

Hardware Resources in Digital Systems Teaching

Yimin Xie, David Wong and Yinan Kong
Department of Physics and Engineering
Macquarie University
Sydney, NSW 2109, Australia

ABSTRACT

This paper provides an overview of all the hardware resources necessary to support the delivery of a sequence of courses in digital systems covering digital fundamentals to hierarchical design of complex digital systems. An example of an effective approach to engineering education is shown through the use of these resources.

Keywords: Digital Systems, Engineering Education, Hardware Design and Problem-Based Learning.

1. INTRODUCTION

The scope of the materials covered in a sequence of courses in digital systems is very wide, and therefore, adequate hardware resources to support the teaching are imperative. Hardware trainers have been developed to satisfy this requirement in the author's department. Some trainers have been designed with a focus on a specific digital concept while others have a much wider application and provide resources for problem-based learning. Trainers of both types are described in this paper.

The four courses involved in digital systems teaching consist of Digital Fundamentals (in the first year), Programmable Logic Design (in the second year) and Computer Hardware and Digital Systems Design (in the

third year). The scope of the topics covered in the four courses is represented by the content of the textbooks and references shown below in Table 1.

2. CONCEPT-SPECIFIC TRAINERS

This set of hardware is developed for the course of Digital Fundamentals. It also needs to be used for demonstrations in class as well as in large activities like university open days. All these require that the concept-specific trainers have to be easy to set up, and also that the PCB must be fully operational after the connection of the power supply (and clock). It must not require any additional wiring (or, in some cases, a minimum amount of wiring), and all the relevant signals must be labelled and monitored by light-emitting diodes (LEDs).

For this reason, a typical trainer of this type was designed to include small interactive printed-circuit boards (PCBs) that focus on digital concepts of parity, multiplexing, adder/accumulators, flip-flops/counters, data bus and shift registers. Then the advantage is realized that the PCB is exercised by setting switches or pressing pushbuttons (to provide a single clock pulse), and by monitoring signals using the LEDs or a logic analyser. This exactly satisfies the requirement of a simple class demo and also achieves the aim of spurring the interest of new undergraduates in digital systems design. Figure 1 shows three of these PCBs.

Table 1 Author(s) of Text/Reference Books

Course	Author	Text/Reference Book
Digital Fundamentals	T. Floyd	Text [1]
Digital Fundamentals	R. J. Tocci, N. S. Widmer and G. L. Moss	Reference [2]
Programmable Logic Design	T. Floyd	Reference [3]
Computer Hardware	P. Spasov	Text [4]
Computer Hardware	R. J. Dirkman and J. Leonard	Reference [5]
Digital Systems Design	C. H. Roth and L. K. John	Text [6]

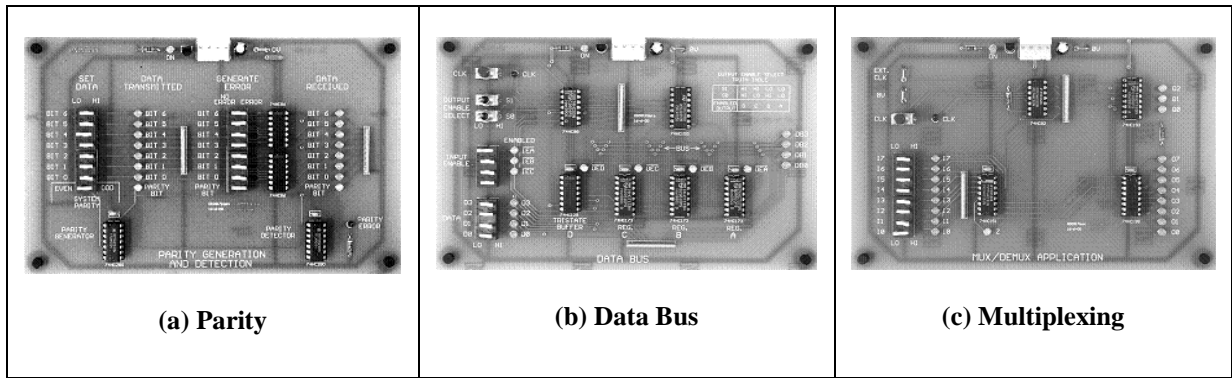


Figure 1: Examples of Concept-Specific Trainers

The present set of trainers has been implemented with medium-scale integrated circuits. Other concepts (such as error-correction codes) have been considered, and will probably have an implementation using complex programmable logic devices (CPLDs).

