VIRTUAL ANALOG AND DIGITAL COMMUNICATIONS LABORATORY: LAVICAD

On line interactive tool for learning communications systems

Margarita Cabrera Bean, Albert Mestres Sugrañes, Carlos Vargas Berzosa, Francisco Vargas Berzosa
ETSETB, Dept. de Teoria del Senyal I Comunicacions
UPC Universitat Politècnica de Catalunya
Contact e-mail: marga.cabrera@upc.edu

***Abstract*— The virtual analog and digital communications laboratory LaViCAD has been designed at the UPC and it results a useful tool to verify different communication systems performance and also signal processing techniques, subjects given in courses typically included in the curriculum of any electrical engineering degree. LaViCAD tool has become a flexible, sustainable and on-line freely offered educational platform and it can be updated whenever new content is required. At pedagogical level, the use of a virtual laboratory facilitates the learning of certain matters, acting as a connection between the theoretical contents of a communications system course and their practical understanding and experimentation. Furthermore, LAVICAD provides resources for professors to organize different teaching activities in their courses. These activities can be used in different environments as for instance in a classroom given in the context of a full attendance course or in a homework activity at a distance learning course.**

The aim of this paper is two-fold: On one hand to describe the main technical features that make LAVICAD an original fully re-usable and reprogrammable tool in signal processing and communication systems courses. On the other hand to show some preliminary academic results obtained with the use of LAVICAD verifying how it improves the level of success.

Keywords-component; Virtual Laboratory, e-learning, re-usability, User friendly environment, Web-based labs.

I. INTRODUCTION

Some theoretical concepts and definitions in a communication system course contain a high level mathematical background. Sometimes the students must develop long paragraphs of mathematical formulas in order to demonstrate a theoretical result. In general, in a basic communication system course the student is faced for the first time to topics that are classified as very difficult by the students. As opposite, when they experiment in an instrumental laboratory, they can verify some implementation errors and misalignments that are inherent to hardware or real time software applications. In this context a graphical and interactive simulator tool can help them to understand better the differences and the similarities between a theoretical result and a real experiment. An accurate designed application tool available to verify a great diversity of communications systems and subsystems can become a powerful and useful learning help. The key idea of the use of LAVICAD consists in its functionality as a bridge from theory to Lab experiments. This idea is shown in Figure 1.

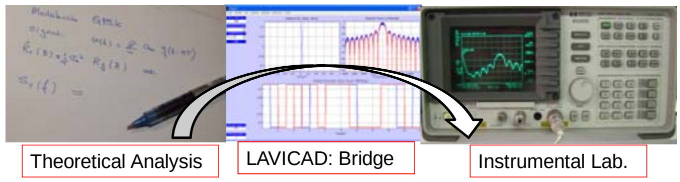

Figure 1. Key Idea: LAVICAD as bridge from theory to practice.

In the last years, the use of virtual labs has spread the engineering education environment with some innovative teaching techniques. Some experiences applied to signal processing and communication system have been presented in [4], [5] and [6]. With LAVICAD, two main advantages are fulfilled. On the one hand the reusability feature to generate whatever new exercise is proposed by the teacher, on the other hand some of the LaViCAD experiments are freely offered in an educational moodle based platform: comweb.upc.edu. The user can access and execute locally without any other software requirement than the JVM (Java Virtual Machine).

The simulation tool LAVICAD has been created to serve in the learning process of the most important basic topics and the most popular advanced topics integrated in a second-year graduate-level course in electrical engineering. The great variety of situations, flexibility and possibilities of emulating the different and not always predictable practical effects in a real laboratory, make of this virtual laboratory a powerful tool that faces the student to problems with different difficulty levels. This tool also constitutes a challenge for educators, who can consider it as a complement or as a substitution of a real and experimental laboratory.

From a user point of view, LAVICAD is formed by an on-line set of four generic and basic communications systems (Digital Modulation, Analog Modulation, etc..) and two popular communications system physical links systems (WiFi and the digital video broadcasting DVD for digital terrestrial television). Consequently, up the date there are six LAVICAD Link Level Simulators (LLS) currently working.

At technological level, all the programmed LLS share a common and structural Java architecture. In order to create a new LLS, a general reprogrammable platform or "container" was designed and programmed at the LAVICAD starting time.

Paper Outline — after an introductory section, a description of the laboratory tool programming process is presented in section II. In section III we present three cases of use for three kinds of learning activity with different degrees of user interactivity. Section IV is dedicated to explain as the use of some LaViCAD systems in a theoretical and practical communications course has improved the academic scores. Finally, some conclusions are presented in section V.

