# New Traffic Signal Controller for Improved Fail-Safe Functions

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A traffic signal controller controls the lighting of traffic signals so that vehicles and pedestrians can travel safely and smoothly. As an erroneous operation of the controller may cause a serious accident, it requires the strictest fail-safe functions in the entire traffic control system. The authors reviewed the fail-safe functions for a newly developed traffic signal controller. This paper introduces the fail-safe functions including G-G abnormality detection.

Keywords: fail-safe, self diagnosis, G-G abnormality

## 1. Introduction

For the safe and smooth travel of vehicles, motor bikes, bicycles, and pedestrians on the road, traffic signal controllers (TSC) turn traffic lights on and off and manage their durations. Erroneous control of traffic lights can easily lead to serious accidents. This is why a TSC in particular requires the strictest fail-safe functions among the variety of devices used in each traffic control system. We have developed a new TSC, with improved architecture and fail-safe functions compared with the previous model. This paper discusses the fail-safe functionality improvements in the new TSC.

## 2. Operational Mode Transition in TSC

**Figure 1** shows the different operational modes in a TSC and their transitions.

(1) Operational Modes of the TSC

(a) Remote Operation Mode

In this mode, the TSC operates according to the instructions from the Traffic Control Center. The Traffic Control Center submits instructions for signal light control to create an optimum traffic condition in a specific road or area based on the traffic volume information obtained by sensors installed along the roadside.

(b) Standalone Operation Mode

The TSC operates in standalone mode when instructions from the Traffic Control Center are not available. The TSC is capable of performing pre-specified operation depending on the time of day to maintain an orderly traffic flow even when communication with the Traffic Control Center is not possible.

(c) Safety Operation Mode

The above-mentioned Remote Operation Mode and Standalone Operation Mode are controlled by a microprocessor. If this microprocessor fails, the TSC goes into the Safety Operation Mode and signal control is carried out safely by the hardware alone.

(d) Abnormal Flashing Mode

When the TSC is incapable of continuing normal signal light control due to a failure etc., it turns on the yellow and red lights alternately (flashing).

(e) Red Light Only Mode

After the TSC's power is turned on, or after the TSC has performed the above-mentioned Abnormal Flashing Mode, the TSC turns on the red light for five seconds to stop all vehicles for safety.

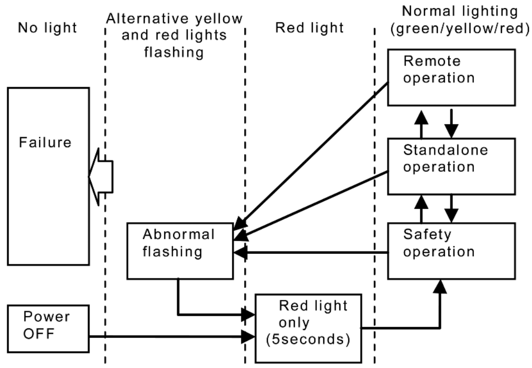


**Fig. 1.** Transition of Modes

(2) Major Abnormal Events in the TSC

(a) G-G Abnormality

Suppose that there is a signal on each of two roads that cross each other. If the TSC detects that both of them go green at the same time, the TSC judges the event as abnormal and sets the signals into the Abnormal Flashing Mode. As concurrent green lighting on the two signals could easily lead to an accident, detection of the G-G abnormality is the most important among all the signal controlling functions.

(b) Timer Abnormality

If the signal control by the hardware (i.e. the Safety Operation Mode) is not carried out correctly, in the other words, the signals stay the same even after the maximum allowed display time has elapsed, the TSC judges the event as abnormal and sets the signals into the Abnormal Flashing Mode.

(c) MPU Abnormality

When the TSC judges that the microprocessor is not functioning correctly, it sets the signals to the Safety Operation Mode.

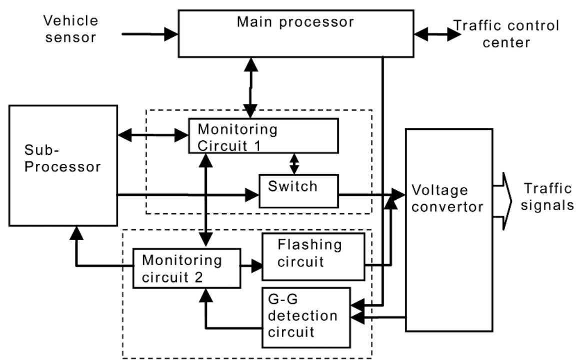


**Fig. 2.** System Configuration

## 3. System Configuration

**Figure 2** shows the configuration of the newly developed TSC system.

(1) Main Processor

The main processor determines the TSC operation mode according to the time, vehicle sensor information, and instructions from the Traffic Control Center. The main processor then submits the instructions to the sub-processor concerning the signal lighting pattern selection and timing for procedural steps through monitoring circuit 1. The main processor comprises a microprocessor and software.

(2) Sub-Processor

The sub-processor controls the signal lights based on the specified lighting patterns and timings. When there is an instruction from the main processor, the sub-processor performs control operation following the instruction. The sub-processor comprises only hardware. If the main processor fails, the signals can be controlled solely by this sub-processor.

