Research on the Application of Binary Search in Finding Faults in Railway Signal Lighting Circuits

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Abstract: Railway signal is a basic equipment in rail transit. The railway signal should be able to correctly light up the corresponding color signal lights when arranging and opening routes, to ensure that the train can run safely and efficiently. Binary search is a fast-converging retrieval method, which can help signal maintenance workers to find the fault location more quickly when looking for faults in the railway signal lighting circuit. This paper uses MATLAB to simulate the basic principle of binary search, analyzes a red-green-yellow three-display railway signal lighting circuit loop, discusses the method of using binary search to find faults, and tests the convergence efficiency of binary search.

1. Introduction

Railway signals play a critical role in ensuring the safe and efficient operation of railway systems.[1] As a key signaling device, they are widely and universally applied in various railway networks. Through their clear signaling system, railway signals provide train drivers with clear and reliable instructions, which in turn ensures the safe and efficient operation of trains on the tracks. Railway signals not only improve the driver's awareness of the operating environment but also reduce the probability of accidents, providing strong protection for the safety of passengers and goods.[2] The widespread application of railway signals enables railway transportation systems to better cope with complex junctions and high-density traffic flows. By integrating with advanced signaling systems, railway signals coordinate train scheduling and optimize transportation processes, thereby improving the operational efficiency of the entire railway network.

The signal lighting circuit is the foundation for ensuring the normal operation of the signal light. It is the basis for both controlling the signal light to turn on or off correctly and for the signal system to collect the signal light status correctly.[3] If the signal lighting circuit fails, it will cause the signal to fail to open properly, which will adversely affect the safety and efficiency of train operation. Therefore, it is very important to quickly locate the fault location when the signal light fails.

2. Signal lighting circuit Overview

Figure 1 shows a typical red-yellow-green signal lighting circuit. This type of signal light is commonly used on main lines as a backup for FAO (Full Automatic Operation System), CBTC (Communication Based Train Control System), or ATC (Automatic Train Control System). When the aforementioned train control systems with higher automation levels fail, they will operate in degraded mode.[4] At this time, the through signal lights on the main line will be activated and put into operation for train traffic organization, providing driving instructions to train drivers in the form of red, green, yellow or different color combinations.[5]

When the route is not set, the signal light shows red, indicating that it is forbidden to pass the signal light; when the route is set to the straight line (positioning), the signal light shows green, indicating that the train is allowed to pass the signal light at the specified speed; when the route is set to the siding (reverse position), the signal light shows yellow, indicating that the train is allowed to pass the signal light at the specified speed with caution; when the approach signal is opened, the

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signal light shows red and yellow, indicating that the train is instructed to pass the signal light at a speed not exceeding 20km/h and be ready to stop at any time.[6]

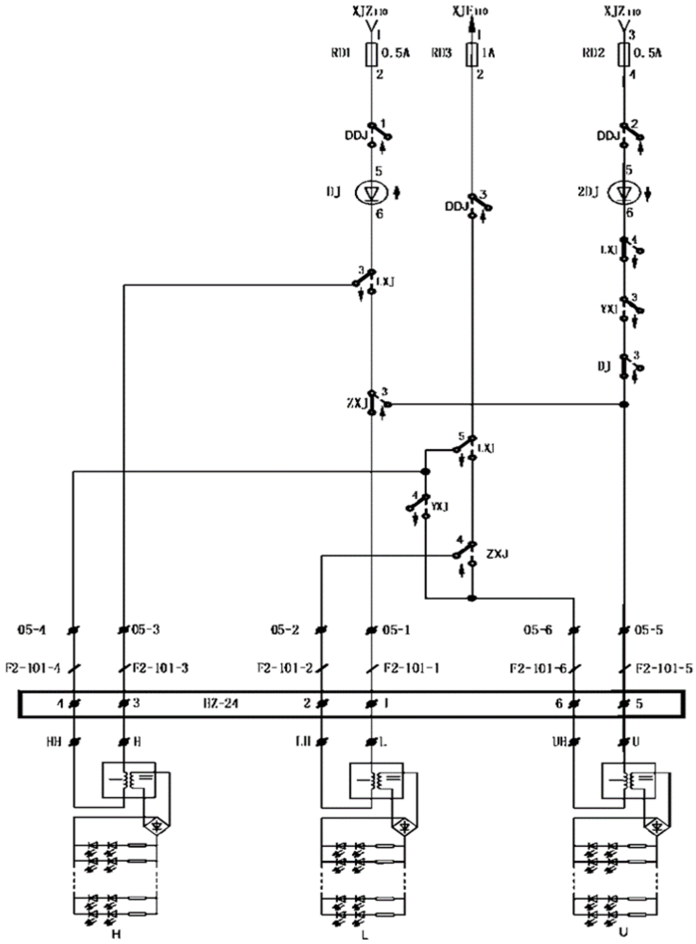

Figure 1 Electrical Schematic Diagram of Signal lighting circuit

The working principle of the red-yellow-green signal light is as follows:

1) The AC power module of the signal power panel outputs the AC 110V voltage after voltage regulation and stabilization to XJZ_{110} and XJF_{110}. XJZ_{110} represents the imaginary positive terminal of the signal AC 110V power supply, and XJF_{110} represents the imaginary negative terminal of the signal AC 110V power supply.

