

A Low Cost Student Constructed Digital Trainer

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Abstract: *This paper describes the development and application of a student constructed digital trainer circuit prototyping system, for students in their first year digital electronic course. The primary goal was to design an inexpensive, simple to use device that could be retained by students, so that they could undertake digital experimentation at home. The device, called the 'PortBuffer', effectively replicates some of the functions available from commercial digital trainers. The PortBuffer consists of a simple external circuit that attaches to the printer port of a computer. The PortBuffer is then operated by a designed MS-Windows controlling software. The student feedback has been positive, with their critical and inclusive comments enabling further improvements to the design.*

Introduction

When prototyping digital electronic circuits, the digital circuits require specific digital (0-5V) input signals, which then generate digital (0-5V) output signals for monitoring. To accomplish this task a teaching device known as a 'Digital Trainer' is utilised. The trainer includes (among other functions) switches for providing digital logic inputs and LED indicators to specify digital logic outputs. The author's university laboratories utilises the 'iNEX Digital Experimental Boards' (iNEX Corporation, 2009) for this task, (see Figure 1).

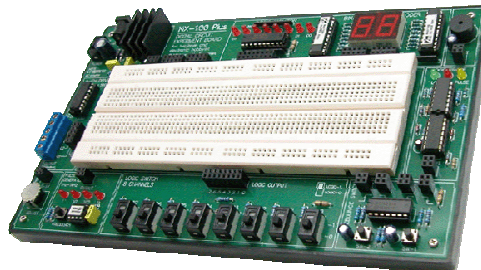


Figure 1: iNEX Digital Experimental Boards

Unfortunately it is impractical to loan out these digital trainers to students, for reason such as: the limited number of digital trainers (compared to the student numbers); the need to use the trainers in multiple repeat laboratories; and the effort required to replace any lost boards. Additionally, the cost of the digital trainer boards makes it unfeasible for students to purchase their own board. Hence students are limited to using the digital trainers within their scheduled laboratory sessions, which inhibits the students gaining extended practice in order to improve their skills.

To provide a method for students to test digital circuits outside the scheduled laboratory times, the author has developed a simple and inexpensive limited version of a digital trainer. The device needed be simple enough for the students to construct themselves, and to be affordable enough so that the students could permanently retain the device. The result was the 'PortBuffer' system; its development and implementation is described in the following sections.

Initial Design of a Student Digital Trainer

When designing the affordable, student constructed, digital trainer, it was necessary to utilise equipment that the students would already possess, that was already directly suited to digital signals.

Today most students possess a computer, which generally incorporates a printer port. Thus they already have a device that is directly compatible with standard digital signals.

The capability of a computer printer port to act as an inexpensive piece of teaching hardware has been well established (e.g. Rodriguez *et al*, 2001; Mallalieu *et al*, 1999; and Mota *et al*, 1998). Indeed the printer port has been identified as a convenient and versatile method for obtaining general purpose input/output signals. Many varied teaching devices had been developed, which utilise the printer port for an educational task. The references state these teaching devices were educationally useful and improved student learning.

Printer Port Specifications

While the full specifications and programming information on the computer printer port is beyond the scope of this paper, these details can be found in many books, such as the on-line book *Parallel Port Complete* (Axelson, 1997). However it is important for clarification and understanding to briefly explain the printer port signals available. The printer port has: 12 digital outputs (the data pins **D0** to **D7**, and the **SEL In**, **Init**, **AutoLF**, and **Strobe** pins); and 5 digital inputs (**Busy**, **ACK**, **PE**, **Sel Out**, and **Error** pins). These printer port pins are shown in Figure 2.

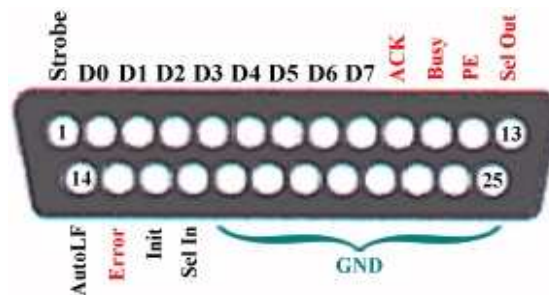


Figure 2: Printer Port Pins

'PortBuffer' Circuit

As previously stated, the pins on the computer printer port are directly compatible with the 5V digital voltage signals. Hence the pins can be directly wired to external digital circuits, using only a connector and no other circuitry. However, when using such a direct connection, there is a danger that improper voltages and short circuits could be incorrectly applied to the pins, possibly damaging the printer port. Thus protection is required between the printer port and the external circuits by the use of protective buffer chips.

