

Development of Online Laboratories for Modulation and Combinational Logic Circuit Analysis Using NI ELVIS II™ Platform

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Abstract

This paper describes the work carried out by the Makerere University iLabs Project Team, hereafter referred to as iLabs@MAK. The procedures followed to develop Online Laboratories using the National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS II™) platform is discussed. The laboratories were developed based on the Massachusetts Institute of Technology (MIT) iLabs Shared Architecture (ISA), a model that provides highly reliable generic services independent of the experiment domains. Modifications were made to the ELVIS version 1.0 code to introduce desired functionalities. Experiments were selected from three fundamental courses offered in the Department of Electrical Engineering, Faculty of Technology, Makerere University. Starting with the rationale for development of iLabs in specific courses, the paper presents the methods employed and the results obtained from the various experiments. Experiences and perceptions from over 300 students who performed the experiments were captured as a core aspect of the Research.

Key Words: *Amplitude Modulation, Digital Logic, Frequency Modulation, iLabs, Pulse Code Modulation.*

1. Introduction

Online Laboratories are real equipment setups that can be accessed and controlled externally over a computer network. iLabs are a case of remote laboratories that are accessed through the internet from anywhere at any time [1]. An Online Laboratory simplifies the logistics and requirements involved in conventional laboratory work, including equipment scheduling, lab space, staffing, training and safety. With Online Laboratories, students can conduct experiments from any computer at their convenience, rather than from a specialized laboratory. Further, an Online Laboratory facilitates efficient sharing of expensive equipment.

At its inception, the iLabs project was developed at MIT as part of the iCampus initiative to enhance the laboratory experience of students in Science and Engineering [2]. The iLabs Shared Architecture was developed to facilitate the

creation, management and distribution of laboratory exercises through the internet.

From the perspective of iLabs management, experiments fall into three broad categories, viz, the Batched, Interactive, and Sensor experiments [2]. *Batched experiments* are those in which all parameters of the experiment are specified before it is run. MIT's WebLab provides an example [3]-[5]. Through WebLab students can characterize a variety of semiconductor devices by preparing a test protocol. This is accomplished by using an interactive editor before the semiconductor characterization executes. *Figure 1* shows the topology of the Batched experiment architecture. *Interactive experiments* are those in which the user monitors and can control one or more aspects of the experiment during its execution. *Sensor experiments* are those in which users monitor or analyze real-time data streams without influencing the phenomena being measured. The Batched iLabs Shared Architecture consists of three tiers, viz, the Client, the Service Broker, and the Lab Server [1]. The *Client* application runs as java applet on the student's workstation in a normal web browser, providing a virtual interface to the experiment hardware. Students use this interface to perform experiments and manipulate results. The *Service Broker* provides shared common services, like user authentication, authorization, experiment record storage and scheduling.

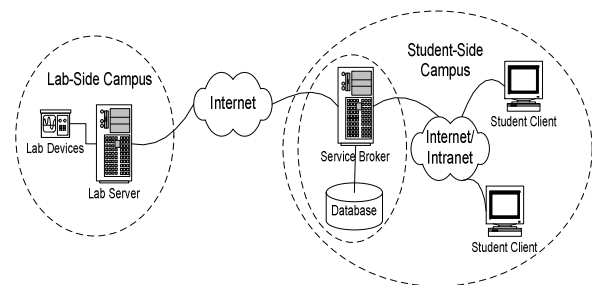


Figure 1: Topology of the batched experiment architecture

The *Lab Server* executes the specified experiments and notifies the *Service Broker* when the results are ready for retrieval. It connects directly to the experimentation

hardware, the NI ELVIS II™, to which plug-in boards can be connected to carry out a particular experiment. The NI ELVIS II™ provides a versatile and affordable platform with twelve fully integrated instruments that can easily be programmed for remote access using NI LabVIEW graphical programming environment.

In a typical experiment scenario the student logs onto the Service Broker and launches the Client of a particular experiment they wish to conduct. In the Client, the student configures the instruments for that experiment setup and submits the set parameters to the lab server for execution. All communication from the Client goes through the Service Broker for effective administration.

