On-vehicle Compact and Lightweight Multi-channel Central Gateway Unit

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With the rising number of electronically controlled devices used in vehicles, the demand for ECUs (electronic control units) has been increased, and it is now required to configure an in-vehicle LAN (local area network) that connects multiple networks. In the past, multistage networks were formed using a two-channel gateway ECU that connects two different networks, making vehicle communication design complicated. We developed a central gateway ECU that is equipped with six network interfaces to relay communication data between channels. This central gateway ECU secures the independence of respective systems, resulting in a simple communication design even with many ECUs being connected. The central gateway ECU, the main ECU for the in-vehicle LAN, allows Sumitomo Electric Industries, Ltd. to offer vehicle infrastructure systems in combination with wiring harnesses and junction boxes.

Keywords: central gateway, in-vehicle LAN, controller area network (CAN)

1. Introduction

As vehicles become progressively more controlled electronically, an increasing number of electronic control units (ECUs) is being installed in vehicles. These ECUs are usually connected to an in-vehicle LAN and communicate with each other to control the car.

For in-vehicle LANs, a communication protocol known as a controller area network (CAN)[1] is used. The CAN protocol has a limitation in the number of ECUs that can be connected to a single bus network line due to signal reflection and other factors, and the maximum is approximately 16 ECUs. Some recent vehicles employ more than 70 ECUs, and this makes it necessary to install multiple CAN buses due to the aforementioned limitation.

Until now, an in-vehicle network with a large number of ECUs has been configured using a 2-channel gateway ECU (2ch GW ECU) that relays messages between two CAN buses. In this paper, the 2ch GW ECU configuration is referred to as a "Function Add-On Network" (Fig. 1).

2. Replacing Function Add-On Network with System-Oriented LAN

2-1 Problems in Function Add-On Networks

The CAN protocol uses the carrier sense multiple access/collision detection (CSMA/CD) access method, which does not include a scheduling function. This means that the transmission time of a message submitted from an ECU to another affected by other messages sent by different ECUs on the same bus.

For example, in the Function Add-On Network shown in Fig. 2, a CAN message submitted by ECU1 is relayed through three GW ECUs before it reaches ECU6. During this time, the message transmission is influenced by other ECUs' messages on each bus. It is extremely difficult to design a network to transmit a message within the permissible delay time (which could be some milliseconds or longer, depending on the message) for the entire vehicle network.

Also, adding a new ECU or changing the settings of

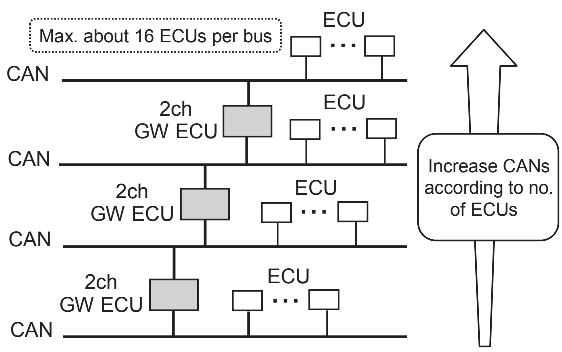

Fig. 1. Function Add-On Network

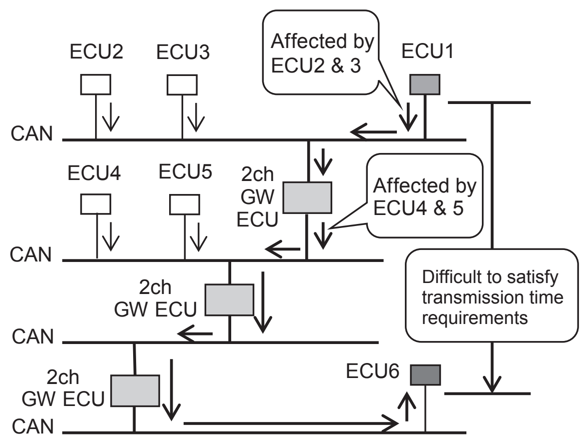

Fig. 2. Problems in Function Add-On Networks (1)

existing ECUs affects the entire transmission conditions on the bus, requiring re-designing the entire network (Fig. 3).

