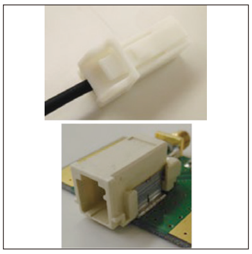

Initiatives towards In-Vehicle 100 M Ethernet for High-Speed Communication Components

Kazuhiro YOSHIDA*, Ryoma UEGAKI, Yoshiharu DEGUCHI, Hiroyuki HIRAMATSU, Kiyoshi KATO, and Akihide KONDO

Driven by evolutions in CASE (connected, autonomous, shared & service, and electric) technology, the need for fast in-vehicle networks has increased, making in-vehicle Ethernet an attractive next-generation communication solution. To comply with the strict communication standards set by the standards organization OPEN Alliance, our focus turned to investigating 100 M Ethernet compatibility. Initial evaluation using existing CAN components revealed disparities in transmission and crosstalk characteristics of wires and connectors. Therefore, we have developed new wires and connectors, as well as terminal processing technology, CAE analysis technology, and communication characteristic evaluation technology, all of which are necessary for the development of high-speed communication components. These efforts ensured compliance with the communication standards. We view high-speed communication components as vital elements of wiring harnesses, and are committed to their ongoing development, recognizing the significance in facilitating efficient in-vehicle communication.

Keywords: 100 M Ethernet, OPEN Alliance TC2, communication standards, UTP cable with a jacket, untwisted length

1. Introduction

Recently, in-vehicle networks connecting between ECUs and between an ECU and equipment require the transmission of a large amount of video and other data due to the evolution of CASE*[1] technology, leading to a growing demand for higher speeds. Previously, relatively low-speed communication protocols, such as the Controller Area Network (CAN: up to 1 Mbps) and CAN-FD (up to 8 Mbps), were used for in-vehicle networks. However, the possibility of using Ethernet, which is used for consumer products, for in-vehicle applications was studied to meet the need for higher speeds. With 100 Mbps as the starting point, in-vehicle standards have been established for each speed range (see Fig. 1).

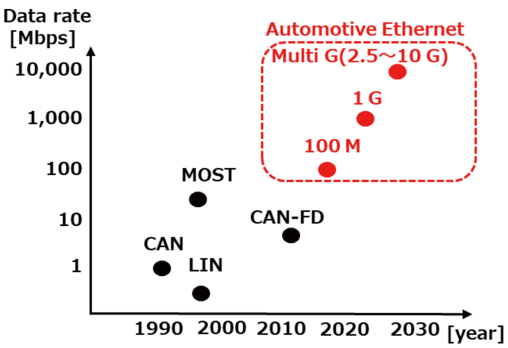

Fig. 1. Communication protocol of in-vehicle Network

Communication standards for in-vehicle Ethernet (hereinafter referred to as "Ethernet") have been increasingly formulated by IEEE, which establishes international standards, and the OPEN Alliance, an Ethernet standardization organization. The communication evaluation methods and standard values have been determined for respective speed ranges (Table 1). Ethernet components (cables, connectors, and wiring harnesses) must meet these rigorous communication standards.

Table 1. Status of establishment of standards for respective Ethernet speed ranges

Dada rate [bps]	100 M	1 G	Multi G (2.5 G/5 G/10 G)
Cable	UTP	UTP/STP	STP
IEEE standard	IEEE802.3bw (published in Mar. '16)	IEEE802.3bp (published in Sep. '16)	IEEE802.3ch (published in Jun. '20)
Open Alliance standard	TC2(OABR) (published in Nov. '14)	TC9 (UTP: published in Jan. '18, STP: published in Jun. '20)	TC9 (published in Mar. '23)

We have been actively working on the development of components based on the belief that Ethernet will become the key communication protocol for in-vehicle networks and that wiring harnesses will become important components.

This paper reports on the results of our study on conformity with the 100 M Ethernet standard and our initiative to develop new components.

