Body Electronics Area Network (BEAN)

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ABSTRACT

This paper describes the multiplex communication protocol, BEAN (Body Electronics Area Network), developed for body control system on passenger cars which in recent years has increased the scope of multiplex communication. BEAN is based on a protocol developed in 1992 (SAE920231) but expands upon the performance in areas, such as the suitability of the ID system for increase of ECUs , the variable data length enabling the transmission of diagnostic data, and the transmission rate, while keeping the cost and radiation noise level low. The software size of BEAN is compact enough to be implemented by general purpose 8bit MCUs which have recently seen improvements in performance. The BEAN communication devices are available corresponding to the scale of the application and configuration of the ECU taking into account the software capability. This protocol was evaluated using simulation with the body control system on luxury passenger cars.

INTRODUCTION

In 1992, we developed a simple and low cost multiplex communication protocol for the body control system. This system was aimed mainly at door control systems such as the power window and door lock control and has been used in mass production on the LEXUS LS400 since 1995.

Recently, the number of functions available in the electronic system for the body control has been increasing, and it has become necessary to enlarge the area with multiplexing to reduce wire harness volume. For example, the power window function incorporates a jam protection control feature as well as remote power window control. Moreover, the door lock control system is linked to the airbag system for unlock control. Figure 1 shows the data to be multiplexed in a body control system built into a passenger car. Switch data has been the main data of the conventional body system, but the use of control data, like vehicle speed, cooling system fluid temperature and ambient temperature are also increasing in order to reduce the wire harness size and to share data among different ECUs. Though the data is not transmitted frequently, it is still several bytes in length.
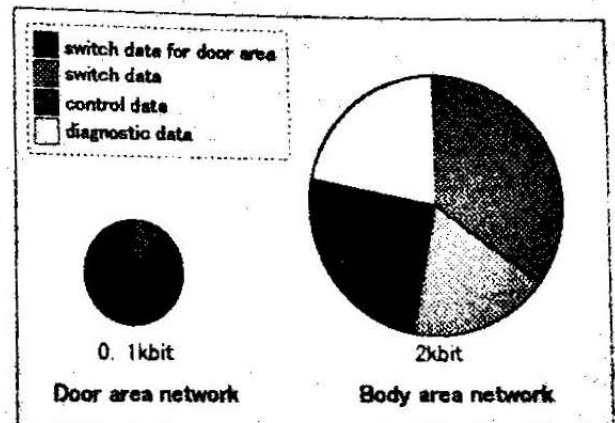

Figure 1: Number of data to be multiplexed

Figure 2 shows an example of a large scale body control system. For the servicing of such large systems, diagnostic capability is required. However, each ECU implementing the diagnostic interface circuit (ISO9141) would result in an increase in cost of the system. To solve this problem, it is more efficient that one ECU has the

interface circuit and function as a gateway for all multiplex transmission to other ECUs via the multiplex bus. Therefore, it is necessary to be able to handle such complex data.

Under these circumstances, the amount and variety of the data to be transmitted is also increasing. In the body electronics area, optional functions frequently change and cost is a strong consideration. We believe that the selection of an optimal network system is needed, and so, we initiated the development of a protocol with both high performance and flexibility that keeps cost at a minimum.

This paper summarizes the requirements of the protocol and describes the specifications of the protocol that was developed for the body electronics system (BEAN). Next, we present some actual examples of the data communication devices and tools necessary for the development of the system. Then, using the LEXUS LS400 as a luxury car example, a case study of the BEAN application is conducted. Finally, the future issues of building an in-vehicle network for the body system are discussed.
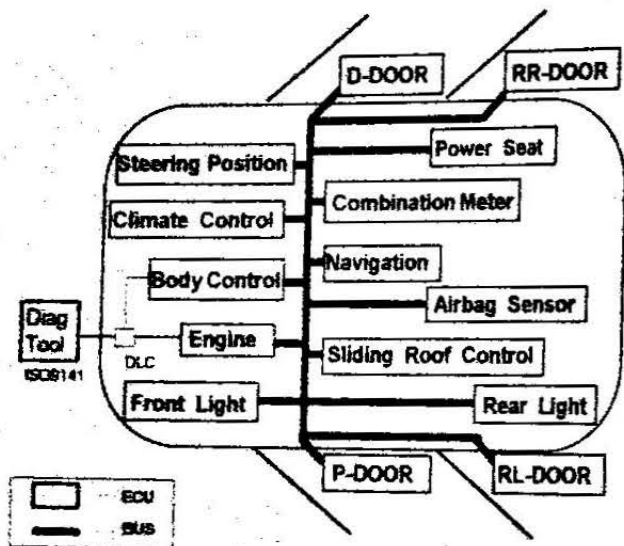

