Research on the Application of Simulation Experiments in the Teaching of Automatic Block Signaling System

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Abstract: This paper investigates the use of computer software for simulation experiments in teaching the working principle of automatic block signaling system to students majoring in rail transit communication and signaling. Automatic block signaling system is a critical railway technology that dynamically adjusts signal displays based on train location and block occupancy. Understanding this principle is crucial for students in the field. The paper explores the implementation of CADe SIMU and Simulink from MATLAB software to construct experimental circuits, showcasing the results of these simulations. By comparing examination scores from classes that did and did not utilize simulation-aided learning, the study demonstrates that simulation experiments significantly improve learning outcomes, as evidenced by increases in average scores, excellent grades, and overall pass rates.

1. Introduction

Automatic block signaling system is an advanced signaling system that can automatically change signal indications based on train movements and block section status.[1] Drivers operate trains according to the indications displayed by the trackside passing signals or the onboard signal system. Automatic block signaling system has three advantages over manual and semi-automatic block signaling system:

1) INCREASED SECTION THROUGHPUT. Automatic block signaling system divides the section into a number of block sections, allowing trains to be dispatched at the minimum running interval. This greatly improves the density of trains and the throughput of the section;

2) AUTOMATIC OPERATION. Automatic block signaling system does not require manual operation of blocking and arrival restoration, and the blocking function is performed automatically. This reduces the complexity of manual operations;

3) IMPROVED SAFETY. The automatic block signaling system can automatically confirm train arrivals and automatically restore blocking. This reduces the risk of human error.

Automatic block signaling system is a crucial component of railway transportation engineering education. However, teaching experience has revealed that most students struggle to fully grasp these concepts, particularly in three areas:

1) Students fail to comprehend the mechanism behind the automatic change in signal indications displayed by ground-based or onboard signaling systems;

2) Students struggle to understand how three-aspect signals can convey more than three distinct signals;

3) Students lack a clear understanding of the principles and functions of low-frequency and carrier signals employed in the ZPW-2000A track circuit.

The prevalent learning difficulties in grasping automatic block signaling system stem from the abstract nature of the subject matter presented in traditional teaching methods. Textbooks often employ structural diagrams, schematics, and circuit diagrams that lack visual appeal and fail to convey concepts in a clear and intuitive manner. Moreover, online video courses frequently fall short

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of providing in-depth explanations, merely repeating textbook content without offering unique insights.

To enhance student comprehension of automatic block signaling system, it is imperative to introduce simulation experiments into the teaching process.[6][9] Simulation experiments leverage computer software to mimic complex systems and processes, generating results that closely approximate real-world scenarios. These experiments offer several advantages, including:

1) ENHANCED SAFETY. Simulation experiments eliminate the risks associated with hands-on training in real-world environments.

2) REDUCED COSTS. Simulation experiments are significantly more cost-effective compared to traditional training methods that require physical equipment and resources.

3) EASE OF MODIFICATION. Simulation experiments can be readily modified to adapt to different teaching scenarios and student needs.

4) REPEATABILITY. Simulation experiments can be repeated multiple times, allowing students to gain a deeper understanding of the concepts at their own pace.

Most importantly, simulation experiments have the unique ability to transform abstract concepts into concrete representations, making them more accessible and comprehensible for students. By incorporating simulation experiments into the teaching of railway transportation automatic block signaling system, educators can effectively enhance student engagement, improve knowledge retention, and foster a deeper understanding of the subject matter. This approach will undoubtedly prepare students for success in their future careers as railway engineers and technicians.

2. Overview of Automatic Block Signaling System Teaching Content

Automatic block signaling system is a railway signaling system that uses track circuits or axle counters to automatically detect the occupancy or vacancy of block sections, and allows trackside signals or onboard signaling systems to automatically change their aspect according to the occupancy or vacancy status of the section.[2][3]

When teaching automatic block signaling system to students in higher vocational colleges, three main objectives should be achieved:

1) Students should gain a comprehensive understanding of the underlying principles, components, and operational mechanisms of automatic block signaling system;

2) Students should acquire a thorough understanding of the functions and working principles of each individual device within the automatic block signaling system.

3) Students should cultivate the skills necessary to perform basic maintenance and repair tasks on automatic block signaling system.

There are several challenges arise due to limitations in laboratory resources and practical training facilities. For example, Students often lack the opportunity to directly observe the changes in signal displays on trackside or onboard signaling systems as trains move through block sections; Most commercially available Automatic block signaling system simulation demonstration systems offer only pre-set scenarios, failing to provide students with a comprehensive understanding of the system's dynamic behavior; Observing pre-recorded simulations may not fully equip students to grasp the intricate control logic of three- or four-aspect automatic block signaling system; Students may struggle to visualize the digital signal modulation process employed in ZPW-2000A frequency-shift automatic block signaling system, hindering their comprehension of how high-frequency signals can carry low-frequency information.

3. Application of Simulation Experiments in the Analysis of Automatic Block Signaling System

To address the challenges of teaching abstract concepts in automatic block signaling system, the author employed electrical simulation software CADe SIMU and Simulink from MATLAB to guide students in creating their own simulation experiment circuits. Through this hands-on approach, students gained a deeper understanding of the operational logic of three- and four-aspect automatic block signaling system. They were able to directly observe the simulated results of frequency-shift signals on oscilloscopes, providing a tangible representation of the abstract concept.

3.1 Three-Aspect Automatic Block Signaling System

Three-aspect automatic block signaling system is a railway signaling system that utilizes trackside signals with three distinct colors – red, yellow, and green – to indicate the status of the two block sections ahead of the train.[4] As illustrated in Figure 1, this system employs the fundamental principle of three-aspect automatic block signaling system.

