USE OF CIRCUITMAKER AS A DIGITAL SIMULATION TOOL IN FRESHMEN EET COURSES

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Abstract ? CircuitMaker (CM) is a digital and analog simulation application that is well suited for the introduction of digital electronics. The author was introduced to CircuitMaker 2000 through his involvement with Project Lead The Way (PLTW). High school teachers teaching the PLTW Digital Electronics course throughout Indiana and the country use this simulation software. The author has taught this package to Indiana teachers at the PLTW Summer Training Institue at Purdue University and he has used it in his freshman digital electronics courses. Because the CM simulations are presented in quasi-real-time with high logic level lines presented in red and low logic levels in blue, the students gain an immediate sense of the dynamic nature of circuit operation. The students have responded enthusiastically to this package. The simulator has been used to introduce students to digital systems such as synchronous and asynchronous serial communication systems, multipliers, keypad encoders, stepper motor positioning systems, data bus display multiplexers, and memory bus systems. This paper presents this software and some of the digital systems that have been implemented.

INTRODUCTION

In the past, many EET freshmen in the author's digital courses have not embraced digital simulation. That posture has changed with the introduction of CircuitMaker in these freshmen classes. The most outstanding impact is that the free-running nature of the simulation operation, in which the high voltage wires are colored red and the low voltage wires are colored blue, engages the student immediately. Problems are more readily identified as the student views the action and "what if" questions are provoked leading to extensions of the circuit under study. The package is easy to use. It has some flashy output devices such as "smart" ASCII displays, stepper motors and even a rocket launcher.

CircuitMaker 2000 [1] is the circuit simulator that Project Lead The Way (PLTW) [2] has selected for the Digital Electronics course delivered in the sophomore year in high school. Project Lead The Way is a non-profit organization that provides a pre-engineering curriculum to middle schools and high schools. Digital Electronics is one of the courses in the PLTW curriculum and CircuitMaker is the circuit drawing and simulation package that high school students in Indiana and across the country are using. The author learned to use this package at a Project Lead The Way Master Teacher training session held at Rochester Institute of Technology. [3] The student version of CircuitMaker based on CircuitMaker 6 is available for students on the web and on the CD-ROM accompanying the class textbook, Tocci and Widmer's *Digital Systems*. Freshman students really liked to work with it.

Selected features of CircuitMaker are presented in the section below followed by a section on digital systems simulation.

CIRCUITMAKER FEATURES

Basic features

CircuitMaker supports both analog and digital simulation. The circuit is drawn in the edit mode and its operation is simulated in the simulate mode. Waveforms at various points in the circuit can be captured and displayed using devices called scopes and probes. The simulation is particularly good as an introduction to digital electronics because low-state lines are presented in blue color and high-state lines are presented in red color. As logic levels in the circuit change by clicking the mouse on input switches and with the transition of clock inputs, the line colors change giving the student and immediate visual feedback showing the operation of the circuit.

This paper is concerned only with the digital mode of operation. In the student version of the package, there are 118 7400-series digital devices (plus some half-device versions) and 48 4000-series digital devices. The student version is the same as CircuitMaker 6 with the following limitations:

? 50 device (any type) maximum per design,
? 1000 device library limit,
? Symbol editor and Macro capability disabled. [4]

Enhanced features

Adding to the attraction of this simulator is the rich set of displays, instruments, actuators, and switches that operate in quasi-real time. Shown below are drawing of some of the devices available.

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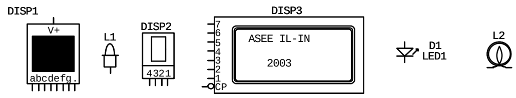

FIGURE. 1
SELECTED DISPLAYS IN CIRCUITMAKER

The array of displays includes common-anode and common-cathode 7-segment displays, 7-segment displays with built-in decoders, LEDs, incandescent lamps, and a smart ASCII display (fourth from the left) that has a moving cursor and the ability to be cleared by entering the HEX value 0xC.

Figure 2 shows input devices. The first two switches allow multiple outputs for a single button push. The third switch is a logic switch for general use. It does not require a pull-up or pull-down resistor. The fourth through the seventh switch act like their real-life counterparts and each requires power, ground, and appropriate resistors. The last device is a cross-point keypad. An application problem is to design, draw, and implement the encoding circuit for this keypad.

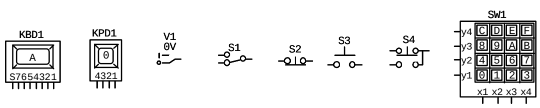

FIGURE. 2
SET OF SWITCHES AVAILABLE IN CIRCUITMAKER

Figure 3 shows some special launching pad devices that add pizzazz to a circuit output. An output signal can launch a rocket or a car. The reset button restores the vehicle. The window acts as an input device. The window is raised and lowered by clicking on it.

