International Journal of Computer (IJC)
ISSN 2307-4523 (Print & Online)
https://ijcjournal.org/index.php/InternationalJournalOfComputer/index

A Validity of in-Vehicle Networks Using CAN-FD

Sukhyun Seo*

Department of Electronics Engineering, Tech Uniersity of Korea, Siheung-si, Gyeonggi-do, Korea
Email: shseo@tukorea.ac.kr

Abstract

The most common communication interface for automotive electronic control units is CAN (Controller Area Network). Since CAN was first introduced in Daimler vehicles in 1991, all automotive manufacturers have adopted CAN communication for in-vehicle networks. However, as the number of electronic control units connected to the CAN network grows rapidly, the CAN protocol is reaching its technological limits. To overcome this limitation, Bosch has introduced a new communication protocol, CAN-FD (Flexible Data-rate). In this paper, we analyse the characteristics and limitations of CAN-FD communication according to the topology under the in-vehicle wiring harness environment designed based on the existing classic CAN communication.

Keywords: Cyber security; Automotive Control System; In-vehicle networks; CAN-FD.

1. Introduction

Currently, the most popular communication interface for automotive electronic control units (ECUs) is the Controller Area Network (CAN) [1, 3]. Since its first series production application in 1991 in a Daimler car, CAN is now used by all automotive manufacturers. By connecting electronic control units that used to operate independently of each other in a CAN network, new functions can be realised in the vehicle by exchanging information. CAN communication is theoretically capable of communication speeds of up to 1 Mbps, but in practice, 500 Kbps has been used to increase the design freedom of wiring harnesses in vehicles. This is to increase the robustness of the communication signal to size and structural changes in the topology by reducing the communication speed. In addition, to overcome the limitations of bandwidth, which has become increasingly scarce as the number of electronic control devices connected to the CAN network has increased, topologies have been designed using multiple CAN subnetworks by separating the channels into networks based on each control domain, as shown in Figure 1 [4, 6]. Despite these efforts, the technical limitations of CAN communication, namely its low bandwidth, have made it increasingly difficult to maintain real-time for high traffic volumes. To overcome these limitations, in 2012 Bosch introduced CAN-FD (CAN Flexible Data-rate), an upgraded version of CAN communication [7, 8].

Received: 8/12/2023
Accepted: 9/17/2023
Published: 9/27/2023
----
* Corresponding author.

In order to solve the bandwidth problem of conventional CAN, CAN-FD communication uses a mechanism with a variable data rate to support communication speeds of up to 10 Mbps, and the size of the payload data that can be sent at a time can be expanded from 8 bytes to up to 64 bytes.

Since the introduction of CAN-FD, many automotive manufacturers have been preparing to switch the main in-vehicle communication interface from CAN to CAN-FD. Unlike other existing communication protocols, CAN-FD has gained the support of many automotive manufacturers not only because of its improved performance, but also because it allows them to take advantage of the long experience and know-how of CAN communication, which has dominated the automotive industry for about 25 years. However, because CAN-FD has to operate at higher communication rates than conventional CAN, it can be sensitive to the characteristics of the physical layer designed on the basis of conventional CAN communication. In particular, signal distortion phenomena that depend on the topology configuration need to be examined more carefully than in conventional CAN. In general, it is known that the number of controllers connected to a CAN network increases with the number of signal distortions. Therefore, the size of the network needs to be designed considering this aspect. In this paper, we will analyse the characteristics and limitations of CAN-FD communication under the network wiring harness environment designed based on the existing CAN communication.

This paper is organised as follows. Section II describes the technical characteristics of CAN-FD communication, Section III describes the construction of an experimental environment to analyse the influence of the physical environment on CAN-FD networks, defines the experimental scenarios, presents and analyses the experimental results, and concludes in Section IV.

