Test Equipment for High School Digital Electronics Designs under Project Lead the Way

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Abstract

The University of Minnesota Duluth, collaborating with Duluth high schools, is participating in "Project Lead the Way" (PLTW, http://www.pltw.org), a national program to incorporate engineering topics into high school courses. The PLTW curriculum covers several engineering areas, one of which is digital electronics. The equipment described here supports the PLTW digital electronics curriculum. This equipment is simple to use and inexpensive. High school students will use this equipment to test their digital designs. Both combinational circuits and synchronous sequential circuits are supported. These are the foundational types of circuits upon which all more sophisticated digital systems rely. This equipment makes digital electronics accessible to high school students, who are sometimes intimidated by engineering topics. As technology dominates applications in society, students must overcome that intimidation and feel comfortable in a technical environment. The equipment described here will ease the introduction of the digital electronics component of "Project Lead the Way."

Setting

The equipment described here will be used in an introductory digital electronics classroom. The course curriculum addresses a scaled-back version of the topics covered in most any university digital circuits course across the country. The difference here is that the students are high school students interested in engineering, not the typical freshman college students to whom these topics are usually addressed. Consequently, less emphasis is placed on the theoretical basis for circuit designs, and more attention is focused on the mechanics of producing designs that work and that satisfy design criteria. The equipment to support this class must be simple, virtually intuitive to use, and inexpensive. Furthermore, the design of this equipment should be open to students, so that they can see and fully understand the equipment they have used in class by the time they complete the course. Although this equipment has not yet been used in an actual class setting, examples of lab experiments that will be presented are included here.

As a minimum, students in any introductory digital electronics course must study two types of digital circuits. *Combinational* circuits are those that include no memory in the circuit, so that outputs of the circuit are functions only of what the inputs are right now. *Sequential* circuits are those that do include memory, so that circuit outputs can depend not only on current values of the inputs, but also on the past history of those input values. A subset of sequential circuits, *synchronous* sequential circuits, imposes some stringent restrictions on the design of the circuit, in order to avoid pesky potential pitfalls of circuit designs involving detailed delay calculations or timing hazards in the circuit that can cause problems when using less-constrained design techniques. Thus, the equipment to be described here is intended to be used to test combinational circuits and synchronous sequential circuits. These basic circuit types form the foundation for all more exotic digital system designs. The instrument to be described here is known as the "Digisplay," a contraction of "digital display." It is a descendent of the an earlier instrument, the "Chipmonk," described in other ASEE papers (Carroll, 1999 and 2001).

To keep costs down and to make the output easy to interpret, the Digisplay supports combinational circuits with a maximum of three input variables, or synchronous sequential circuits with a maximum of eight states. These limitations are artificial, but not serious restrictions in a high school environment, and they significantly simplify the design of the Digisplay itself. The Digisplay can show a maximum of five variables and how they depend on the input variables or the state in which the circuit under test is operating. The display of the variables is produced on an LED dot matrix array consisting of eight rows and five columns of LEDs. This is a standard component usually used for alphanumeric indicators. Each column of the display shows the value of one variable in the digital circuit, and the vertical axis is time, measured in clock cycles, with one clock cycle per row.

Testing Combinational Circuits

To test a combinational circuit, one merely must supply the circuit with all possible input values and record the resulting output values. Figure 1 shows the functional layout involved in testing combinational circuits. Since there is no memory in a combinational circuit, the sequence in which input combinations are tested is unimportant. The Digisplay is limited to testing circuits producing functions of up to three variables. To test the student's combinational circuit, the three input variables are supplied by a three-bit binary counter in the Digisplay, which cycles through all eight possible combinations of values on those three variables. Those three variables are also shown on the left-most three columns of the Digisplay output. The student's circuit produces functions of those variables, which are shown on the right-most two columns of the display,