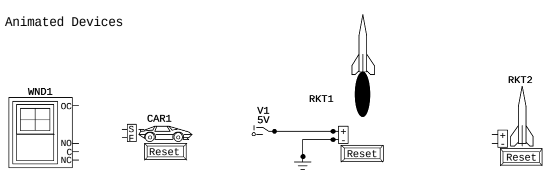

FIGURE. 3
ANIMATED DIGITAL DEVICES IN CIRCUITMAKER

One would hope that the students would not get stuck on using these devices. And they do not. There are plenty of problems in digital electronics to keep them busy.

A stepper motor is shown in Figure 4. This motor does not require the driver circuit that is necessary for a real stepper motor. The simulation is shown as the movement of the radius shown in the center circle.

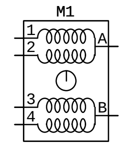

FIG. 4: STEPPER MOTOR

A full step is indicated as a movement of 90 degrees. A half step is indicated as the movement of 45 degrees.

The simulator has the usual set of analog and digital electronic devices, mulitmeters, and a scope feature. Simulation is separated into the analog mode and the digital mode. The digital mode performs the simulation in terms of clock ticks. Some devices are typed as analog, digital, or mixed (analog/digital). The 555 timer must be implemented in the analog mode as is the case for the A/D converter.

DESIGNING DIGITAL SYSTEMS

The devices above are merely shown as an introduction to the types of auxiliary devices that are available. The real power of the simulator is in easily assembling and demonstrating digital systems.

Large circuits are sometimes too complicated to construct in the laboratory without devoting valuable time and resources. Such was the case when designing the circuit shown in Figure 5 that was used to illustrate data buses and device addressing.

In this circuit, the data sequencers are like memory devices. In the simulator, the dark blocks in the diagram are the 7 LED segments being displayed. Each display in this circuit is multiplexed to show a letter in an 8-letter word or phrase. One of two phrases or words can be displayed depending on the data sequencer selected. In a previous laboratory, the student designs a state machine that displays an 8-character message, such as 'ColdSodA', on a single 7-segment display one character at a time. An attempt was made to have the students parallel their circuits in the fashion shown above. But it soon was evident that the wiring across many boards would have turned the exercise into a major project at a time that we needed to get on to different issues.

Figure 6 shows an asynchronous serial communication circuit in which the ASCII characters stored in the Data Sequencer (a sequential memory device) are transmitted serially across a single data line from transmitter to receiver. This circuit was the culmination of a project that was started as a simple shift register transmitter that evolved into a synchronous transmit/receive circuit with LEDs as outputs. After the initial design, the instructor provided a working circuit and asked the students to provide modifications to extend the design. The final circuit above is implemented within the 50-component limit imposed by the student version of CircuitMaker.