3. GENERAL-PURPOSE TRAINERS

The general-purpose trainers focus on logic circuits and small/medium-scale integrated circuits (ICs). This type of trainer provides basic building blocks that may be interconnected by patch leads to build combinational or sequential circuits of simple or modest complexity. This is exactly the kind of techniques students need to be equipped with in their second and third year. Two versions of this type have been used in the experiments to enrich the students' hands-on experience in circuit design.

The first consists of a PCB with top-over-layer printing showing distinctive shapes of gates and flip-flops with associated sockets for inputs and outputs that may be physically interconnected. Each output is monitored by an LED, and constructed circuits may be exercised using switches and pushbuttons. The second version is a PCB with several zero-insertion-force (ZIF) sockets for small/medium-scale integrated circuits. This version provides students with the experience of selecting and handling a wide range of ICs. Figure 2 shows the two versions of general-purpose trainers described as the Digital Fundamentals Trainer and the Integrated Circuit Trainer. The integrated-circuit trainer contains only two 20-pin ZIF sockets. Circuits of greater complexity may be handled by the GAL8 Trainer which has eight 24-pin ZIF sockets.

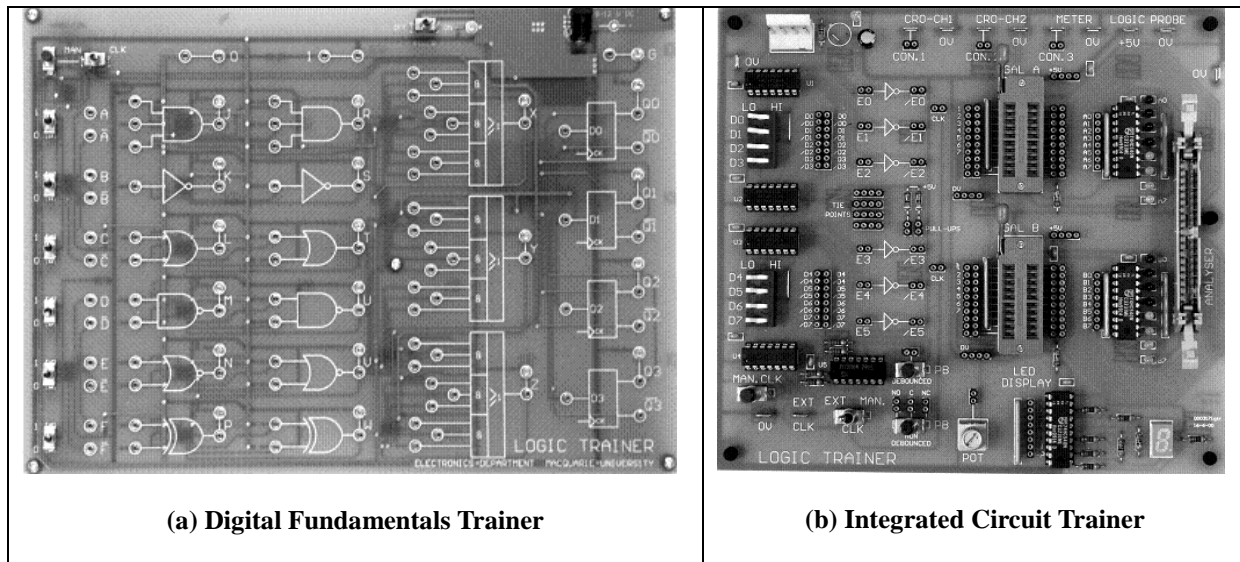


Figure 2: General-Purpose Digital Trainers

4. PROGRAMMABLE LOGIC TRAINERS

Programmable Logic Trainers are trainers that exploit the flexibility and immense functional capability of programmable logic devices (PLDs). They have been used in the experiment sessions in the course of Programmable Logic Design and Digital Systems Design.

Programmable Logic Trainers have been developed using Generic Array Logic (GAL) devices and Field Programmable Gate Arrays (FPGAs). The GAL devices were chosen because their architecture, consisting of a programmable AND array followed by an OR gate and flip-flop, with feedback connections from the flip-flop to the AND array, provides students with a smooth transition from concepts of finite state machines (FSMs) studied in the earlier course. Modern FPGA devices have a huge functional capability, and this type of PLD is the logical choice for the implementation of complex digital systems. In addition, the mandatory use of computer-aided-design (CAD) software introduces students to state-of-the-art procedures used in industry for the implementation, simulation and synthesis of FPGA-based systems.