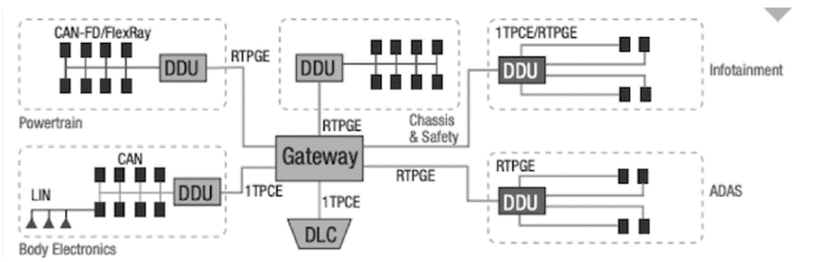

Figure 1: In-vehicle Network Topology.

2. Introduction of CAN-FD

2.1. Datalink Layer of CAN-FD

Simulink not only supports dynamic simulations, but also real-time systems by interfacing with such tools as the Matlab tool-box. Simulink provides an advanced user friendly integrated engine and GUI(Graphic User Interface) environment. Simulink allows developers to implement algorithms and simulate real-time systems.

The CAN-FD communication protocol is defined in ISO11898-1, revised in 2015 [9]. The main features are illustrated by a CAN-FD message frame as shown in Figure 2.

First, the payload data can have a higher transmission rate than in conventional CAN. However, the CAN message header and trailer are transmitted at the same communication rate as conventional CAN. The same header and trailer speed is intended to solve the problem of asynchronisation in the arbitration area. As shown in Figure 2, CAN-FD is transmitted in three phases: Arbitration phase, Data phase, and ACK phase. The Arbitration phase and ACK phase are transmitted at the same speed as conventional CAN, and the Data phase supports up to 10 Mbps. The BRS (baud-rate switch) bit in the control field distinguishes between the arbitration phase and the data phase and is the point at which the transmission rate changes.

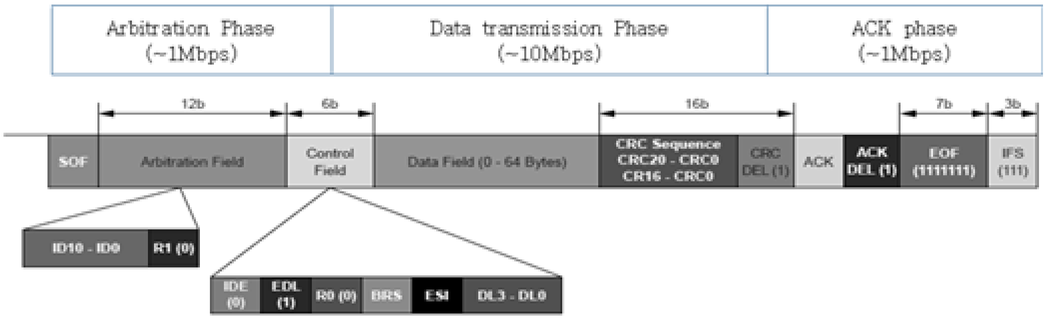

Figure 2: CAN-FD Message Frame format.

Second, CAN FD messages can have up to 64 bytes of payload data (data field) at a time. This means that eight times more data can be sent at once than in conventional CAN. For example, if the data field is 64 bytes and the data phase is set to send at a rate of 4 Mbps, it takes about the same time as conventional CAN sending 8 bytes at 500 Kbps. This means that the real-time nature of the CAN message database, which has been designed with a lot of experience and know-how, can be maintained.

2.2. Physical Layer of CAN-FD

The physical layer specification of the CAN-FD communication protocol is defined in ISO11898-2, revised in 2016 [10]. At the beginning of the specification definition, it was assumed that the upgrade from CAN to CAN-FD would require few new specifications for the physical layer. This was because the physical layer of the existing CAN communication was to be used. However, as the length of a single bit decreases when transmitting signals at higher communication speeds than before, constraints on symmetrical bit signals [11, 12] were added, as areas that were not a major problem in CAN became sensitive at higher speeds. Table 1 shows the allowable minimum, maximum and timing symmetry values for the transmitter and receiver bit times at a communication rate of 2 Mbps. The timing symmetry ensures that the difference between the bit time at the receiving node and the bit time at the transmitting node does not exceed a certain amount.