II. LABORATORY TOOL DESIGN

This section is dedicated to explain the main design guidelines for the LAVICAD tool.

A. *Program Structure*

To understand the structure design of the LAVICAD tool it is necessary to take in mind how a communication system works. A typical communication system functional diagram is composed by a set of basic elements sorted from first to last. Each basic element represents a step. An input signal is processed sequentially through all the steps to produce an output signal. Typically the input signal is produced by an information source and the output signal is registered at a destination terminal. The general pattern for a general communication system is shown in Figure 2. In the figure each step is characterized as a closed box. The input signal to each step (box) is the output signal from the previous step (box).

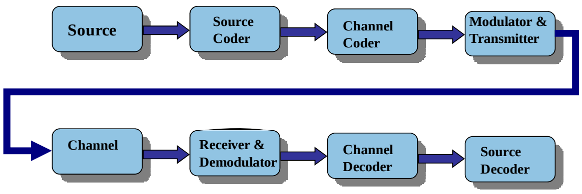

Figure 2. General Communication System functional diagram.

Each one of the experiments that integrate the LAVICAD tool represents a system Link Level Simulator (LLS). All of them admit the pattern shown in Figure 2. Each LLS emulates a different communication system or a subsystem. Depending on the process to be executed on the signal, each step is configured by means of a configuration parameter set and each step produces a set of numerical and graphical results.

Each step represents a single simplified subsystem and illustrates a part of the complete LLS. It processes the signal resulting from the previous step. The signal process is developed attending some configuration parameters. The new processed signal is analyzed in order to present the screen different graphical and numerical results and it is transmitted to the next stage.

Summarizing, there is a set of sequential actions that are developed with each step or stage:

- Acquire the signal from the previous step: Input Signal for the present step.
- Acquire the configuration parameters for the present step. These configuration parameters are introduced by the user by means of a user friendly interface window.
- Process the input signal in order to obtain the output signal.
- Analyze the output signal and present numerical and graphical results.
- Deliver the output signal to the next step or stage.

As additional features, in each one of the stages it is allowed to exchange both the input signal and the output signal with extern stored signals.

As it can be concluded, there is a high degree of repetition when programming the different LLS, and furthermore when programming the different steps included in a LLS. In order to take profit of these features, the LAVICAD tool has been programmed following a model defined at the project startup and described in section II.B.

B. *The functional structure of a Communication System*

LaViCAD is composed by two different parts: a development container platform and a set of differentiated LLS.

The generic container structure is represented in Figure 3.

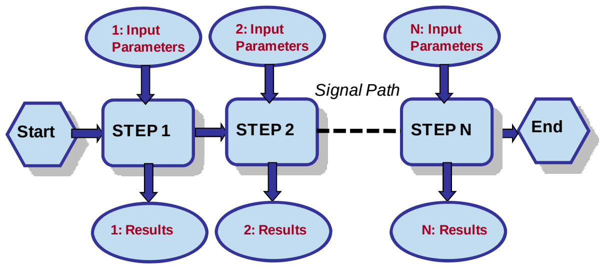

Figure 3. Container Structure.

The container platform is a Java software package that contains the guidelines and associated Java files to program the graphic interface, the variables shared between the different steps that form a LLS and the multiple menus included in each step to interact with the user. A "Container Program" has been designed to integrate all the necessary packages for actions that are sequentially executed. The application has been programmed using the Java programming language. As Java is an object-oriented programming language, the container program includes all the classes, objects and libraries necessary to execute the repetitive actions.

When a new LLS is generated it is compiled with the container platform. It has been fully documented and it is useful for those interested in creating new communications systems simulators.

When programming a new LLS, the following two phases must be followed before the compilation process:

- Phase 1: To accurately design what the new LLS must represent: Number of stages, input configuration parameters, signal processing for each one of the stage input signals and output results including numerical and graphical ones.
- Phase 2: To program all the functionalities designed in the previous phase, using, among others, the Java classes corresponding to the program container.

The set of LLS currently programmed in LAVICAD is formed by six completed LLS and two more in construction.

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C. User Interface.

From the user point of view, each completed LLS is friendly accessible from our project website [10]. When the user accesses a LLS, the main window presents him the set of sequential steps to be executed like in Figure 4. In turn, each of these steps gives access to a new interface. On this interface window the user can set up different configuration parameters, and view a wide range of results, like in Figure 5. An option provides the user with the possibility of exchanging signals with those obtained when performing a similar experiment in a different platform or just from a different LaViCAD LLS.

