Interfaces between Sensors and ECUs

Hiroaki Hoshika and Shinya Igarashi

Hitachi Automotive Systems, Ltd., Hitachinaka, Japan

1 INTRODUCTION

Nowadays, automotive electronics systems use a lot of Electronic Control Units (ECUs) and sensors. In general, multiple sensors are connected to one ECU. They are connected with various interfaces. We are going to describe several types of interfaces that connect sensors to ECUs as well as their characteristics and synopsis.

2 REQUIREMENTS NECESSARY FOR INTERFACES BETWEEN SENSORS AND ECUs

Sensors convert some physical quantity, displacement, and/or the like into electric signals. The signals are used as an input to control an ECU. Therefore, various types of interfaces are used that are able to suppress deterioration and time lag to surely transmit sensor-collected information to an ECU. In automotive environments, various types of external electric disturbances can happen. This is why various measures are taken, for example, to minimize the influence of such disturbances, surely let an ECU know a failure of the sensor for a prompt failsafe process if a sensor fails, and transfer information to an ECU with some low cost communication means even from a sensor located at a distance from the ECU. Conventional interfaces have only such functions that transmit sensor-collected information to ECUs. In recent years, however, the needs are high for bidirectional information exchanges involving direct connections to vehicle networks such as LIN (local interconnect network) and CAN (controller area network).

3 CLASSIFICATION OF INTERFACES

Table 1 lists some of the typical interfaces that connect sensors and ECUs.

4 ANALOG INTERFACES

This is one of the interfaces that have been used for the longest time, and is still widely in use nowadays. The physical quantity detected by a sensor is replaced by a voltage or amperage for transfer. In automotive systems, the voltage type is frequently in use.

Analog interfaces convert the voltage acquired on the side of ECU into another physical quantity. Therefore, the relationship between voltage and physical quantity needs to be interrelated as the output characteristics of a sensor in advance. These characteristics do not necessarily need

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Table 1. Typical interfaces.

Classification by hardware	Classification by information transfer methods	Characteristics
Analog interface	Voltage	Physical quantity is transferred through voltage signal. This is one of the most common methods and is still applied in wide fields. This method, however, is under influence of voltage drops, external noises, grounding voltage, ECU's reference voltage, and so forth and, therefore, tends to cause errors. This is why precautions are necessary at the stage of designing wiring and signal filters
Analog interface	Current loop	Physical quantity is transferred through current in the signal lines. A current loop is formed with a sensor and an ECU. Consequently, this method is not susceptible to signal deterioration or external noises. However, electric circuits are somewhat more complicated than those of voltage methods
	Differential voltage	Physical quantity is transferred through voltage difference of two signal wires. This method is not susceptible to external noises that are not often in phase with two signal wires simultaneously. This method, however, has a complex electric structure and, therefore, is not usually used for automobiles
Pulse interface	Frequency modulation	Physical quantity is transferred in linkage with the frequency of pulse signals. This method is not susceptible to the fluctuation in signal voltage if some appropriate threshold is selected. This method has been in use with sensor signals for a long time but is not free from errors in modulation and demodulation caused by errors in frequency sources
	PWM modulation	Physical quantity is transferred in linkage with the duty ratio of a pulse signal. Duty ratio is acquired by dividing a high or low level time by the periods of pulse signals. This method, therefore, is not susceptible to errors in frequency sources, but obscure waveforms processed by a noise removal filter can be an error factor
	Frequency and PWM modulation	Frequency modulation and PWM modulation are processed simultaneously to link two types of physical quantities with one signal wire. Two types of signals are transferred with a single wire. Therefore, it is possible to reduce the wiring cost to connect an ECU
Serial communication interface	SENT (SAE-J2716)	This is the unidirectional communication with the pulse time modulation of 4 bits per pulse and 2 bytes per message. This method is seen as a replacement of analog signal communications. This method, however, supports IDs and CRCs in transfer data; therefore, multiple channels and error detections are compatible. Circuit configurations are simple enough to use LSIs. This method is used for angle sensors and so forth
	DSI/PSI5	Only two wires are used to enable power supply and signal transfer. Multiple sensors can be connected in parallel. Amperage readings are processed in Manchester encoding for data transfer. This method is suitable for an environment where you need to position a large number of sensors with relatively low power consumption. This method is used in, for example, airbag systems
Network nodes	CAN(ISO11519-2) (ISO11898)	This is a two-line differential type and enables multimaster bidirectional communications of 1 Mbps at the maximum. This method is widely used for inter-ECU communications. This method is one of the international standards but is rarely applied to sensors because of its cost of circuits. For more information, see Section 7.2
	LIN (LIN 2.x) (SAE-J2602)	This is a single-line type and enables single-master bidirectional communications (semiduplex communications) of 20 Kbps at the maximum. As the circuits are not expensive, this method is used for sensors that do not require very high response performance. For more information, see Section 7.1