(3) Monitoring Circuit 1

Monitoring circuit 1 monitors the components, such as the main and sub-processors, and performs fail-safe operations depending on the detected abnormality. When an abnormality is reported from the G-G detection circuit or sub-processor (i.e. timer abnormality), the monitoring circuit 1 switches the source of the signal lighting instruction from the sub-processor to the flashing circuit. Monitoring circuit 1 also relays the instructions from the main processor to the sub-processor.

(4) Monitoring Circuit 2

Monitoring circuit 2 is a backup circuit of monitoring circuit 1, and delivers the same functions as monitoring circuit 1. However, it does not relay instructions from the main processor to the sub-processor.

(5) G-G Detection Circuit

The G-G detection circuit compares the green light status from the voltage convertor with the pre-installed green light combination data to detect any G-G abnormality, and reports the results to monitoring circuits 1 and 2.

(6) Flashing Circuit

Following the instructions from monitoring circuits 1 and 2, the flashing circuit submits instructions to flash the lights.

(7) Voltage Convertor

According to the lighting instruction from the sub-processor or flashing circuit, the voltage convertor supplies the lighting voltage (AC 100V) to the traffic lights. The convertor also detects the voltage supply to the green lights and reports the resulting green light status to the G-G detection circuit.

## 4. Revision of the Fail-Safe Functions

To revise the TSC's fail-safe functions, the Failure Mode and Effects Analysis (FMEA) technique was utilized. However, the components used in the TSC circuits are many and diverse, and therefore, the analysis was carried out per component block as shown in **Fig. 2**: System Configuration. Based on the possible signal instruction combinations and their correctness, we simulated 326 function failures in total and ran a risk analysis.

For possible failures with high risk, the abnormality detection methods and response methods were determined in advance and implemented as the TSC's fail-safe functions.

The following sections describe the major fail-safe functions in the TSC.

(1) Diagnosis by the G-G Detection Circuit

The G-G detection circuit detects an erroneous combination of signal lighting outputs based on the green light status received from the voltage convertor. To date, an instruction creating an erroneous combination has been actually submitted to make sure that the circuit can detect the mistaken lighting outputs. However, this causes the actual signal lights to be illuminated in an erroneous combination for a short period of time. The number of LED signal lights is increasing in recent years and such lights are more sensitive to respond to given instructions. Even though the instruction is only for a fraction of time, it actually lights the signal, causing confusion and danger for traffic users. This method is therefore no longer viable.

To examine the G-G detection circuit's detection capability, it is possible to input a mock green light status to the circuit. However, this does not examine whether or not the voltage convertor can correctly feed the green light status to the G-G detection circuit.

To overcome this problem, the following diagnosis method was used.

**Figure 3** shows the circuit input flow and **Fig. 4** shows the diagnosis logic.

The G-G detection circuit comprises the G-G combination judgment circuit and the OR circuit. The OR circuit performs logical disjunction operation on the green light status from the voltage convertor and the mock green signals from the main processor, and then outputs the results to the G-G combination judgment circuit. The G-G combination judgment circuit compares the received signal and the G-G combination data. If the comparison result is found to be the "simultaneous lighting prohibited" combination, the G-G combination judgment circuit outputs the G-G prohibition signal.

With this circuit configuration, it is possible to supply the actual green light status and mock green signals, en-

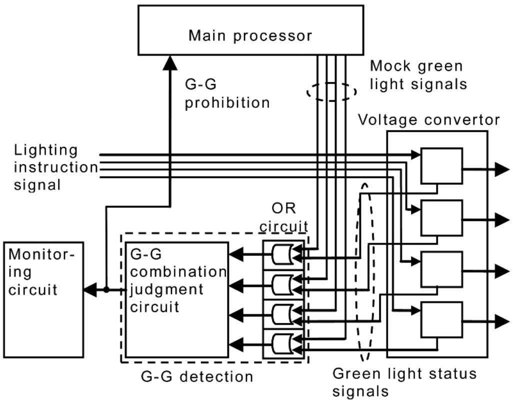


**Fig. 3.** G-G Detection Circuit

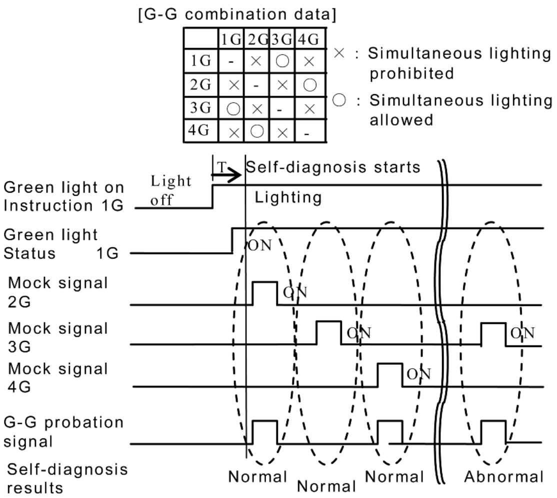


**Fig. 4.** Self-Diagnosis Logic

abling the G-G detection circuit to judge whether it is a real G-G combination abnormality or not. With this method, the G-G abnormality detection can be examined using the actual input of the green light status from the voltage convertor while the signal light is in operation yet without displaying the unnecessary erroneous lighting combination.