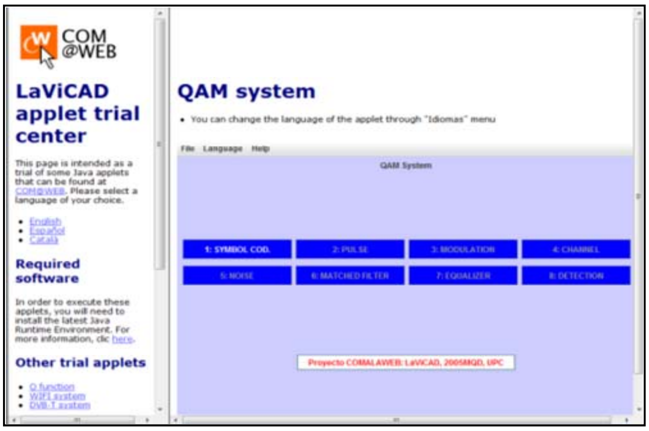

Figure 4. QAM LLS main user window.

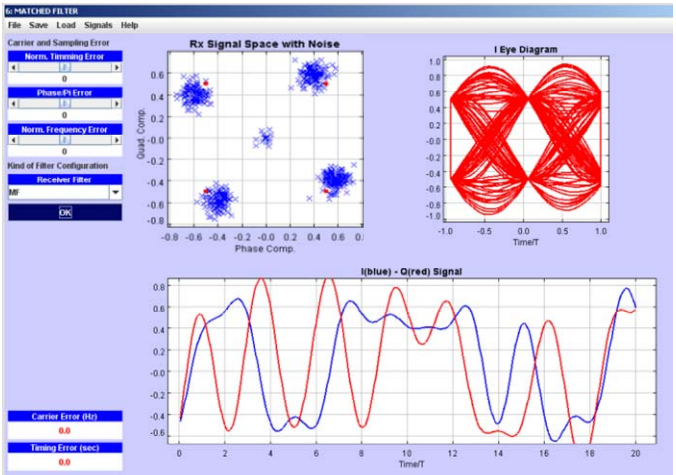

Figure 5. QAM LLS single step user window.

D. Completed Comunication Systems Simulators.

All LLS generated to date can be classified in two types: The academic ones and the diffusion ones. The academic set is used as an important support in a basic course learning process. In this case, a LLS represents a generic simple system and the steps are configured to illustrate some mathematical properties without particularizing any standardized system. They contain the fundamental basis of a certain subject in the area. They are commonly used by the students to complement a theoretical development exercise. The diffusion set has been selected to incentive the students and other occasional users with daily life popular communication applications. They are commonly used by teachers to show examples at the end of each subject that overview the scope of the initial objectives with the aim of motivate the students to enhance and expand their background knowledge on the area.

Some of the Academic LLS currently available within the application LAVICAD are:

- QAM Modulator: This system supports baseband and passband formats, RRC and rectangular pulseshape, AWGN selective frequency channel, matched filter and displaying effects produced by different kind of synchronism errors, FIR equalization and theoretical and measured Bit Error and Symbol Error rates.

- AM-FM Modulator: This system departs from an information source signal generated as a digital modulation, an audio signal or as a single sinusoid. The channel is modeled as AWGN and the demodulation can be coherent demodulation or envelope detection. There is the option to simulate non linear effects on the received signal. At the end of each stage all the signals can be displayed and the user can listen to the baseband signals.

- Channel Convolutional Codification: The main features are convolutional codes with the potential for puncturing, AWGN frequency selective channel, and soft and hard Viterbi decoding. At the last step different error measures are displayed in order to evaluate the improved performance with the use of a convolutional code.

Some of the Diffusion LLS currently available LAVICAD are:

- WiFi system, estandard 802.11g, (Physical Level): This LLS has been designed following the recommendations given by the Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications document [8]. This communication system is the basis of the WiFi connections between an access point and different terminals. It is widely used to give network access to PC terminals, laptops, PDAs, mobile phones, etc. It has been chosen for its simulation within the project LAVICAD because it is one of the most popularly used today and the population of university students is acutely very aware of this fact.