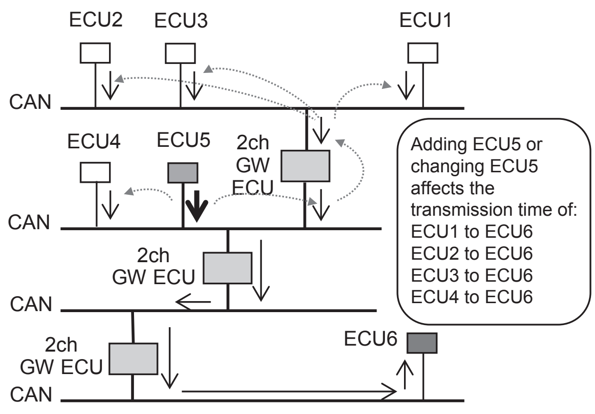

Fig. 3. Problems in Function Add-On Networks (2)

2-2 Central ECU as problem solution

One of the solutions to the aforementioned problems is to use a central gateway ECU (hereafter, Central GW) that has multiple CAN channels as shown in Fig. 4, and configure multiple LANs each of which is assigned to individual systems responsible for control, body, safety, and information.

In this configuration of a system-oriented LAN, the number of bus-to-bus relays can be limited to one regardless of the number of ECUs. Therefore, the transmission delay for a pair of ECUs can be addressed within the interaction between only two buses, and this helps resolve the problem shown in Fig. 2.

Also, the influence of adding a new ECU or changing the settings of an existing ECU can be absorbed by redesigning exclusively the communications between the bus that submits a message from the new or changed ECU and the relayed bus. This eliminates the necessity of redesigning of the entire network described in Fig. 3.

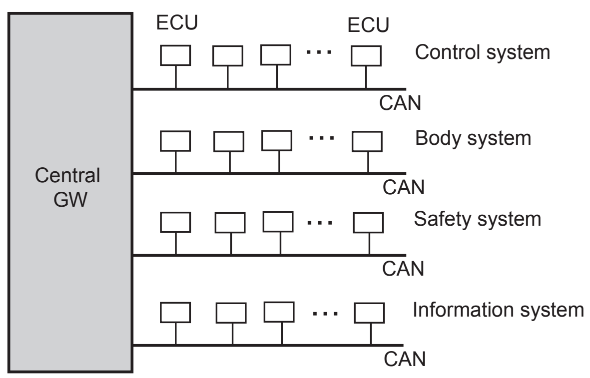

Fig. 4. Configuration of LAN per System using Central GW

2-3 Trends in car manufacturers

The use of Central GWs and system-oriented LANs is more advanced in European car manufacturers. However, this trend is now expanding to Japanese and U.S. manufacturers due to the recent increase in the number of ECUs in a vehicle resulting from the progressing electrification of vehicle control.

3. Development of Central Gateway ECU

As requirements for a Central GW vary depending on the manufacturer or the model of a vehicle, it is inefficient to develop individual Central GWs separately. Taking this into account, we developed a Central GW with common specifications that can be customized for different requirements depending on the manufacturer or car model. While equipped with six CAN channels, it is compact and lightweight, allowing easy installation in a vehicle.

This chapter describes the functions and features of the newly-developed Central GW.

3-1 Relay function

The main function of a Central GW is to relay messages between CAN buses. There are three major relay functions: (1) simple relay, (2) cycle change relay, and (3) data rearrangement relay.

(1) Simple relay

In on-vehicle LAN communications, some data items whose value constantly changes (e.g. engine speed) are often submitted cyclically at some tens or hundreds of millisecond intervals. Such data items are included in a single CAN message along with other data items (e.g. data items concerning engine speed and intake temperature are put together) in order to reduce the number of messages.

In a simple relay, CAN messages received by the Central GW are immediately transmitted to the destination CAN bus without changing the message cycles or the contents (Fig. 5). The Central GW can also transmit a single CAN message to multiple CAN buses.

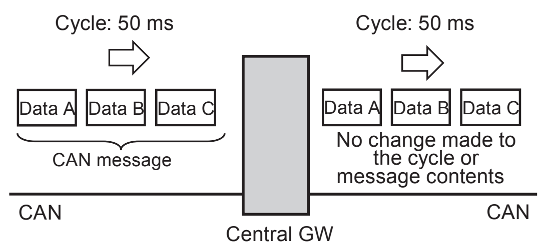

Fig. 5. Simple Relay

(2) Cycle change relay

Some data may need to be updated in a short cycle at the ECUs on the source bus, and the same data may be needed at other ECUs on the destination bus but not at the same frequency. In this case, lengthening the submission cycle from the originating ECU helps reduce the load on the destination bus and decrease the transmission delay between the originating and destination ECUs.

This is achieved by the cycle change relay function of the Central GW (Fig. 6).