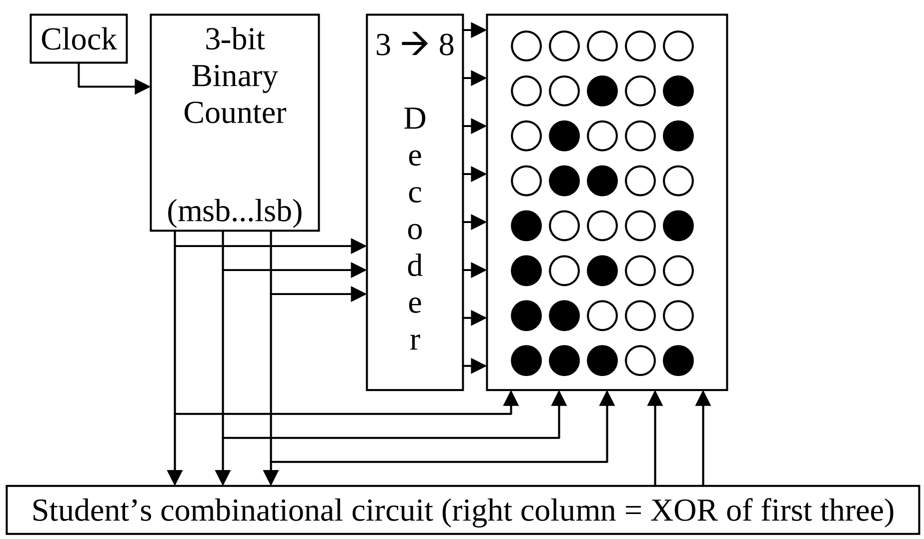

Figure 1. Digisplay layout for testing combinational digital circuits

producing a truth-table-like display of the functions generated by the student circuit. The truth-table format is the same format students are used to using for describing functions, so it is easy to interpret. Lit LEDs (black circles in Figure 1) correspond to 1's, and dark LEDs (open circles in Figure 1) correspond to 0's in the truth table. The clock runs at a few hundred Hertz, just fast enough to avoid noticeable flicker on the display.

Testing Synchronous Sequential Counters

Counters are a subset of general sequential circuits that merely progress through a fixed pattern of states. Counters can have various features, but a plain vanilla counter merely advances through its prescribed state sequence unconditionally, advancing one state with each rising edge of the clock signal. Counters are often included as first examples of sequential circuits because there are no input variables. The number of states in the sequence depends on the design, but the Digisplay is limited to testing counters with a maximum of eight states in the count sequences.

Testing such a circuit merely involves connecting a clock signal to the counter's clock input (from the Digisplay) and observing the counter output variables (state variables, or any other signal of interest in the circuit). The Digisplay can display up to five variables showing what's happening in the counter. Often displaying flip-flop outputs is the best way to see how the state of the counter changes, but displaying flip-flop steering inputs can be useful in debugging a malfunctioning circuit. Figure 2 shows the Digisplay layout used to test synchronous counters.