Figure 2: An example of body area network system

REQUIREMENTS FOR THE NETWORK OF BODY ELECTRONICS SYSTEM

The requirements for the network of body electronics system are summarized as follows:

1. Maximum transmission rate using a single wire.
2. Data transmission interface which is designed at a low cost.
3. Low noise level that does not affect in-vehicle systems.

4. Over twenty nodes with two hundred possible messages.
5. Protocol is compact enough to be realized by a general purpose 8bit MCU.
6. Power saving function to reduce power consumption when the ignition key is off.
7. Ability to transmit diagnostic messages.

The protocol developed for the LS400 does not have enough expandability, but is able to achieve reduction in cost. Since the body control system is severely limited by cost and ECU size, we determined that it was best to enhance the communication ability of the Toyota protocol to attain both low cost and expandability.

SPECIFICATIONS FOR BEAN PROTOCOL

In this section, the physical layer and data link layer, the primary features of BEAN, are discussed.

PHYSICAL LAYER - The specifications taking the adaptability to passenger cars into consideration for the physical layer of BEAN are as follows:

1. Low electromagnetic radiation noise
2. CSMA/CD method
3. Non-shielded single wire
4. Resistance to ground offset among ECUs
5. Resistance against surge noise
6. Larger clock tolerance

Low Electromagnetic Radiation Noise - Recently, the use of the glass printed antenna for the radio has been increasing. Because this antenna, however, is easily influenced by noise as compared with the conventional rod antenna, it is vital that we limit the electromagnetic radiation noise generated from electronic components. In the bus interface circuit adopted for LS400, the wave form output to the communication line was controlled in the form of a trapezoid to reduce the noise. The bus interface circuit is shown in Figure 3.
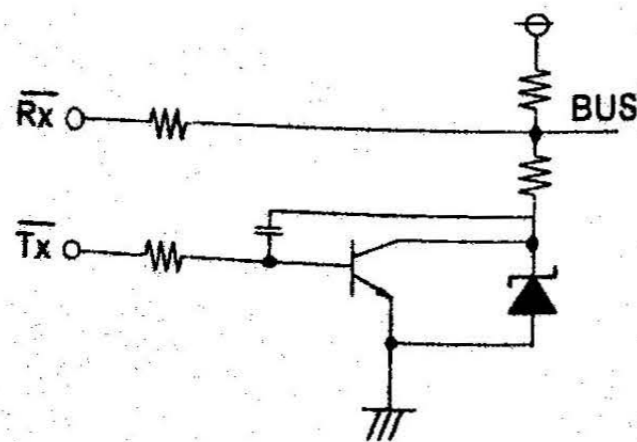

Figure 3: Bus interface circuit

Now, we confirmed the radiation noise level with a similar control method by changing the transmission rate to 10kbps. (We chose NRZ as the bit encoding method and adopted bit stuffing to increase the clock tolerance.) However, as a result, the noise increased largely because the wave form edge had to be increased in slope with the transmission rate. (Figure 4)

Accordingly, we newly developed a new current control type driver which could achieve a low noise level with a transmission rate of 10kbps. The details of this driver will be explained in the next section.
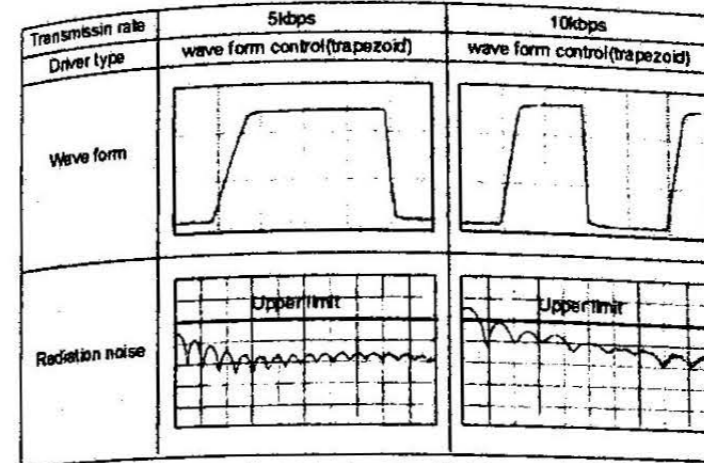

Figure 4: Comparison between 5kbps and 10kbps using similar control methods.