- Digital Terrestrial Television based on the DVB European standard, ETSI EN 300 744 (Physical Level): [7] Framing Structure, channel coding and modulation for digital terrestrial television. This is the TV broadcast system operating currently in Spain. It still coexists with the analogue system, but just until 2010th. Of course its popularity is undisputed.

Other LLS are currently integrating in LAVICAD but we don't describe here to not extend a lot this description.

III. Cases Of Use

The general and wide range of possibilities to be used in a learning activity offered by LAVICAD is highlighted in this section by describing three different exercises. Each one of them has been devised to be used in a different context, involving inside and outside classroom sessions and depending of the proposed activity is given in a fundamental basis course or I an application course with different degrees of interactivity levels.

A. *Acompanying a theoretical development exercise.*

This activity can be proposed for the teacher in a fundamental communication system course in order their students begin to work with spectral density issues.

By LAVICAD the user can emulate most of proposed exercises in a textbook, as for instance [1], [2] or [3]. Through the QAM LLS some exercises proposed by the author in [1] can be studied. Let's solve exercise 8.7, part 1 in page 563. The statement of the problem can be summarized as:

Problem Statement:

Consider a four-phase PSK (QPSK) signal that is represented by the equivalent lowpass signal.

$$v(t)=\sum_n a_n g(t-nT) \quad (1)$$

In (1) a_n takes on one of the four possible values $\frac{\pm 1 \pm j}{\sqrt{2}}$ with equal probability. The sequence of information symbols $\{a_n\}$ is statistically independent.

Determine and sketch the power-spectral density of $v(t)$ when $g(t)=\begin{cases} A & 0 \le t \le T \\ 0 & \text{otherwise} \end{cases}$

Theoretical Solution: The student faced to previous analysis proposal, must obtain, after some calculus that the demanded spectral-density equals:

$$A^2\left(\frac{\sin \pi fT}{\pi fT}\right)^2 \quad (2)$$

Practical Solution: Setting adequately the QAM parameters set from the first step to the third step, the theoretical and the real spectrum for a generated random symbol sequence can be sketched as in Figure 6.

B. *Accompanying a laboratory experiment.*

A utility of interest and wide acceptance among students is the real-time comparison of results obtained in an instrumental laboratory with the use of LaViCAD. It is of great pedagogical interest to compare the different functions measured in practice, with the functions explained in a lecture session.

The use of LAVICAD in a laboratory session can serve as a complement during the experiment execution or as a previous mandatory homework to prepare the laboratory session.

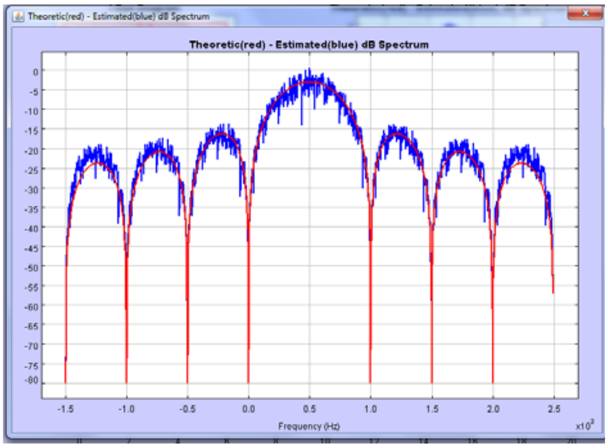

Figure 6. QAM Spectrum for the Exercise proposed in III.A.

Let's assume that in a digital modulation practice (QPSK) it is mandatory to visualize the spectral-density on a spectrum analyzer screen. The students are faced simultaneously to the theoretical spectral density generated by LAVICAD and to the measured real one, presented on the spectrum analyzer screen. They realize of the imperfections and alignments errors obtained in practice and develop their critical thinking skill oriented to analyze what causes the alignment errors.

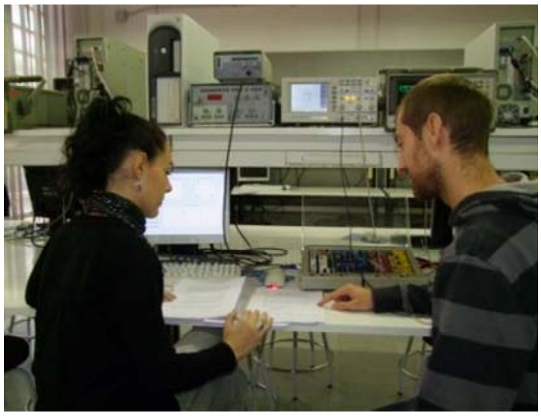

Figure 7. Use of LAVICAD accompanying an instrumental laboratory practice. LAVICAD is being executed at he computer whose screen can be seen on the table.