Figure 3 illustrates the programmable logic trainers. The GAL4 trainer consists of a PCB with four 20-pin ZIF sockets for four GAL16V8 devices. The GAL8 trainer consists of a PCB with eight 24-pin ZIF sockets for eight GAL22V10 devices, together with a microcontroller and a variable clock generator. An important feature of this type

of trainer is that all outputs may be labelled and monitored with LEDs. In the case of the GAL8 trainer, there are 80 LEDs, and 32 signals may be monitored by a 32-channel logic analyser. The FPGA trainer consists of a FPGA (Spartan-3) development board interfaced to a desk-top computer with input and output boards. This system provides the capability to design and synthesise complex digital systems.

The Xilinx Spartan 3 FPGA has sufficient capacity to design and build complex systems such as those developed for final-year thesis projects (e.g. [7]).

5. MICROCONTROLLER TRAINERS

Microcontroller trainers have hardware and software resources that give students the experience of exercising and developing microcontroller-based systems. Microcontroller interfacing is important and experiments should cover parallel ports, serial ports, interrupts, timing and digital/analogue inputs/outputs. As bit-level manipulation is required, especially for a memory-mapped input/output architecture (such as that of the Motorola 68HC11 microcontroller), some experience with assembler coding is required. The microcontroller trainer consists of a microcontroller development board interfaced to a desktop computer and a specially designed input-output PCB. This supports a number of experiments on computer interfacing. the 68HC11 Evaluation Board and the Input/Output Board are shown in Figure 4.