2) RD1, RD2 and RD3 are fuses that serve as circuit breakers. 05-1 to 05-6 are the 6 combination side terminals in the relay cabinet. F2-101-1 to F2-101-6 are the 6 terminal blocks on the wiring board. 1 to 6 in HZ-24 are the 6 terminal blocks in a terminal box with 24 terminal blocks installed outdoors. H and HH, L and LH, U and UH are the outgoing and return lines for lighting the red light (H), green light (L) and yellow light (U) respectively. Roman numerals I and II represent the primary and secondary sides of the transformer.

3) When the train has not reached the station section, the arrival relay (DDJ) is de-energized, and the signal light can be lit. When the train reaches the station section, the DDJ is energized, and the signal light is extinguished. When the filament of the signal light is intact or the LED light panel is damaged not exceeding the specified value, the first filament relay (1DJ) and the second filament relay (2DJ) are energized, and the lighting circuit is connected. When the filament of the signal light breaks or the LED light disk is damaged beyond the specified value, 1DJ and 2DJ are de-energized, the lighting circuit is disconnected, and the filament failure alarm circuit is connected.

4) The train signal relay (LXJ), the main line signal relay (ZXJ), and the approach signal relay (YXJ) are operated by the interlocking system. According to the instructions of the route setting and the interlocking conditions, they are energized or de-energized respectively to connect the circuits for different signal indications.

When a fault occurs in the lighting circuit of the signal machine, the signal maintainer will take different measures according to different fault phenomena. After determining that the fault occurs in a certain circuit, the signal maintainer will use the voltage range of the multimeter to measure the circuit using the voltage method, and judge the location of the fault based on the measurement results. In general, the signal maintainer will first measure the feeder panel according to the drawings to determine whether the fault is indoor or outdoor, and then go to the indoor or outdoor location and measure according to the order of the circuits on the drawings.

Since the contacts on the circuit of the signal machine are arranged in a fixed sequence, the binary search method can be used for measurement to achieve the purpose of improving convergence efficiency and shortening the troubleshooting time.

3. Basic Principles of Binary Search for Circuit Fault Finding

Binary search is a search algorithm used to search a specific element in an ordered array or list.[7] The basic idea is to repeatedly divide the search interval in half until the target value is located. When applied to troubleshooting signal lighting circuit faults, binary search can quickly narrow down the scope of the fault point, shorten the troubleshooting time, improve the efficiency of fault handling, and reduce the losses caused by the fault.[8][9]

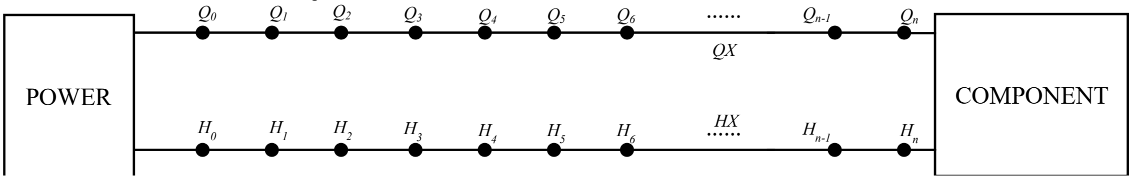

Figure 2 Circuit Diagram of a Component

Figure 2 shows the schematic diagram of a circuit for a certain component. As can be seen, the circuit consists of a power source, a go-wire *QX*, a return wire *HX*, and a component. There are *(n+1)* pairs of terminal blocks and a total of *2(n+2)* sections of wire on the go-wire *QX* and the return wire HX. As shown in Figure 3, if a break occurs in the wire between Q_{k-1} and Q_k on the go-wire *QX*, then when using the voltage range of a multimeter to measure Q_{k-1} and H_{k-1}, the voltage is normal; when measuring Q_k and H_k, the voltage is 0; when measuring Q_k and H_{k-1}, the voltage is 0.

