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# Experiential Learning in Computer Engineering using Medium Complexity Logic Design Circuits

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# Experiential Learning in Computer Engineering using Medium Complexity Logic Design Circuits

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***Abstract-*** **One of the main tracks of research is about Low-cost computing devices in engineering educations. This track faces the problem that conventual methods are either too trivial demonstrative educational examples, or too abstracted that it hides away the necessary details students should learn, or too complex industry grade demonstrations. This research targets to utilize lost cost computing devices, and produce medium complexity educational component using analog to digital, digital to analogy circuits integrated with Field Programmable Gate Array (FPGA) devices. A medium level complexity example is illustrated in this paper using Analog to Digital and Digital to Analog converter board attached to FPGA development board. A comparison between conventional methods and proposed methods is also presented showing advantages of FPGA based logic design implementations.**

***Keywords-*** **Higher education enhancement, Technology in education, Field Programmable Gate Arrays (FPGA)s, Prototype Laboratory development. Analog to Digital and Digital to Analog conversions.**

## I. INTRODUCTION

Data acquisition systems (DAQ) have broad applications in industrial control systems, medical diagnosis field, and even in educational institutions. These DAQ systems are used to sample analog signals, convert them to digital forms, process them digitally, store them, and most of the time we need also to convert results back to analog forms [1,2]. According to Nyquist-Shannon sampling theorem, a signal with maximum frequency component of $f$ Hz, must be sampled with a sampling frequency of at least $2f$ Hz [1]. In sophisticated data acquisition system applications such as in [2-7], input channels are not of similar characteristics unlike most signal processing algorithms which make the assumption that samples of a signal are equally spaced.

Since Field Programmable Gate Arrays, were introduced in 1985 by Xilinx [8], it has become a very mature technology, especially it was patented in 1992. Its market share today is in the billions of US dollars. FPGAs are based on fundamental ideas of the use of memory cells to connect wires as desired, specify logic functions in a reconfigurable fashion, and even to specify the mode of operation of most of the pins of the integrated circuit [9].

Figure 1 shows an example of a Configurable Logic Block CLB of 4 inputs, and two 3-input LUTs, Full-Adder (FA), sequential D-type flip flop (DFF), multiplexers (MUX) with select lines. One of the MUXs select lines is connected to the input d of the CLB, while the other is connected to the CLB sequential/combinational configuration choice to use or bypass the DFF correspondingly.

Figure 2 shows an example of a typical FPGA, with an array of CLBs, and reconfigurable interconnection wires. The modules of General-Purpose Input/Outputs (GPIO) are also of paramount importance, since they configure the mode of each of the pins of the chip to be input, output, bidirectional, buffered, etc. Modern FPGAs are based on the same concept, but they may also offer non-reconfigurable components, such as memory cells, microprocessors, input/output transceivers, and so on. Figure 3 shows how a logic circuit can be modeled in different ways, and eventually be described in hardware description language (HDL) as a mean to implement it in FPGA.

Logic circuit designers are also equipped with sophisticated design tools, which make the FPGA a feasible choice for implementing, testing, evaluating multitude of integrated circuit components. Furthermore, FPGA technology allows designers to use already fabricated integrated circuits to implant logic circuits and changed them later. Thus, FPGAs become a perfect technology for educators who are involved in reconfigurable hardware design courses.

## II. CHALLENGES OF DAQ SYSTEMS

To sample multiple signals simultaneously, it is possible to purchase multiple single-channel DAQs, but this is usually an expensive approach. Thus, a multi-channel DAQ can be used instead. Consequently, one DAQ can process the data for multiple channels at once, leading to a lower cost.

