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Application of Multisim in Teaching Reform of Digital Circuit Experiment

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Abstract: In digital circuit experiment teaching, the traditional single practice teaching mode is limited by the number, type, time, and location of experimental equipment, which leads to the solidification of experimental items and the difficulty in completing the comprehensive experiment that is crucial to improve students' ability, thus resulting in unsatisfactory experimental results. However, at this time, it is possible to solve this problem by using Multisim simulation software to assist experimental teaching. In this paper, through the analysis and discussion of the comprehensive experiment example of using Multisim14.0 software to design the three-way time-limited rush-answering device, the breadth and depth of the experiment are expanded. The design is convenient and reliable and the simulation analysis is accurate, which can quickly meet the design requirements and help students better understand the working principle of digital circuits. At the same time, it effectively mobilized the enthusiasm and subjective initiative of students, laying a good foundation for the design and production of electronic circuits. It is thus concluded that Multisim simulation software is an effective tool to cultivate students' ability to analyze, solve problems, and practice.

Keywords: Digital circuit experiment; Multisim simulation; Experimental teaching; Ability cultivation

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1. Introduction

Digital circuit is an important professional basic course for electronics majors [1-3]. The traditional experimental teaching has the advantages of intuitionistic authenticity and operability [4,5], but at the same time, it has the following disadvantages: (1) Strict requirements for the location of the class and high requirements for hardware conditions; (2) Due to the limited experimental class hours, students often can only learn a few basic experiments, limiting the number of experiments to be carried out, especially comprehensive design experiments; (3) The digital circuit experiments involve a wide variety of chips, and the storage and sorting work is particularly heavy [6-9]. With the rapid development of electronic technology, new devices and circuits are constantly emerging. The existing laboratory conditions can no longer meet the design and debugging requirements of various circuits, which has affected the teaching effect of this course and the cultivation of students' innovation ability to a certain extent [10,11].

With the popularization of computer technology, Multisim software, as an auxiliary teaching method, is more frequently used in the practical teaching of digital circuits. Multisim software has the following advantages: (1) It is not limited by time and place. As long as students have installed and mastered Multisim software in the computer, they can carry out digital circuit simulation experiments; (2) Multisim software package contains a wide range of chips and instruments, saving purchase costs, and can be real-time operated and modified on the computer; (3) As the first step before the experiment, the Multisim simulation experiments mainly use Multisim software to draw the circuit diagram, so that students can understand the experimental principle, verify whether the experimental circuit diagram design is correct, and facilitate the connection of lines in the experiment [12-18].

2. Overview of Multisim software

Multisim is a schematic diagram capture and interactive simulation software launched by National Instrument Co., Ltd. It mainly completes schematic diagram input, circuit simulation, and PLD design functions of circuit design [19,20]. Its humanized interface, huge virtual device instrument library, and perfect analysis method are competent for most occasions of circuit design and simulation, and can effectively simulate and analyze the actual analog circuit, digital circuit, and analog digital mixed circuit [21,22]. The feature of the software is that it places various virtual instruments on the same operation interface with the circuit schematic diagram very realistically to test various parameters and waveforms, eliminating the complexity of traditional circuit simulation in a graphical way.

A computer and a set of software enable one to form a virtual experimental workbench. Students can complete the central links of electronic technology course design, such as selecting components, creating circuits, calculating and adjusting parameters, and observing simulation results in a virtual environment, and the design and experiment can be carried out simultaneously, which is convenient for modification and debugging. At the same time, using the test instrument in the software library to test can complete various types of circuit design and experiments. Finally, the physical assembly and debugging are carried out to achieve the optimization of the circuit design and ensure that the design requirements are met [23,24]. It can be seen that the introduction of Multisim software into digital circuit experiment teaching is of great significance in enriching the experiment content.