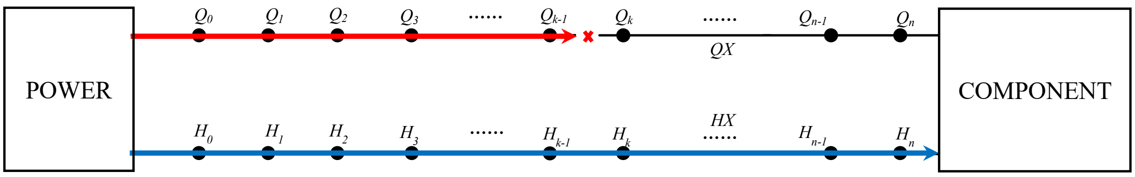

Figure 3 Circuit Fault Diagram of a Component

If the sequential search method is used, it is necessary to measure the voltages of Q_0 and H_0, Q_1 and H_1, Q_2 and H_2, ..., Q_{k-1} and H_{k-1} in sequence, and the voltages of Q_k and H_k and Q_k and H_{k-1} are 0 to find the exact location of the open-circuit fault. The sequential search method requires *(k+2)* measurements. Similarly, the reverse search method requires *(n-k+2)* measurements to find the location of the fault.

Figure 4 shows the method of using the binary search method to find faults. Suppose $n=2^m$, where *m* is a positive integer. When using the binary search method, measure $Q_{n/2}$ and $H_{n/2}$. If the voltage is normal, measure $Q_{3n/4}$ and $H_{3n/4}$ backwards. If the voltage is 0, measure $Q_{n/4}$ and $H_{n/4}$ forward. By analogy, each measurement can reduce the fault range to half of the original. For a circuit with *(n+1)* pairs of terminal blocks on the go-wire *QX* and the return wire *HX*, after m measurements, the fault range can be reduced to the wire between Q_{k-1} and Q_k or H_{k-1} and H_k. At this time, only one more cross measurement is needed, that is, to measure Q_k and H_{k-1} as 0, or to measure Q_{k-1} and H_k as normal voltage, to accurately find the location of the short-circuit fault. No matter where the fault occurs, the binary search method can be used to accurately find the fault location with only *(m+1)* measurements.

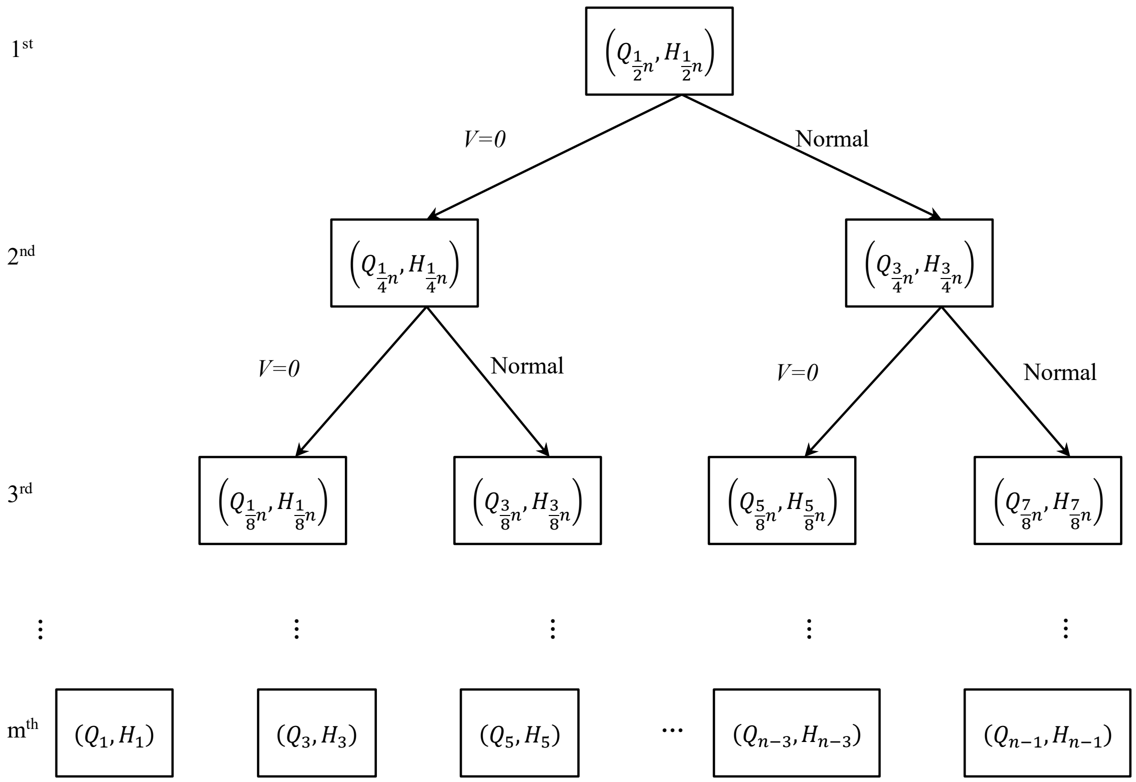

Figure 4 Method of Finding Faults Using Binary Search

4. Convergence Efficiency of Binary Search Fault Finding

The convergence efficiency of binary search fault finding can be simulated using MATLAB to obtain very intuitive experimental results. The function named "bisection_search(m)" can perform binary search on m elements and calculate its convergence efficiency. It should be noted that the target value of each search is random, so the convergence efficiency obtained for the same m value in the experiment is not always the same.[10]

Therefore, in order to obtain more accurate convergence efficiency, MATLAB programs can be used to conduct multiple simulation experiments, and the experimental results can be presented in the form of graphs and annotations. Figures 5a, 5b, 5c and 5d show the average convergence efficiency of binary search fault finding simulation experiments for 100, 1000, 10000 and 100000 times. Figures 6a, 6b, 6c and 6d show the average convergence efficiency of sequential search fault finding simulation experiments for 100, 1000, 10000 and 100000 times.