Conventional multi-channel DAQs [2-7] make use of a simple sampling technique called Round-robin to time-multiplex the sampling of all connected signals. When using the Round-robin sampling technique, the minimum sampling frequency of any channel is limited by the minimum required sampling frequency of the highest frequency input signal. If the input signals contain a heterogeneous mix of both high frequency and low frequency signals, the low frequency signals are oversampled. This results in redundant data and uses up ADC resources that could be used to sample additional signals.
Various research has been done to resolve some of the disadvantages of conventional DAQs, particularly in its time schedule to sample multiple channels [2-7, 10-26]. For example, non-uniform sampling techniques tries to relax the constraint of a uniform interval for sampling. The Weighted

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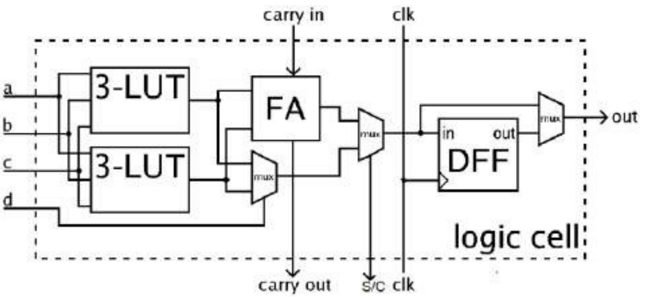


Figure 1: Example Configurable Logic Block of a generic FPGA

Periodic None-uniform Sampling (WPNS) [10-11], estimates the frequency spectrum of a signal that has a highest bandwidth, and cycles through a list of processes and allocates multiple blocks of time to each process for its continuous execution behavior based on its priority.

Most of existing solutions to DAQs used either simulation results, or were implemented on Very Large Scale Integrated (VLSI) circuits. Both options are not optimal for learning. Simulation only abstracts away physical details (i.e., in simulations only), or hinders the ability of hardware reconfiguration (i.e., VLSI technology). Thus, the author believes that the introduction of Analog to Digital, Digital to Analogy conversion with a reconfigurable integrated circuit technology could be used to alleviate these disadvantages. Of a Some of latest research work used FPGA in DAQ systems such as in [27-46]. For clarity, and completeness purposes, the following figures show fundamental basics of FPGA, with an example of a multiplexor circuit.

Instructors using Experiential learning need to only show directions of how to accomplish a task, and not giving the learners all the details of how to take the route to the desired destination [47]. Thus, it makes learning an experience (i.e., not just perform an experiment) that moves beyond the classroom instruction and allows students the opportunity to draw conclusions, and being more involved in their own learning process.

Experiential Learning is thus considered as Learning by reflection on Doing [48-56]. It is not a new concept, and various philosophers stressed it in their teachings. It was conceptualized by Aristotle about Ethics as "for the things we have to learn before we can do them, we learn by doing them (first!)" [57]. However, in the 1970s, David A. Kolb developed a fundamental modern model of experiential learning [58]. According to Kolb, [59-60] the learner must be actively involved in the experience; reflect on the experience; analyze the outcomes; and perform decision making and problem-solving skills in order to use the new ideas gained from the prior experience. In this process, instructors to give constructive feedback to the learners, but they should not rush to provide the answer [61-62], especially when creative abilities are to be developed (critical thinking, design, synthesis, etc.), and particularly when there is not a single right answer. They will use their experience to judge or evaluate an outcome of a targeted component and share it with the learners [63-64].

Experiential learning was used in different fields of engineering education. For example [65], it was used via hardware emulators, and FPGA were used in latter stage of complex multi-part designs. Also, in 2020, two different comparative studies for experiential learning were done in two different universities in China, and New Zealand considering virtual reality applications, concluded that it enhances learning experience [66-68]. Furthermore, researchers investigated the incorporation of experiential learning at a Canadian university, in 2017, but they implemented it in a single engineering course, without FPGAs, and thus results

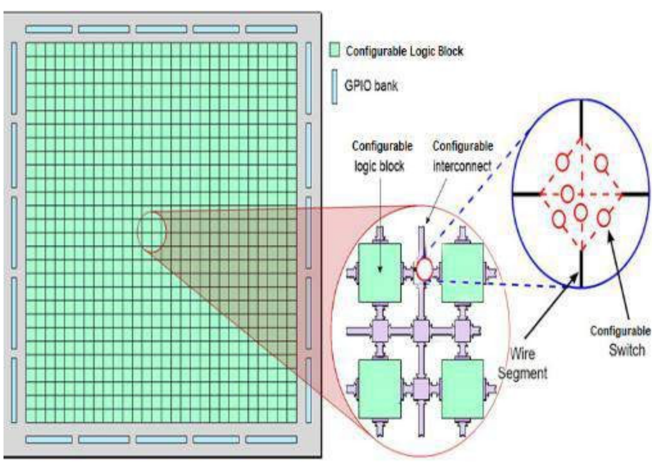


Figure 2: Illustration of a typical FPGA, with an array of CLBs, and reconfigurable interconnection wires via configurable switches