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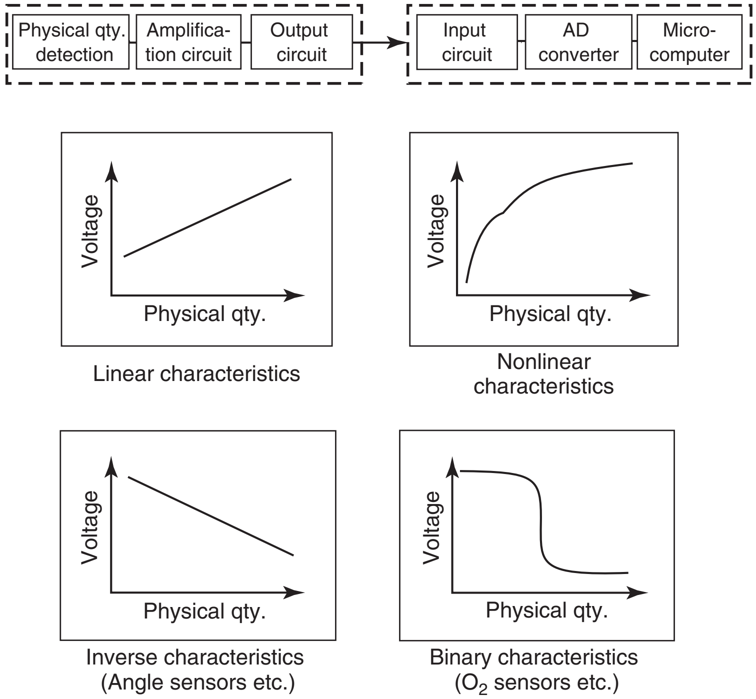

Figure 1. An example of the relationship between voltage and physical quantity. (Reproduced by permission of Hitachi Automotive Systems.)

to take a linear form. Contrarily, these characteristics can take various forms depending on the detection principle of such a physical quantity and/or the range of significant measurements (Figure 1).

When an analog interface is in use, signals are transferred from a sensor by way of a wire harness. On the side of an ECU, there is a filter to remove any intrusion of signal noises that may be caused by external electrical disturbance. Generally speaking, a low pass filter (LPF) is provided to cut off high frequency elements equal to or higher than the cut-off frequency (f_c). Figure 2 shows an example of such LPFs.

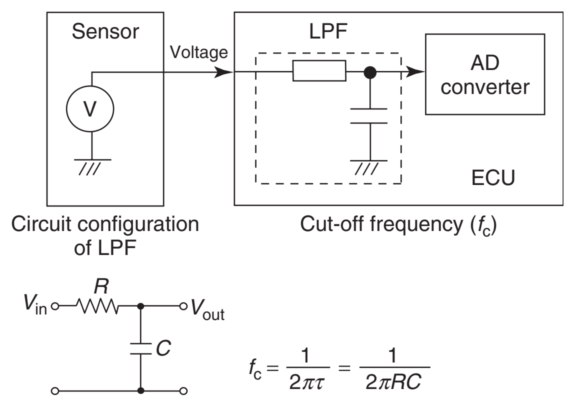

Figure 2. An example of low pass filters. (Reproduced by permission of Hitachi Automotive Systems.)

4.1 Precautions for using analog interfaces

If the voltage at the input terminal is different from the output of the sensor signal, the ECU causes an error in the physical quantity recognized on its side. Therefore, some measures should be taken to prevent any difference from being generated at the sensor output signal and the terminal voltage on the side of ECU. Such measures can differ depending on the situations. For example, a wire harness generates resistance. Accordingly, the current flowing down a signal wire or a grounding wire causes a voltage drop. Further, an overshoot can be generated in a grounding wire. As countermeasures, for example, the amperage in signal wires is reduced, and/or the grounding current is separated using a dedicated grounding wire. If, moreover, the reference sources are different between the side of a sensor and its corresponding ECU, such a configuration can cause errors. For this reason, when some high precision is required with respect to voltage, a ratiometric-type output circuit may be used where a reference voltage is provided from the side of the ECU to the sensor. Figure 3 shows some elements that tend to cause problems while a voltage-type analog interface is used.