Makerere University's experience with iLabs dates back to 2004. In February that year, Prof. Jesus del Alamo, in his visit to the University, introduced the online Microelectronics Device Characterization laboratory (WebLab) [6] to the Faculty of Technology Staff. In the same year, the iLabs Shared Architecture Service Broker was set up and WebLabs were introduced to the first year students of Bachelors of Science in Electrical and Telecommunications Engineering. With this, the labs at MIT were accessible to the students over the next three years.

In 2007, a team of three undergraduate developers embarked on research that led to the establishment of a comprehensive iLabs infrastructure at Makerere University. iLabs@MAK comprising of the administration, graduate fellows and undergraduate developers then entered a phase of continuous research and development to tailor iLabs to the native curriculum. The project is implemented in collaboration with MIT and the other two Universities (University of Dar es Salaam, Tanzania and Obafemi Awolowo University, Nigeria) that constitute the iLab Africa partnership. Currently it is implemented under the Department of Electrical Engineering in the Faculty of Technology, Makerere University.

The Department, like others, continues to experience inadequacy of experimentation equipment and space in the face of increasing student numbers. In a bid to fully integrate iLabs into the curriculum of Engineering in the University, iLabs@MAK with its ongoing research started with development of Laboratories in courses involving Analog and Digital Modulation techniques and Digital Electronics. The developed experiments were based on Remote Engineering concepts using the Batched iLabs Shared Architecture, and were in no way a replacement to the prevailing conventional laboratories, but simply a much needed supplement. In some instances, the experiments developed had no counterparts in the conventional laboratory. These Laboratories are described in the sections that follow.

2. Pulse Code Modulation Laboratory

This Laboratory was intended for use in the Basic Telephony Course, offered by third year students in the Bachelor of Science in Telecommunications Engineering programme. This course encompasses two major concepts pertinent to Telecommunications Systems, Switching and Transmission. Switching entails techniques used to ensure delivery of signals to the intended subscriber while transmission deals with digital and analog mechanisms of ensuring delivery of quality signals to the subscriber [7].

The research focused on developing experiments on digital transmission techniques using NI ELVIS II™ and EMONA Digital Analog Telecommunications Experimenter (DATEX) plug-in board. The subject areas selected for experimentation in the Pulse Code Modulation Laboratory were Nyquist Sampling Theorem, Quantization and Line Coding [8].

Specifications were formulated from which experiments were designed and implemented on the laboratory hardware. Experiments were designed to use the Function Generator and Oscilloscope, instruments on the NI ELVIS II™. A Virtual Instrument (VI) was built in LabVIEW, to remotely control the experimental set up on the board. The Function Generator was the signal source and the outputs were obtained from the Oscilloscope channels. The VI was compiled into a dynamic link library (dll) which was used by the labserver to communicate with NI ELVIS II™. Configurations were made in the ELVIS version 1.0 iLab code to make it compatible with NI ELVIS II™.

2.1 Nyquist Sampling Theorem

This experiment was developed to reinforce the theoretical concepts about signal sampling techniques covered that the student would have acquired in the course of lectures. The student was then expected to identify the sampling scheme used, natural or sample and hold, and then investigate the frequency range for which the original signal can be reconstructed out of the samples, as portrayed in *Figure 2*.

2.2 Quantization and Encoding

The objective of this experiment was to test the student's understanding of the concepts of quantization and encoding, as the second and third steps in Pulse Code Modulation, after Sampling. Specifically, it featured encoding of the sampled zero Voltage DC value. The PCM encoder module takes in an analog message (dc voltage) which is sampled periodically with a clock input. The samples are assigned to a set of finite amplitude levels (quantization) which are then assigned symbols that are transformed into a digital code (encoding) as depicted in *Figure 3*.