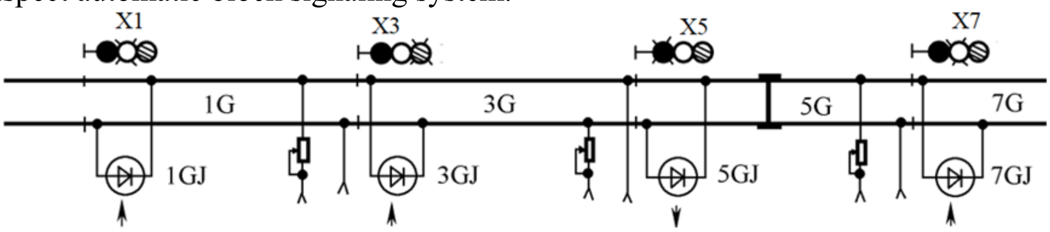

Figure 1 Basic Principle Diagram of Three-Aspect Automatic Block Signaling System

When the train in front occupies the 5G section, the X5 signal shows a red light, the X3 signal shows a yellow light, and the X1 signal shows a green light. Assuming that when the train behind reaches the front of the X1 signal, the driver sees that the X1 signal is green, indicating that there are at least two sections free in front. The driver can drive according to the specified speed and pass the X1 signal. When the train behind reaches the front of the X3 signal, the driver sees that the X3 signal is yellow, indicating that there is only one section free in front, and the next passing signal is red. The driver should drive cautiously and slow down to pass the X3 signal. When the train behind reaches the front of the X5 signal, the driver sees that the X5 signal is red, indicating that the section in front is occupied. The driver should stop immediately and is prohibited from passing the X5 signal.

If the train in front continues to the 7G section, then the X7 signal will show a red light, the X5 signal will show a yellow light, the X3 signal will show a green light, and the X1 signal will show a green light. The driver of the train behind will drive the train according to the green, yellow, or red lights displayed by the signals.

During the simulation experiment, students created a file named "3 Aspects Automatic block signaling system.cad" in the CADe SIMU software. Students selected powers, circuit breakers, relay coils, relay contacts, and light bulbs to build a simulation circuit diagram of the three-aspect automatic block signaling system as shown in Figure 2.

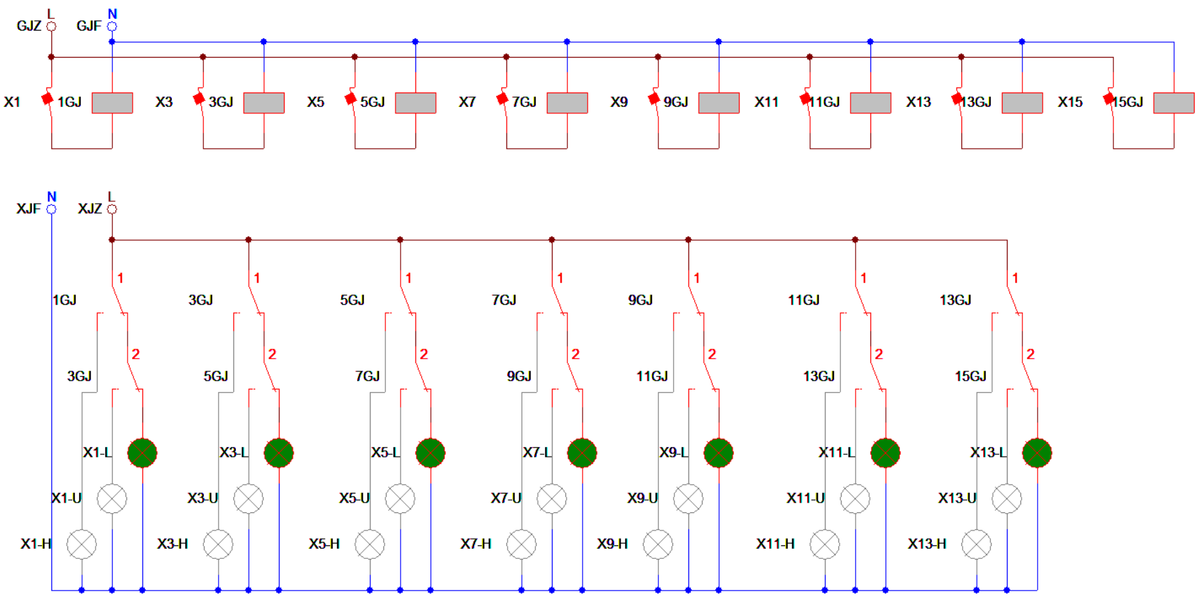

Figure 2 Simulation Circuit Diagram of Three-Aspect Automatic Block Signaling System

As shown in Figure 2, when all sections are free, all track relays are picked up, and all passing signals show green lights. When the train occupies 3G, 5G, and 7G in sequence, the signal light displays are shown in Figures 3a, 3b, and 3c.

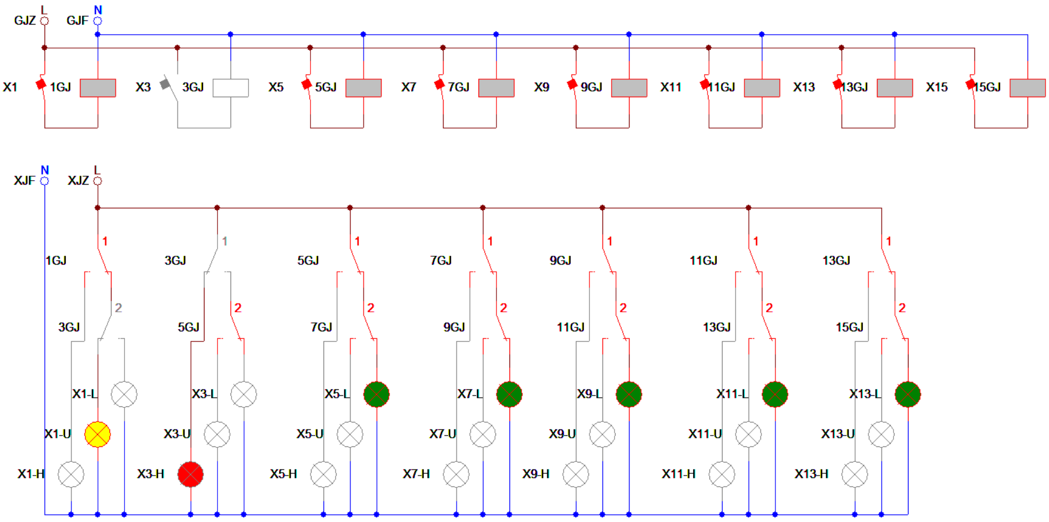

Figure 3a Simulation Circuit Diagram of Three-Aspect Automatic Block (3G Occupied)

