AN INTRODUCTION TO *DIGITAL SYSTEMS LABORATORY* EXPERIENCE USING PRINTED CIRCUIT BOARD TECHNOLOGY

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Abstract *– The curriculum for electrical engineering students and computer engineering students at South Dakota School of Mines and Technology includes an Introduction to Digital Systems course. Students generally enroll as sophomores or second-semester freshmen. The course is four semester credits with 25% of the effort devoted to weekly laboratory exercises closely tied to the classroom presentations. Typical laboratory topics include: Logic Gates, Binary Adder Circuits, Multiplexers, JK and D Flip-Flops, Shift Registers, Programmable Array Logic, EPROM Programming, and Control Logic Implementation. Students are required to connect circuits using appropriate ICs on breadboards and test the circuits for proper operation. As a "capstone" project for this course students are required to design a circuit and encouraged to implement that design on a printed circuit board. In this paper I present the details of implementing such a project, and plans for future enhancement of the laboratory portion of this course.*

Index Terms – Algorithmic State Machine (ASM), Breadboarding, Digital Systems Laboratory, Printed Circuit Board.

INTRODUCTION

One of the common concerns about the early part of engineering curriculums is the perception by students that they don't get a chance to take the courses that relate to their major soon enough. Mathematics prerequisites for circuit analysis courses and general education requirements are viewed by students as obstacles preventing them from getting "into" courses within their major as quickly as they desire.

An *Introduction to Digital Systems* course is available to students at South Dakota School of Mines and Technology during their freshman year. Enrollment statistics indicate that many students indeed take the course during their first year of college and find it to be fulfilling. Typically students first view the course as being a bit advanced when they learn what will be covered in the course. However, as they study the material and progress through the topics, students quickly realize that they are learning a lot and they understand the importance of knowing fundamental concepts. Perhaps the most important outcome of the experience is the development of a sense of accomplishment and a sense of self-confidence in their own abilities.

LABORATORY EXPERIENCES

During the first two-thirds of the course, weekly laboratory exercises demonstrate the fundamentals of integrated circuits ranging from logic gates to flip-flops to PALs. Students are required to connect circuits using the appropriate ICs on breadboards and to test the circuits for proper operation.

Course Capstone Project Overview

The purpose of the "capstone" project for this course is to introduce students to design concepts where they consider alternate solutions to completing the four-week exercise. Students will generally be interconnecting several different components including combination gates, flip-flops, 555 timers, voltage regulators, decoder/drivers, seven-segment displays, switches, LEDs and resistors. The source of power is a 9-volt battery.

As a "capstone" project for this course, students are required to design a circuit and implement their design on a printed circuit board. Project components include breadboarding to verify proper operation, layout processing using "Protel" software, printed circuit board fabrication using a milling machine, soldering the components, and testing the circuit to verify proper operation. Students work in groups of two or three. On some occasions I have let the students choose their own projects; on other occasions I have assigned a specific project with small differences. For example, one of the projects that I have assigned is to design a counter using some "weird" counting sequence. Assigning different sequences to each group encourages groups to work independently.

Breadboarding Circuits

Breadboarding circuits causes a bit of frustration for students who do not pay close attention to details. A missing or loose connection often results in a painful debugging exercise.

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Relief is noticeable when functional breadboarded circuits are realized.

Protel Software

Students are introduced to Protel software to prepare a computer-generated design file that includes all of their circuit connections properly routed. The Protel files must then be isolated and converted to machine files useable by the milling machine.

Printed Circuit Board Fabrication

Although students observe the milling machine operation, they are not generally required to become proficient with its operation. Two-sided milled boards are returned to the students for component placement and soldering. First experiences in soldering often result in failure and necessitate the preparation of a second milled board.

PROJECT REQUIREMENTS

Each of the "capstone" projects has a certain set of requirements. First of all students must complete an ASM (Algorithmic State Machine) Diagram describing the sequential operations in a digital system. From the ASM Diagram students prepare a State Diagram showing the transition between states. Implementation of the state transitions can be accomplished by any one of several techniques. The most common methods include 1) D Flip-Flop and Decoder, 2) One Flip-Flop per State, and 3) Multiplexers. The Control Logic Diagram shows the logic used to implement the required state transitions. Finally the Data-Processor System shows the hardware necessary to realize the desired functionality of the digital design.