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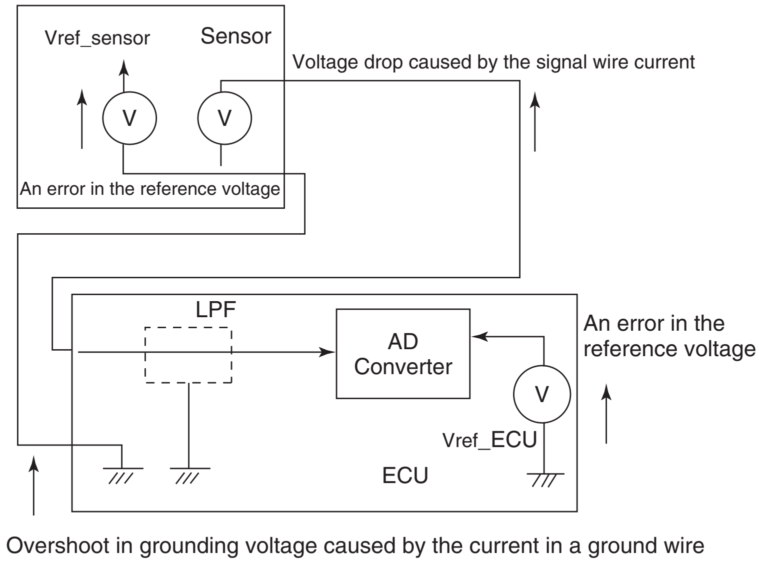

Figure 3. Elements that tend to cause problems when a voltage-type analog interface is used. (Reproduced by permission of Hitachi Automotive Systems.)

5 PULSE INTERFACES

When analog interfaces are used, absolute voltage and absolute amperage are susceptible to various types of external disturbances. When pulse interfaces are used, on the other hand, external disturbances are not so influential because only two levels of voltage, a high level and a low level, need to be transferred as signals. This means that it is only necessary to reach and exceed the threshold of each level. On top of that, in this method, it is possible to replace the AD converter in an ECU with a timer circuit. Furthermore, it is also possible to simplify the signal output circuit on the side of the sensor. It is, more often than not, analog signals that are detected by a sensor. Consequently, these signals are converted into pulse signals in a modulation circuit.

The pulse frequency modulation is the so-called FM modulation; that is, the signals detected by a sensor are replaced with the frequency of pulse signals. For example, the analog voltage signal acquired on the side of a sensor is converted into the frequency with a VCO (voltage-controlled oscillator). On the side of an ECU, a counter circuit counts the number of pulses in pulse signals with regular intervals to acquire the counts in proportion to the average frequency in one period. VCO circuits are not too complicated. This is why they are widely in use as automotive sensors, which are mostly analog circuits. They, for example, are used to acquire output signals from an airflow sensor.

The PWM (pulse-width modulation) modulation is a type of information transfer where the ratio (the duty ratio) between the high and the low level times is used. The pulse frequency from one rising pulse to the next rising pulse (called a *carrier frequency*) is always constant, whereas the ratio between the high and the low level times of signals is varied. The ECU includes a timer circuit to detect each of the high and the low level times. If you divide the high or the low level time by the period of signals (the sum of the high and low level times), you can obtain the duty ratio. The PWM modulation does not change the duty ratio even if the period of pulses fluctuates. This is an advantage that enables the signal transfer with little errors, not requiring a stable oscillator on the side of the sensor. Figure 4 shows

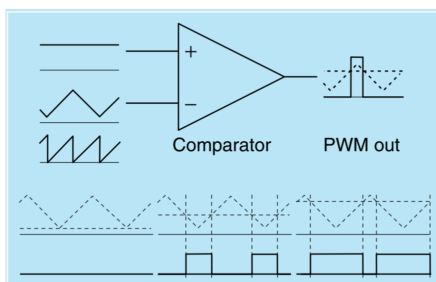

Figure 4. A schematic view of a PWM modulation circuit based on an analog circuit. (Reproduced by permission of Hitachi Automotive Systems.)