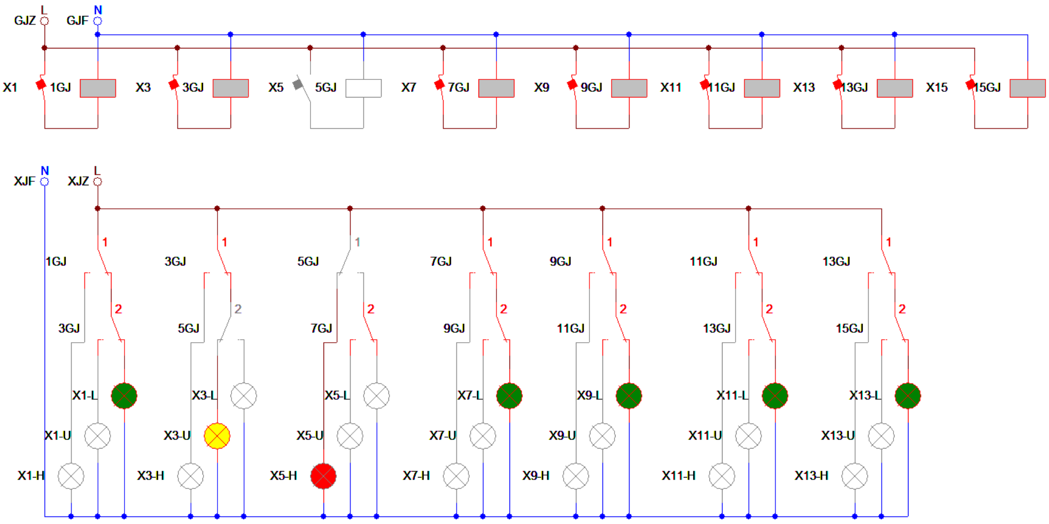

Figure 3b Simulation Circuit Diagram of Three-Aspect Automatic Block (5G Occupied)

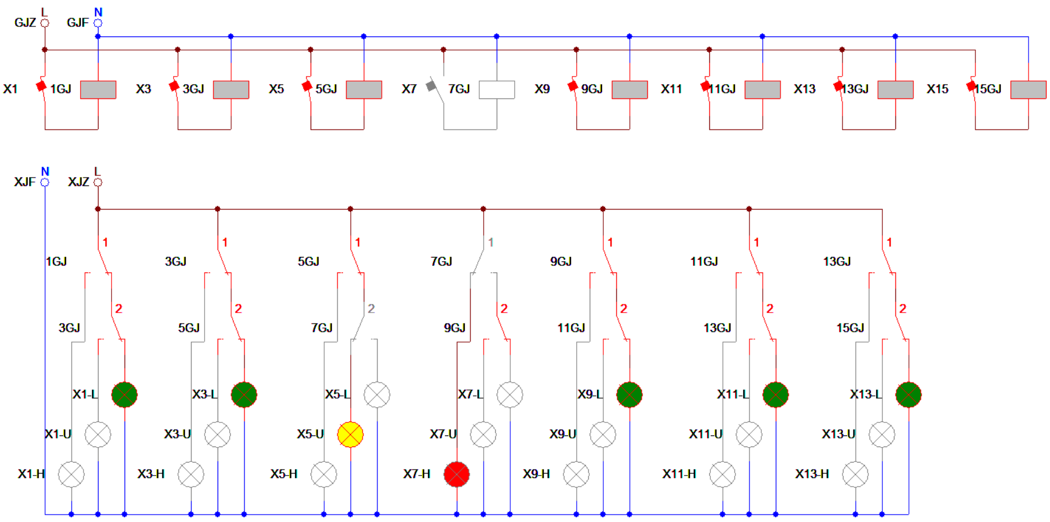

Figure 3c Simulation Circuit Diagram of Three-Aspect Automatic Block (7G Occupied)

After undergoing a rigorous verification process, the functionality of the simulated three-aspect Automatic block signaling system circuit was confirmed to match real-world behavior. The results of this verification are summarized in Table 1. This successful validation demonstrates that the simulation accurately reflects the operational principles of a three-aspect Automatic block signaling system.

Table 1 Logic of the Simulation Circuit of Three-Aspect Automatic Block Signaling System

Situation	Section nG	Section (n+2)G	Section (n+4)G	Signal Light Xn
1	Available	Available	Available	Green
2	Occupied	Available	Available	Red
3	Available	Occupied	Available	Yellow
4	Available	Available	Occupied	Green
5	Occupied	Occupied	Available	Red
6	Available	Occupied	Occupied	Yellow
7	Occupied	Available	Occupied	Red
8	Occupied	Occupied	Occupied	Red

3.2 Four-Aspect Automatic Block Signaling System

The four-aspect automatic block signaling system is a railway signaling system in which the passing signals have four displays: red, yellow, yellow-green, and green.[4] It can indicate the status of the three block sections in front of the train. Figure 4 shows the basic schematic diagram of the four-aspect Automatic block signaling system.