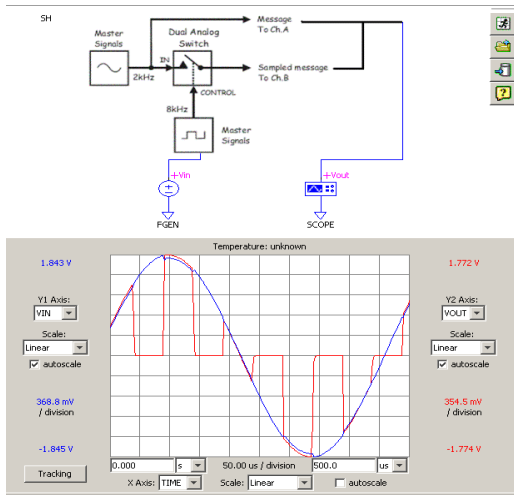


Figure 2: Nyquist sampling scheme

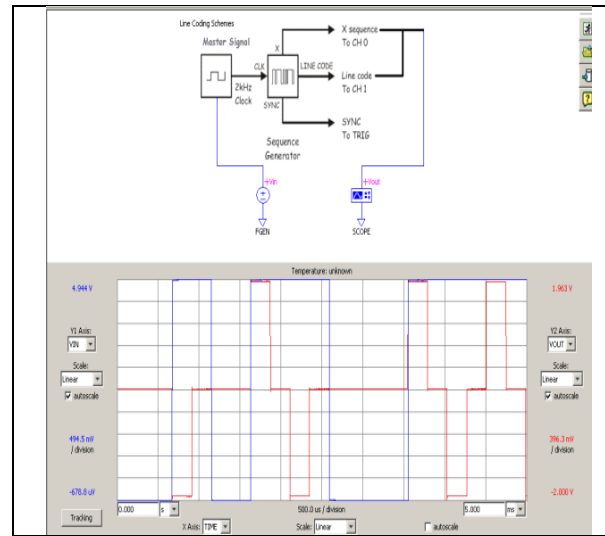


Figure 4: Return to zero - alternate mark inversion

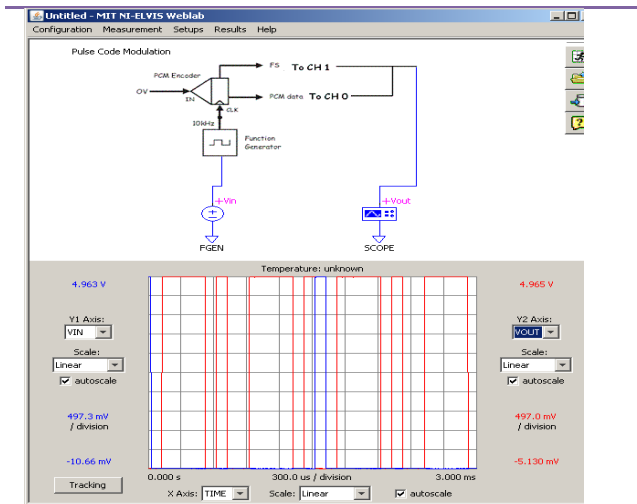


Figure 3: PCM encoding of a zero voltage DC value

2.3 Line Coding

The objective of this experiment was to identify the line coding schemes used to transform a given arbitrary 32 bit binary code. The schemes that were employed included Manchester encoding, Non Return to Zero - Mark, **Return to Zero - Alternate Mark Inversion** (see *Figure 4*) and Non Return to Zero – Level.

3. Amplitude and Frequency Modulation Laboratory

The ideal objective of any communication system is to replicate at the receiver, a message generated at a source and transmitted over a medium. The success of this process largely depends on the type of transmission medium, modulation and demodulation techniques employed.

Generally, the generated message is not in a state appropriate for direct transmission over majority of the physical media. Modulation is thus required to prepare the message in readiness for transmission over these media.