3. Application of Multisim software in digital circuit experiment teaching

The course of digital electronic technology is generally divided into more than 10 modules, and the analysis methods and research contents of each module differ. Students feel that the content is too much and messy to master thoroughly when learning, and some students even call it the “Devil Circuit.” Traditional experimental methods often use confirmatory experiments, and students often follow the instructions of the experiment and rarely study the reason behind them. At the same time, due to the restriction of the hardware environment, there is a lack of comprehensive experiments to achieve the combination and comprehensive application of modules, which greatly limits the experimental content. The use of Multisim software as an auxiliary teaching method and experimental tool for experimental course teaching not only makes up for the deficiencies caused by the lack of experimental sites, instruments and equipment, funds, and other factors, but also avoids damage to the instruments caused by various misoperations [25-28]. In addition, it can also simulate some phenomena that are difficult to observe in practical experiments. It can be predicted that introducing Multisim simulation and operation into classroom-aided teaching will play an important role in deepening students’ understanding and mastering of knowledge, stimulating their enthusiasm and creativity to a greater extent, and improving the quality of experimental teaching [29,30].

This paper takes the comprehensive design experiment of a three-way time-limited rush-answering device as an example to illustrate the feasibility and important value of the Multisim software in the digital circuit experiment teaching. The three-way answering device has the functions of several basic modules, such as gate circuit logic function, 555 timer, counter, decoder, digital display, data selector, trigger, etc. One is the comprehensive application of the knowledge and technology learned, which is helpful to familiarize with the characteristics of the IC used. The second is the practice and training of the engineering careful design process.

3.1. Design requirement

The circuit has a time-limited preemptive answer function. After the host clears and sends the preemptive answer command, the timer starts timing. If there is no preemptive answer within the specified time of 9s, the voice and photoelectric alarm signal will be sent, and the subsequent preemptive answer signal will be invalid. If a group of contestants presses the preemptive answer switch for the first time to preemptive answer successfully within 9s, the input signal shall be locked immediately to make the preemptive answer signal of other groups invalid, and the timer display will stop timing. The sound and photoelectric alarm signals will then be sent out, and the time of answering and the group number of the contestant will be displayed.

If two or more groups of preemptive signals are generated at the same time within the time limit of 9s, all the preemptive signals are invalid, and the group symbol display displays the 0 character.

3.2. Design and analysis

First, the overall circuit is designed according to the design requirements, the overall principle block diagram is drawn, and then the design circuit is gradually refined.

3.2.1. Overall analysis

(1) As the design requirements involve timing logic, the signal processing circuit for preemptive response must be composed of triggers. For this purpose, the design principle block diagram of the rush-answering device is composed of 4D trigger 74LS175 (rising edge trigger), encoding circuit, 555 timer, timer, seven segments digital display, etc., as shown in **Figure 1**.

(2) Then the schematic block diagram design shown in **Figure 1** is further refined, and there is a schematic diagram of a three-way time-limited rush-answering simulation design as shown in **Figure 2**. In the figure, "X" is the host reset signal, which is effective at a low level.

3.2.2. Design simulation analysis

(1) In **Figure 2**, After reset, the $\overline{CLR} = 0$ in U1 (74LS175), then its output is cleared, the LD = 0 in U9 (74LS190), the parallel asynchronous number setting function is effective, and $Q_3Q_2Q_1Q_0 = d_3d_2d_1d_0 = 0000$. The decoding/driving circuit U11 (74LS248) drives the timing nixie tube U12 to display the 0 character.

(2) Click the switch control key "X" to access the high level, the $\overline{CLR} = 1$ in 74LS175, the preemptive answer starts, and the subsequent preemptive answer signal is valid. At the same time, the $\overline{LD} = 0$ in 74LS190 and the setting function is invalid. The initial output state of 74LS190 (U_9) is $Q_3Q_2Q_1Q_0 = 0000$, the NAND gate U8B outputs a high level, and the rush-answering device enters the time-limited

counting state.