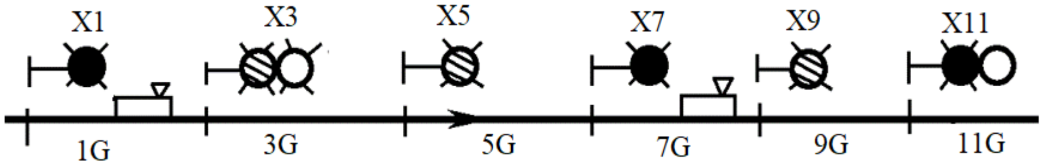

Figure 4 Basic Principle Diagram of Four-Aspect Automatic Block Signaling System

When the train in front occupies the 7G section, the X7 signal shows a red light, the X5 signal shows a yellow light, the X3 signal shows a yellow-green light, and the X1 signal shows a green light. Assuming that when the train behind reaches the front of the X1 signal, the driver sees that the X1 signal is green, indicating that there are at least three sections free in front. The driver can drive according to the specified speed and pass the X1 signal. When the train behind reaches the front of the X3 signal, the driver sees that the X3 signal is yellow-green, indicating that there are only two sections free in front, and the next passing signal is yellow. The driver of a light-load or low-speed train can drive according to the specified speed and pass the X3 signal, while the driver of a heavy-load or high-speed train should drive cautiously and slow down to pass the X3 signal. When the train behind reaches the front of the X5 signal, the driver sees that the X5 signal is yellow, indicating that there is only one section free in front, and the next passing signal is red. The driver should drive cautiously and slow down to pass the X5 signal. When the train behind reaches the front of the X7 signal, the driver sees that the X7 signal is red. The driver should stop immediately and is prohibited from passing the X7 signal.[5]

If the train in front continues to the 9G section, then the X9 signal will show a red light, the X7 signal will show a yellow light, the X5 signal will show a yellow-green light, and the X3 signal will show a green light. The driver of the train behind will drive the train according to the green, yellow, yellow-green, or red lights displayed by the signals.

During the simulation experiment, students created a file named "4 Aspects Automatic block signaling system.cad" in the CADe SIMU software. Students selected powers, circuit breakers, relay coils, relay contacts, and light bulbs to build a simulation circuit diagram of the four-aspect automatic block signaling system as shown in Figure 5.

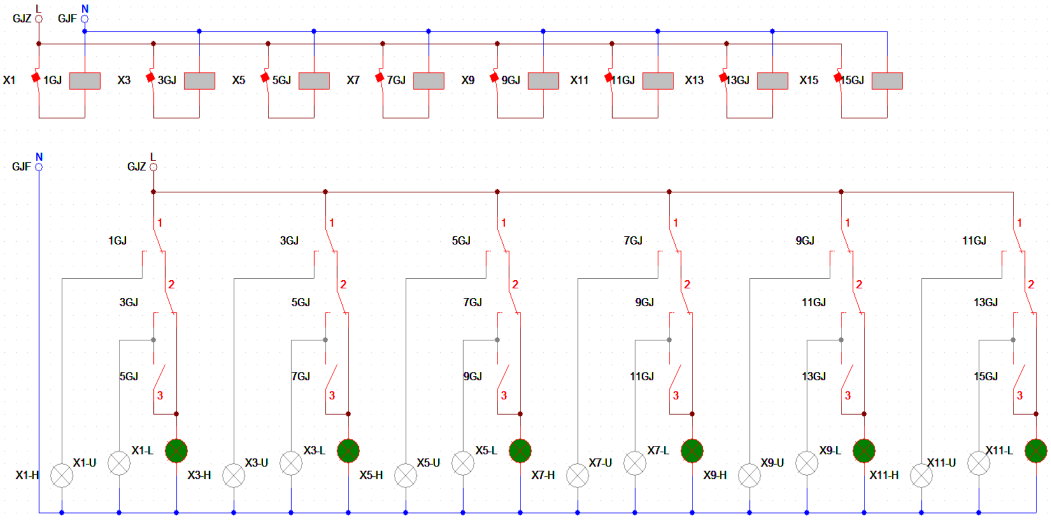

Figure 5 Simulation Circuit Diagram of Four-Aspect Automatic Block Signaling System

Figure 5 depicts the scenario where all track sections are unoccupied. In this state, all track relays are energized (picked up), and all passing signals illuminate green lights, indicating a clear track for train movement. However, as a train progressively occupies the track sections, the corresponding signal light displays change accordingly. Figures 6a, 6b, 6c, and 6d illustrate the specific sequence of signal light displays as the train occupies sections 3G, 5G, 7G, and 9G, respectively.

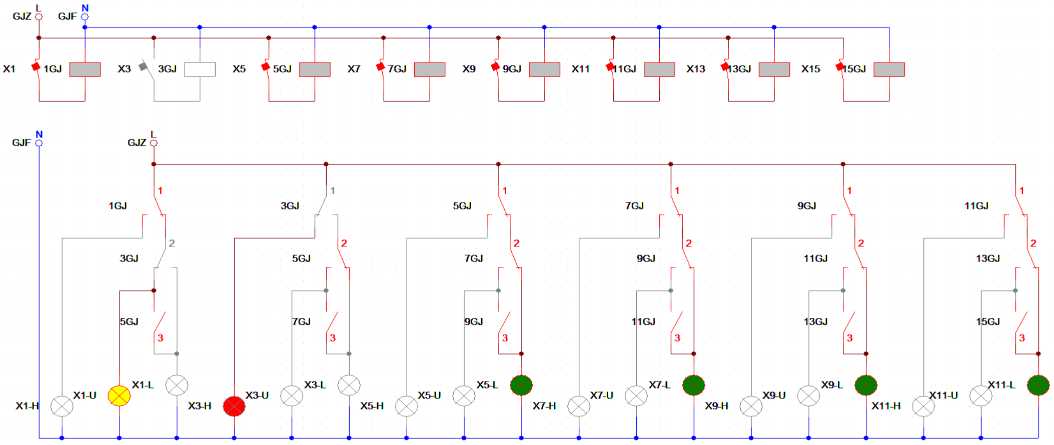

Figure 6a Simulation Circuit Diagram of Four-Aspect Automatic Block (3G Occupied)