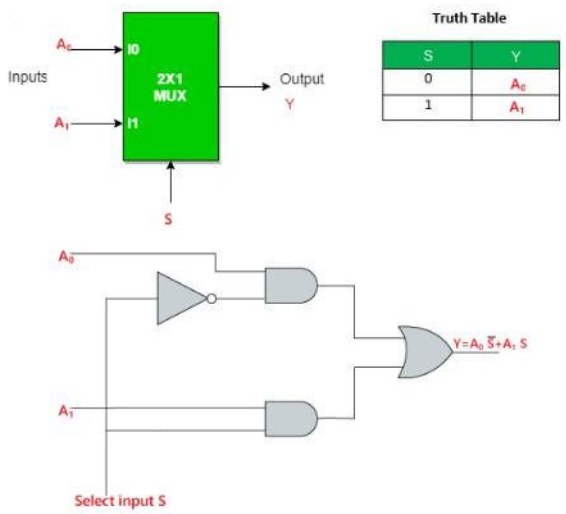


Figure 3: A two to one Multiplexer: Block diagram, truth table, and logic circuit

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were limited [69]. Recently, a research team in Horus University-Egypt adopted the use of FPGAs in experiential learning [ 27-29].

## III. Experiential Learning via a Basic Logic Design Example using Advanced FPGA Board

The author founded the Experiential Learning Research Lab in the Faculty of Engineering at Horus University-Egypt

Figure 4: The Experiential Learning Research Lab (EXL-Research) showing multiple stations

via funds made available both internally and externally. Figure 4 shows an angle of this lab, where stations are set to design different students experiences. [27, 28, 29]

Of the acquired boards, is the Altera Cyclone II (2C70) DE2-70 [70], FPGA board, shown in Figure 5. We attached the ADA board [71] to the GPIO connections on the DE2-70, as shown in Figure 6. Then we configured the FPGA to operate as an interface for the A/D converter board, generate a digital approximation to sine wave with its D/A converter, connect the output to an analog input channel, then acquire it back via the A/D converter for testing purposes. We used an analog input of the A/D converter input. Then we used a logic analyzer on the FPGA design tool to verify that conversion process.

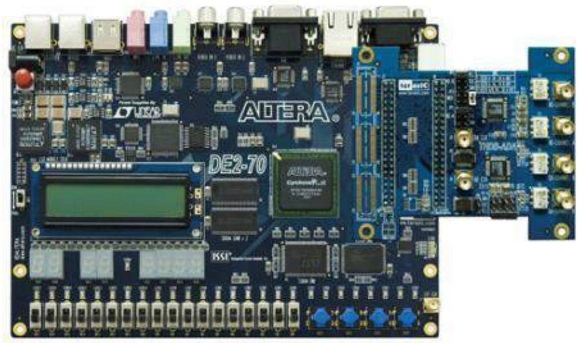


Figure 6: Altera DE2-70 board, with the A/D converter card


Figure 7: Experimental setup for the Altera DE2-70 board, with the A/D converter card

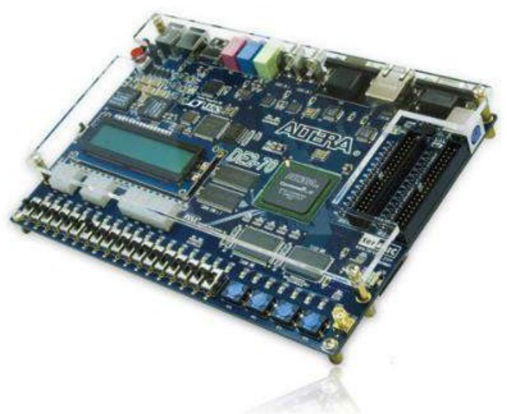


Figure 5: Altera DE2-70 board

To initially verify the conversion process, we used the Quartus II FPGA development tool to load an on-chip logic analyzer component. As shown in Figure 8, we observe that the D/A output is made to generate a sine wave, which was connected to the A/D input, where its output is shown at the top of the graph. Figures 7, and 8 show the graphical and text output of such conversion process respectively.