(3) After the host sends a preemptive signal, if no valid preemptive response signal is generated within the specified time (9 seconds), the AND gate U2A outputs a high level, and the NAND gate U8A outputs a low level, so that the $\overline{CT}$ = 0 in 74LS190, 74LS190 works in the count-up mode, and counts from the initial 0 state, and the Nixie tube U12 displays the count-up character. When the count is added to 9, the low-level signal output by NAND gate U8B makes NAND gate U8A output high level, the $\overline{CT}$ = 1 in 74LS190, 74LS190 works in the holding state, the display character 9 of Nixie tube U12 remains unchanged, while generating audio and photoelectric alarm signals, and making NAND gate U2B output low level, the clock pulse signal CLK (effective rising edge) of U1 (74LS175) is 0, U1 is blocked, and the subsequent preemptive signal is invalid.

(4) In the stage of the preemptive answer, if an effective preemptive response signal is generated within the specified time (9 seconds), the AND gate U2A outputs a low level, so that the NAND gate U8A outputs a high level, the $\overline{CT}$ = 1 in 74LS190, and works in a holding state. The Nixie tube U12 keeps the time character displayed to generate the effective preemptive response signal unchanged, and simultaneously generates audio and optical alarm signals. At the same time, the AND gate U2B outputs a low level, and the clock pulse signal CLK (effective rising edge) of U1 (74LS175) is 0, U1 is blocked, and the subsequent scramble signal is invalid.

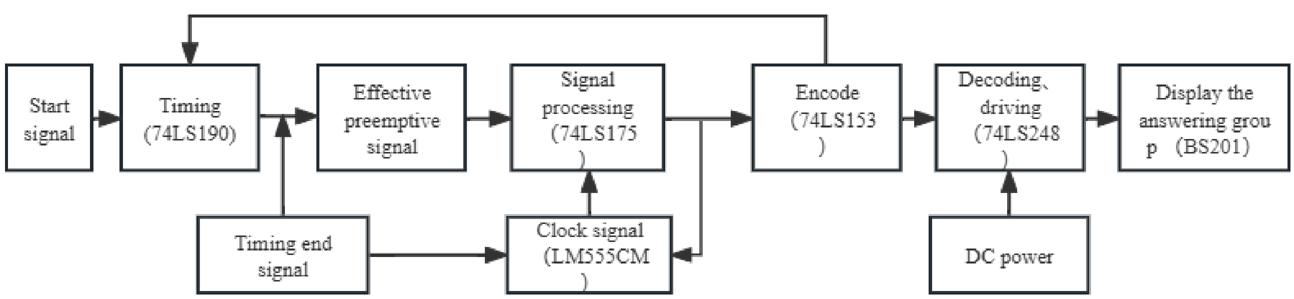

Figure 1. Design principle block diagram of the three-way answering device

3.3. Main modules design analysis

In the design process, the selection of coding circuits and the connection of counters play an important role in students' mastery and expansion of knowledge, so the two parts are analyzed and introduced.

3.3.1. Encoding circuit

The selection of coding circuit components is an important link in circuit design, which is rich in content and flexible. According to the design requirements, there is a coding Encoding circuit table corresponding to the seven segments digital display decoding/driving circuit U4(74LS248), as shown in **Table 1**.

Table 1. Coding table of decoding display circuit

4D trigger 74LS175 output			Decoding/driving circuit 74LS248 input				Corresponding display
Q3	Q2	Q1	D	C	B	A	U6
0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	2
0	1	1	0	0	0	0	0
1	0	0	0	0	1	1	3
1	0	1	0	0	0	0	0
1	1	0	0	0	0	0	0
1	1	1	0	0	0	0	0

According to the output logic function expression of data selector 74LS153 as shown in Formula (1) and **Table 1**, by drawing Karnaugh map, the corresponding logic expressions of input terminals D, C, B, and A of 74LS248 are shown in Formula (2).