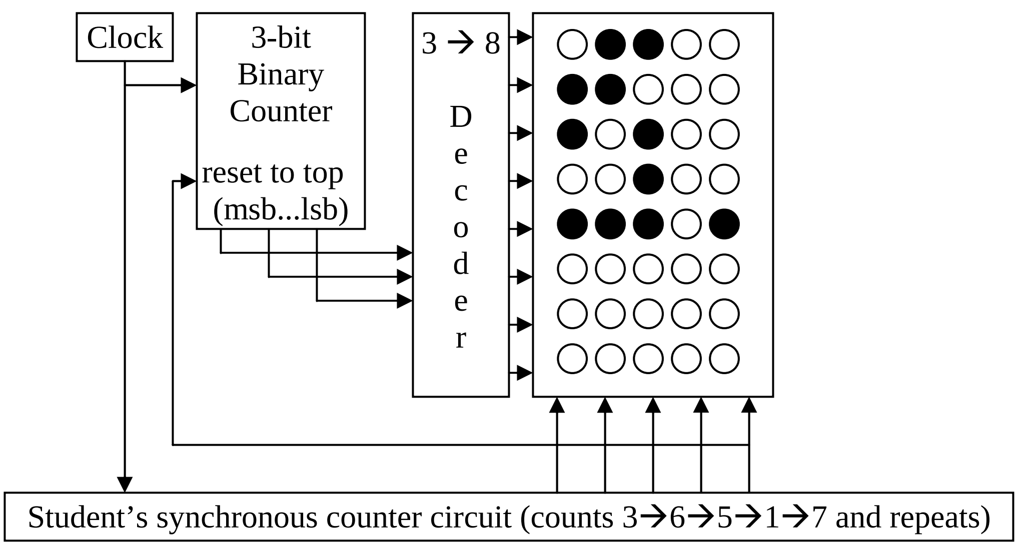

Figure 2. Digisplay layout for testing synchronous counters

In order to synchronize the Digisplay output to a counter cycling through a sequence of other than eight states, as shown in Figure 2, the student circuit must supply a special signal back to the Digisplay that is active in the last state of the count sequence. This signal is used to reset the Digisplay's counter so that the display returns to the top row each time the user's counter restarts its sequence. Figure 2 shows this signal displayed in the right-most column of the display, but it need not be displayed at all if it is not needed for debugging.

Testing Synchronous Sequential Sequence Detectors

Sequence detectors are the other subset of sequential circuits that often form the basis for experiments in introductory digital courses. These circuits have one input variable on which a sequence of values is supplied, and the goal of the circuit design is to respond in some way when a specified pattern is observed on the input variable as time passes. The response can be as simple as turning on an output variable coincident with the last element of the observed sequence, or can be more complicated. Regardless, testing sequence detectors requires that an input sequence be supplied to the user's circuit under test. The Digisplay supplies a sequence that is eight clock cycles long and that can be adapted to any pattern by merely changing connections of the data inputs on a multiplexer, as shown in Figure 3. Typically the display on the Digisplay would be used to show the input sequence and the circuit's output response, as well as any other variables of interest in the circuit under test, such as state variables, for example.

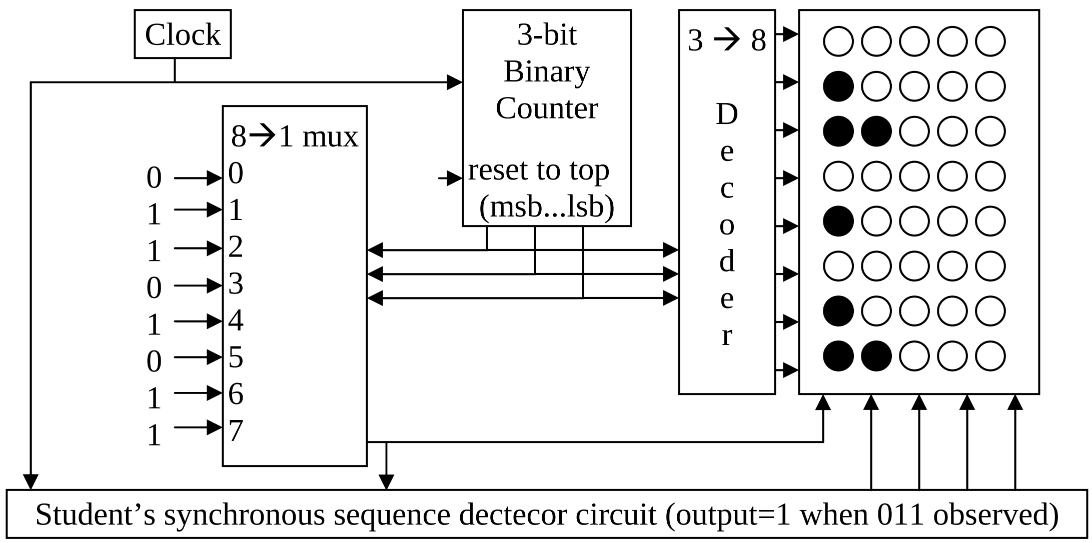

Figure 3. Digisplay layout for testing synchronous sequence detectors

Digisplay Interface

The interface between the Digisplay and the student's circuit under test consists of a ribbon cable ending in a DIP plug, inserted into a breadboard on which the student has constructed his or her circuit. Figure 4 shows the generic Digisplay components and the signals that connect to the user's circuit through the ribbon cable. The student circuit receives its power through the ribbon cable from a power supply that is part of the Digisplay instrument. The power provides support to operate the logic functions in the chips used in the student's circuit, and also serves as a source for constant 1's and constant 0's as needed in the student's circuit. No other knowledge about the electrical nature of the student's circuit or the Digisplay is required. The student needs to be concerned only with the logic functions in his or her circuit and the constant values 1 and 0.