The ISO11898-2 standard does not define a topology. Typical CAN buses have a bus, star, or mixed topology. The most common bus topology is shown in Figure 3, with two terminating resistors at each end of the main bus line (MBL) and a stub line (SL) connecting the nodes in the middle. In CAN or CAN-FD networks with more than two nodes, ringing occurs due to the reflected waves of the communication physical signals. This phenomenon is mainly caused by the mismatch between the signal frequency and the impedance of the network. The ringing phenomenon is affected by the configuration of the topology, i.e., the length of the MBLP, the length of the SL, etc. regardless of the communication speed. However, as the communication speed increases, the bit time becomes shorter, and even a small ringing effect increases the probability of bit errors.

Table 1: Number of Reverse-Shuffle Attempts.

Parameter	Notation	Value	
		Min(ns)	Max(ns)
Transmitted recessive bit width at 2Mbps	$t_{Bit(Bus)}$	435	530
Received recessive bit width at 2Mbps	$t_{Bit(RXD)}$	400	550
Receiver timing symmetry at 2Mbps	Δt_{Rec}	-65	+40

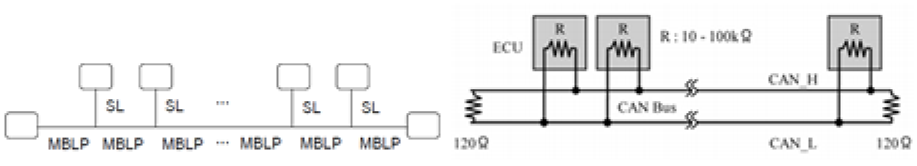

Figure 3: CAN-FD BUS Topology.

3. Validation for Reliability of CAN-FD Network

3.1. Parameter definition

Figure 4 shows the waveform of a 1-bit CAN signal. In the 1-bit waveform, the dominant bit is driven by the transceiver and therefore shows a fast response, but this is not the case for the recessive bit. Therefore, in order to accurately analyse the 1-bit waveform, this paper presents three measurement points for the recessive bit as shown in Table 2. CAN considers it logically high (dominant bit) if it is above 0.9V, and logically low (recessive bit) if it is below 0.5V. Here, under shoot is the lowest voltage value that falls below 0.5 V and over shoot is the highest voltage value that rises above 0.5 V. These two numbers indicate how severe the ringing is. These two numbers are used as a reference value to determine how severe the ringing phenomenon is. In addition, the settling time is the time from 90% of the high voltage to the last 0.5 V, which shows how long it takes for the signal to settle down. This settling time is used to set the optimal samping point in CAN communication. The sampling point is a reference point for determining whether a signal is high or low in 1 bit time and can be changed in the CAN communication protocol settings.

Table 2: Definition of Measurement Parameter.

Parameter	Description
Undershoot (V)	Lowest value after passing 0.5V
Overshoot (V)	Highest value after passing 0.5V
Settling time(ms)	Times between 90% of high voltage and last point passing 0.5V

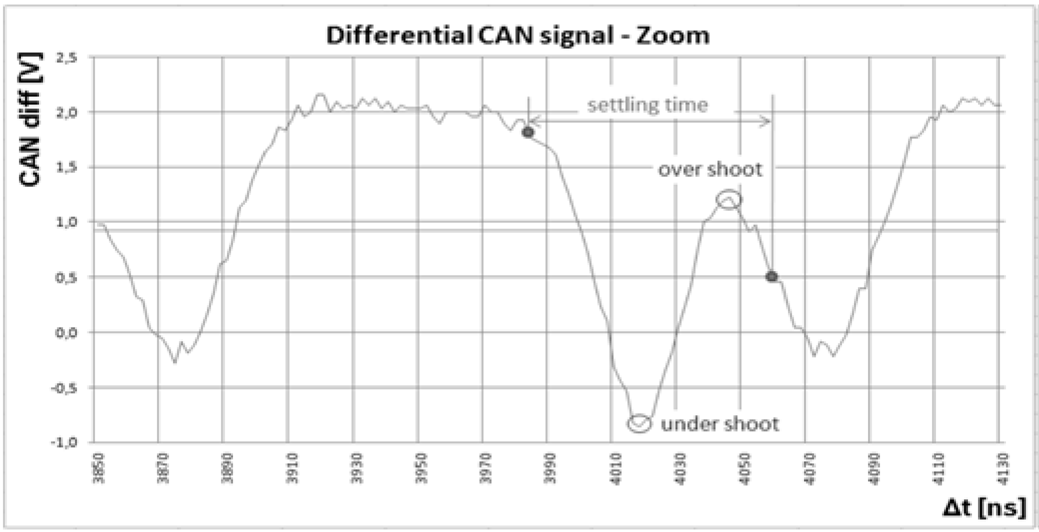

Figure 4: 1 bit timing of CAN communication signalwave.