$$Y = \overline{\overline{ST}} \sum_{i=0}^{3} m_i * D_i \tag{1}$$

$$A = \overline{Q_3}\,\overline{Q_2}Q_1 + Q_3\overline{Q_2}\,\overline{Q_1} = m_0 Q_1 + m_2\overline{Q_1} = 1Y \quad 1C_0 = Q_1 \quad 1C_2 = \overline{Q_1} \quad 1C_1 = 1C_3 = 0 \tag{2}$$

$$B = \overline{Q_3}Q_2\overline{Q_1} + Q_3\overline{Q_2}\,\overline{Q_1} = m_1\overline{Q_1} + m_2\overline{Q_1} = 2Y \quad 2C_1 = 2C_2 = \overline{Q_1} \quad 2C_0 = 2C_3 = 0$$

$$C = D = 0$$

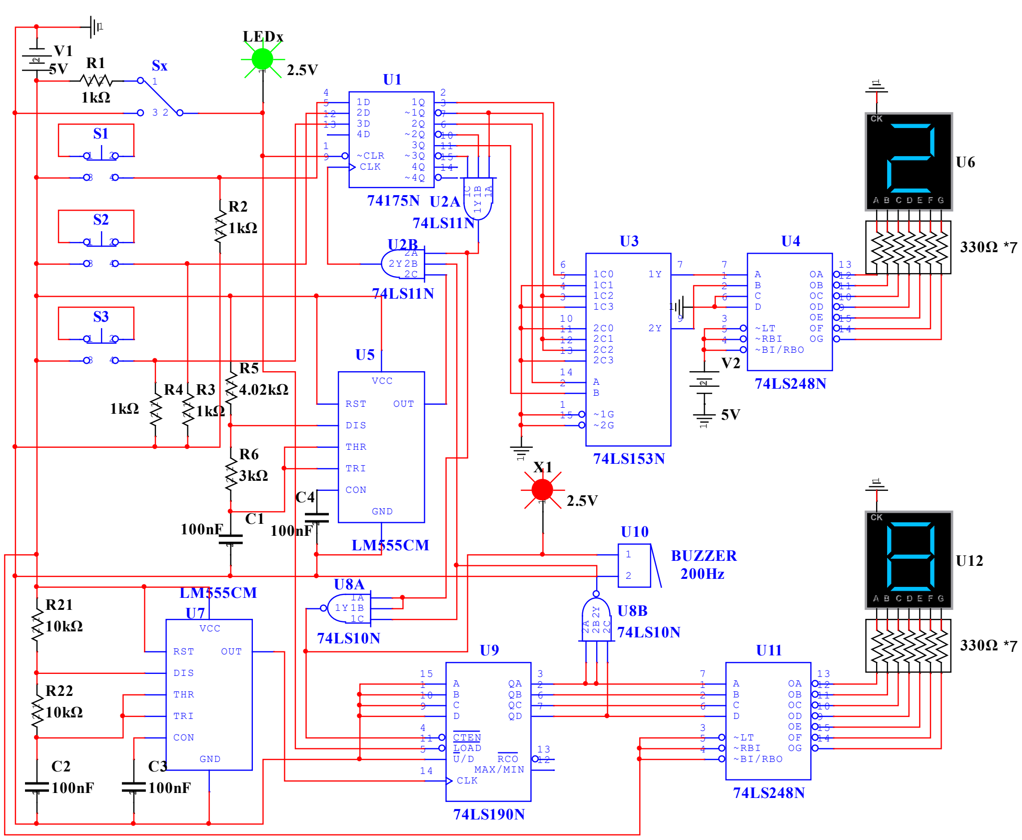

Figure 2. Schematic diagram of simulation design of the three-way answering device

According to Formula (2), the encoding function can be realized by using the double four-choice data selector 74LS153, as shown in the corresponding part of the circuit in **Figure 2**. Here we can see that Formula (2) can be transformed to obtain Formula (3).