2. Compatibility Study of 100 M Ethernet Using Existing Components

As the first step, we conducted a study using existing CAN components from the viewpoint of cost. Because CAN uses the differential transmission protocol*[2], unshielded twisted pair (UTP) cables and general in-vehicle connectors, whose terminals are inserted into resin housings, were used (Photo 1).

The CAN standard was compared with the OPEN Alliance's TC2 (hereinafter referred to as "TC2"), which is the communication standard for 100 M Ethernet (Table 2).

Photo 1. CAN cables and a connector

The transmission speed of 100 M Ethernet is 100 times faster than that of CAN, and therefore the communication standards for components are significantly different. Specifically, regarding CAN's transmission characteristics*[3], only the characteristic impedance defferential mode (CIDM)*[4] for cables is specified, and the conformity range is wide (95 to 140 Ω). Meanwhile, the differential characteristics are specified for TC2 cables, connectors, and wiring harnesses, and the CIDM conformity range is narrow (100 ±10 Ω). Regarding the transmission characteristics, RL,*[5] IL,*[6] and mode conversion*[7] are also specified in addition to the CIDM. Furthermore, crosstalk characteristics*[8] with adjacent harnesses are also specified. Thus, the TC2 communication standard is more rigorous than the CAN standard.

Table 2. Comparison of communication standards between CAN and 100 M Ethernet (TC2)

		CAN	100 M Ethernet		
Communication standards		ISO11898 ISO11519	IEEE802.3bw Open Alliance TC2		
Data rate		1 Mbps	100 Mbps		
components		cable	cable	connector	harness
Transmission characteristics	CIDM	95～140 Ω CIDM [Ω]: 140 Ω Fail / Pass / 95 Ω Fail	100+-10 Ω CIDM [Ω]: Fail / 110 Ω Pass / 90 Ω Fail Conformity range : Narrow		
	Other	Not specified	RL/IL Mode conversion		
Crosstalk characteristics		Not specified	Not specified	Specified	

We evaluated transmission and crosstalk characteristics using a network analyzer in the respective TC2 evaluation configurations (Fig. 2) using the CAN cable and general connector described above.

First, regarding the transmission characteristics, the CIDM of the UTP cable was found to be rather high and failed to conform to the TC2 standard. To ensure conformity, it was considered necessary to reduce the twist pitch of the cable. An increase in the CIDM was also observed for the connector. The increase was mostly attributable to the untwisted part of the cable to connect the terminal. To ensure conformity with TC2, it was necessary to reduce the untwisted part. Second, regarding the crosstalk characteristics, the UTP cable failed to meet the TC2 standard. It was found necessary to secure wide separation between cables and between connector signal terminals, as shown in Fig. 3.