3.2. Experiment Setup

The overall experimental environment is shown in Figure 5. The topology is basically a bus topology, with terminating resistors connected to both ends of the bus and a stub line connected to each control node through a connector that can branch in the middle. In this topology, a cable is made to connect the length of the main bus and the length of the stub line so that the length of the stub line can be adjusted. Oscilloscopes are connected to the transmitting and receiving nodes for bit signal measurement, and CAN-FD interface equipment is connected for error frame detection. In this paper, the above experimental environment is used to determine whether the wiring harness designed based on the existing CAN communication can be used in CAN-FD and to analyse the problems. For the experiments, a total of 15 experimental boards with CAN-FD communication are configured as shown in Figure 5. Each board has two CAN-FD interfaces, allowing up to 30 nodes to be connected to a network. Two experimental scenarios were selected as shown in Table 3. The two scenarios are representative of the wire harnesses in current vehicles, as they are topologies that are commonly used in real vehicles and are environments where stable communication performance has been verified in existing CAN communications. The scenarios presented are as follows The first network topology scenario (SC#1) consists of a data phase communication rate of 1Mbps, a main bus length of 40m, a total number of 30 controllers, and a stub line length of 0.5m. This scenario is currently the most widely used network topology in automotive environments with existing CAN networks. The second network topology scenario (SC#2) consists of a data phase communication rate of 4 Mbps, a main bus length of 20 ms, 20 controllers, and a stub line length of 0.5 metres. SC#2 is a widely used network topology in domain-based architectures, as shown in Figure 1. SC#2 is designed assuming that the architecture is designed in the form of an integrated controller with higher communication speed and fewer controllers than SC#1. In both scenarios, the stub line is fixed at 0.5m because the ringing effect caused by the stub line length is the largest, and if the stub line length is designed to be the same in a network, the ringing effect is maximised and the signal distortion phenomenon is greatly manifested, so the worst-case verification can be performed. In both scenarios, the communication speed of the arbitration phase of CAN-FD is fixed at 500Kbps, which is the most widely used in existing CAN communication, and the samping point is set to 75%.

Based on these topology scenarios, changes in the 1-bit signal and the occurrence of error frames were checked.

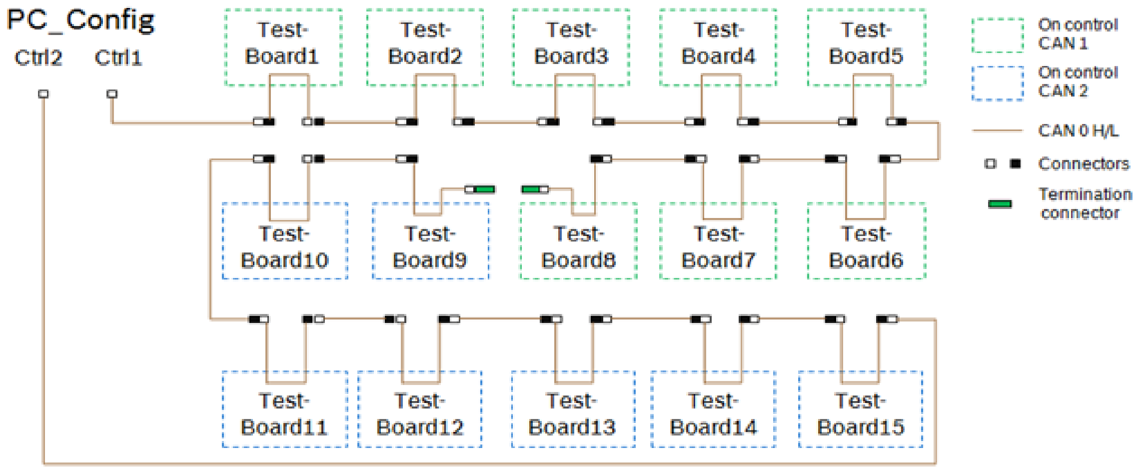

Figure 5: In-vehicle Network Topology.