Modulation schemes are broadly classified into analog and digital forms. Initially modulation was predominantly of the analog type until the advent of digital technology. Although there is a general trend toward digital modulation, there is still a significant presence of analog modulation in such areas as audio and video broadcasts [9]. To address the requirements of these areas, the Communication Engineering Course offered in the Department of Electrical Engineering incorporates Amplitude and Frequency modulation techniques as core topics. Four experiments were designed to cater for the practical components of the course in these topics. These included Double Side Band Full Carrier Modulation (AM), Double Side Band Suppressed Carrier Modulation (DSBSC), Single Side Band Suppressed Carrier Modulation (SSBSC) and Frequency Modulation (FM). The experiments were designed and implemented using the block modules on the EMONA-DATEX board based on the mathematical models of the modulation techniques [10]-[11], where, $AM = (DC + Message) \times Carrier$, $DSBSC = Message \times Carrier$, $SSBSC = (Message \times Carrier) + (Message \text{ with } 90^\circ \text{ Shift} \times Carrier \text{ with } 90^\circ \text{ Shift})$. The FM experiment was implemented using the Voltage Controlled Oscillator.

A VI incorporating the Function Generator, Oscilloscope and Variable DC Power Supply (VPS), instruments required to conduct the AM experiment was developed. The VI was compiled into a dynamic link library (dll) and the Lab Server code was then reconfigured to use this dll.

From the lab manual developed, students were guided to select the required parameters for the Function Generator (signal input) and the Oscilloscope (sampling rate). *Figure 5* shows the results for the over modulated signal in the AM

experiment as graphed by the Client, vis-à-vis the results from the conventional set up. *Figure 6* shows the Java applet client with a display of the results for the Double Side Band Suppressed Carrier Modulation experiment whereas *Figure 7* shows the results for the Single Side Band Suppressed Carrier Modulation experiment. *Figure 8* illustrates the results for the Frequency Modulation experiment.

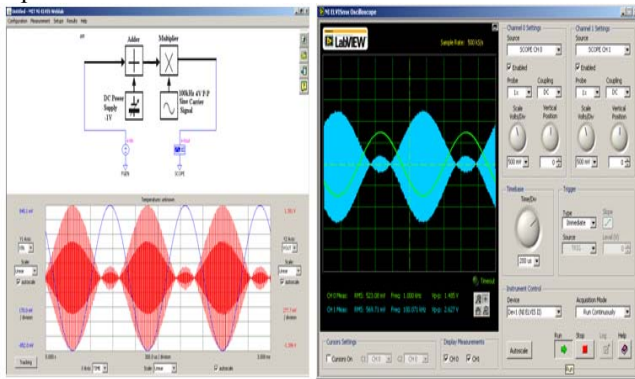


Figure 5: Over modulated AM signal experimental results

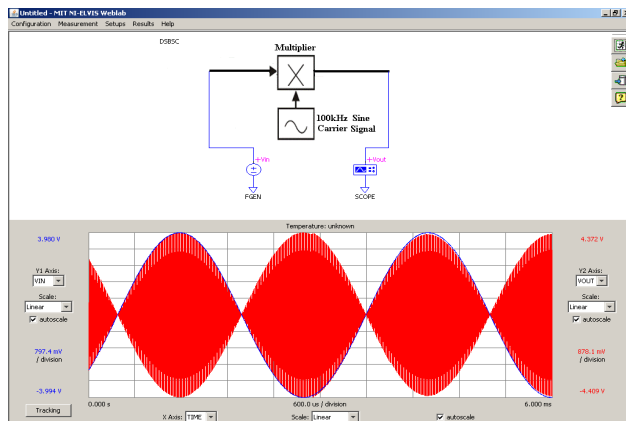


Figure 6: Results for the DSB-SC modulation experiment

The Amplitude Modulation Experiment was deployed on the Faculty of Technology intranet for two weeks and used as part of course work assessment for third year students offering Communication Engineering. A survey was conducted to get feedback from students through use of questionnaires. The survey also set out to test the effectiveness of the developed laboratory in the reinforcement of theoretical concepts.

The questionnaire required students to rate their laboratory experience while performing the Amplitude Modulation experiment. The results showed that students responded satisfactorily to the conduct of the experiment and were confidently able to relate theory and practice as illustrated in *Figure 9*.