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a schematic view of a PWM modulation circuit based on an analog circuit (Kumagai, 2011).

PWM modulation pulses are also easily generated by a digital circuit. Therefore, microcomputer-equipped sensors, in general, use PWM output units without any alteration. As for ECUs, they usually include a built-in microcomputer equipped with a timer/counter unit that provides an operation mode suitable for acquiring a duty ratio from these PWM signals.

The ratio between the high and the low level times is significant for PWM modulation pulse signals. The time duration necessary for a level transition generates an error. Therefore, only a minimum number of processing units such as an LPF, necessary for noise reduction, should be inserted in the signal I/O circuit, depending on the carrier frequency. We ought to pay attention in order to avoid increasing transition time.

Both the frequency and the PWM modulations require one signal wire for one piece of analog information. On the other hand, complex PWM modulation is also used, which varies the carrier frequency of the PWM modulation to transfer two pieces of analog information via one signal wire. For example, analog signal A varies the frequency of pulse signals, whereas analog signal B varies its duty ratio. This modulation reduces the number of wires, which means a cost reduction.

6 SERIAL COMMUNICATION INTERFACES (PULSE CODE MODULATION)

Serial communication interfaces use AD converters or similar to encode analog signals from sensors. After this, they transfer such signals one by one by the unit bit. A clock synchronization type processes the transferring timing of each of such bits with a dedicated clock line, whereas a start–stop synchronization type has a fixed duration of transmission time for each one bit and controls only starting points. Of these two types, the start–stop synchronization type is more commonly used in automotive systems. In the broad meaning of the word, network communications such as CAN and LIN belong to serial communications. In this section, however, we classify as serial communication interfaces those that do not establish mutual communications between sensors and ECUs and, besides this, that mainly use signal transfer from sensors to ECUs.

SENT (Single Edge Nibble Transmission) and DSI/PSI5 (distributed system interface–peripheral sensor interface), for example, are among the ones that are standardized and already spread.

6.1 SENT

SENT is one of the communication standards based on SAE-J2716. The widths of 5-V amplitude pulses are defined and classified into 16 levels. Every one pulse transfers 4-bit information (called a *nibble*). Every one message transfers 8-nibble information (32 bits). Among the information, two nibbles convey a status and CRC (cyclic redundancy check). To sum up, a sensor practically transfers 24-bit data. The smallest unit of pulse widths is a tick. One tick is equivalent to 3 μs. The pulse width varies depending on data transferred. One message takes 152–272 ticks (456–816 μs) to complete a transfer. In the field of automobiles, analog signal sampling periods are approximately 1 ms per signal at the shortest. Therefore, the performance of this interface, able to transfer two-channel signals (24 bits in total) with the accuracy of 12 bits in one wire in 816 μs or shorter, is sufficient. As the pulse widths are controlled, a reference clock is required on the side of a sensor. The fluctuation of the reference clock on the side of a sensor is allowed within the range of 20%, as the pulse widths are classified into no more than 16 levels and synchronized pulses are measured on the side of an ECU to correct pulse-width information. Accordingly, even a simple oscillator can work as a sensor. In addition, you can use a timer with a small number of bits as a pulse-generating timer. No communication-receiving functions are available from an ECU. The signals are something like what you would obtain by replacing conventional analog signals with serial communication signals to improve the reliability in information transfer. This interface has already been applied to the interface of angle sensors (Figure 5).

6.2 DSI/PSI5

As of now, these two are not international but noninternational standards under management of consortiums joined by parts suppliers, semiconductor manufacturers, and so forth. These two are different communication standards. However, they, besides both being a two-wire-type sensor interface, share several common features as described later. Figures 6 (DSI Consortium, 2011) and 7 (PSI5 Consortium, 2011) show their connection topologies.

1. Operation requires only two wires for the power supply and for signals.
2. Communications are based on master–slave interactions. The master sends a command and the slave returns a response.