C. *Use of LAVICAD in a project.*

LAVICAD can also be used in a more complex activity integrated in a project based learning course with a multidisciplinary range of areas. With the activities described in III. A and III.B the user interaction with the simulator is limited to introduce in each step the setting parameters and watch the results, and the setting parameters must be previously calculated from the exercise proposed by the teacher. The third use we propose in this section consists on the implementation of a new system or a new step. Some kinds of activity are identified and ordered from low difficulty degree to high:

- To form a new communication system by combining two or more generated LLS. In this case, the user can introduce as input signal to a LLS step the output signal obtained from a different step. Depending on the new communication system to be verified, the user must design and select the different steps to be combined in the new system.
- To modify a single step in a generated LLS.
- To add a new step to a generated LLS.
- To design and program a new LLS using the LAVICAD container application in the compilation process.

The proposed activities are helpful in a process to train the students in some general skills, as engineering problem solving, quality awareness and self learning.

IV. Preliminary Academic Results

The use of LAVICAD based learning activities has been implemented in two different courses: the course of "Communications I" and the course of "Communications Laboratory I". These courses are among the current ones in the second and third year of our studies. An introduction to digital and analogue modulations is given in "Communications I". "Communications Laboratory I" is dedicated to develop experiments based on the theory given in "Communications I".

In a 45 students group (2008 spring semester) "Comunications I" course, two mandatory theoretical exercises were proposed by the teacher to the students. The qualification of these two exercises represented a 5 percent of the final course score. The teacher proposed the students to use some LAVICAD LLS in order to complement the exercise development, like the learning activity described in III.A, but the use of LAVICAD was not mandatory. Two weeks later than the second activity delivery term ended there was a midterm exam to evaluate the skills of two subjects included in the course program and partially related to the proposed exercises. The qualification of this exam represented a 20 percent of the final course score. The success levels of the course are shown in table I.

TABLE I. Avaluation Results with the use of LAVICAD in the course of Comunications I

	Number of students	Midterm exam approval percentage	Final Score approval percentage
Use of LAVICAD	31	25 (80%)	20 (64%)
No use of LAVICAD	14	5 (36%)	6 (43%)
	45	30 (67%)	26 (58%)

The third row in the table shows as the success level is highly correlated with the use of LAVICAD to complement the theoretical developments

Authors are aware of the sample size is small in this preliminary startup, but after that semester, the use of LAVICAD activities has been introduced from time to time with some student groups and they have always produced results similar to those shown in the table.

The laboratory course program ("Communications Laboratory I") is composed by five subjects or experimental works dedicated to analog and digital communications. The use of LAVICAD is mandatory for all the students as an accompanying activity of the two last subjects.

With the new European higher education adaptation process startup, the contents and methodologies of both courses will be integrated in a new course, entitled "Fundamental of Communication Systems". This course will start on February 2011 at the Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona - ETSETB, UPC .

V. Conclusions

The integration of the LAVICAD tool in the daily teaching activities of fundamental and laboratory communication system courses is becoming a useful resource in order to provide students with some typical engineering education skills. The tool is composed by a set of web access simulators (LLS) that can be applied to a wide range of academic or practical exercises. The use of the "Container Program" to generate new LLS results a very low consuming effort process. As a limit of use of LAVICAD there is a memory resource restriction that cannot be exceeded. This is a JVM feature and the upper limit depends on each user computer or laptop.

There are currently several e-learning tools available for academic purposes, but few of them regarding signal processing and communication systems courses. This represents one of the innovative points of this paper and can be considered as an add value of LAVICAD.

From preliminary LAVICAD experiences it can be concluded that final scores have increased when some LAVICAD based teaching activities are proposed in the course. As last conclusion, authors can assure that the student satisfaction level has also increased. This statement was deduced as a consequence of spontaneous successful students comments addressed to the teachers and referencing the LAVICAD based activities and as a consequence of the increasing number of queries presented by the students at the teacher's office hours.

The challenge of introducing LAVICAD based activities in a communication system course consumes a great amount of teacher time and teacher effort. With the EHEA startup some new teaching uses must be renovated. In our course each teaching activity must be designed to cover some generic skills and dome specific skills and this is one of the most effort demanding features to be considered in a LAVICAD based activity design.

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