Table 3: Scenarios for CAN-FD network validation.

Scenario(SC)	Data phase data-rate	Main bus length(MBL)	Stub line length (SL)	Number of nodes
SC#1	1Mbps	40m	0.5m	30
SC#2	4Mbps	20m	0.5m	20

3.3. Experiment Result

The verification results for the first scenario (SC#1) are shown in Figure 6. The over shoot at the message sending node is 0.55V, the under shoot is -0.15V, and the settling time is 48ns. At the receiving node, the over shoot is 0.36V, the under shoot is -0.09V, and the settling time is 44ns. There were no error frames and stable communication was achieved. Since the communication speed was set to 1MBps, the length of 1 bit is 1000ns. Since the settling time is 48 ns at the sending node, we can say that only the first 4.8% of a bit is affected by ringing. If the sampling point is set after this point, the probability of communication error is almost zero. The results of the second scenario are shown in Figure 7. The over shoot at the message sending node is 0.52V, the under shoot is -0.44V, and the settling time is 204ns. At the receiving node, the over shoot is measured to be 0.23V, the under shoot is -0.05V, and the settling time is 32ns. Intermittent error frames were measured. The communication rate is set to 4 MBps, so the length of 1 bit is 250 ns. Since the settling time is 204 ns at the transmitting node, the first 81.6% of the bits are ringing, and a stable signal cannot be guaranteed. This means that the probability of error is very high if the sampling point is set below about 82%. It also means that even if the sampling point is set to 82% or more, communication errors may occur due to small changes in the topology. These results indicate that wiring harnesses and network topologies designed based on conventional CAN communication may be vulnerable at high communication speeds. In other words, although CAN-FD can increase the communication speed, it is limited by the ringing phenomenon that occurs depending on the configuration of the network topology. Therefore, it is necessary to determine the data phase area communication rate of CAN-FD communication that can be realised through physical layer analysis of the designed network topology of conventional CAN communication.