Current Control Type Bus Interface Circuit- The block diagram of Figure 5 shows the structure of the driver/receiver corresponding to a non-shielded single wire, transmission rate of 10kbps and NRZ encoding method.

The driver/receiver gradually outputs current to the bus in order to reduce the radiation noise. The voltage wave form is quickly changed to stably receive the data. The functions of the circuit are described as follows and the wave form is shown in Figure 6.

The driver consists of an integrator circuit and voltage-current conversion circuit.
The terminating circuit functions as a constant current source.

When the output (VTx) of the communication IC shown in Figure 5 changes, the integrator circuit changes the output (VIC) voltage gradually. The output signal of integrator circuit is connected to the voltage-current conversion circuit. The voltage-current conversion circuit gradually changes the output current (IVC) according to the output wave of the integrator circuit. In this way, the driver outputs current to the BUS. The voltage of the BUS (VBUS) is shown in Figure 6.
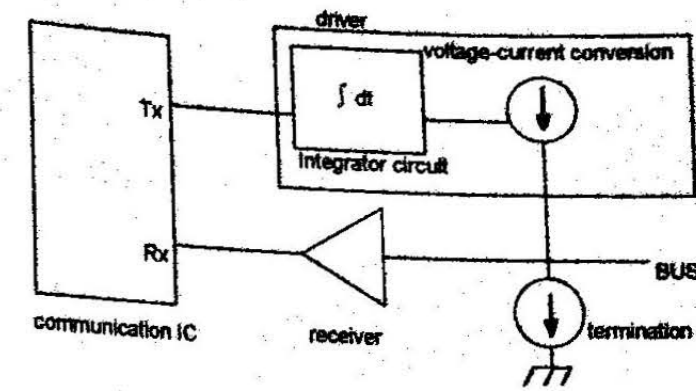

Figure 5: Block diagram of bus interface circuit

The terminating circuit consists of a constant current source working as current limiting circuit. When the output current of the driver begins to drain current greater than the limit of the terminating circuit, the voltage of the bus is high, and when it begins to drain a current less than the limit of the terminating circuit, the voltage of the bus is low.
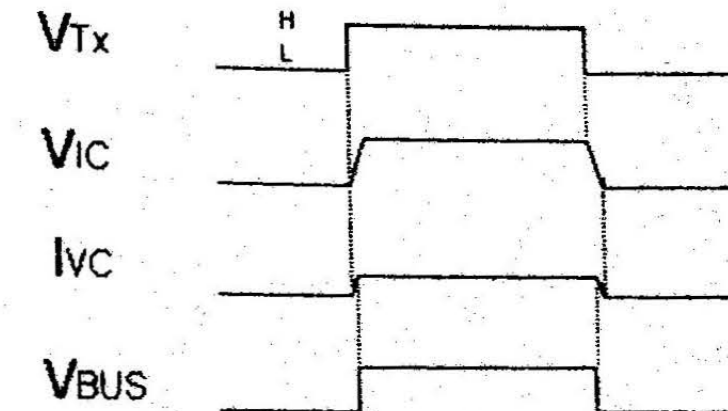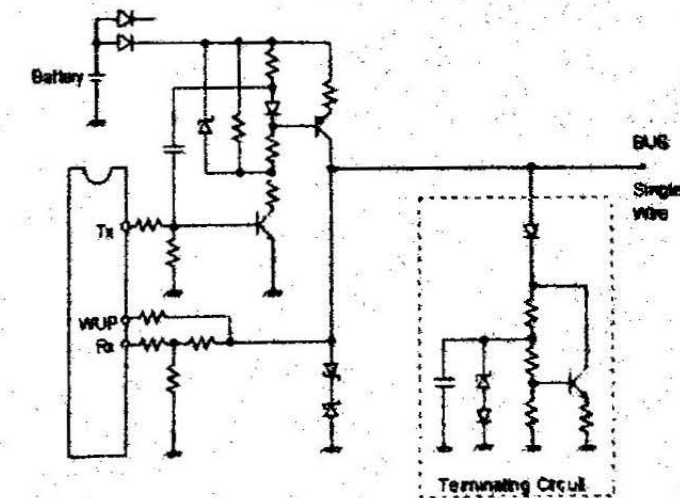