Additionally the printer port provides no power output, so an extra 5V regulator circuit is required. The regulator circuit can use any DC plug pack (with a range of voltages) as its external power source, while the regulator outputs the required stable 5V supply for the digital circuits.

From its inception, the *PortBuffer* device was designed so that students could retain the device, which required the device to be as inexpensive as possible. The inclusion of the buffer chips, and the regulator circuit, only added minimal extra cost (less than \$3AUS), yet the additions greatly improved the functionality of the circuit. The final developed circuit diagram is provided in Figure 3.

Within the author's digital electronic course, the PCB fabrication and component soldering of the *PortBuffer* circuit is undertaken by the students themselves, in a dedicated circuit fabrication laboratory. This laboratory has the benefit of providing students with the experience to undertake the full construction of a functional circuit, which increases the student's interest in the task, and gives them a sense of 'ownership' of their device. Importantly, with students undertaking the construction, there are no manufacturing costs to the university. With students undertaking construction, and with minimal component costs, the expenditure was within the university's laboratory consumable budget, which facilitated the requirement that students could retain the constructed device. An image of the fully constructed circuit is shown in Figure 4.

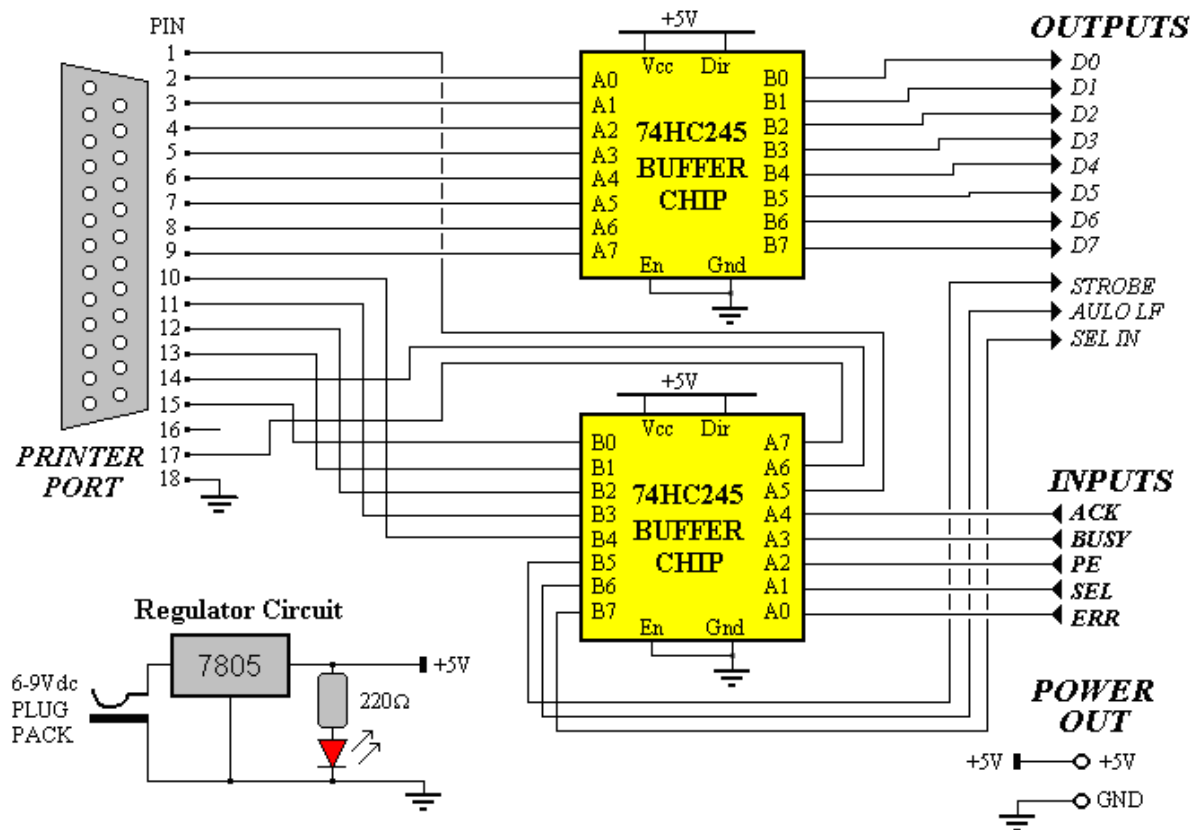


Figure 3: PortBuffer Circuit Diagram

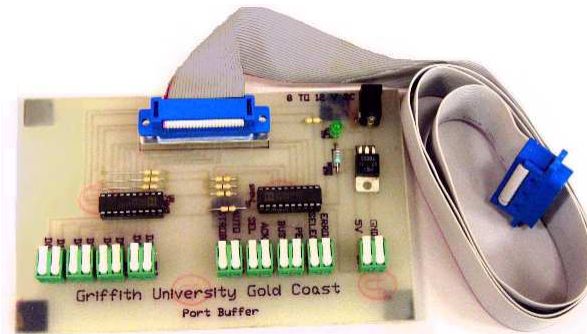


Figure 4: Constructed PortBuffer

The inclusion of a supplied 'Prototyping Board' (where test circuits were actually constructed) enabled the complete computer, PortBuffer, and prototyping board to function as a limited 'Digital Trainer', (see illustration in Figure 5).