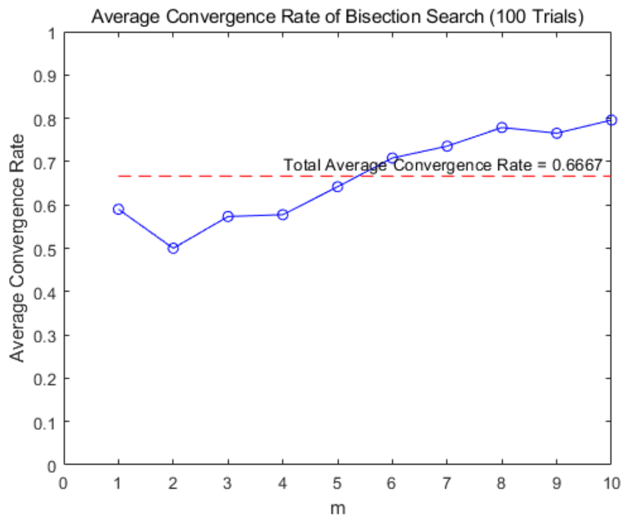

Figure 5a Average Convergence Rate of Bisection Method (100 Trials)

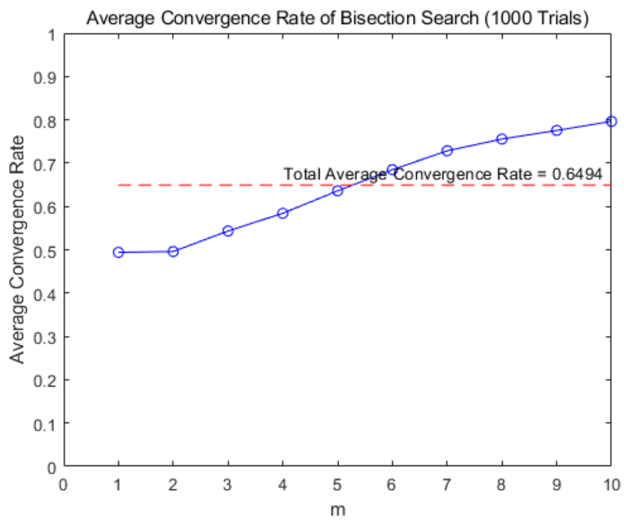

Figure 5b Average Convergence Rate of Bisection Method (1000 Trials)

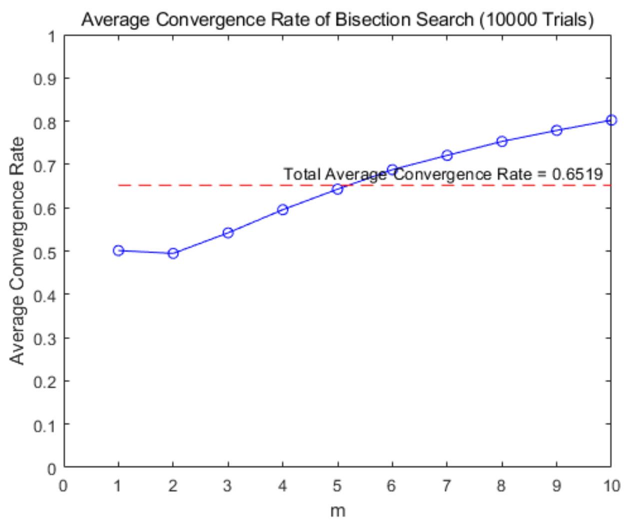

Figure 5c Average Convergence Rate of Bisection Method (10000 Trials)

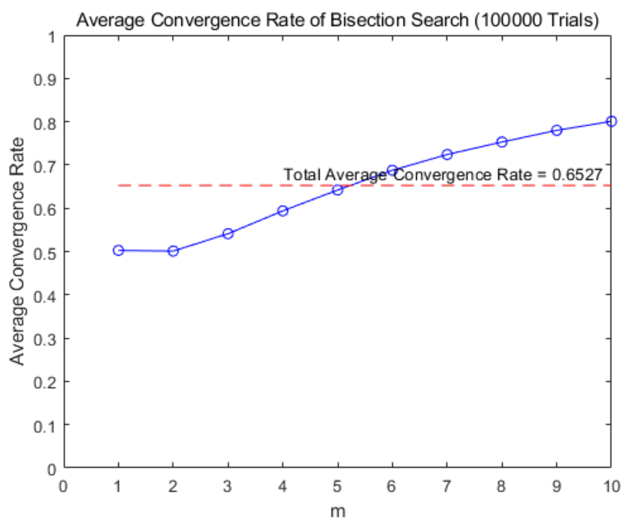

Figure 5d Average Convergence Rate of Bisection Method (100000 Trials)