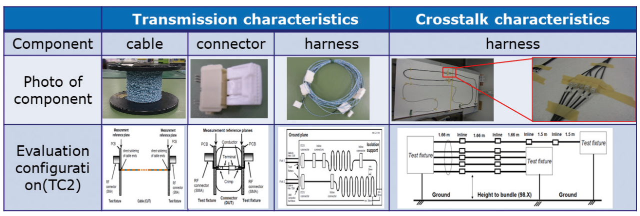

Fig. 2. Photos of components and TC2 evaluation configurations

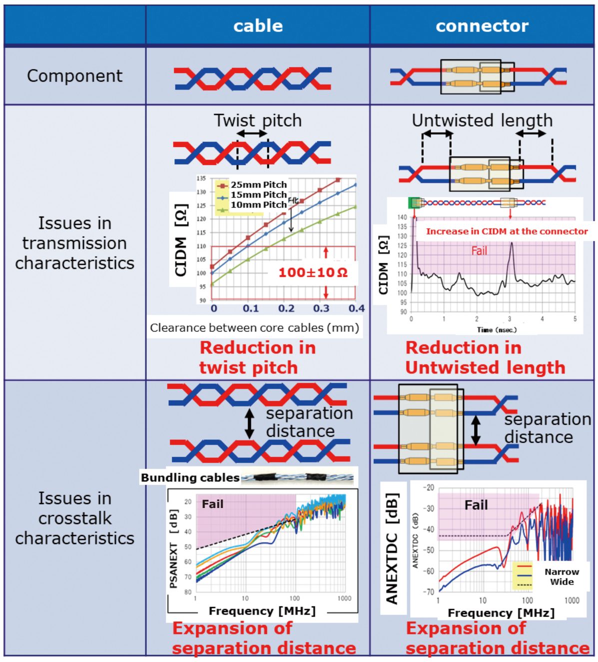

Fig. 3. TC2 conformity issues of CAN components

Based on the above study, we judged that it was difficult to apply existing components for CAN to 100 M Ethernet and that dedicated components were required.

3. Development of 100 M Ethernet Components

We developed dedicated components (cable and connector) conforming to TC2. We also studied terminal processing technology to ensure mass productivity of automotive components and worked on the development of CAE analysis technology and communication performance evaluation technology capable of predicting communication performance conforming to TC2.

3-1 Cable

Photo 2 shows the 100 M Ethernet cable that we developed. A twisted pair cable, which consists of two wires, is sheathed in a jacket to reduce the impact from the surrounding environment. Sheathing by the jacket reduces characteristic fluctuations, making it possible to meet the rigorous TC2 standard of transmission characteristics in the in-vehicle environment. We also established a manufacturing method to stably hold a twisted pair cable using a hollow jacket structure, including an air layer whose permittivity is low. This led to the development of a thin, flexible, and easy-to-handle 100 M Ethernet cable (outside diameter: 2.5 mm).

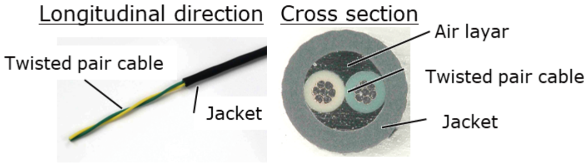

Photo 2. 100 M Ethernet cable (UTP cable with a jacket)

3-2 Connector

To improve the transmission characteristics of connectors, it is necessary to reduce the untwisted length. In UTP cables that ensure conformity with the CIDM in a twisted condition, the CIDM increases at the untwisted part, which connects the cable with the terminal, resulting in deterioration of the transmission characteristics. In general connectors, the untwisted length increases to insert the terminal into the resin housing and to check the insertion (Fig. 4). It is therefore necessary to reduce the untwisted length. We calculated the target untwisted length based on the correlation between the cable insulation stripping length and the increase in the CIDM value (see Fig. 5) and employed a modular structure wherein the terminal to which the cable is connected is sandwiched by a resin module as the connector structure whose untwisted part is the target length or less, as shown in Fig. 6. We also determined the shape based on CAE analysis and performance evaluation to ensure conformity with other connector transmission and crosstalk characteristics.