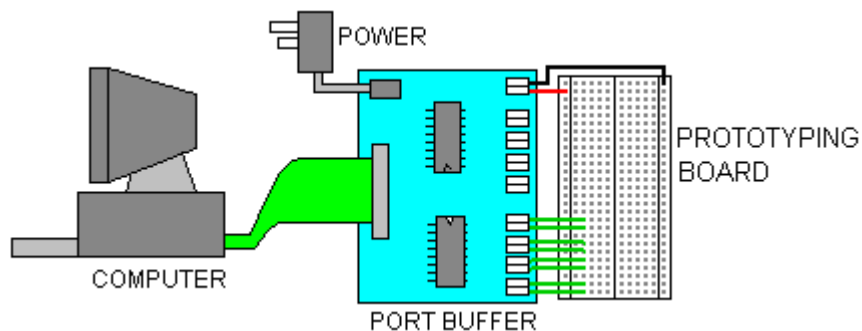


Figure 5: PortBuffer Connection to the Computer and Prototyping Board

‘PortBuffer’ Software

To complete the ‘Digital Trainer’ system, the author developed an MS-Windows software (entitled ‘PortDevice’) to control the *PortBuffer*. The *PortDevice* software allows the student to manipulate various virtual software switches that will cause the *PortBuffer* to output associated digital signals. The software also displays, as different state virtual LED indicators, the digital input signals to the *PortBuffer*. The *PortDevice* software screen shot, with the associated ‘Digital Trainer’, is shown in Figure 6.

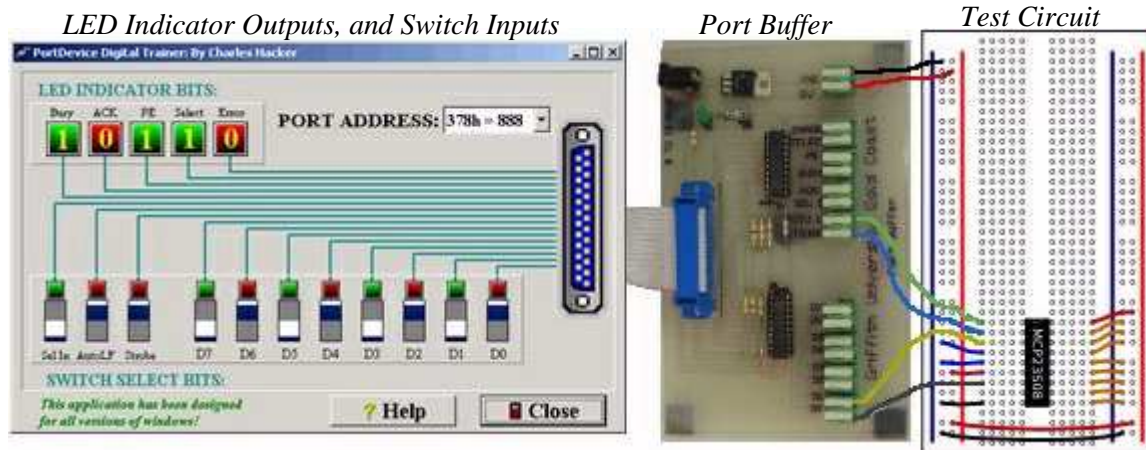


Figure 6: The PortBuffer Digital Trainer System

Students are able to alter the virtual switch positions on the *PortDevice* software, which, through the *PortBuffer* hardware, applies digital signals to the test circuit. The test circuit digital outputs are then detected by the *PortBuffer* hardware, which in turn, set the virtual logic level LED indicators on the *PortDevice* software.

Alternate Software for Digital Interfacing

While the *PortDevice* software provides user input switches and a view of the logic outputs, the student may need more advanced autonomous control. If so, they can also use the author’s ‘WinLogiLab’ software for the task (Hacker and Sitte, 2004). WinLogiLab consists of many modules for the teaching and simulation of digital circuits, it is provided freely on the author’s university webpage (<http://www.griffith.edu.au/professional-page/charles-hacker/resources>).