At this time, the teacher can guide students to replace the 74LS173 chip with a combinational logic circuit, so the 74LS153 chip in **Figure 2** can be replaced by **Figure 3**.

$$A = \overline{Q_3}\,\overline{Q_2}Q_1 + Q_3\overline{Q_2}\,\overline{Q_1} = \overline{\overline{\overline{Q_3}\,\overline{Q_2}Q_1} * \overline{Q_3\overline{Q_2}\,\overline{Q_1}}} \quad (3)$$

$$B = \overline{Q_3}Q_2\overline{Q_1} + Q_3\overline{Q_2}\,\overline{Q_1} = \overline{\overline{\overline{Q_3}Q_2\overline{Q_1}} * \overline{Q_3\overline{Q_2}\,\overline{Q_1}}}$$

$$C = D = 0$$

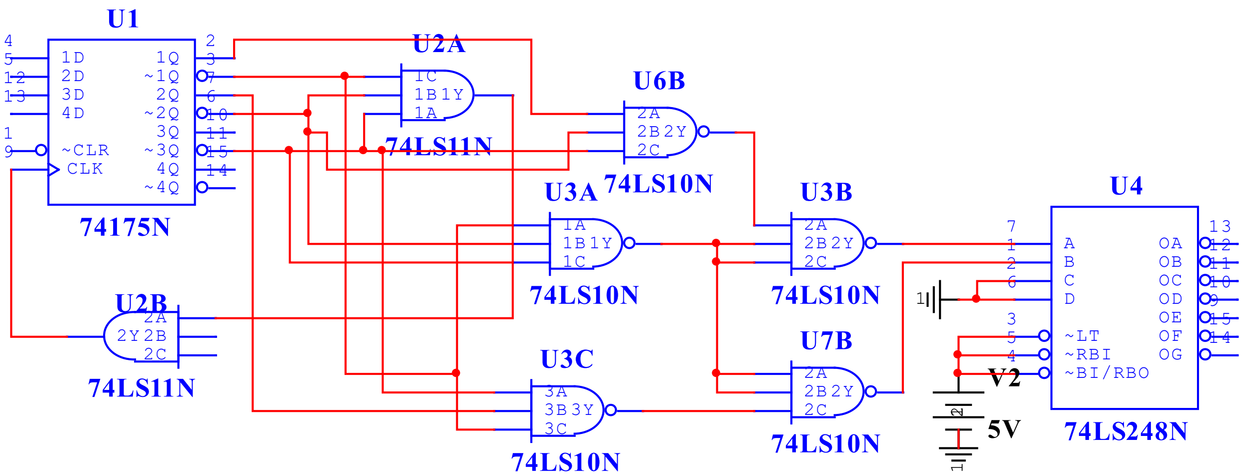

Figure 3. Diagram of replacing 74LS153 chip with combinational logic gate circuits

Moreover, according to the output logic function expression of the 3-wire 8-wire decoder 74LS138 as shown in Formula (4) and **Table 1**, Formula 2 can be converted into the form of the following Formula (5).

$$\overline{Y_i} = \overline{G_1 * \overline{\overline{G_{2A}}} * \overline{\overline{G_{2B}}} * m_i} \quad (4)$$

$$A = \overline{Q_3}\,\overline{Q_2}Q_1 + Q_3\overline{Q_2}\,\overline{Q_1} = \overline{\overline{\overline{Q_3}\,\overline{Q_2}Q_1} * \overline{Q_3\overline{Q_2}\,\overline{Q_1}}} = \overline{\overline{m1} * \overline{m_4}} = \overline{\overline{Y_1} * \overline{Y_4}} \quad (5)$$

$$B = \overline{Q_3}Q_2\overline{Q_1} + Q_3\overline{Q_2}\,\overline{Q_1} = \overline{\overline{\overline{Q_3}Q_2\overline{Q_1}} * \overline{Q_3\overline{Q_2}\,\overline{Q_1}}} = \overline{\overline{m_2} * \overline{m_4}} = \overline{\overline{Y_2} * \overline{Y_4}}$$

$$C = D = 0$$

Therefore, the 74LS153 chip in **Figure 2** can also be replaced by the common 74LS138 chip with a logic gate circuit as shown in **Figure 4**.