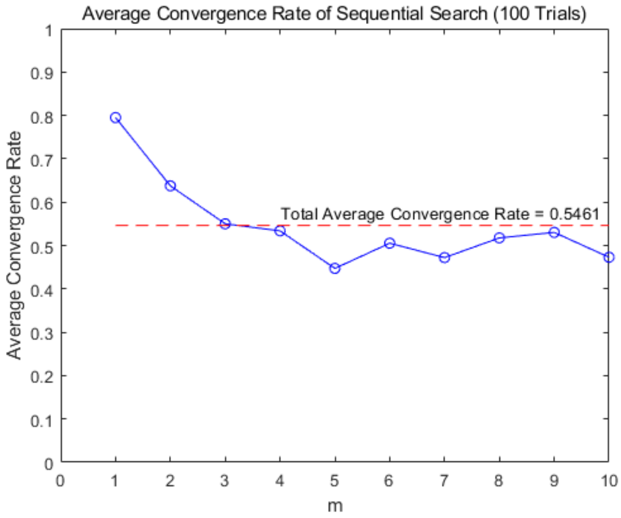

Figure 6a Average Convergence Rate of Sequential Search (100 Trials)

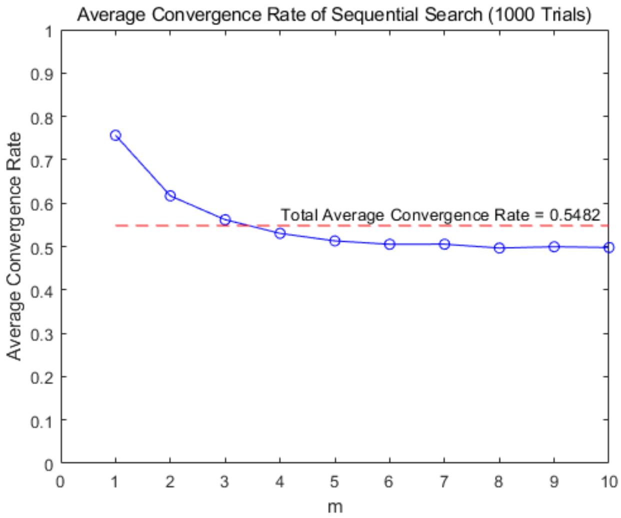

Figure 6b Average Convergence Rate of Sequential Search (1000 Trials)

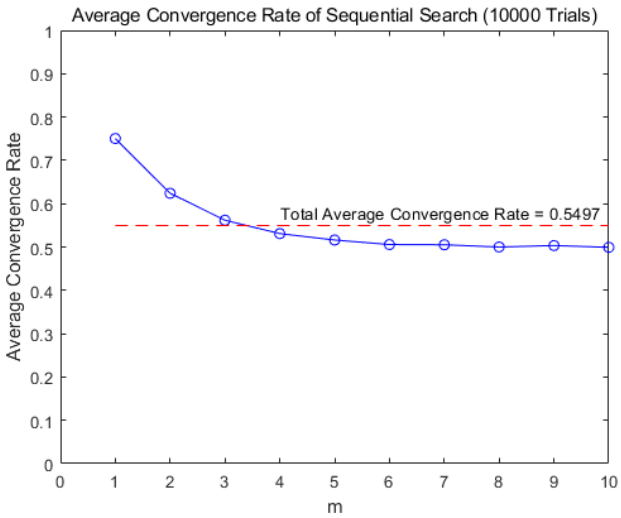

Figure 6c Average Convergence Rate of Sequential Search (10000 Trials)

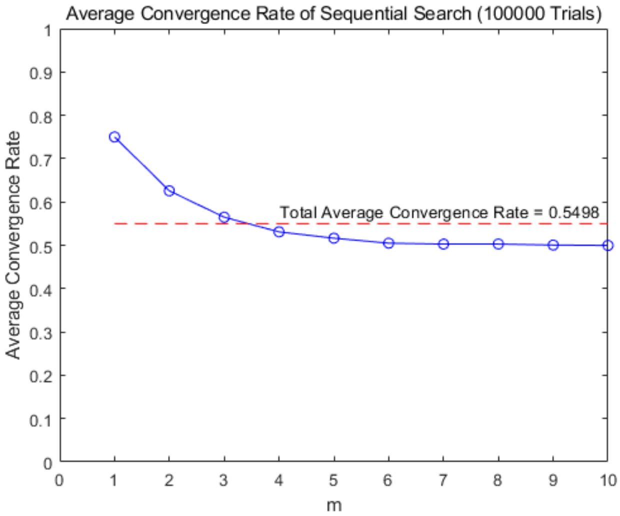

Figure 6 d Average Convergence Rate of Sequential Search (100000 Trials)

As shown in Table 1, the convergence efficiency of the binary search method is higher than that of the sequential method in 100, 1000, 10000 and 100000 trials. The average convergence efficiency of the binary search method is about 0.65, and the average convergence efficiency of the sequential method is about 0.55.

