, space vehicle control, chemical process control, aircraft control systems, etc. Moreover, it is interesting to note that most control system designs are based on second-order system analysis. Even, if the system is of higher order, as it usually is, the system may be approximated by a second-order system in order to obtain a first approximation for preliminary design purposes with reasonable accuracy.

Session 1 : First order system

The figure 2 shows the classical diagram of a closed-loop control system. Here, the process is represented by a first order transfer function.

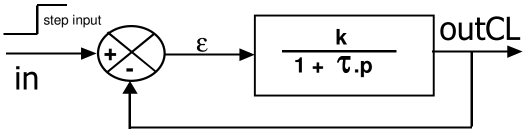


Figure 2 : First order closed-loop control system

In the first part of this session, students study the step input response of the open-loop system. From their measurement, they have to identify the system i.e. the speed response **τ** and the gain factor **k**. Figure 3 presents the structural schematic of the open-loop first order system in the AnadigmDesigner® environment (the thick white lines are present only for a better understanding of the schematic).

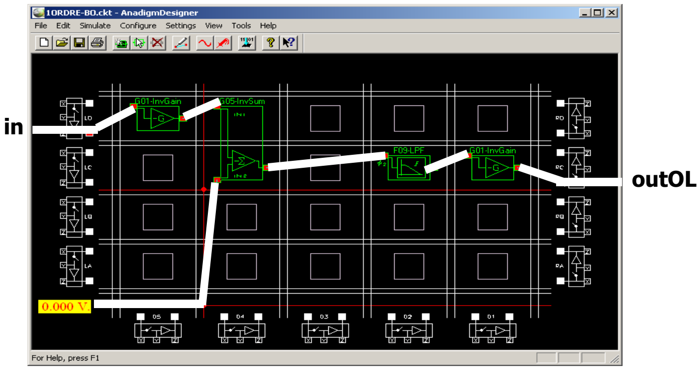


Figure 3 : First order open-loop

Students have to implement in the FPAA four analog functions such as two inverter amplifiers, one summer amplifier and the first order filter. The two inverter amplifiers who have both an unity gain are just here for a structural purpose. After the configuration (or bit) stream is implemented in the FPAA, the students connect the square function generator at the FPAA input pin "in". Figure 4 gives the open-loop response acquired by an oscilloscope. From this measurement students are able to extract the **τ** and the factor **k.** In this case, **τ**=1ms and **k**=1.

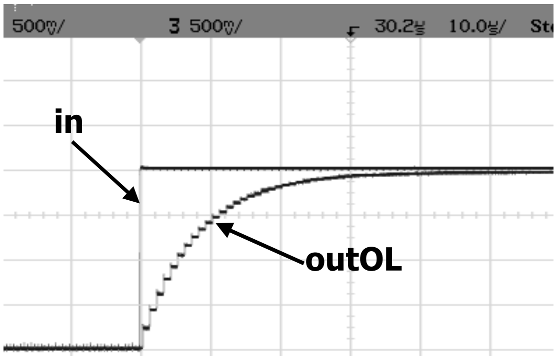


Figure 4 : First order open-loop step response

After the open-loop study, the loop is closed. Students perform the same measurement (Figure 5), extract the same parameter **τ'** and the gain **k'** from it and have to justify the new values obtained. In this case, because of the unity value of the gain factor, **k'**=**k**/2 and **τ'**= **τ**/2. Here, the numerical values obtained are **τ'**=0.5ms and **k'**=0.5.