It can be seen that the use of Multisim simulation experiment plays an important role in the expansion of students' design ideas, effectively improving their comprehensive application ability of knowledge, thus improving students' creativity and stimulating students' interest in the course.

3.3.2. Counter selection

In **Figure 2,** the counter is implemented with a 74LS190 chip, and its function table is shown in **Table 2**. According to the inquiry, the 74LS192 chip also has the function of adding and subtracting counting, so it can also be considered to replace the 74LS192 chip. The function list of the 74LS192 chip is shown in **Table 3**.

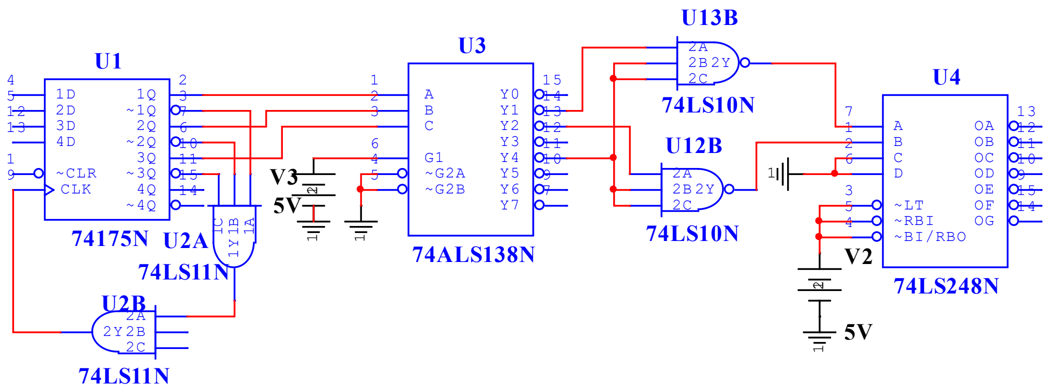

Figure 4. Diagram of 74LS153 chip replaced by 74LS138 chip and logic gate circuits

Table 2. Function table of 74LS190 chip

Input								Output			
			CP	**D3**	**D2**	**D1**	**D0**	**Q3**	**Q2**	**Q1**	**Q1**
0	X	X	X	d3	d2	d1	d0	d3	d2	d1	d0
1	0	0		X	X	X	X	Add counting function			
1	0	1		X	X	X	0	Subtract counting function			
1	1	X	X	X	X	1	0	Keeping function			

Table 3. Function table of 74LS192 chip

Input								Output			
				D3	**D2**	**D1**	**D0**	**Q3**	**Q2**	**Q1**	**Q0**
1	X	X	X	X	X	0	0	0	0	0	0
0	0	X	X	d3	d2	d1	d0	d3	d2	d1	d0
0	1		1	X	X	X	X	Add counting function			
0	1	1		X	X	X	X	Subtract counting function			
1	1	1	1	X	X	X	X	Keeping function			

Therefore, we can guide students to try to replace the 74LS192 counting module in **Figure 2** with the 74LS192 chip. Through the comparative analysis of their function tables, the partial diagram after replacement is shown in **Figure 5**. Thus, the students' understanding and mastery of relevant knowledge are deepened through simulation.

3.4. Simulation analysis

System simulation experiments and analysis are carried out according to the design requirements to verify the design functional requirements. When working, the host first connects the reset button "X" of the rush-answering device to the low level and then to the high level (issue the command of "start answering"), and then one nixie tube starts to display the timing. The group number of contestants who successfully answered the first time within 9 seconds is displayed on another nixie tube. At this time, the subsequent answering signals should be invalid. If there are two or more groups of answering at the same time, all the answering signals are invalid, and the corresponding nixie tube displays the 0 character. Through simulation detection, the measured function is normal and meets the design requirements.