Table 1 The Average Convergence Efficiency Over Multiple Trials.

Number of Trials	Binary Search	Sequential Search
100	0.6667	0.5461
1000	0.6494	0.5482
10000	0.6519	0.5497
100000	0.6527	0.5498

5. Application of Binary Search Fault Finding in Traffic Signal Circuit Faults

In the signal lighting circuit diagram shown in Figure 1, when the route is not set, the arrival relay DDJ falls, the train signal relay LXJ falls, and the red light is turned on. The red-light circuit is:

XJZ_{110} → RD1(1,2) →DDJ(11,13) → DJ(5,6) → LXJ(31,33) → 05-3 → F2-101-3 → HZ-3 → Transformer(I) → HZ-4 → F2-101-4 → 05-4 → LXJ(53,51) → DDJ(33,31) → RD3(2,1) → XJF_{110}

After the red-light circuit is redrawn into the model shown in Figure 7a, it is more conducive to using binary search to find faults.

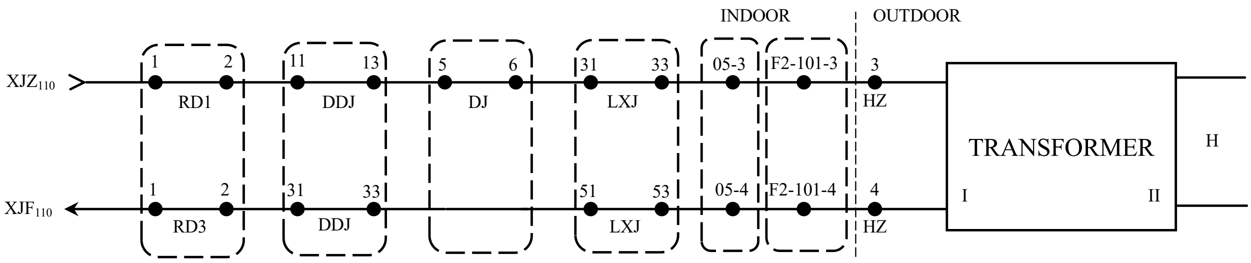

Figure 7a Circuit Diagram of Red Light

When the straight route is set, the arrival relay DDJ falls, the train signal relay LXJ is energized, the main line signal relay ZXJ is energized, and the green light is turned on. The green-light circuit is:

XJZ_{110} → RD1(1,2) → DDJ(11,13) → DJ(5,6) → LXJ(31,32) → ZXJ(31,32) → 05-1 → F2-101-1 → HZ-1 → Transformer(I) → HZ-2 → F2-101-2 → 05-2 → ZXJ(42,41) → LXJ(52,51) → DDJ(33,31) → RD3(2,1) → XJF_{110}

The modified green light circuit is shown in Figure 7b.

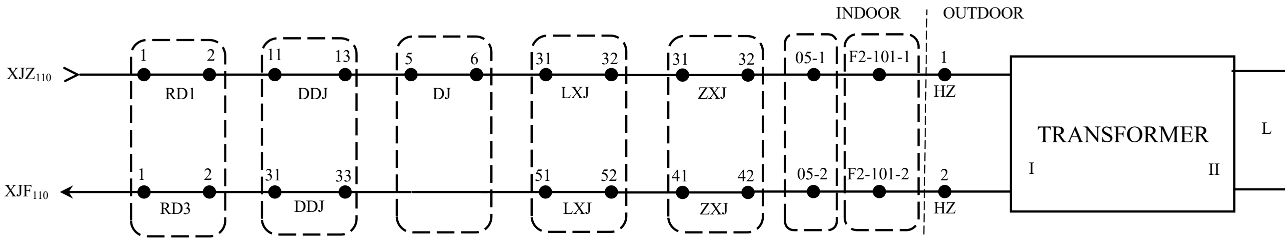

Figure 7b Circuit Diagram of Green Light

When a shunting route is set, the arrival relay DDJ falls, the train signal relay LXJ is energized, the mainline signal relay ZXJ falls, and the yellow light is turned on. The yellow light circuit is as follows:

XJZ_{110} → RD1(1,2) → DDJ(11,13) → DJ(5,6) → LXJ(31,32) → ZXJ(31,33) → 05-5 → F2-101-5 → HZ-5 → Transformer(I) → HZ-6 → F2-101-6 → 05-6 → ZXJ(43,41) → LXJ(52,51) → DDJ(33,31) → RD3(2,1) →XJF_{110}

The modified yellow light circuit is shown in Figure 7c.