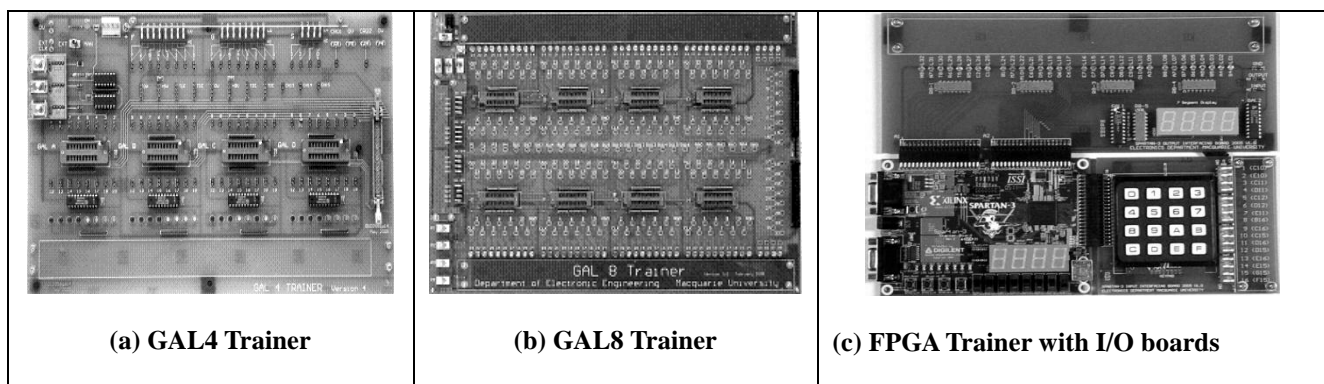


Figure 3: Programmable Logic Trainers

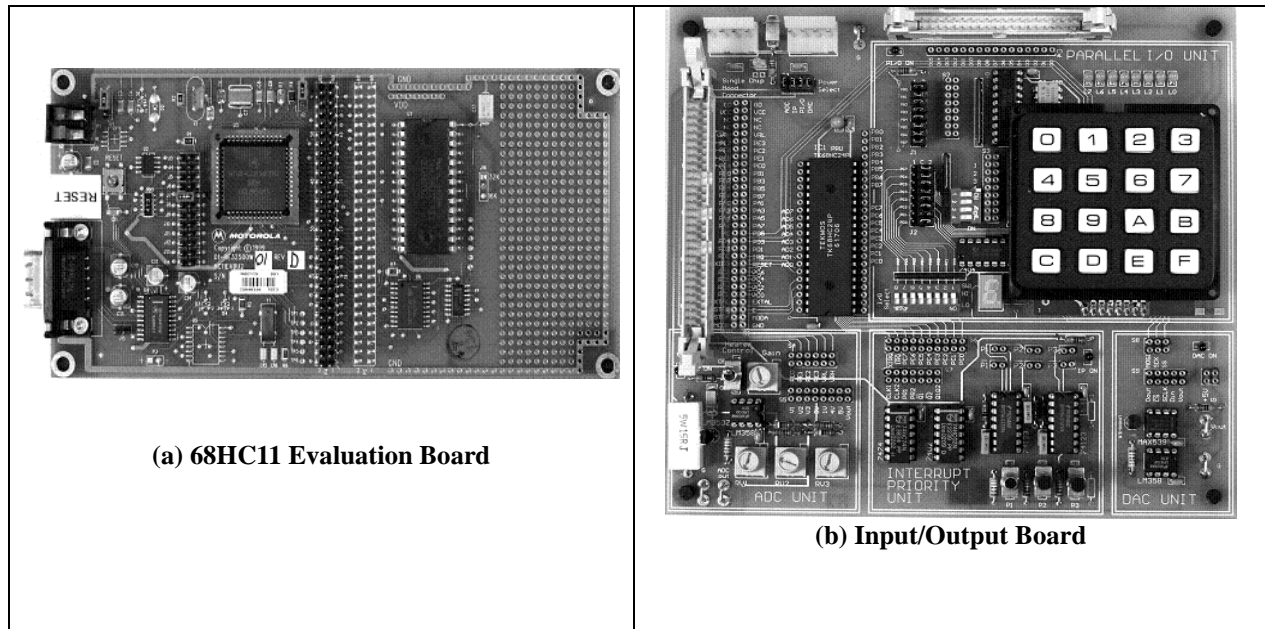


Figure 4: Microcontroller Trainer

6. HARDWARE RESOURCES FOR PROBLEM-BASED LEARNING

Problem-based learning (PBL) was a feature of a new course on Programmable Logic Design [8]. For this course, the main project involved the design, construction and testing of a digital controller to control the traffic lights of a complex traffic intersection. A PCB with LEDs in positions corresponding to those in the physical intersection was prepared to facilitate testing. This is shown in Figure 5 (a). To support those teams who may opt for VHDL implementation, a new PCB containing a CPLD and a microcontroller, together with a model of the intersection, has been developed. This is shown in Figure 5 (b). A PBL approach has also been used in the course Digital Systems Design, in which the main project is the development of a bus-structured computer. A hierarchical design approach has been used, and component modules are designed, built and

tested using the GAL8 Trainer. To facilitate the development of a prototype, a PCB with a static RAM and tri-state buffers has been built. This is shown in Figure 5 (c). This PCB may also be used when a FPGA implementation using VHDL is chosen. The hardware resources for PBL have helped students gain the skills necessary to develop complex digital systems.

7. SOFTWARE RESOURCES

The GAL-based experiments use OPALjr. This allows the use of Boolean algebra for the specification of combinational circuits for GAL outputs and flip-flop inputs. The microcontroller software used is the AS11 cross-assembler. The FPGA experiments use Xilinx ISE Version 9.2.04i software (Xilinx, 2009) for schematic/VHDL entry, simulation and synthesis.

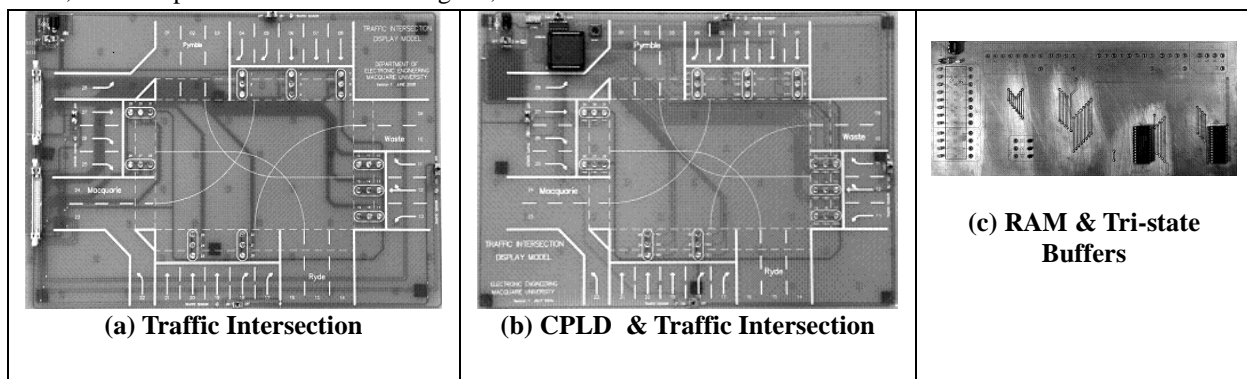


Figure 5: PBL Hardware Modules

8. CONCLUSION

Hardware resources developed for digital systems teaching have been presented. Concept-specific and general-purpose logic trainers were developed for the introductory courses, programmable-logic trainers were aiming at handling complex digital systems and microcontroller trainers were particularly designed for the course on microcontroller teaching. In addition, dedicated hardware was implemented to assist with problem-based learning.

All of these hardware resources have found their places and are playing an important role in the continuum of digital systems teaching. They help to integrate a systematical stream of digital systems in the education of Electronic Engineering in the author's department.

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