The students undertaking their final digital electronic project, are able to model complex simulated circuits using the digital simulator of WinLogiLab, and thus control more complex external instruments. For example, the students can model simulation circuits to control such diverse devices as robotic arms (as shown in Figure 7).

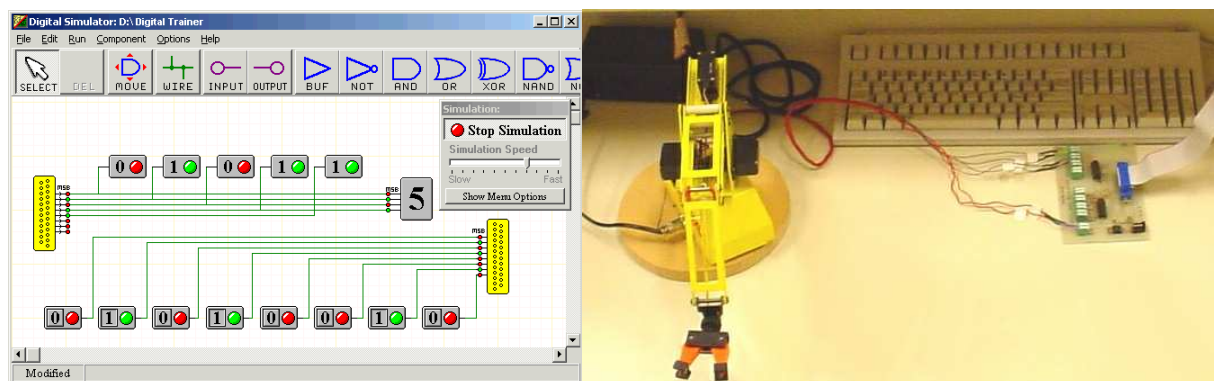


Figure 7: Example of WinLogiLab Controlling the PortBuffer Interfaced to an External Robot

All the software is provided freely to the students, and is made available for anyone to download from the author's university webpage.

With the *PortBuffer* attached to the standard PC printer port, many other controlling software applications can be used. For example, the author provides MATLAB and LabView drivers, and example programs in Borland C Builder and Microsoft Visual C to control the *PortBuffer*. Additionally, there are many freeware software applications available from Internet web sites that can also monitor and control the *PortBuffer*.

Student Evaluation

The *PortBuffer* 'Digital Trainer' was tested and successfully used in the author's Digital Electronics course over a period of four years. As part of the standard semester student evaluations, the students are requested to comment on the laboratory program. The following are some of the positive, as well as negative, comments that relate specifically to the *PortBuffer* 'Digital Trainer'.

The favourable comments included: "the significant hands on activities provided by the PortBuffer makes the course interesting"; "the 'real life' laboratory projects provide valuable experience for the future workplace"; and "the digital circuit fabrication laboratory (in which the PortBuffer was built) is the most interesting laboratory the students had undertaken that semester".

Although the comments were mostly positive (with students usually evaluating the appropriateness of the PortBuffer 'Digital Trainer' at >80%), some negative comments were also given. Such comments were: "the 'real life' laboratory projects are more difficult than the standard laboratories, requiring substantial student effort and time"; there were suggestions that the lecturer assigns more comprehensive time consuming laboratories, as the students were expected to use their digital trainer out-of-hours; and that the students modern laptops had no printer port (only USB ports), and so they were unable to operate the device.

While the 'real life' laboratory projects are more complex than the 'follow the steps laboratories', continuous effort is undertaken by the author to make the tasks straightforward enough for students to achieve the required outcomes. Similarly, the student laboratory workload is continuously assessed to ensure that student time involvement is appropriate for the course. Reflecting on the student comment that modern laptops do not provide printer ports, work is currently underway to update the hardware to facilitate USB connection.

Conclusion

The simple affordable device, the *PortBuffer*, was designed to function as a circuit prototyping tool, to facilitate the teaching of digital design and digital interfacing in the first year Digital Electronics course. The device, designed with minimal components that are constructed by students, with author supplied software, allows for an affordable device that can be retained by students for personal use. By utilising the standard printer port many varied software sources are available. As a consequence students can develop more complex control applications for a wide variety of digital interfacing experiments.

The educational benefits of the device were practically and successfully explored by the students during the author's Digital Electronic course. The student feedback was overwhelming favourable, and reinforced the *PortBuffer*'s role as a valuable teaching resource. Additionally, any student reported problems were used as the basis for continuous improvements to the device and the associated laboratory activities. With the move for modern computers, particularly laptops, to only utilise USB ports, a modification to the device is being developed to suit the new technology.

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