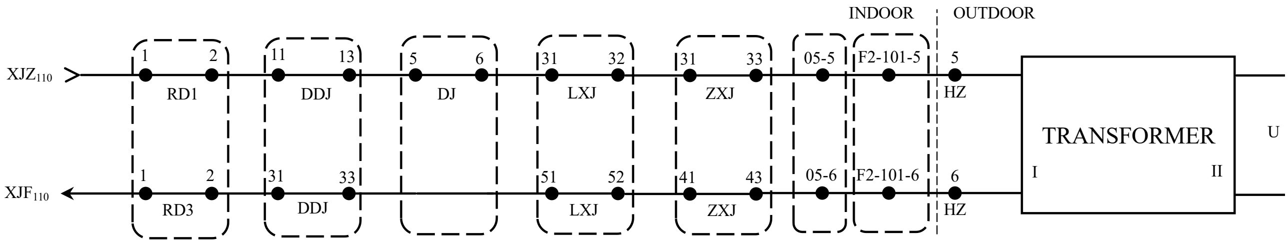

Figure 7c Circuit Diagram of Yellow Light

When an approach route is set, the arrival relay DDJ falls, the train signal relay LXJ falls, the approach signal relay YXJ is energized, and the red and yellow lights are turned on at the same time. There are two light circuits for the red and yellow lights.

The red light circuit for the approach signal is as follows:

XJZ_{110} → RD1(1,2) → DDJ(11,13) → DJ(5,6) → LXJ(31,33) → 05-3 → F2-101-3 → HZ-3 → Transformer(I) → HZ-4 → F2-101-4 → 05-4 → LXJ(53,51) → DDJ(33,31) → RD3(2,1) → XJF_{110}

The yellow light circuit for the approach signal is as follows:

XJZ_{110} → RD2(3,4) → DDJ(21,23) → 2DJ(5,6) → LXJ(41,42) → YXJ(31,32) → DJ(31,32) → 05-5 → F2-101-5 → HZ-5 → Transformer(I) → HZ-6 → F2-101-6 → 05-6 → YXJ(42,41) → LXJ(53,51) → DDJ(33,31) → RD3(2,1) → XJF_{110}

The modified red and yellow light circuit for the approach signal is shown in Figure 7d.

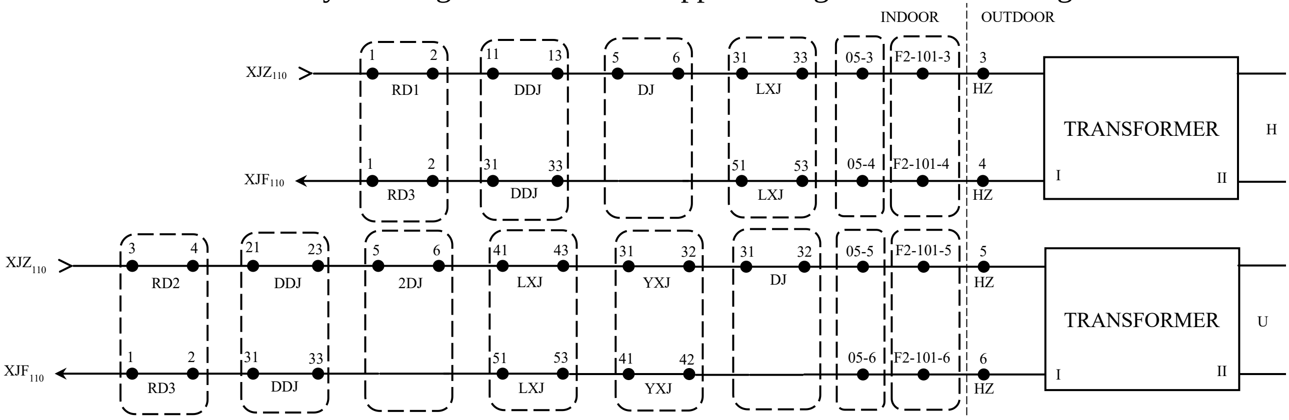

Figure 7d Circuit Diagram of Red and Yellow Light

Assume a straight-line route is arranged, and it is found that the green light signal cannot be opened. After receiving the fault notification, the signal maintainer shall follow the prescribed work procedure and then go to the front of the relay combination cabinet in the signal equipment room to observe the status of the relay. Assuming that the signal maintainer observes that the train signal relay LXJ is picked up and the arrival relay DDJ is dropped, it proves that the driving circuit is normal, and the green light signal lamp circuit should be considered for troubleshooting. First, use the AC voltage range of the multimeter slightly higher than 110V to measure the voltage of the dividing plate F2-101-1 and F2-101-2. If the measured voltage is 110V, it proves that the fault occurs outdoors, and you should immediately rush outdoors to find it. If the measured voltage is around 110V, it proves that the fault occurs indoors. Since there are few measurement points in the outdoor part, the efficiency of using the binary search method and the sequential method is very close, so it will not be discussed here. Only the indoor part will be discussed.