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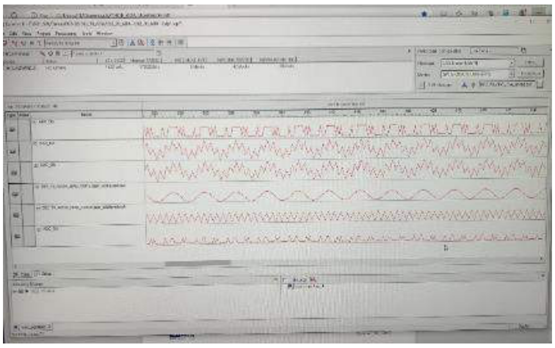

Figure 7: Logic Analyzer graphical output for the Altera DE2-70 board, with the A/D converter card

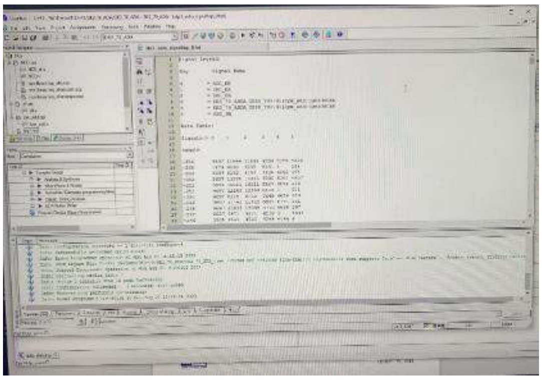

Figure 8: Logic Analyzer text output for the Altera DE2-70

Based on a Cyclone II FPGA board, the instructor may further challenge the students by projects of high complexities. Examples include time using multiple channels at once, downloading data to computer for further processing, and so on. Thus, students will need to use more capabilities of the FPGA design tools. Also, for advanced courses, the same project can be extended to send the outputs to a network interface, thus using a web browser, and a microprocessor on the FPGA chip and so on. In those later experiences, students will need to learn more about Hardware Description Languages (HDL), such as Verilog or VHDL together with Schematic editors, in-chip logic analyzers, functional simulations, and timing simulations.

## IV. FPGA BASED EXPERIENTIAL LEARNING COMPARISON WITH CONVENTIONAL METHODS

Conventual ways to implement basic logic circuits include:

- Logic simulation
- Discrete component implementations
- Ready off-the-shelf logic blocks

Int the following we list advantages and disadvantages of these choices as they compare with

- Modern, FPGA based logic circuit implementations

Logic simulation: This is typically a computer based simulation of the logic circuits (such as LogiSim, ModelSim, etc). Although very useful to illustrate teaching concepts, but they fail to give the necessary physical experiences, and students may still find it not convincing that their design will actually work.

Discrete component implementations: This is straight forward buy, and try approach. Usually, students are asked to acquire parts on their own, and build the circuit. Most of the time, due to lack of prior experiences, students break many parts, and may get frustrated from having to buy more parts to replace failed ones. Also, it requires a very thorough attention to details of all wirings, which can be sometimes too time consuming and also frustrating.

Ready off-the-shelf logic blocks: This tries to remedy the problems of previous choice, but for its simplicity, fails to give the student the proper hardware experiences of industrial implementation technology.

Furthermore, none of the implementation methods used above are actually used in the computer logic design industry today.

FPGA technologies have reached a maturity level that is used in industry and can be also used in multi level (i.e., basic to complex) design circuits.

## V. CONCLUSIONS AND FUTURE WORK

In this paper, we presented a medium-level design experience using FPGA DE2-70 board, and A/D, D/A converter board for the experiential learning pedagogy. Detailed step by step illustrations were give, so that instructors can use it to duplicate the experiences and benefit from them. Furthermore, we compared such developed experiences with conventual methods, showing that experience learning, even in its basic form resolves the problems found in traditional teaching.

In future work, further computer-based analysis will be done. To do so, A/D converter acquired data must be downloaded to the computer and analyzed via Matlab to compare the acquired data with an synthesized sine wave. We can use auto-correlation function to measure the mean-square error of the between the synthesized wave, and the acquired wave.

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**Conflicts of Interest:**
All authors declare that they have no conflict of interest regarding this research paper and that they comply with research ethics.

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