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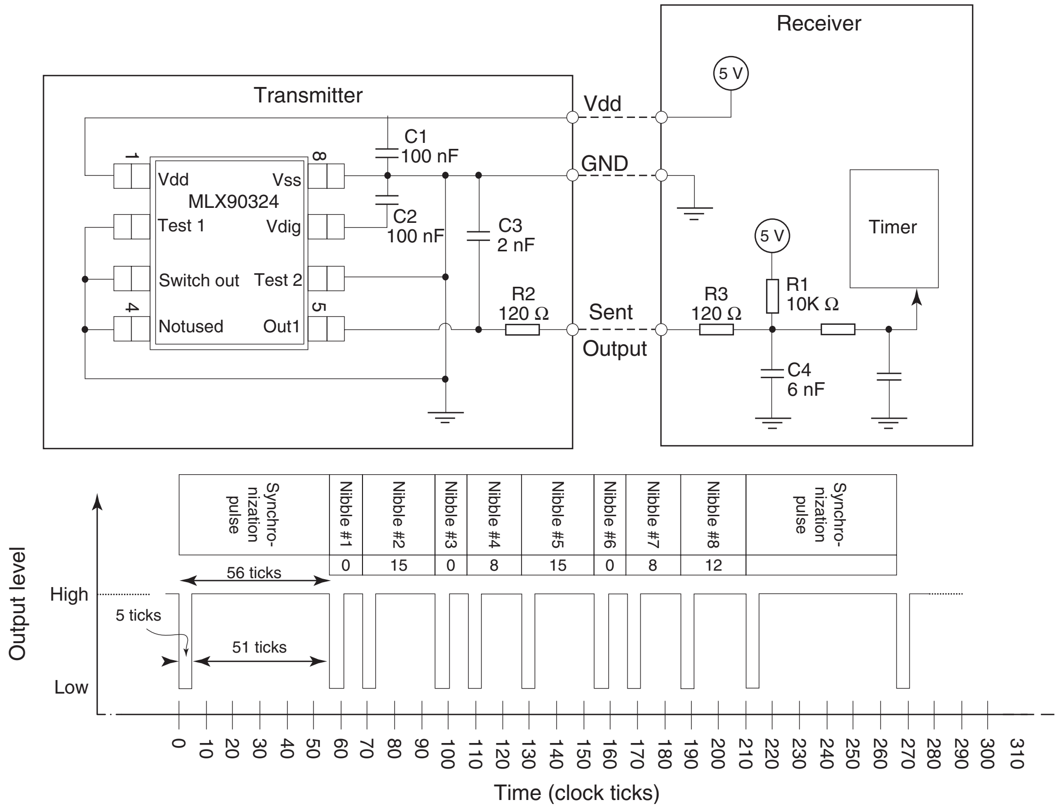

Figure 5. An example of interfaces based on SENT. (Reproduced by permission of Hitachi Automotive Systems.)

3. Supported connections include topologies such as separate connections, bus connections, and daisy-chain connections.
4. The master (ECU) controls the voltage of the power supply line. The slave (sensor) manipulates electricity for its own consumption to process communications.

These two look alike as types of interfaces. They, however, do not have any compatibility. DSI, for example, supports the commands of Manchester encoding based on voltage (it is not a level but a direction of transition that has logical significance). In its logic, responses are in the unit of nibble (4 bits) with which the electric current of a slave is controlled to one of three levels. PSI5, on the other hand, supports the commands based on the logic of voltage, whereas the responses are generated with Manchester encoding based on current C amperage. Their communication rates are also different from each other. DSI has a function that supports the power function class, an operation of an actuator. It is possible to operate an actuator by temporarily raising the voltage and amperage. These two standards are already in practical use in applications that require multiple sensors arranged in a wide range on one vehicle such as airbag systems.

7 NETWORK NODES

In recent years, there has been growth in the needs for sensors that support connections with networks. Automobiles use networks of various standards that correspond to their purposes. In this section, we are going to describe LIN and CAN, two typical communication standards generally used for sensors.

7.1 LIN (local interconnect network)

This was, at its origin, a network standardized by automobile manufacturers and parts suppliers in Europe, as a network they were able to configure with low cost hardware that did not require very fast communication speed such as small actuators and ECUs. Nowadays, this network is under management of a consortium joined by automobile manufacturers and parts suppliers from all over the world. This network has the characteristics described later. In general, this network is used as a subnetwork of a CAN.