As shown in Figure 8, it is assumed that the fault occurs on the line between the front contact 32 of LXJ and the middle contact 31 of ZXJ.

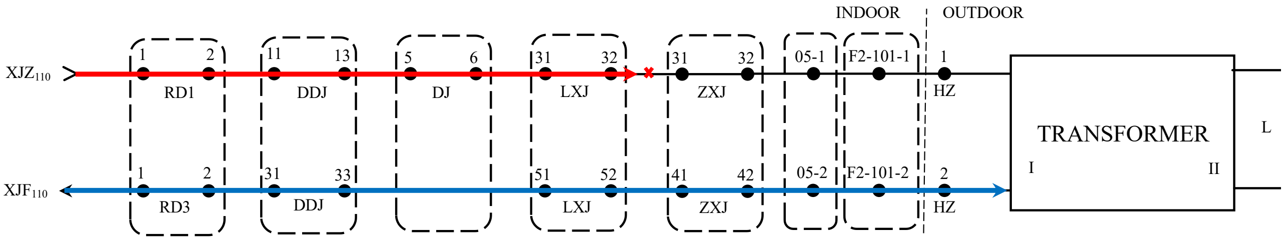

Figure 8 Diagram of Green Light Fault

If the sequential method is used, it is necessary to measure the voltage between the front contact 32 of LXJ and the front contact 52 of LXJ to be around 110V for the 8th time, the voltage between the middle contact 31 of ZXJ and the middle contact 41 of ZXJ to be 0V for the 9th time, and the voltage between the front contact 32 of LXJ and the middle contact 41 of ZXJ to be around 110V for the 10th time, in order to determine the location of the fault.

If the binary search method is used, the first measurement should be between the back contact 33 of DDJ and the 6th contact of DJ, and the measured voltage should be around 110V. The second measurement should be between the front contact 32 of LXJ and the front contact 52 of LXJ, and the measured voltage should be around 110V. The third measurement should be between the middle contact 31 of ZXJ and the middle contact 41 of ZXJ, and the measured voltage should be 0V. The fourth measurement should be between the front contact 32 of LXJ and the middle contact 41 of ZXJ, and the measured voltage should be around 110V. At this point, the location of the fault can be determined.

Comparing the two methods, it is not difficult to find that: only when the indoor fault occurs on either side of the back contact 13 of DDJ or the back contact 33 of DDJ, the efficiency of the sequential method is not lower than that of the binary search method. However, for this circuit, no matter where the fault occurs, the number of measurements required to find the exact fault location using the binary search method is a fixed 5 times.

Analyzing Figures 7a, 7b, 7c, and 7d, it can be seen that when the red light or the red light of the approach signal has an indoor fault, the number of contacts to be tested is 9, excluding the measurement points at the dividing plate; 11 for the green light or yellow light; 13 for the yellow light of the approach signal. After simulation experiments, the average convergence efficiency of fault finding using binary search and sequential methods is obtained as shown in Table 2. The average convergence efficiency of fault finding using binary search is about 0.58, and the average convergence efficiency of fault finding using sequential method is about 0.54.

Table 2 Convergence Efficiency of Binary and Sequential Searching in Signal Faults

Lighting Circuits	Number of Contact	Binary Search				Sequential Search			
Number of Trials		100	1000	10000	100000	100	1000	10000	100000
Red Light	9	0.5899	0.5751	0.5606	0.5612	0.5100	0.5466	0.5523	0.5558
Green or Yellow Light	11	0.5955	0.5784	0.5785	0.5783	0.5382	0.5486	0.5532	0.5461
Yellow Light of Approaching	13	0.5486	0.5978	0.5867	0.5822	0.5146	0.5204	0.5418	0.5383

6. Conclusion

Binary search is a simple, efficient, and intuitive search method that can be effectively applied to troubleshooting the lamp circuit faults of railway signal machines. Simulation experiments on large-scale element retrieval show that the average convergence efficiency of binary search is about 0.65, and that of sequential search is about 0.55, indicating that binary search has a higher convergence efficiency than sequential search. In the context of troubleshooting signal machine faults, simulation experiments show that the average convergence efficiency of binary search is about 0.58, and that of sequential search is about 0.54. The actual application of binary search to troubleshooting signal lamp circuit faults has verified that the number of measurements required to find the fault with binary search is a fixed value, which is lower than that required with sequential search in most cases.

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