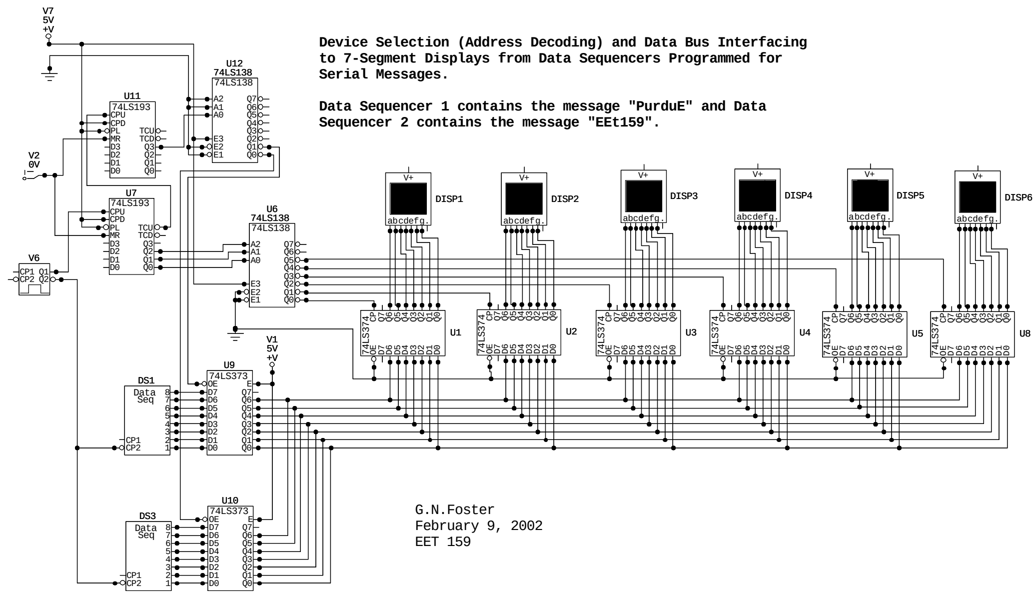

FIGURE. 5:
DISPLAY CIRCUIT WITH DATA BUS AND CHIP ADDRESSING

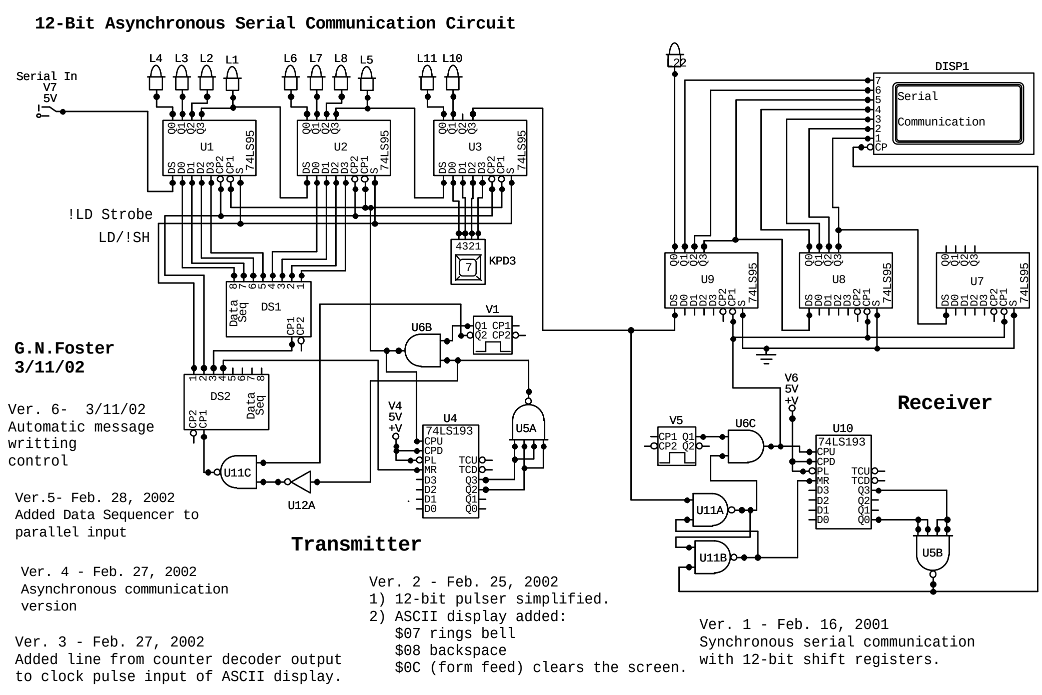

FIGURE 6.
ASYNCHRONOUS SERIAL COMMUNICATION SYSTEM WITH ASCII DISPLAY

The final system shown in Figure 7 is that of a memory system showing how logic lines can be consolidated into buses. This circuit shows the inclusion of two 1K RAMs and a 32-byte PROM. The RAMs are volatile and do not hold the stored values after closing the software.

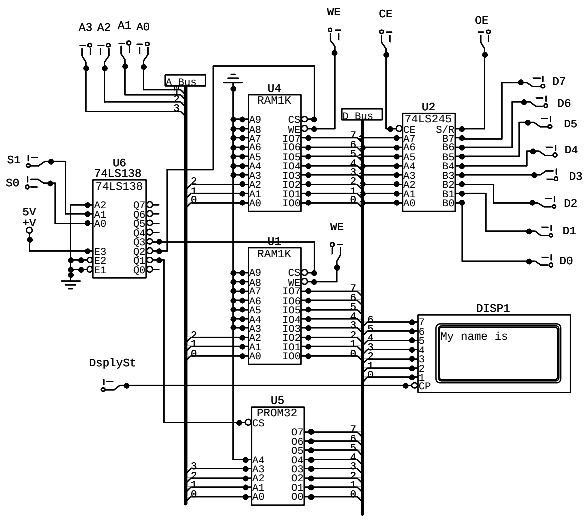

FIGURE 7.
MEMORY DEVICES WITH DATA AND ADDRESS BUSES

The author has created a number of other digital systems with this simulator include a stepper motor positioning circuit with feedback, a keypad encoder built from MSI devices, and two types of 4-bit multipliers made with adders and made sequentially with shifters and adders.

CONCLUSION

This paper is a brief introduction to CircuitMaker. It is currently the digital simulation package that high school students in the Project Lead The Way curriculum are learning. It is also a useful tool for introducing college students to digital electronics. A verbal description of this simulator does not have the impact of a live presentation. . The operation of this simulator is best presented live.

Students took to the simulator almost immediately due to its ease of drawing a circuit in the edit mode and the dynamic action in the simulation mode whereby the wires on the circuit change color from blue at low logic levels to red at high logic levels. In the past, the students were not keen on the analysis and plot setup required to determine the operation of the circuit and some students did not like to simulate a circuit. Now the students ask to simulate the circuit and are more eager to use the simulator at home. The author still believes in requiring students to breadboard a circuit first, although some students are beginning to question why they need to breadboard at all.

The simplicity of editing a CircuitMaker file and the directness of the simulation's presentation make circuit simulation enjoyable and manageable. Motivation to simulate circuits is high among the students.

CircuitMaker has proven to be an excellent means of giving students experience in using digital concepts in complex digital systems as well as a great way to introduce the students to the basic operations of simple digital circuits. Taking the student from the elementary stages of digital analysis to an understanding of how larger digital systems work is an important step in their future use of digital electronics in applications such as microcomputer architecture.

REFERENCES

[1] Protel International Limited, *CircuitMaker 2000, the virtual elctronics lab*, 1988-2000.

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[4] Altium Limited, "CircuitMaker Resources", www.microcode.com/downloads/student.htm.