The physical layer consists of single wires, which is the same as the standard of ISO9141 (International Organization for Standardization). The network has a bus structure

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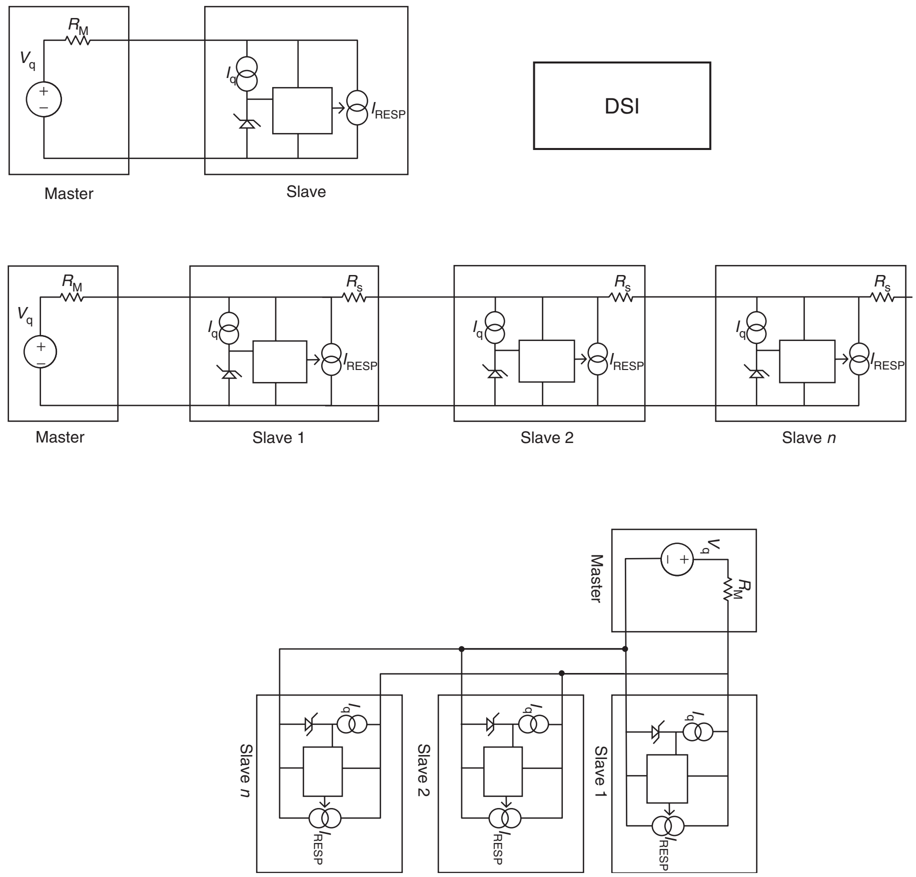

Figure 6. DSI connection topologies. (Reproduced by permission of Hitachi Automotive Systems.)

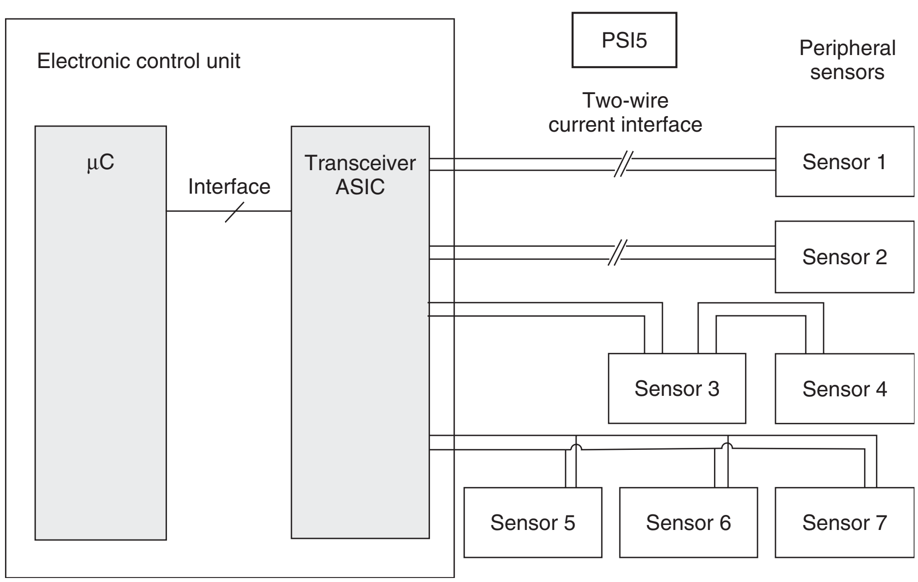

Figure 7. A connection topology of PSI5. (Reproduced by permission of Hitachi Automotive Systems.)