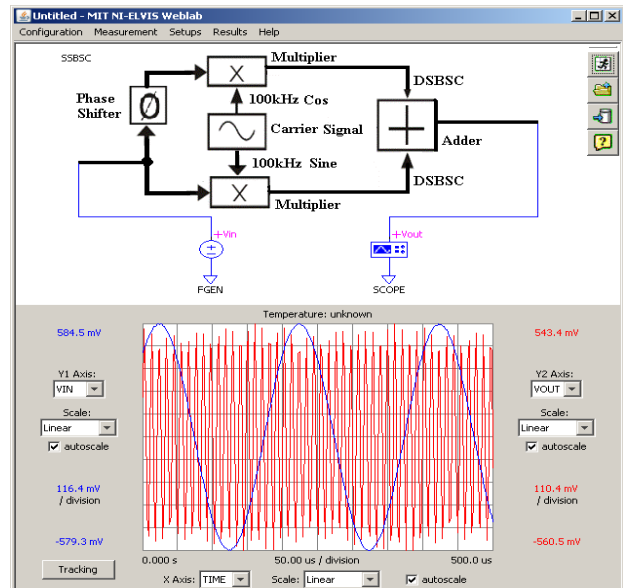


Figure 7: Results for the SSB-SC modulation experiment

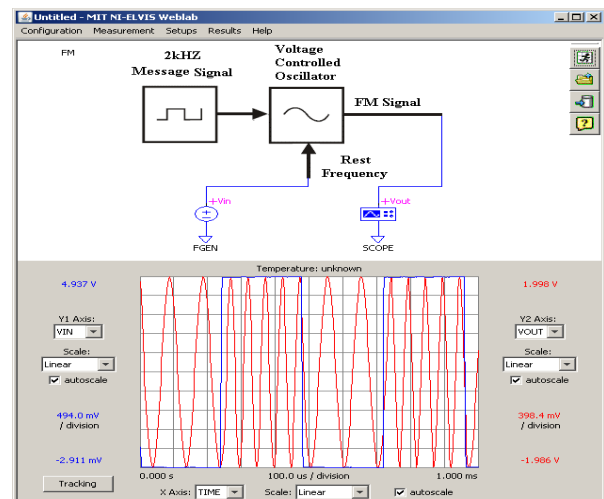


Figure 8: Results for the frequency modulation experiment

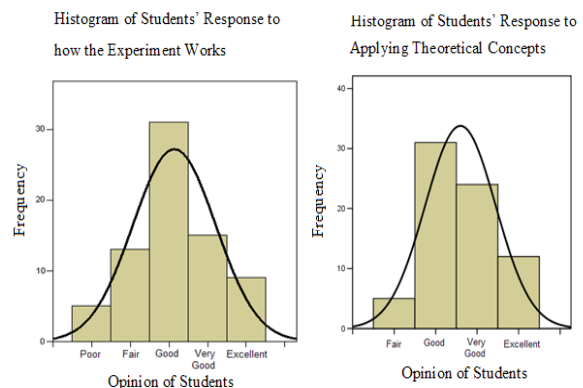


Figure 9: Student response to the AM experiment

4. Combinational Digital Logic Laboratory

With the advent of digital technology, courses in digital electronics are fundamental in the field of Electrical Engineering and related disciplines. In the Department of Electrical Engineering, students are introduced to this field through two courses, namely, Introduction to Digital Electronics and Applied Digital Electronics.

The research focused on developing experiments for the Introduction to Digital Electronics course which mainly deals with fundamentals of combinational logic circuits. Three experiments were designed in the fields of Logic Gate Characterisation, Logic Gate Application and construction of memory elements.

NI ELVIS II™ with the Free Scale prototyping board, for electronics circuit design, was used. The NI ELVIS II™ instruments used in the design of the Combinational Digital Logic laboratory were the Digital Reader and the Digital Writer. The Digital Writer inputs user-defined logic combinations to the circuit on the Free Scale Board and the Digital Reader outputs the ensuing values depending on the Logic implemented by the circuit. The NI ELVIS II™ has 23 Digital input/output (DIO) lines which can be programmed to either read digital data or have digital data written onto them using LabVIEW [12].