Thirteen signals are present in the DIP cable that links the Digisplay to the user's circuit. Those thirteen signals are:

+5 volts	- source of logic 1's, and power to run the chips
ground	- source of logic 0's, and power to run the chips
clock	- oscillates at a few hundred Hertz
msb	\
middle	- outputs from Digisplay to test combinational circuits
lsb	/
sequence	- output from Digisplay for testing sequence detectors
column 1	\
column 2	\
column 3	- variables for display in columns 1-5
column 4	/
column 5	/
reset to top	- input to Digisplay to synchronize display to counter operation

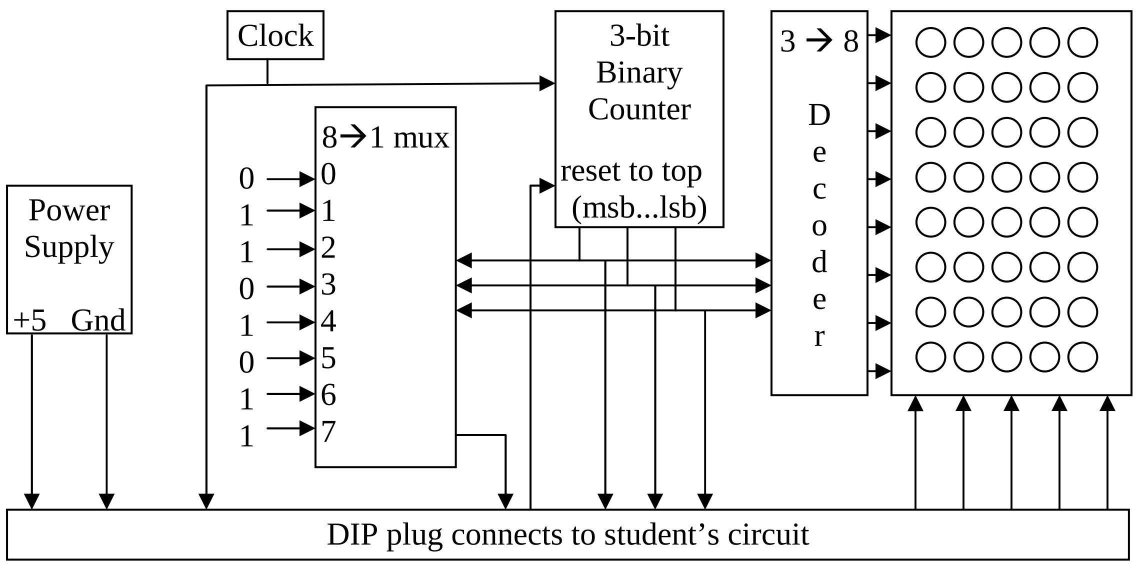

Figure 4. Complete Digisplay *instrument interface to student's circuit under test*

To use the Digisplay, the student simply plugs the ribbon cable into his or her breadboard and examines the display on the Digisplay to view circuit operation. The only adjustments that need to be made to the Digisplay are the values applied to the multiplexer data inputs to establish the sequence used to test sequence detector circuits, and those values can be established by the instructor on the Digisplay instruments outside of class. There are no other adjustments.

Summary

The Digisplay provides a simple instrument to test student digital circuit designs in a high-school lab setting under the "Project Lead the Way" curriculum umbrella. The Digisplay is very easy to operate, with no settings or adjustments required of the student users, and is very easy to describe to students. Input and output between the student's circuit and the Digisplay is intuitive, and matches the formats with which students are already accustomed. In addition, the Digisplay is an inexpensive instrument, requiring very little investment to equip a lab to be used by students. This is welcome news to high school administrators faced with limited budgets to support elective courses such as those in PLTW. The Digisplay is an effective and efficient tool for teaching the digital electronics component of the "Project Lead the Way" curriculum to high school students.

References

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Biography

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