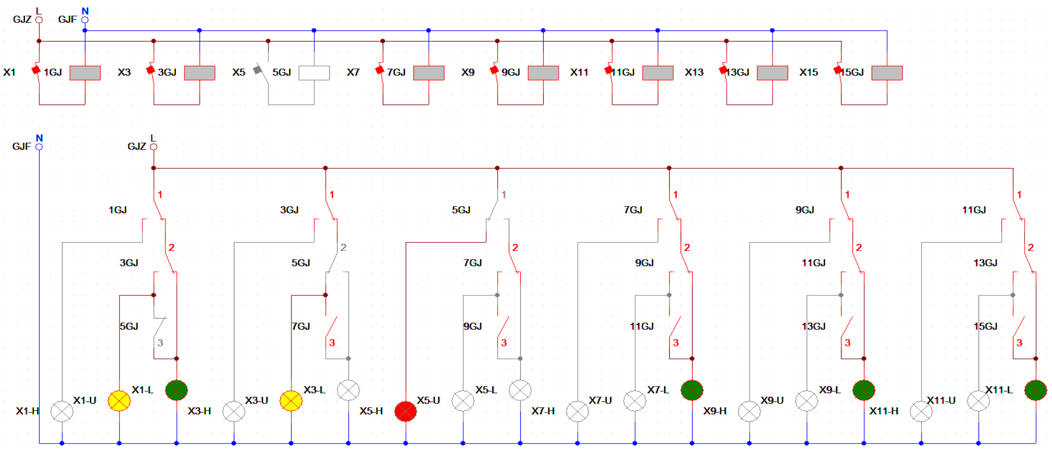

Figure 6b Simulation Circuit Diagram of Four-Aspect Automatic Block (5G Occupied)

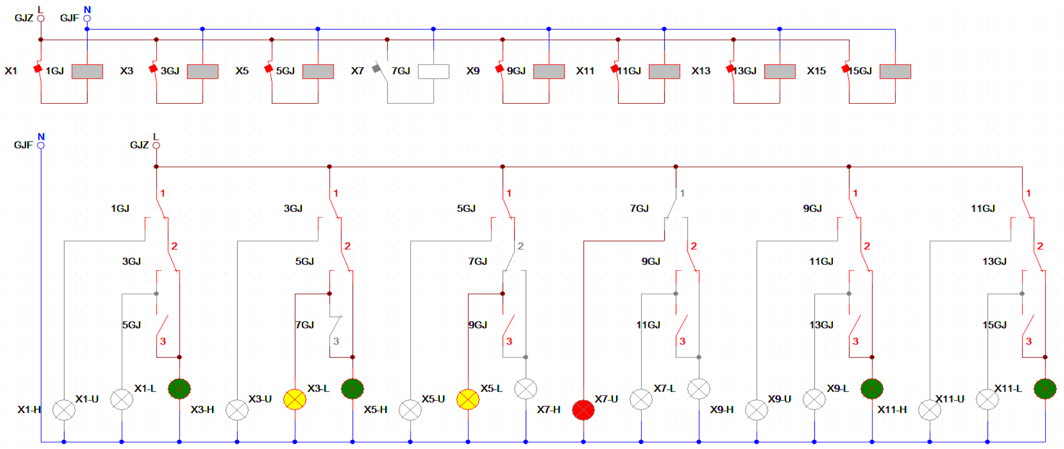

Figure 6c Simulation Circuit Diagram of Four-Aspect Automatic Block (7G Occupied)

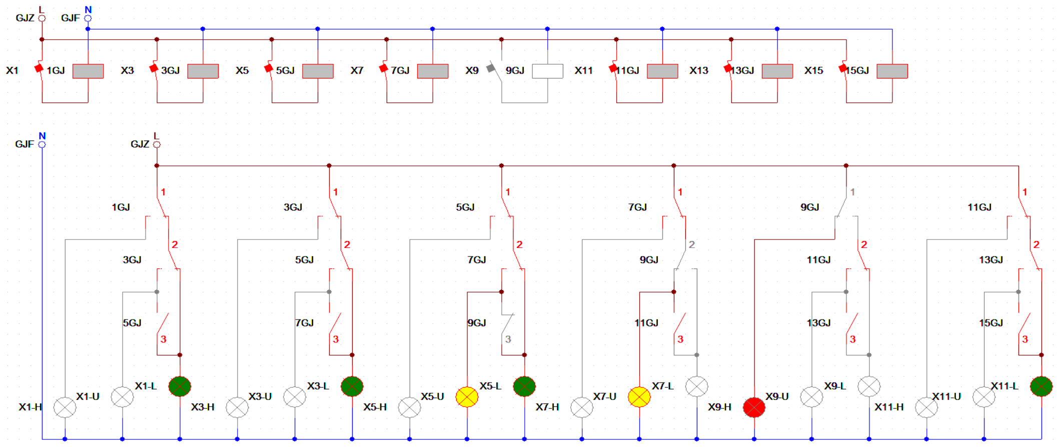

Figure 6d Simulation Circuit Diagram of Four-Aspect Automatic Block (9G Occupied)

Following a comprehensive verification process, the operational logic of the simulated four-aspect Automatic block signaling system circuit was found to be consistent with real-world operation, as detailed in Table 2. This successful validation demonstrates the simulation's ability to accurately capture the behavior of the four-aspect automatic block signaling system.

Table 2 Logic of the Simulation Circuit of Four-Aspect Automatic Block Signaling System

Situation	Section n G	Section (n+2) G	Section (n+4) G	Section (n+6) G	Signal Light Xn
1	Available	Available	Available	Available	Green
2	Available	Available	Available	Occupied	Green
3	Available	Available	Occupied	Available	Yellow-Green
4	Available	Available	Occupied	Occupied	Yellow-Green
5	Available	Occupied	Available	Available	Yellow
6	Available	Occupied	Available	Occupied	Yellow
7	Available	Occupied	Occupied	Available	Yellow
8	Available	Occupied	Occupied	Occupied	Yellow
9	Occupied	Available	Available	Available	Red
10	Occupied	Available	Available	Occupied	Red
11	Occupied	Available	Occupied	Available	Red
12	Occupied	Available	Occupied	Occupied	Red
13	Occupied	Occupied	Available	Available	Red
14	Occupied	Occupied	Available	Occupied	Red
15	Occupied	Occupied	Occupied	Available	Red
16	Occupied	Occupied	Occupied	Occupied	Red