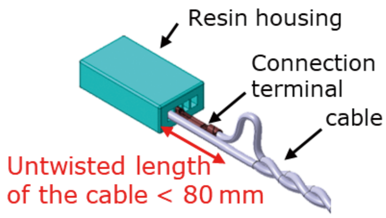

Fig. 4. Untwisted length for a general connector

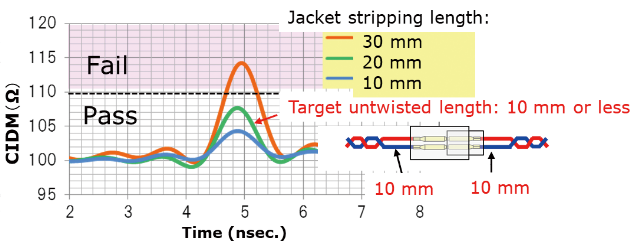

Fig. 5. Calculation of the target untwisted length

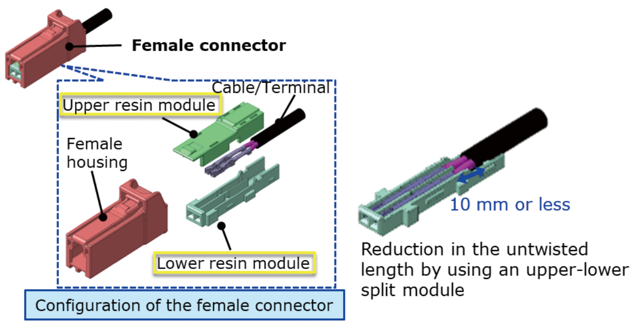

Fig. 6. Connector module structure

3-3 Terminal processing technology

We also studied the processing method to reduce the fluctuation of transmission characteristics during processing of connectors and wiring harnesses, and guarantee the performance required of wiring harnesses, such as retention strength. We also aimed to develop a connector structure and processing method that would ensure ease of processing at wiring harness manufacturers while guaranteeing performance.

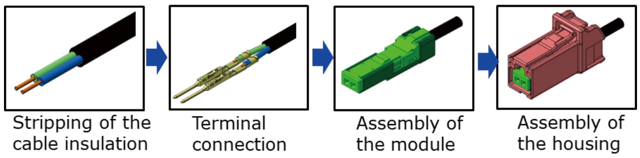

Fig. 7. Procedure of terminal processing

3-4 CAE analysis technology

When designing the communication performance of high-speed communication components, it is required to predict the performance based on high-frequency electromagnetic analysis (CAE analysis). We have made it possible to predict the characteristics fluctuations attributed to components and processing tolerance in advance, in addition to during the design of components (cables and connectors), based on CAE analysis, and to use CAE analysis as a tool to guarantee the performance of mass-produced components to conform to the standard.

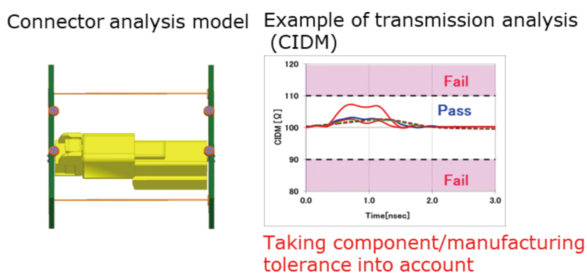

Fig. 8. Example of CAE analysis
(consideration of the connector, CIDM, and tolerance)

3-5 Communication performance evaluation technology

Regarding the transmission, crosstalk, and shielding characteristics of respective in-vehicle Ethernet standards (IEEE and OPEN Alliance [TC2 and TC9]), we acquired equipment, jigs, and know-how and built an in-house evaluation environment. This has enabled us to efficiently verify the conformity to the respective standards. It has also become possible to verify and analyze the deterioration factors of transmission characteristics attributed to wrapping of cables and the environmental conditions that are expected in vehicle operation when our product is built into wiring harnesses, and to quickly implement measures in product development.

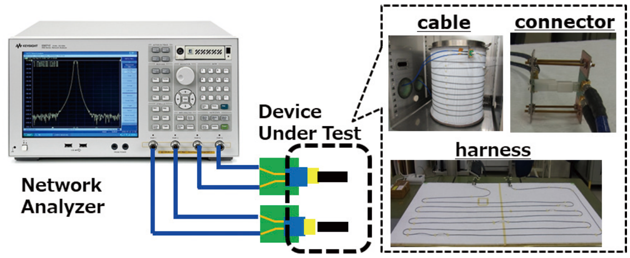

Fig. 9. Example of the environment to measure the communication performance

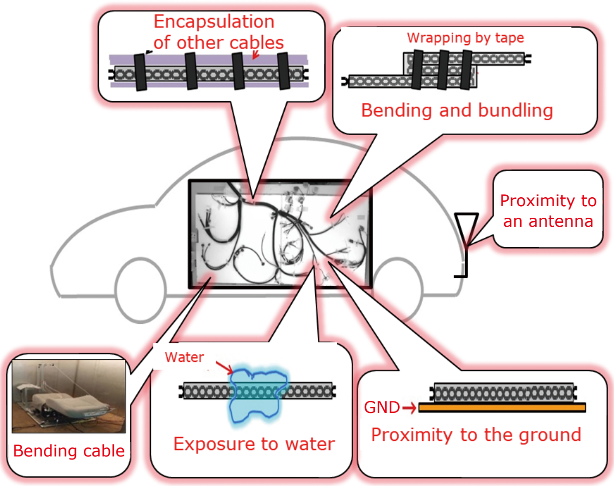

Fig. 10. Performance deterioration factors attributed to the in-vehicle environment