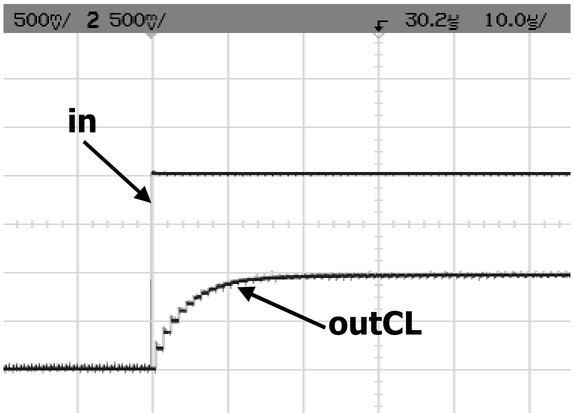


Figure 5 : First order close-loop step response

Session 2 : Second order system

In the second part of this practical work, students have to characterize a second order system (see Figure 6).

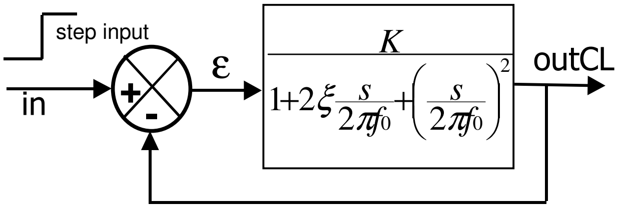


Figure 6 : Second order closed loop control system

For this study we impose the values of the gain K = 3, the undamped natural frequency f_0 is set at 5kHz and the damping factor ξ = 0.2. Obviously, this second order systems is unstable. First of all, students have to implement this second order control loop system in the FPAA. Afterward, students apply a step input to the closed-loop system. Figure 7 gives the response obtained by measurement. As students can see, the system is clearly unstable and not accurate.

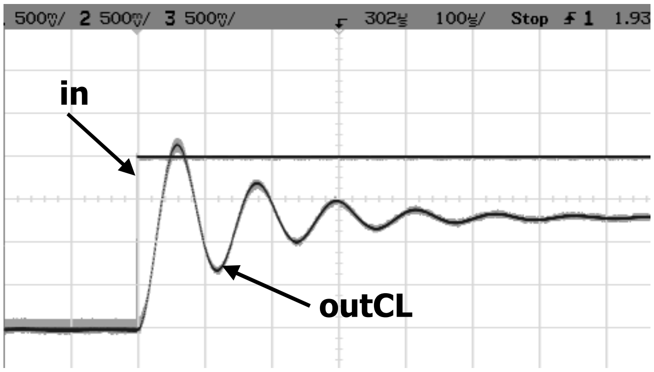


Figure 7 : Second order step response

To corroborate the previous observation of stability, for the next step, students use the electrical PSPICE simulator to compute the open loop frequency response. And then, from this simulated response they extract the phase margin at 0dB gain (see figure 8). Because of the weak phase margin, it also clearly appears for students that the system is unstable.

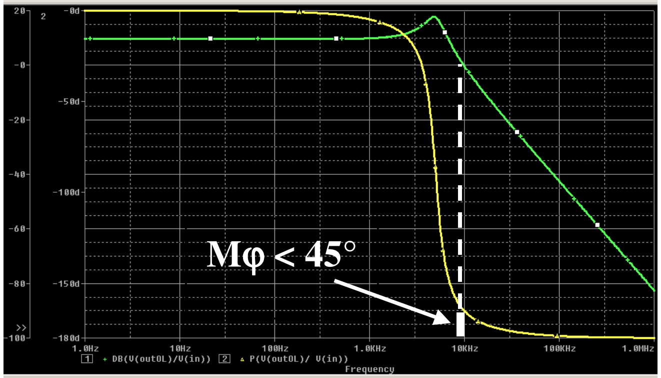


Figure 8 : Open-loop spice simulated frequency response

Because, stability is an important issue in control system design, we propose students to cascade with the system a compensating phase-lead transfer function *J(p)* to improve the system stability (Figure 9).