3.3 ZPW-2000A Automatic Block Signaling System

The ZPW-2000A automatic block signaling system is based on frequency-shift track circuits. It uses frequency parameters as control information and frequency modulation to modulate low-frequency signals and carrier signals into frequency-shift signals with unchanged amplitude and frequency that varies with the low-frequency signal. The frequency-shift signals are used as transmission channels along the rails to control the display of passing signals, achieving the purpose of automatically commanding train operation.[4]

The ZPW-2000A uninsulated track circuit divides the track circuit into two parts: the main track circuit and the short track circuit in the tuning zone. The transmitter sends frequency-shift signals to both the main track circuit and the short track circuit in the tuning zone. The frequency-shift signals are modulated from the carrier signal and the low-frequency signal using FSK. The standard frequencies of the carrier signals are 1700Hz, 2000Hz, 2300Hz, and 2600Hz. Each carrier signal has two types: -1 and -2, which represent +1.4Hz and -1.3Hz above the standard frequency, respectively. For example, 1700-1 represents 1701.4Hz, and 2000-2 represents 1998.7Hz.

The frequency of the low-frequency signal satisfies the formula:

$$Fn = 10.3 + 1.1\,(18 - n),\ (n = 0, 1, 2, 3, \ldots, 17)$$

As can be seen from the formula, the minimum value of the frequency of the low-frequency signal is 10.3Hz, the maximum value is 29.0Hz, and the frequency interval between two adjacent low-frequency signals is 1.1Hz.

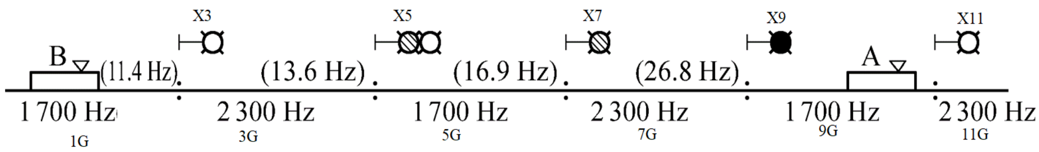

Figure 7 Basic Principle Diagram of ZPW-2000A Automatic Block Signaling System

Figure 7 shows the basic block diagram of the ZPW-2000A automatic block signaling system. When the train ahead occupies 9G, the transmitter sends an HU information code with a frequency of 26.8Hz to 7G, indicating that the train behind should stop immediately. At the same time, the transmitter sends a U information code with a frequency of 16.9Hz to 5G, indicating that the train behind should slow down to a specified speed level and pass the approaching ground signal. At the same time, the transmitter sends an LU information code with a frequency of 13.6Hz to 3G, indicating that the train behind should proceed cautiously at the specified speed. At the same time, the transmitter sends an L information code with a frequency of 11.4Hz to 1G, indicating that the train behind should proceed at the specified speed.

In order to simulate the transmitter functionality within the ZPW-2000A track circuit, the students leverage Simulink from MATLAB software environment. They begin by creating a new file named "ZPW-2000A Automatic Block Signaling System.slx". This file serves as a container for the simulation model they will construct. To build the model, the students utilize a variety of pre-built Simulink modules. These modules offer specific functionalities that can be combined to create more complex systems. The chosen modules for this task include Constants, Pulse Generators, Multiport Switches, a Product, and a Scope. Each module plays a specific role:

1) Constant modules likely provide fixed signal values used throughout the simulation.

2) Pulse Generator modules are likely used to create digital pulses representing information codes.

3) The Multiport Switch modules might be used to selectively route these pulses based on specific conditions.

4) The Product module may be used to perform calculations on the signals, such as multiplying them to create frequency-shift keying modulations.

5) The Scope module serves as a virtual oscilloscope to display and analyze the generated signals.[7][8]

By strategically connecting these modules and configuring their parameters, the students can construct a simulation model that replicates the behavior of the ZPW-2000A track circuit's transmitter. The resulting model is visualized in Figure 8, providing a detailed schematic of the simulated system.