4. Evaluation Results of TC2 Communication Characteristics

Photo 3 shows the components for 100 M Ethernet (and connectors).

We evaluated the TC2 transmission and crosstalk characteristics of the cable, connectors, and wiring harness using the components (see Figs. 11 and 12). The results were within the standard values for the respective characteristics of all the components. (The no-good regions are indicated in red.) We confirmed conformity with OPEN Alliance TC2, the communication standard for 100 M Ethernet.

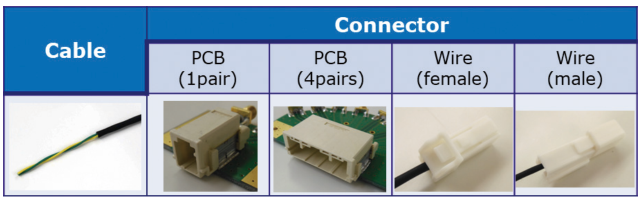

Photo 3. Components for 100 M Ethernet (cable and connectors)

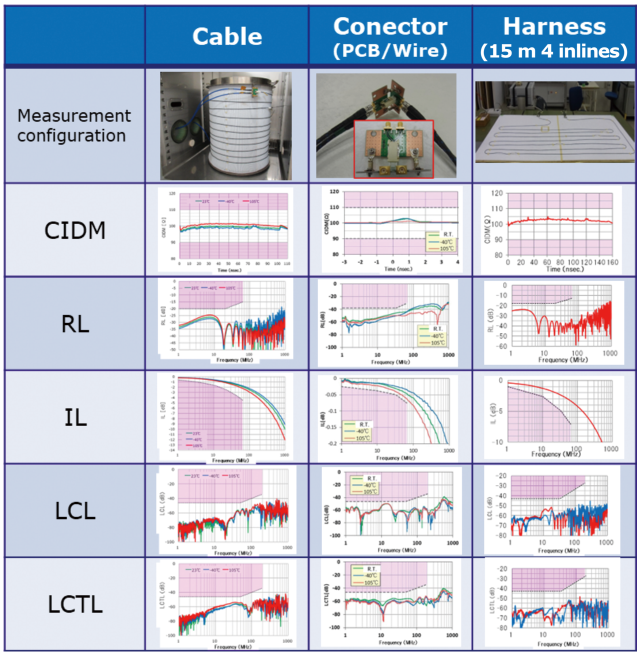

Fig. 11. Evaluation results of the TC2 transmission characteristics (cable, connector, and harness)

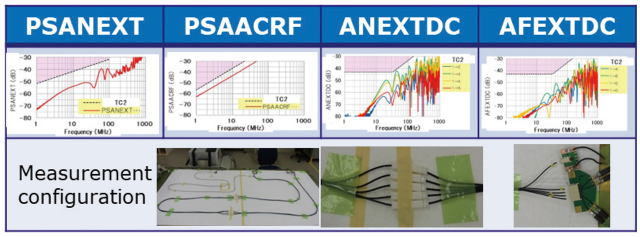

Fig. 12. Evaluation results of the TC2 crosstalk characteristics (wiring harness)

5. Conclusion

This paper explained the results of our study to apply CAN components to the 100 M Ethernet standard (OPEN Alliance TC2) and our initiative to develop new components.