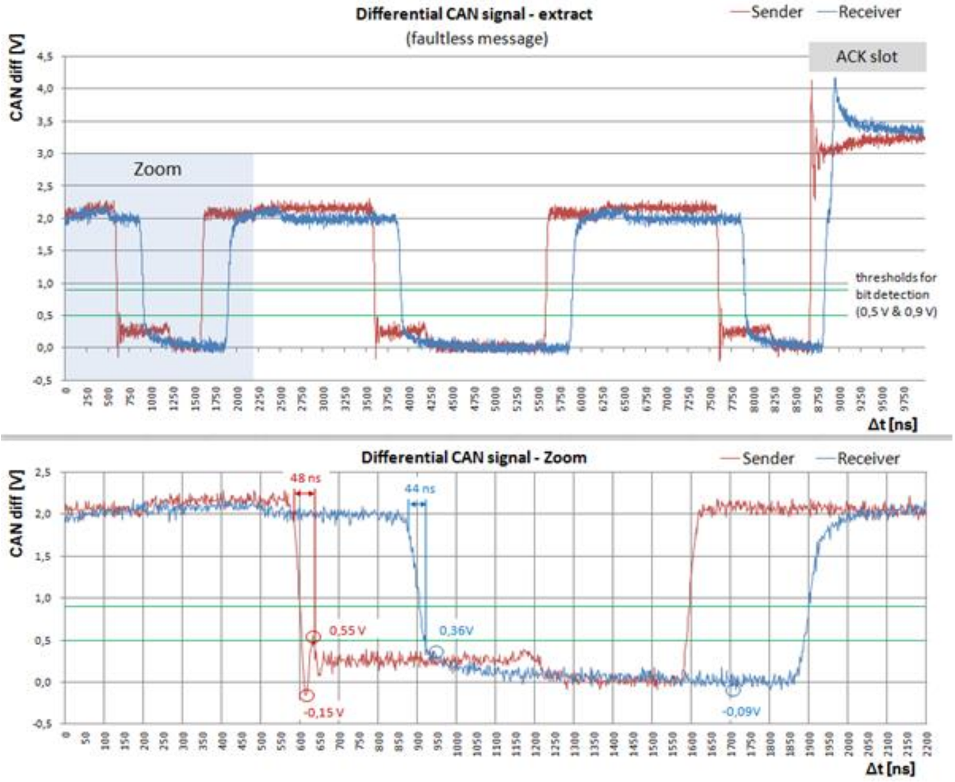

Figure 6: 1bit Signal Waveform of Scenario 1(SC#1).

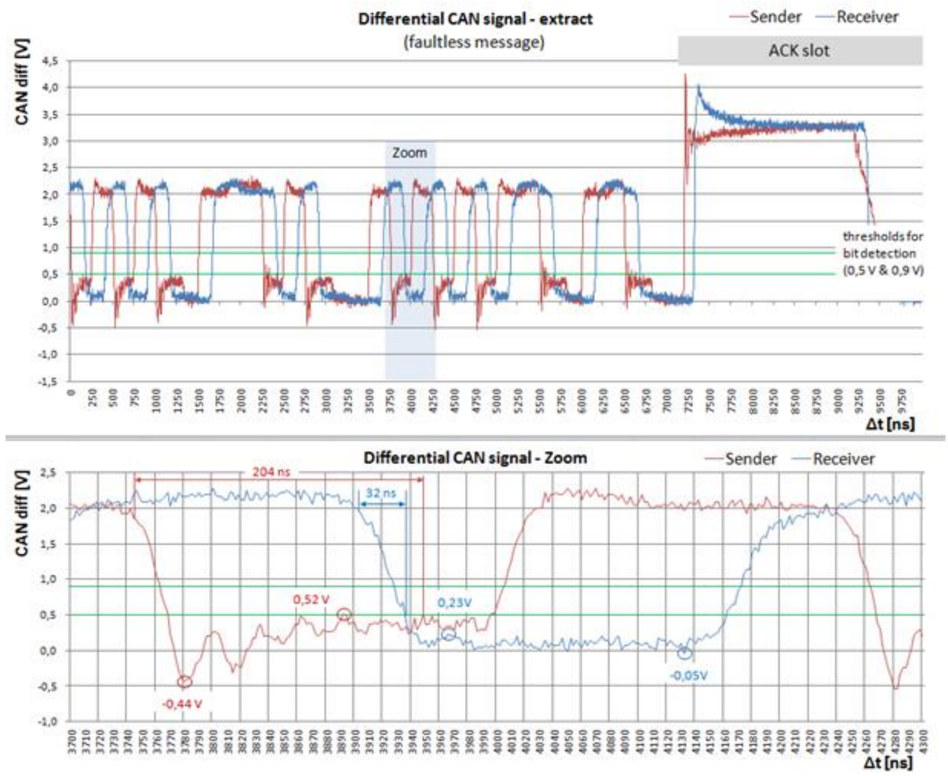

Figure 7: 1bit Signal Waveform of Scenario 1(SC#2).

3.4. Discuss of the Result

The results of the experiments conducted in this paper are shown in Table 4. In particular, in the case of scenario SC#2, error frames were partially generated and further experiments were conducted. Under the same conditions as scenario SC#2, when the communication speed was set to 6Mbps, error frames continued to occur and communication was not possible. This is because the 1 bit time becomes shorter as the communication speed increases, but the settling time due to ringing phenomenon remains long. In the end, the problem that ringing remains regardless of the communication speed and depending on the shape of the topology is considered to be a limitation of CAN-FD. Therefore, in order to apply CAN-FD to vehicles, it is necessary to first analyse the extent of ringing phenomena in the current CAN-based vehicle topology in terms of settling time and then predict how much the 1 bit time can be reduced. Once the size of the 1 bit time for stable communication has been determined, it can be assumed that this is the maximum communication speed for which CAN-FD communication can be applied.