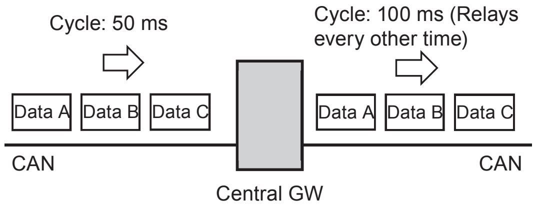

Fig. 6. Cycle Change Relay

(3) Data rearrangement relay

A single CAN message contains multiple data items as described earlier, and at times the destination ECU may not require all data items contained in the message. In this case, the Central GW can rearrange the data items to reduce the number of CAN messages sent to the destination bus, alleviating the loads on both the destination bus and the destination ECU (Fig. 7).

This can also be known as the signal relay because the data items contained in a CAN message an on-vehicle LAN is called "signals."

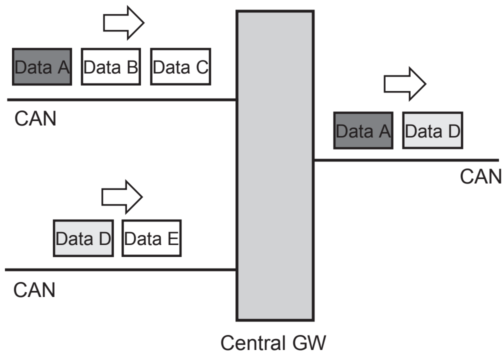

Fig. 7. Data Rearrangement Relay

3-2 Data transmission delay and buffer structure

Each CAN message has its own ID, and when more than one message is scheduled to be submitted at the same time within a bus, the message with the smaller ID is submitted first (Fig. 8). This is specified by the CAN protocol and the mechanism is called "arbitration."

Each CAN message has a different permissible transmission delay time, and, in principle, a message with a shorter permissible transmission delay time is given a higher transmission priority.

When relaying CAN messages, the Central GW first stores the received messages in a relay buffer. Depending

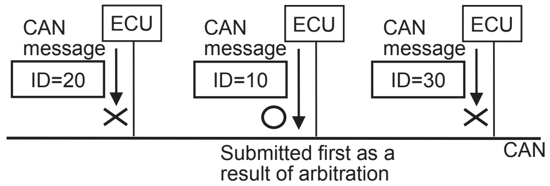

Fig. 8. CAN Arbitration

on the buffer structure, a message with a lower priority may be retained in the buffer longer by not being able to pass the multiple arbitrations, and this can cause subsequent messages with a high priority to wait — even beyond their permissible transmission delay times (Fig. 9).

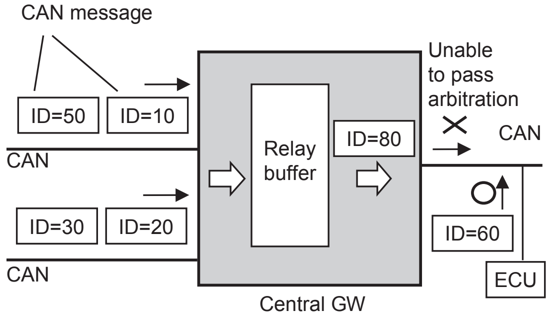

Fig. 9. Impact on Relay from CAN Arbitration

To minimize the transmission delay time, we have developed an algorithm to determine the order in which messages are stored in a relay buffer depending on each message's priority setting. Based on this algorithm, we also developed a tool that automatically determines the buffer structure based on the entire set of messages used in the car, regardless of the manufacturer or car model. We then built an environment to test whether each message could satisfy the data transmission time requirements utilizing a network simulator.

All of these mechanisms enabled us to design networks that suit a variety of car models from different manufacturers.

3-3 Other functions of the Central GW

(1) Wakeup and sleep control

The Central GW operates in two modes: one is the working mode in which the Central GW carries out CAN message relaying, and the other is the sleep mode when GW does not perform relaying and remains in a low power consumption state.

To minimize battery power consumption while the car is parked, the Central GW shifts into the sleep mode when certain conditions are met (for example, when the GW does not receive any CAN messages for a specified period of time after the car engine stopped). Conversely, the GW in sleep mode wakes up and goes into the working mode after detecting the engine starting or after receiving a CAN message.

The Central GW is equipped with a wakeup and sleep function that manages transitions between the working and sleep modes.

(2) Failure diagnosis

The Central GW has the function to record the phenomena of a failure, such as when a relay message cannot be submitted after a specified time. This record can then be read by a failure diagnosis tool used by a car dealer.

