DIGITAL CIRCUITS EMULATOR

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Abstract: The equipment proposed in this paper is an FPGA based Digital Circuits Emulator that permits to test the majority of the standard TTL circuits without the need to mount or wire any of them. This equipment provides an easy way of teaching the Digital Electronics basic concepts, complementing the theoretical explanation of the circuits behaviour.

Keywords: Arithmetic circuits, Combinational circuits, Sequential circuits, Digital circuits, Electronic systems, Programmable.

1. INTRODUCTION

In many countries, the basic Digital Electronics laboratory teaching is still based in the same primitive methods: to mount and wire the old 74xx TTL circuits (Mandado, 1998). Then, when the students are familiarized with these circuits, they start working with Programmable Logic Devices and CAD tools.

The equipment proposed in this paper is an FPGA based Digital Circuits Emulator (see figure 1) that permits to test the majority of the standard TTL circuits without the need to mount or wire any of them. This is because the FPGA is configured to contain every circuit and to select them.

The basic Digital Electronics is covered through the emulation of many common digital circuits, as well combinational, as aritmethic and sequential, without any mounting nor wiring.

Not only the basic TTL functional blocks are included, but some complete synchronous sequential systems that the students must program to do any state graph they want. This help them to understand the operation of the sequential circuits.

In addition to the Emulator function, this equipment is useful when the students are already familiarized with the standard functional blocks because with Xilinx Foundation software tools and a low cost programming cable, the equipment serves as an FPGA based application development platform, with an XC4005E (5000 gate equivalent) FPGA included (Xilinx, 1994b).

2. EQUIPMENT OPERATION

This is an stand-alone equipment that can be used without the need of any additional instrumentation (only a wall-mounted 9 V. transformer or a 5 V. DC power source).

The operation is very simple. Once the equipment is powered up, the FPGA downloads its configuration automatically. Then, the user can select the circuit he wants to test through some switches (X5, X4, X3, X2, X1 y X0). This selection is validated when the SEL button is pushed. The switches X5 and X4 select the type of the circuit being tested among combinational (state 00), arithmetic (state 01) or sequential (state 10). The state 11 of these switches is not implemented. The switches X3, X2, X1 and X0 select up to 16 different circuits of each type.

The selected circuit is shown in the two seven segment displays. In the table 1, included in the following section, some of the emulated circuits are listed, though the Emulator includes many more.

Once the circuit is selected, the user can test its behaviour inmediately, using the switches, push-buttons, LEDs and displays that are mounted in the Emulator board.

It is important to point up that the Emulator includes the possibility of implement some synchronous sequential systems (state machines), both register based and counter based.(Mandado,1998). The user must program the content of the RAM memory, included in the FPGA, to make the sequential system evolve through the desired state graph.

But, besides this autonomous operation, it has been developed a Digital Circuits Emulator software that allows to select the circuits through the parallel port of a personal computer. This software includes basic information about the emulated standard TTL circuits (IEEE symbol, truth table and a brief explanation) that makes the Emulator more complete and adequate for teaching.

At last, it is also important to make the Emulator more useful with the possibility given by the connection of the eight outputs of any emulated circuit to an external system. This is achieved through an output amplifier and the output connector. In this way a simple external system can be controlled by the emulated circuit (i.e. a sequential system).

3. EXAMPLES OF EMULATED CIRCUITS

Table 1 contains a few examples of some circuits of each type that this equipment can emulate.

Table 1. List of some emulated circuits.

COMBINATIONAL CIRCUITS
3 input AND/NAND gates.
1 among 8 decoder with three inhibition inputs and inverted outputs.
8 channel multiplexer with inhibition input and normal and inverted outputs.
8 bits priority encoder with inhibition input and propagation outputs.

ARITHMETIC CIRCUITS
Binary comparator with propagation inputs.
Parity generator/checker.
4 bits adder/substracter with carry/borrow input and output and overflow output.

SEQUENTIAL CIRCUITS
RS, JK, D and T synchronous flip-flops with asynchronous reset.
8 bits register with inhibition input and asynchronous reset.
4 bit synchronous binary up/down counter with synchronous parallel load and inhibition input.
4 bit synchronous left/right shift register with synchronous parallel load, inhibition input and asynchronous reset.
16x4 RAM memory with write enable input.
User programmable, register based synchronous sequential system (state machine).

4. EQUIPMENT DEVELOPMENT

Although almost any expert designer knows how to use any of the basic digital circuits in the context of a particular application implemented with programmable logic, it is not so easy to combine them all in one FPGA to achieve this emulator.