Music Box Project

One of the most interesting projects was a Music Box. Tones were generated at various frequencies and sent to a speaker in specified sequences to represent music. A series of seven 555 timers was designed to operate at frequencies representing seven different musical notes. The multiplexer select bits were controlled by the contents of EPROM data to provide the proper sequences of sounds to play a song. A separate 555 timer provided the timing used to transition form one state to another and hence the length of each "note". Another built-in feature of the Music Box was to partition the memory into eight segments. A "Select" key was used to select which of the eight memory segments would be sequenced when the "Play" key was pushed. The ASM Chart for the Music Box Project is shown in Figure 1; the accompanying State Diagram is shown in Figure 2; the Control Logic Diagram using the "One Flip-Flop per State" method is shown in Figure 3; and the Data-Processor System is shown in Figure 4. Finally, a picture of the Music Box as

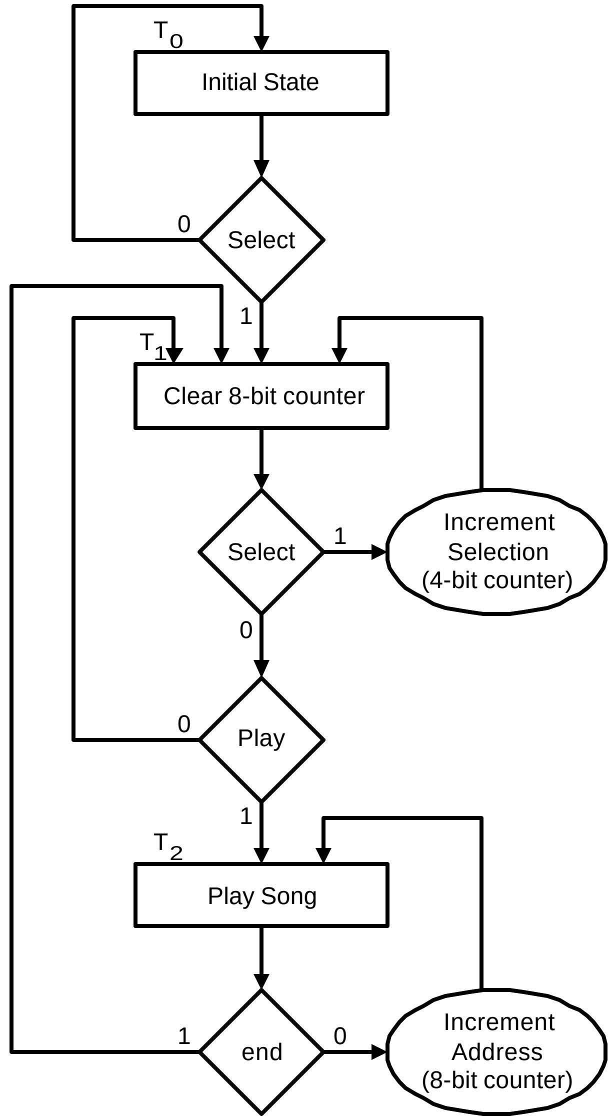

FIGURE. 1
ASM CHART FOR THE MUSIC BOX PROJECT

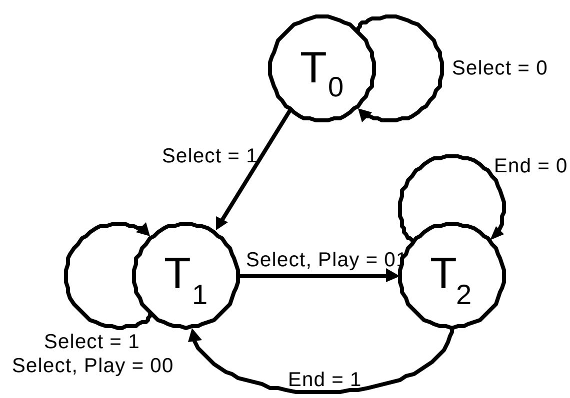

FIGURE. 2
STATE DIAGRAM FOR THE MUSIC BOX PROJECT

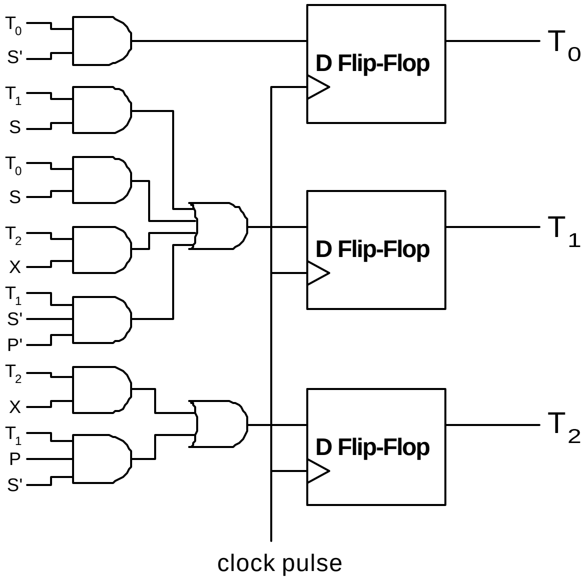

FIGURE. 3
CONTROL LOGIC DIAGRAM FOR THE MUSIC BOX PROJECT

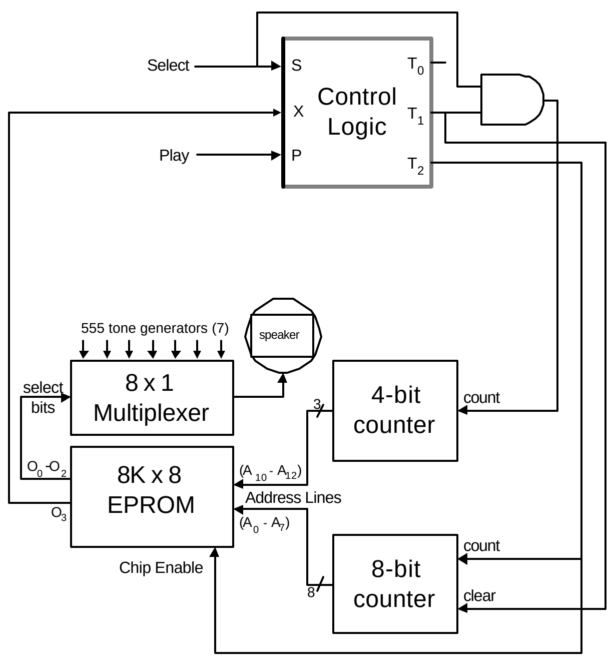

FIGURE. 4
DATA-PROCESSOR SYSTEM FOR THE MUSIC BOX PROJECT

implemented on a printed circuit board is shown in Figure 5.

Scrolling Marquee Display Project

Another very interest project was the Scrolling Marquee Display. A 16 x 7 LED Array was designed and the message

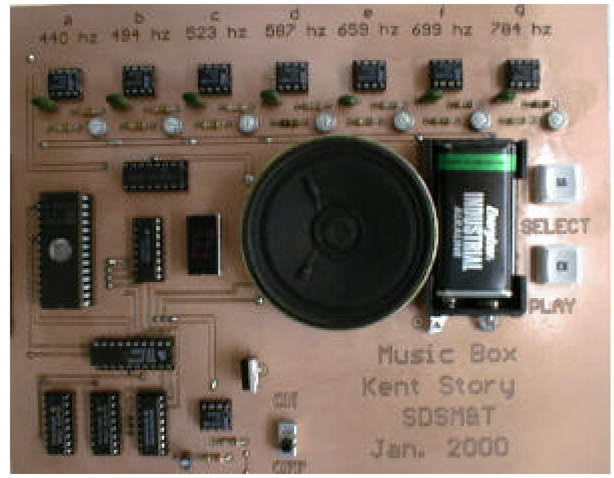

FIGURE. 5
CONTROL LOGIC DIAGRAM FOR THE MUSIC BOX PROJECT

to be displayed was placed into EPROM. The ASM Chart for the Scrolling Marquee Display Project is shown in Figure 6; the Control Logic Diagram using the "One Flip-Flop per State" method is shown in Figure 7; and the Data-Processor System is shown in Figure 8.