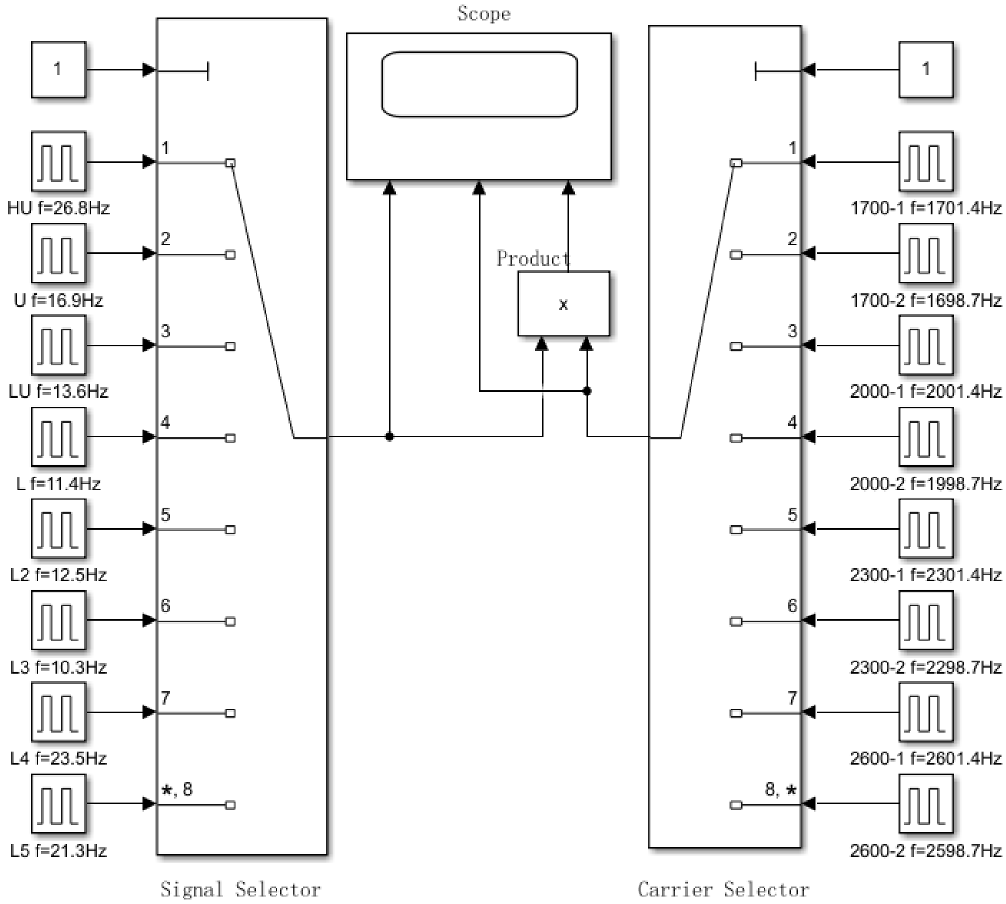

Figure 8 Simulation Model of ZPW-2000A Generator

When the low-frequency signal selects the HU information code with a frequency of 26.8Hz, the U information code with a frequency of 16.9Hz, the LU information code with a frequency of 13.6Hz, and the L information code with a frequency of 11.4Hz in sequence, and when the frequency-shift signal selects 2300-2, 1700-2, 2300-1, and 1700-1 in sequence, the digital modulation signal shown in Figures 9a, 9b, 9c, and 9d can be observed on the scope module.

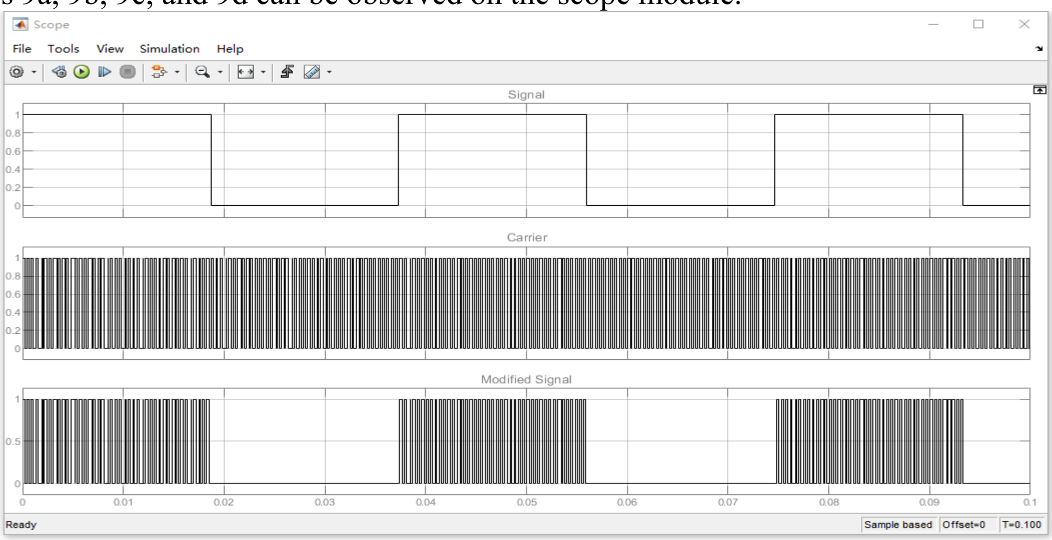

Figure 9a Simulation Model of ZPW-2000A Generator (2300-2 and HU)

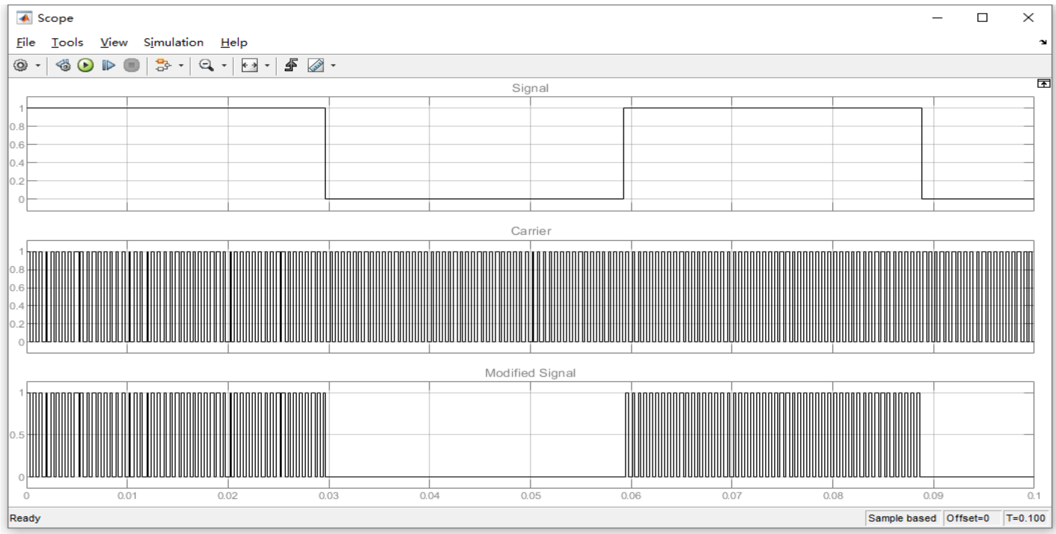

Figure 9b Simulation Model of ZPW-2000A Generator (1700-2 and U)