Conversely, if there is a target CAN-FD communication speed, the current topology must be optimised to reduce the ringing phenomenon to a minimum. Since the ringing phenomenon is generated in a complex form that cannot be defined by one or two parameters, it must be observed by creating and varying various conditions. In this paper, we changed the topology based on the main bus length, stub line length, and number of controllers, but there is not enough data to understand how much each condition affects the ringing phenomenon. Therefore, topology optimisation should be done after collecting enough data in an experimental environment where independent conditions can be set for each evaluation criterion.

Table 4: Experiment Result for Scenarios of CAN-FD network validation.

Scenario(SC)	Location	Over shoot [V]	Under shoot [V]	Settling time [ns]	Error Frame
SC#1	Transmitter	0.55	-0.15m	48	None
	Receiver	0.36	-0.09	44	None
SC#2	Transmitter	0.52	-0.44	204	Partly
	Receiver	0.23	-0.05	32	Partly

4. Conclusion

As automotive companies compete to introduce the most advanced features into their vehicles, the long-standing CAN communication is facing limitations. To solve these problems, a new communication protocol called CAN-FD communication has been introduced, and many automobile manufacturers are planning to switch to CAN-FD communication. However, as shown in this paper, it will be difficult to successfully apply CAN-FD communication to vehicles if only high communication speed is pursued without a detailed analysis of the existing CAN communication-based topology. It is believed that the overall architecture design of the ever-increasing number of electronic control units, the optimisation of the network topology, and the analysis of the influence of communication signals on the wiring harness must be applied in parallel before it can be successfully applied to vehicles. In the future, we plan to build a virtual simulation environment that can perform various verification scenarios for CAN-FD network topologies and define design constraints in more detail, so that analyses of various topologies can be performed efficiently and at low cost.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government, MSIT (No.2020R1F1A1071819). In addition, this research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2023-2018-01426) supervised by the IITP(Institute for Information & communications Technology Promotion.

References

[1] J. Kim, J. Baek, K. Kwon, S. Lee, "Fast ECU Software Update Algorithm Using by Extending AUTOSAR CAN Interface," IEMEK, J. Embed. Sys. Appl., Vol. 8, No. 3, pp. 163-169, 2013 (in Korean).

[2] W. Zeng, M.A.S. Khalid, S. Chowdhury, "In-vehicle Networks Outlook: Achievements and Challenges," IEEE Communications Surveys & Tutorials, Vol. 18, No. 3, pp. 1552-1571, 2016.

[3] B. V. Kumar, J. Ramesh, "Automotive in Vehicle Network Protocols," Proceeding of International Conference on Computer Communication and Informatics, 2014.

[4] J.H. Kim, S. Seo, N. Hai, B.M. Cheon, Y.S. Lee, J.W. Jeon, "Gateway Framework for In-vehicle Networks Based on CAN, FlexRay, and Ethernet," IEEE Transactions on Vehicular Technology, Vol. 64, No. 10, pp. 4472-4486, 2015.

[5] N. Nowdehi, P. Kleberger, T. Olovsson, "Improving In-vehicle Network Architectures Using Automated Partitioning Algorithms," Proceeding of IEEE Vehicular Networking Conference, pp. 259-266, 2015.

[6] G. Andrei, S.V. Alexandru, "On the Communication Network Inside Vehicles," Proceedings of International Conference on Electronic, Computers and Artificial Intelligence, pp. WW-13-WW-18, 2015.

[7] F. Hartwich, "CAN With Flexible Data-Rate," Proceedings of International CAN Conference, pp. 1-9, 2012.

[8] O. Esparza, W. Leichtfried, F. Gonzalez, "Transitioning Applications From CAN 2.0 to CAN FD," Proceedings of International CAN Conference, 2015.

[9] ISO11898-1:2015-Road Vehicles — Controller Area Network (CAN — Part1:Data Link Layer and Physical Signalling.

[10] ISO11898-2:2016-Road Vehicles — Controller Area Network (CAN — Part2:High-speed Medium

Access Unit.

[11] M. Hell, “The Physical Layer in the CAN FD World,” CAN Newsletter, 2014.

[12] F. Hartwich, “Bit Time Requirements for CAN FD,” Proceedings of International CAN Conference, 2013