A VI integrating the Digital Reader and Writer was developed. The input of the VI was customised to cater for Logic patterns of all the possible input combinations to the Logic Circuit. The lab server code was modified to use the compiled VI and handle digital data [13]. The client was also modified to graph Digital data.

The Logic gate Characterisation experiment was deployed on the Faculty of Technology intranet and availed for students in the first year course of Introduction to Digital Electronics as part of continuous assessment coursework. The experiment was setup on the NI ELVIS II™ Free Scale board using IC logic gates (see Figure 10). The student was required to establish the identity of an unknown Gate using combinational logic circuit analysis, given the identity of the other Gates.

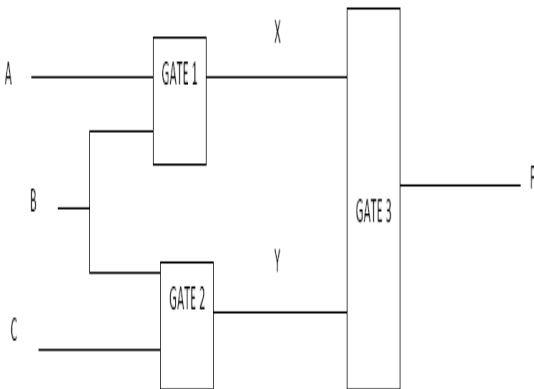


Figure 10: Combinational circuit schematic

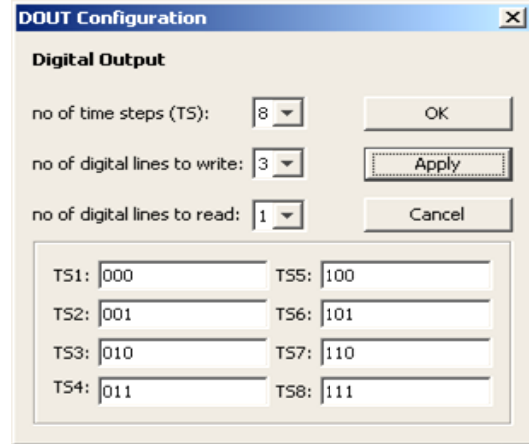


Figure 11: Configuring the digital writer

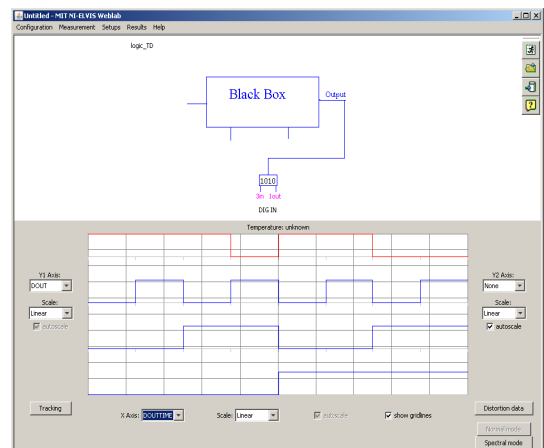


Figure 13: Digital waveforms for the input and output

The Client presented the student with a dialog box for configuring the Digital writer as shown in Figure 11. With three inputs and one output, the expected parameters were eight time steps, equal to the number of input combinations. Running the experiment yielded the output and input digital waveforms, characteristic of the implemented logic as shown in Figure 12. From the waveforms, the student would construct a truth table and thereby establish the identity of the unknown gate.

5. Conclusion

This paper has presented the processes through which the iLabs@MAK project has advanced in the development of remote laboratories currently being used by students in selected courses in the Department of Electrical Engineering. This has contributed to mitigation of the challenge of inadequate equipment, lab space in the face of increasing student numbers and student-staff ratio.

It is demonstrated that Online Laboratories offer students immense benefits through the provision of a convenient and flexible laboratory schedule. The experience acquired from

this research presents opportunities to extend Online Laboratories to other courses in the Department of Electrical Engineering and other related disciplines. Nevertheless, there is still need to sensitize the student community and the faculty on the versatility and benefits that can accrue from adoption of Online Laboratories in science education.

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