Therefore, it can be seen that through the introduction of simulation software, on the one hand, the design of comprehensive experiments that cannot be completed in the hardware environment of the laboratory has been completed, on the other hand, students can deepen their understanding and mastery of the relevant content through the constant conversion of the equivalent circuits of each module. It can be seen that the introduction of multimedia software into experimental teaching is of great significance to the improvement of students' design ability and creativity.

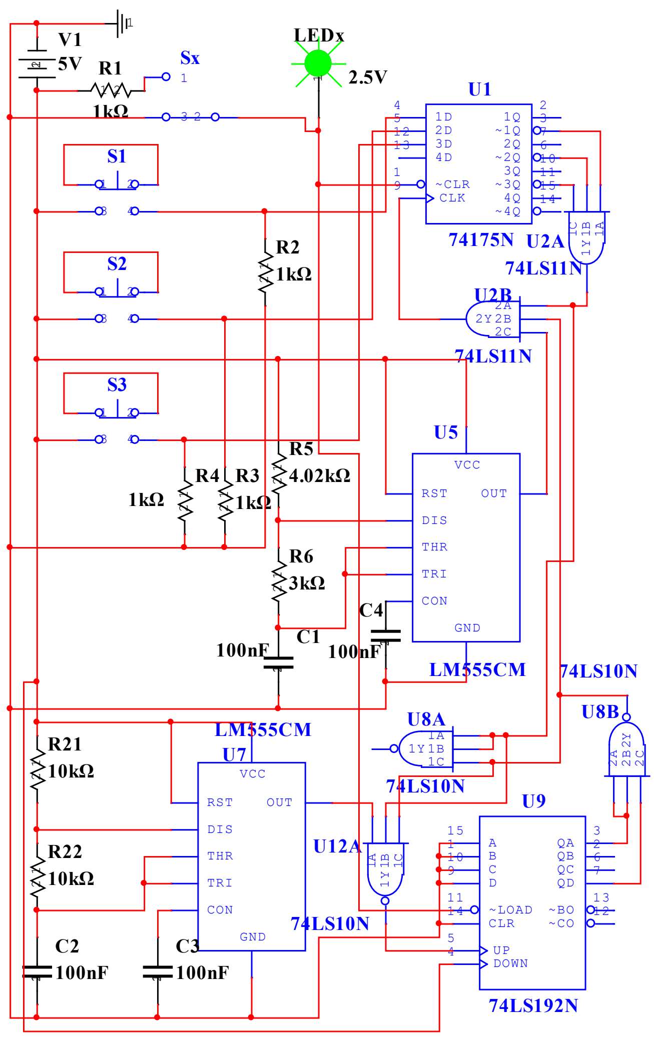

Figure 5. Diagram of 74LS190 chip replaced by 74LS192 chip

4. Conclusion

The practice of using Multisim to design digital circuits shows that the application of Multisim in digital circuit experiment teaching has great advantages. It can greatly increase the content of classroom teaching. Students can conduct experiments and exercises on the computer anytime and anywhere, and the content can also be selected at will. They can also preview the actual lesson in the multimedia environment, which improves the teaching effect. At the same time, Multisim software has promoted the cultivation of students' innovation awareness and innovation ability, creating good conditions for students to carry out innovative design activities. Through the constant change of the parameters of each component in the circuit through the simulation software, students can more clearly understand the change in circuit performance, which not only enables students to learn to debug and design circuits, improves their cognitive ability of circuits, but also stimulates their enthusiasm and initiative in learning. This enables students to explore in a deeper, broader, and more comfortable environment.

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Disclosure statement

The authors declare no conflict of interest.

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