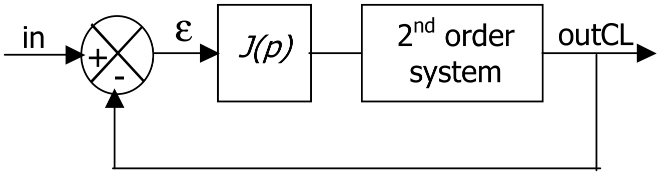
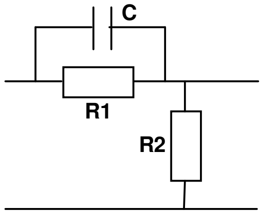


Figure 9 : Cascade compensated system

The phase-lead network has to create a phase shift for 10kHz, the corresponding 0dB frequency, to improve the phase margin at this frequency.

To implement the phase-lead network [5] of Figure 10-a, students have to calculate the passive component values. With a imposed time constant ratio a = 4, students obtain a phase shift of approximately 37° (Figure 10-b). The maximum phase shift must be set at 10kHz. Finally, the computed parameter values are R1=3.3kΩ, R2=1kΩ and C=10nF.

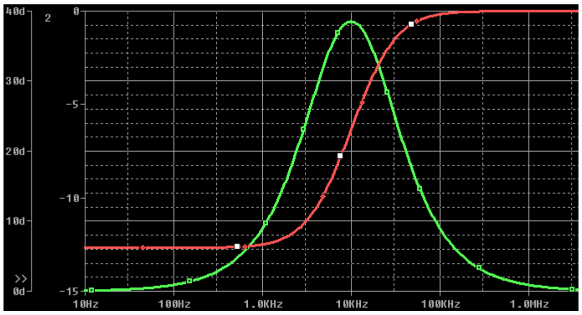


$$J(p)=\frac{1}{a}\cdot\frac{1+a\tau p}{1+\tau p}$$

with : $$a=1+\frac{R1}{R2}$$

$$\tau=\frac{R1\cdot R2\cdot C}{R1+R2}$$

a) Passive phase-lead network schematic

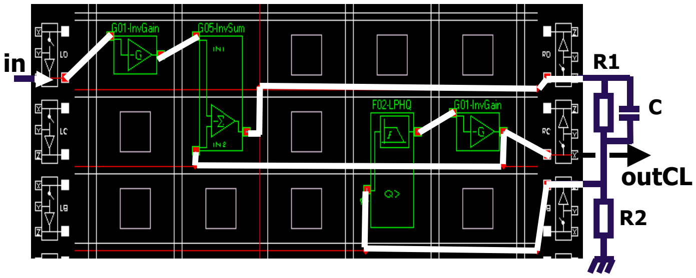


b) Phase-lead network spice simulation

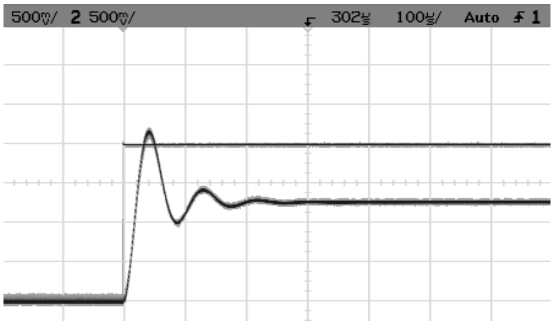
Figure 10 : Compensating phase-lead network

Figure 11-a gives the AnadigmDesigner® equivalent schematic of the cascade compensated second order system. As it can be see, the phase-lead network is external to the FPAA. The passive components connection to the development board is relatively straightforward for the students.

Finally, students verify the dimensioning of their compensated network by measuring the compensated system step response. As we can see in Figure 11-b, now the system if well stable.



a) Cascade compensated schematic



b) Step response

Figure 11 : Compensated second order

5- Conclusion

This control system practical work has been used for two years in our engineering school and it turns out to be of great help as regards the improvement of student's enthusiasm in control systems. Students are highly satisfied with this method. Likewise, it has been confirmed by professors in charge of control systems lectures that the students' ability in this field had also established during classes.

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