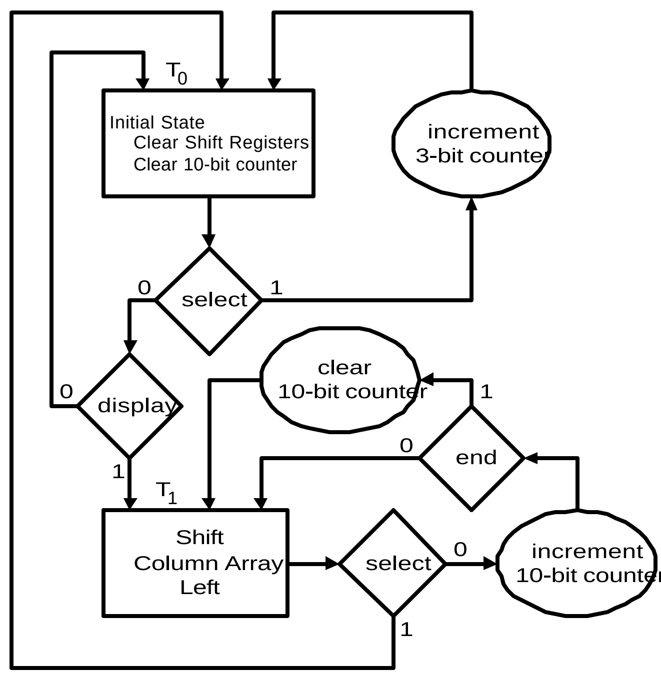

FIGURE. 6
ASM CHART FOR THE SCROLLING MARQUEE DISPLAY PROJECT

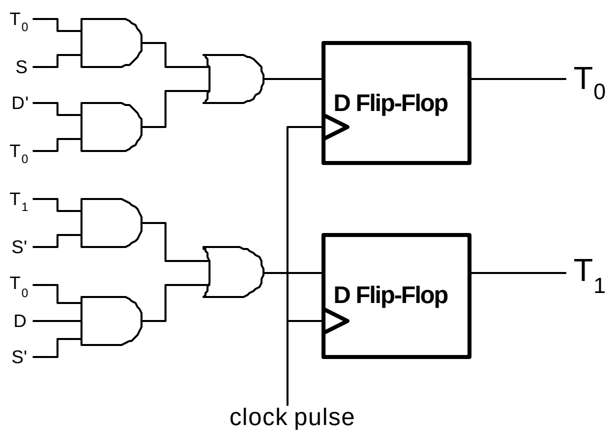

FIGURE. 7
CONTROL LOGIC DIAGRAM FOR THE SCROLLING MARQUEE DISPLAY PROJECT

RESULTS AND CONCLUSIONS

About half of the "capstone" projects result in a properly operating digital system, oftentimes after the diagnoses and repair of "bad" solder junctions or the identification of missing connections and the subsequent addition of "jumper" wires.

Students are generally delighted to see their digital systems "capstone" projects operate properly and take great pride in their accomplishments. Each lesson learned serves the students well as they gain confidence in their abilities to implement design concepts.

PLANS FOR FUTURE ENHANCEMENTS

In the future I would like to provide a link to the next digital systems class that most students would take by demonstrating some of the capabilities offered by the use of FPGAs. It seems like a natural extension of the work learned earlier in the course. For example, it is learned early that logic gates are very limited in use by themselves. Logic gates appear as the main building block of more advanced ICs such as multiplexers and flip-flops. Flip-flops and logic

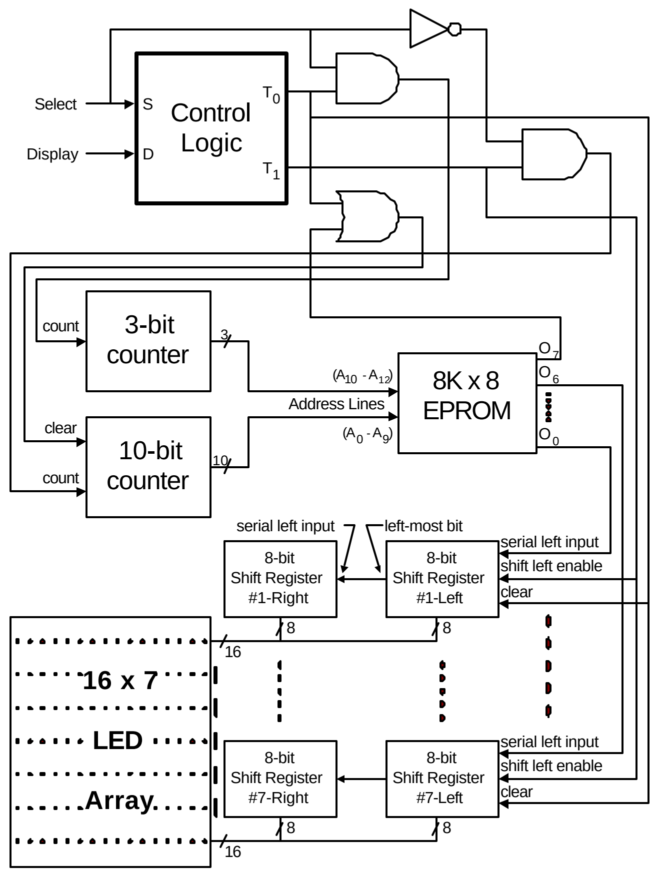

FIGURE. 8
DATA-PROCESSOR SYSTEM FOR THE SCROLLING MARQUEE DISPLAY PROJECT

gates can then be programmed into PALs. In the future I plan to demonstrate how FPGAs can further replace a set of other building blocks. After going through the process of designing a digital system starting with the ASM Chart and working with the control section and the Data-Processor System, it would be nice for the students to realize that there are software tools available that can further reduce some of the labor intensive processes presented in an *Introduction to Digital Systems* course.