(3) Reprogramming

Without changing a component part, such as a microcomputer or memory, the Central GW's software can be re-written by a failure diagnosis tool through a vehicle diagnosis connector.

(4) Information security

The Central GW communicates with the said failure diagnosis tool, which is used in both failure diagnosis and reprogramming, via CAN messages. As the failure diagnosis tool is an external device, secure communications between the tool and the car must be ensured. In this way, the Central GW functions as a firewall.

3-4 Separating common functions and specific functions

How each CAN message should be relayed varies depending on the car manufacturer and the car model, and therefore, we created a route map for these messages. We also categorized Central GW functions into two types: one is the functions commonly used among manufacturers, and the other is those specific to each model. Table 1 shows the function categories, including the relay function. Identifying the common and specific functions helped efficient designing of the Central GW with scalability for the future.

Table 1. Common and Specific Functions

Functions \ Common/Specific		General	Specific to manufacturers	
			Common in models	Specific to a model
Relay function	Simple relay	✔		
	Cycle change relay	✔		
	Data rearrangement relay	✔		
	Route map			✔
Wakeup & sleep control			✔	
Failure diagnosis			✔	
Reprogramming			✔	
Information security			✔	

3-5 Downsizing and weight reduction

The newly developed Central GW has a total of six channels, four channels more than the previous model. Our development efforts, such as (1) increasing the component mounting rate by adopting surface-mounting connectors, (2) employing small electronic parts, and (3) using a multi-layered printed circuit board, enabled us to reduce the size and weight of the Central GW to 79 mm × 55 mm × 18 mm (Fig. 10) and 42 g, respectively, without sacrificing the on-board product quality. Compared to the previous model, the printed circuit board surface and weight are reduced by 27% and 23%, respectively.

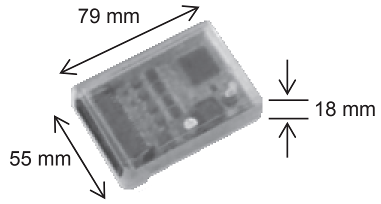

Fig. 10. Dimensions of Central GW

As described above, the new Central GW is compact and lightweight, therefore easily installed in a vehicle, with specifications customizable to the needs of manufacturers or models for efficient production.

4. Future Prospects

As further advancement in vehicle functions and autopilot mechanisms progresses, in-vehicle communications are required to be fast and capable of interacting with external equipment. For the faster communications, it will be indispensable to implement CAN-FD[1] (CAN with flexible data rates) that can accelerate the data transmission speed to approximately 5 Mbit/s from the conventional 500 Kbit/s, and also support Ethernet. For external communications, it will also be necessary to implement the LTE or WiFi function to interact with servers and smartphones. Further, such communications require information security at the equivalent level of commercial computer telecommunications such as encryption and authentication mechanisms.

Figure 11 shows a configuration example of the next generation Central GW. The dotted line in the figure represents the area discussed in this paper.

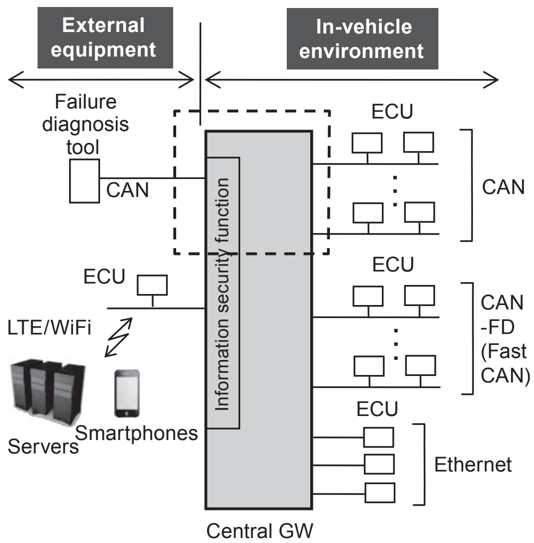

Fig. 11. Next Generation Central GW

5. Conclusion

We successfully developed a six-channel Central GW that features a compact and lightweight body and customizable specifications to suit different car models.

We are going to continue developing next generation Central GWs that support high-speed multiprotocol communications and reinforced information security.

• Ethernet is a trademark or registered trademark of Xerox Corporation.

Reference

(1) ISO 11898-1:2015, Road vehicles -- Controller area network (CAN) --Part 1: Data link layer and physical signaling

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