The main processor starts the self-diagnoses when the specified time T (ms) has elapsed after a green light on instruction is output (to the green light 1G in **Fig. 4**). The main processor outputs mock green signals one-by-one to the G-G detection circuit. The G-G combination judgment circuit then compares the actual green light status and mock green signals and outputs the G-G prohibition signal when the combination is "simultaneous lighting prohibited." The main processor continues to monitor this G-G prohibition signal. If no G-G prohibition signal is output due to the "simultaneous lighting allowed" combination, the processor judges the signal operation is normal. If the G-G prohibition signal is detected, the processor judges the signal operation is abnormal.

(2) Flashing Circuit

When the TSC is unable to carry out the normal operation due to the G-G abnormality, etc., flashing operation must take place. However, it is not possible to test the flashing operation while the TSC is in operation. This restricted the opportunity to test the flashing circuit to the time when regular maintenance was carried out, and left the TSC potentially incapable of flashing in the event of a flashing circuit failure, as the failure would be unnoticed until the next regular maintenance.

The flashing circuit diagnoses can simulate circuit operations, but do not guarantee that the actual signal lights flash. In the new TSC, the following measures were taken to ensure the flashing circuit operates as intended.

(a) Triple Circuits

Three flashing circuits that carry out identical operations were installed. The color of the light to turn on is based on a majority rule among these circuits prior to the flashing operation taking place. The chance that all three circuits fail during the period between regular maintenances is small, and therefore, the TSC is likely to remain capable of flashing as necessary.

(b) Backup Flashing Operation by the Sub-Processor

The sub-processor was also designed to conduct light flashing operations. The sub-processor monitors the operation of the flashing circuits, and if their operation is determined to be abnormal, the sub-processor takes over the management of flashing operation.

(c) Separation of Power Supply

The flashing circuits use a separate power supply from the other component blocks, including the main and sub-processors. The component blocks other than the flashing circuits are made of a number of electronic parts and circuits. Failure in these devices may lead to an abnormality in the power supply. Providing power separately to the flashing circuits ensures that flashing operations can be performed in the event of a power abnormality due to the failure of another component.

(3) Mutual Monitoring among Component Blocks

The component blocks were designed to monitor each other. If an abnormality is detected in any of the component blocks, the designated response operations are carried out (**Table 1**).

**Table 1.** Mutual Monitoring among Component Blocks

| Blocks | Monitored blocks | Operations to be performed in the event of an abnormality |
|---|---|---|
| Main processor | Monitoring circuit 1 | Light the abnormal monitor |
| Main processor | Sub-processor | Light the abnormal monitor |
| Main processor | G-G detection circuit | Light the abnormal monitor |
| Main processor | Voltage convertor | Light the abnormal monitor |
| Sub-processor | Main processor | Light the abnormal monitor, Shift to Safety Mode |
| Sub-processor | Monitoring circuit 2 | Shift to Flashing Mode |
| Monitoring circuit 1 | Main processor | MPU abnormality and shift to Safety Mode |
| Monitoring circuit 1 | Sub-processor | Timer abnormality and shift to Flashing Mode |
| Monitoring circuit 1 | Monitoring circuit 2 | Light the abnormal monitor and shift to Flashing Mode |
| Monitoring circuit 2 | Monitoring circuit 1 | Light the abnormal monitor and shift to Flashing Mode |

## 5. Other Features

The following functions were also improved in the new TSC.

(1) Improved Signal Operation History: Further Detailing and Increased Number of Records

The earlier TSC was already equipped with a history function to record executed TSC operations. This function was improved by significantly increasing the number of historical records. Approximately three week's worth of records can be stored by default and this can be increased to more than a year's worth of records by installing optional additional memory. The history details have also been improved by including the colors of lights that were lit, which was not recorded in the previous model. Detailing of the operation history enables post-operation analysis, making it easier to revise settings for the better control procedures.

(2) Improved Operation Panel

The abnormal statuses and the signal input and output statuses with external devices can be viewed through a monitor on the operation panel. This improvement makes it easier to tune equipment in the field and isolate a failed component block.

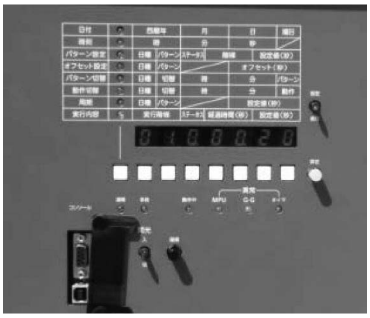

**Photo 1.** Earlier Model

**Photo 2.** New TSC

## 6. Conclusion

We developed a new TSC with improved fail-safe functionality. Based on this new model, we are continuing to develop new functions to ensure safety for both vehicles and pedestrians and to further improve road traffic flows.


**Reference**

(1) National Police Agency: Specifications for traffic safety facilities "the traffic signal controller"



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