Of course, the first thing to have in mind is the logic capacity of the circuit to be chosen. This is a compromise between logic density and cost. The main restriction in this Emulator was to obtain a low cost equipment, so a capacity of about 5,000 gates was initially selected.

But the internal architecture is also important. All the emulated circuits in this equipment are operated through the same 20 switches and 4 pushbuttons and the state of their outputs are checked through the same 10 LEDs.

So, the matrix-based architecture of the Programmable Logic Devices (PLDs) is not suitable and a Field Programmable Gate Array (FPGA) was chosen.

The XC4005E (5000 gate equivalent) FPGA from Xilinx (Xilinx, 1994b) was the ideal solution. The possibility to implement three-state buses inside the FPGA was definitive to combine the outputs of every emulated circuit into the common outputs of the equipment.

Another challenge was the programmability needed in some sequential circuits. The RAM memory and, mainly, the synchronous state machines must be programmable by the user to implement any graph and so, to teach their internal operation.

The solution is multiplexer based and it leads to two different working modes of the sequential circuits. In the first one, the user only “sees” a memory module, so he can access the address and data inputs to program its content and check it through its data outputs, displayed in the LEDs. In the second one the sequential circuit performs the programmed graph, so the user only has access to the graph inputs and outputs and its internal state through the LEDs.

Finally, it was necessary to implement two different configurations in the FPGA. The first one contains all the basic combinational, arithmetic and sequential circuits and the second one includes the synchronous sequential systems (programmable state machines).

The FPGA was almost used at its maximum capacity in both configurations as the following extract of the implementation report for the first one, confirms:

Number of CLBs:	190 out of	196	96%
CLB Flip Flops:	90		
4 input LUTs:	340 (4 used as route-throughs)		
3 input LUTs:	60 (20 used as route-throughs)		
16X1 RAMs:	4		
Number of bonded IOBs:	53 out of	61	86%

Many of the solutions used and the ideas involved in this development are really new, so it was decided to solicitate the equipment patent, that it is now pending.

5. FPGA BASED DEVELOPMENT PLATFORM

One of the inherent benefits of using an FPGA it is the possibility of reprogramming it. So, when the user has learned the basic digital circuits operation, he can design his own applications through a standard CAD tool package, like Foundation Xilinx.

So, if the user has access to the Foundation software (there is a student version (Xilinx, 1998) (Álvarez, 2001)) or the older XACT software and to the Xchecker programming cable (Xilinx, 1994a), he can work with the Emulator board as an FPGA application development board, programming the FPGA through a personal computer standard port.

To test the designs, all the switches, pushbuttons, seven-segment displays and LEDs in the equipment are available, as well as an 8 input connector and the 8 output connector that can be connected to other circuits, including computer ports (i.e. the parallel port).

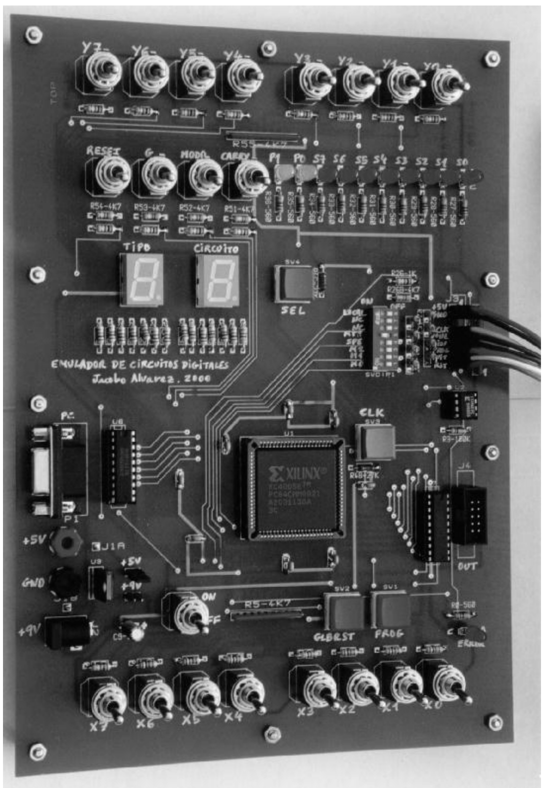

Fig. 1. Photograph of the Emulator board.

6. CONCLUSIONS

As the main conclusion, it is sure that this Digital Circuit Emulator constitutes a complete learning equipment for Digital Electronics, that can emulate many of the basic digital circuits as well as act as an FPGA based development platform.

Although the original idea is really simple, it is a new approximation to the teaching of Digital Electronics that has never been implemented before, so this equipment is being patented.

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