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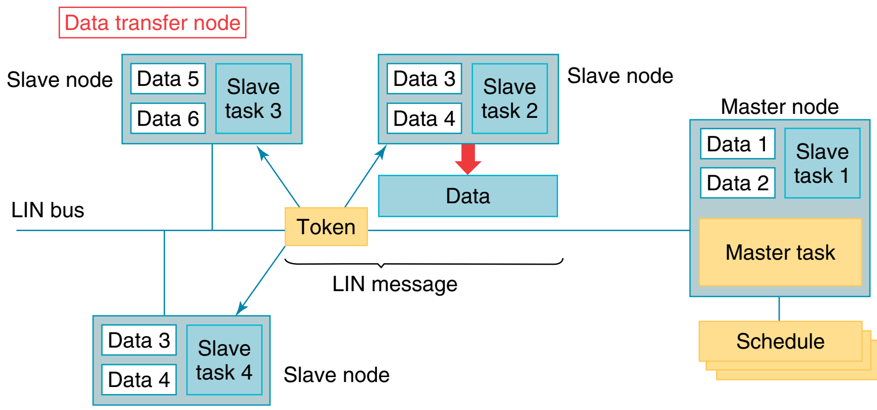

Figure 8. Schematic view of a token in LIN. (Reproduced by permission of Hitachi Automotive Systems.)

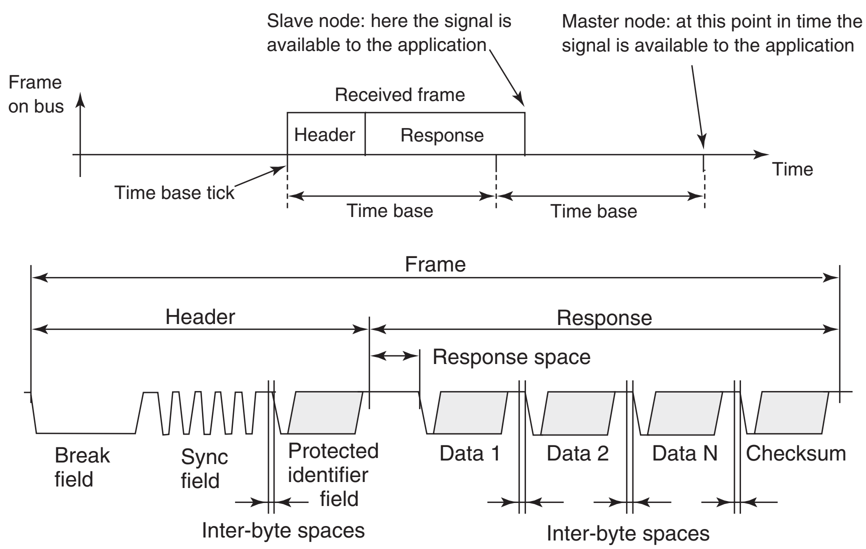

Figure 9. Configuration of the LIN communication frame. (Reproduced by permission of Hitachi Automotive Systems.)

of a linear type. There is only one master that sends tokens, which are received by a plurality of slaves at the same time. As message addressing is used, only the slave with the corresponding ID sends back a response to the master. In networks with sensors, the ECU works as the master, while the sensors work as the slaves. During communications, a time trigger protocol is used. Communication timings are all controlled by the master. The data transfer rate is 20 kbps at the maximum (10.4 kbps according to SAE-J2602), which is not suitable for transferring the signals in high speed responses. Figures 8 and 9 show a schematic view of tokens and the configuration of a communication frame (ITmedia Inc., 2010; Lin Consortium, 2006).

These serial communications make use of the UART (universal asynchronous receiver/transmitter) interface (start–stop synchronization). Slaves are synchronized based on the synchronization signal included in the message sent from the master. Therefore, slaves do not need any high accuracy oscillator. Messages are as short as 8 bytes at the maximum, including parity bits and checksums for protecting transferred data.

The transport protocol is based on ISO15765. Diagnoses and standard transport mechanisms are available. Therefore, various types of bidirectional communications are possible.