With 100 M as the starting point, there is a growing need for higher speeds, namely, 1 G and multi-gigabit (2.5 G/5 G/10 G) in-vehicle Ethernet. We are studying the possibility of adapting components to the respective speed ranges. Given that components for in-vehicle communication are expected to meet the need for higher speeds, we will achieve higher speeds and frequencies through communication design based on CAE analysis, component design, and the development of manufacturing methods and communication evaluation technology, to promote efficient product development (Fig. 13).

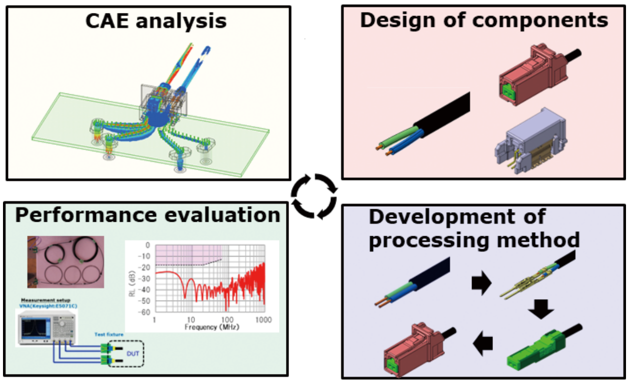

Fig. 13. Development cycle of high-speed communication components

Technical Terms

∗1 CASE: Abbreviation for "connected," "autonomous," "shared & service," and "electrification." In these fields, new technological innovation, which is considered to be revolutionizing the concept of vehicles, is underway.

∗2 Differential transmission protocol: This protocol uses two signal lines as a pair of transmission lines. The cable is twisted. The signal protocol is characterized by superb noise resistance performance capable of canceling noise applied from outside by transmitting high-frequency signals whose phase is half-shifted between the two lines.

∗3 Transmission characteristics: Loss of high-frequency signals when they pass through a transmission route. It shows the performance of components (cables and connectors) for high-speed communication. The transmission characteristics of communication components must conform to the communication standards.

∗4 CIDM: Abbreviation for "characteristic impedance differential mode," which indicates the difficulty of high-frequency signals to pass through a differential transmission route. It varies depending on the cross-section of signal lines and the separation between two lines in the cross- section of the transmission route as well as the permittivity in the surrounding environment. For Ethernet, the standard value between transmission routes is set to 100 Ω. However, the deviation of cables and connectors from the standard CIDM value leads to the deterioration of the IL and RL.

∗5 RL: Abbreviation for "return loss," which indicates the amount of signal reflection when high-frequency signals pass through the transmission route. The RL mainly depends on the deviation of connectors and cables from the standard CIDM value.

∗6 IL: Abbreviation for "insertion loss," which represents the amount of signal attenuation when high-frequency signals pass through the transmission route. The IL mainly depends on the performance and length of cables and deviation from the standard CIDM value.

∗7 Mode conversion: (LCL: longitudinal conversion loss; LCTL: longitudinal conversion transmission loss)
This shows the amount of differential signals converted to in-phase signals. Components with poor mode conversion are likely to be influenced by noise.

∗8 Crosstalk characteristics: (PSANEXT: power sum alien near end crosstalk loss; PSAACRF: power sum attenuation to alien crosstalk ration far end; ANEXTDC: alien near end cross conversion loss common to differential; AFEXTDC: alien far end cross conversion loss common to differential)
These characteristics represent the loss of signals on the transmission route due to leakage to the surrounding transmission routes. PCB multi-pair connectors are the deterioration factors in particular.

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Contributors The lead author is indicated by an asterisk (*).

K. YOSHIDA*
• Assistant General Manager, AutoNetworks Technologies, Ltd.

R. UEGAKI
• Assistant Manager, AutoNetworks Technologies, Ltd.

Y. DEGUCHI
• Senior Assistant Manager, Sumitomo Wiring Systems, Ltd.

H. HIRAMATSU
• Manager, Sumitomo Wiring Systems, Ltd.

K. KATO
• General Manager, Sumitomo Wiring Systems, Ltd.

A. KONDO
• Manager, Sumitomo Wiring Systems, Ltd.