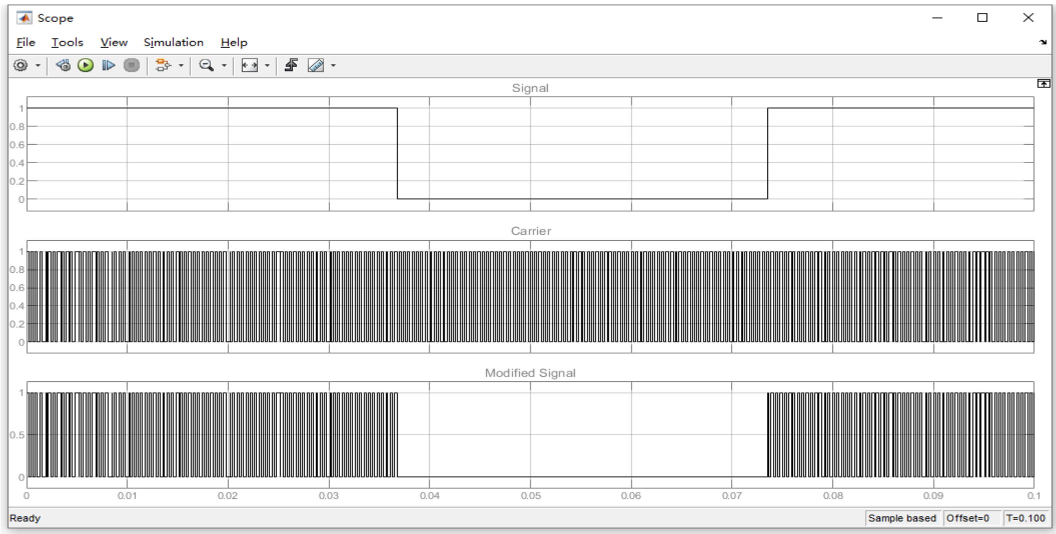

Figure 9c Simulation Model of ZPW-2000A Generator (2300-1 and LU)

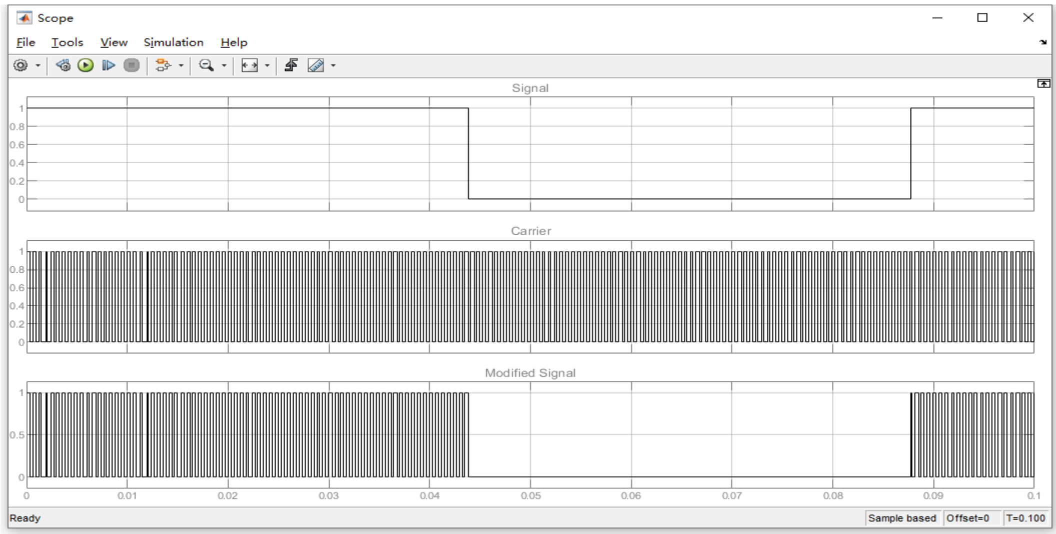

Figure 9d Simulation Model of ZPW-2000A Generator (1700-1 and L)

By observing the oscilloscope display, it can be seen that the frequency-shift signal exhibits the characteristics of the carrier signal on a microscopic scale and the characteristics of the low-frequency signal on a macroscopic scale.

4. Teaching Effect Evaluation

The author, as the instructor for the Urban Rail Traffic Communication and Signaling major in the School of Rail Transit Engineering of our institute, taught and evaluated a total of 111 students in 3 classes of 1 grade. Table 3 shows the teaching situation and evaluation results of the automatic block signaling system.

As can be seen from Table 3, when teaching Class C, no simulation experiments were used to assist teaching. The main teaching method was to analyze the principle diagram in the classroom and use multimedia equipment for demonstration. When teaching Class A and Class B, simulation experiments and multimedia equipment were used to assist teaching, and practical teaching was also carried out in the laboratory. In terms of the assessment results, the average score of Class A and Class B, which conducted simulation experiments, was higher than that of Class C, which did not conduct simulation experiments. The excellent rate of Class A was lower than that of Class C, and the excellent rates of Class A and Class B were significantly higher than that of Class C. Among them, the excellent rate of Class B reached 71.43%. The passing rates of Class A, Class B, and Class C were all above 90.00%, and the passing rate of Class B was 100.00%. This shows that simulation experiments have a positive effect on improving students' average score, excellent rate, and passing rate.

Table 3 Teaching and Assessment Situation of Automatic Block Signaling System

Class		A	B	C
Class Size		41	35	35
Simulation Experiment		Y	Y	N
Score	Excellent	3	7	3
	Good	12	18	15
	Average	14	9	12
	Pass	11	1	2
	Fail	1	0	3
Average Score		78.7	84.3	76.6
Excellent and Good Rate		36.59%	71.43%	51.43%
Passing Rate		97.56%	100.00%	91.43%

5. Conclusion

Simulation experiment is a simple, efficient, fast, low-cost, safe, and intuitive method for verifying and exploring existing knowledge and theories. In the professional course teaching for students in higher vocational colleges, the reasonable use of simulation experiments is conducive to improving students' learning interest, cultivating students' self-learning ability, helping students understand abstract concepts and theories, and improving the teaching effect.

This paper reviews the actual situation of the author's teaching and evaluation of the railway traffic automatic block signaling system, describes the methods of simulation experiments used in the teaching of the automatic block signaling system, lists the examples of the application of simulation experiments in the teaching of the three-aspect, four-aspect and ZPW-2000A automatic block signaling system, analyzes the achievements of simulation experiments in improving the teaching effect, and proves that simulation experiments have a promoting effect on improving the average score, excellent rate and passing rate in the teaching of automatic block signaling system.

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