7.2 CAN (controller area network)

The specifications of CAN were published by Robert Bosch in Germany in 1986. Afterward, the specifications were standardized (ISO11898/ISO11519). As of now, this bus-type network is applied to almost all vehicles. Figure 10 shows an example of CAN connection and its data frame

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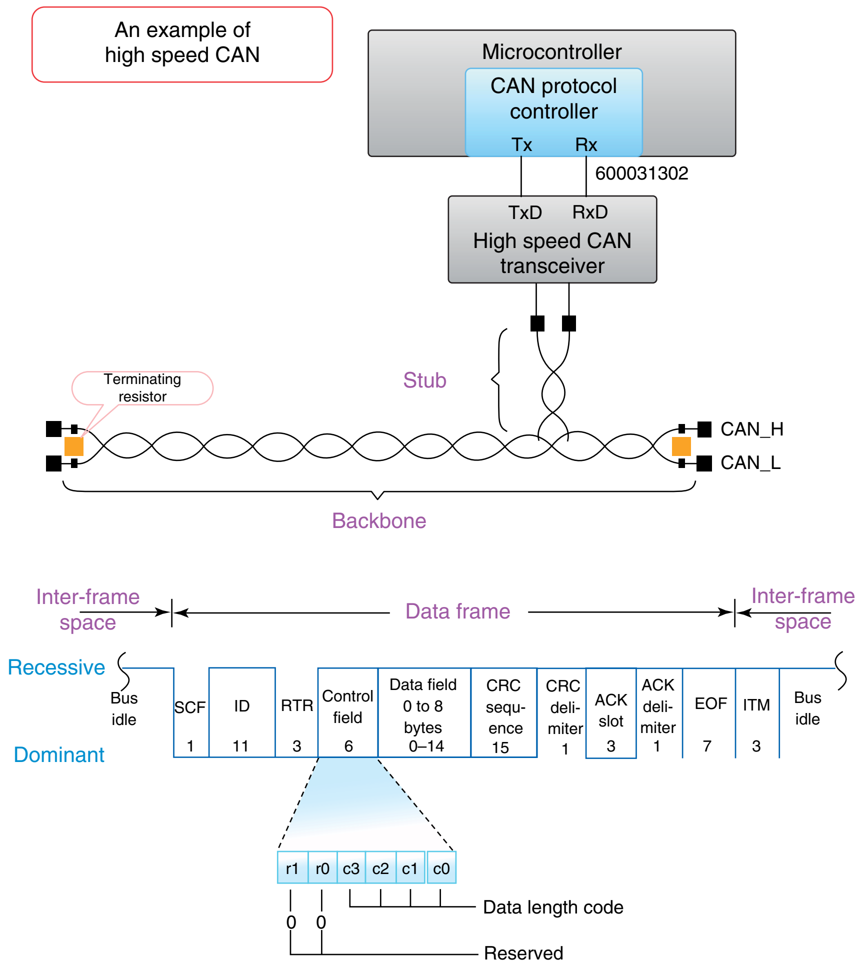

Figure 10. An example of CAN connection and its data frame configuration. (Reproduced by permission of Hitachi Automotive Systems.)

configuration (ITmedia Inc., 2008). This network is roughly classified into two types; that is, low and high speeds. The low speed CAN is mainly used for vehicle body systems, whereas the high speed CAN is mainly used for power train systems. Besides these, the single-wire CAN is also standardized. The high speed CAN is based on the two-wire voltage operation with twisted pair wires. This network is highly reliable. The standard maximum communication speed is 1 Mbps. However, the communication speed of 500 kbps is used for high speed CAN. Any node can start communications when the CAN bus is open. If, on the other hand, two or more nodes are trying to start communications at the same time, the node with the smallest ID number is given the right to start communications. This system makes it possible to control communication priorities.

This system requires a microcomputer. In most cases, a microcomputer equipped with a CAN controller is used. In addition, a CAN transceiver is used for the physical layer of CAN. As circuits are necessary for the network communication processing as well as a high performance microcomputer, this network is not suitable for small-scale sensors. This network is used for sensors and/or sensing systems with high reliability and complex functions. On top of that, this is a multimaster network, and it is easy to add CAN nodes. For example, if you want to add a sensor to a system for the purpose of control, and if it is difficult to modify the ECU, you only have to modify the software to add a sensor to a CAN bus.

8 CONCLUSION

As a trend of electrical interface between sensor and ECU, signals are generally shifting to digital transmission type such as SENT, LIN, DSI, and PSI5. It brings less cost of total vehicle electrical systems, higher safety redundancy,

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and shorter development time of vehicle. In the future, it is expected that some of simple sensors will be managed by multifunction sensor-integrated communication unit to link vehicle network system. This maybe makes optimized sensor information topology.

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