Figure 6: Wave forms

Figure 7 Bus interface circuit (current control type)

A bus interface circuit that meets the above specifications is shown in Figure 7. Although this circuit has a single wire construction, the electromagnetic radiation noise has been reduced. The wave form and the noise level is shown in Figure 8.
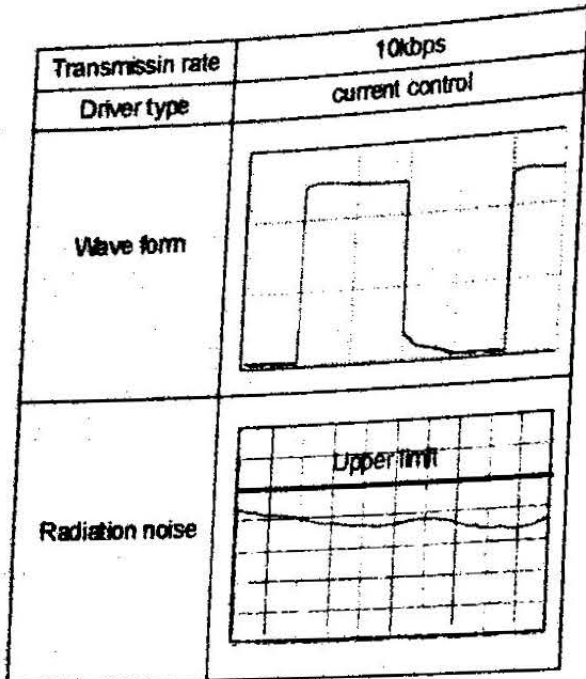
Transmissin rate	10kbps
Driver type	current control
Wave form	
Radiation noise	Upper limit

Figure 8: Radiation noise (current control type)

DATA LINK LAYER - The data link layer is a very important section that plays a large part in determining the system performance and greatly affects the cost of the communication IC. Optimization of the data link layer of the protocol is studied by taking into consideration the requirements described in the previous section and the scale of the communication device.

Optimization Of The Data Link Layer - In the in-vehicle network of the body control system, major communication data is triggered by the operation of a driver. Therefore, the most efficient transmission method is the CSMA/CD method, suited to signals with fewer periodical properties.

The system's drawback, namely its inability to ensure the data delay time except for messages which have the highest priority, may be neglected in a body control system. It is improbable that two or more transmission requests originate at the same time, because the probability that a driver and a passenger operate switches at the exact same time is considered to be an extremely rare case (most of the signals are triggered by switch operations). Features of the CSMA/CD, such as better expandability and capability of easily adding or

deleting nodes, also make it advantageous in the body control system.

Also, to efficiently transmit the various application signals (i.e. switch signals, diagnostic data), it is necessary to make the length of data area variable.

In a multiplex system, external noise may cause communication errors. In this protocol, 9 types of error check methods, such as checking of the frame format in addition to the error check by CRC, are defined to ensure the reliability of the data. If an error occurs, the data is automatically resent up to three times to prevent the omission of data.

Outline of data link layer -The outline of data link layer for the newly developed in-vehicle network is described. Table 1 shows the primary specifications. Figure 9 shows the communication frame format.

Table 1: Specification of data link layer

ITEM	SPECIFICATION
Access method	CSMA/CD with bit wise arbitration
Error check	8-bit CRC
Response	ACK: Acknowledgment
	NAK: Non-Acknowledgment
Data length	1 - 11bytes

SOF	ML		MES-ID	CRC8		RSP	IFS
H							
L	1	4 4	8 8	8×1~11	8	1 6 1 11	6 1
	PRI	DST-ID	DATA1~11		EOM	EOF	IDL

· SOF (1bit) shows the start of a frame.
· PRI (4bits) shows the priority and with a maximum of 16 priority levels.
· ML (4bits) shows the length of the message and the number of bytes of [ID + DATA](3 - 13).
· DST-ID (8bits) is an ID showing the communication destination.
· MES-ID (8bits) is an area showing the contents of the message.
· DATA (8 - 88bits) represents the data area and has length variable from 1byte to 11bytes.
· CRC (8bits) represents the area of error check code.
· EOM (8bits) shows the end of the message and controls the time to prepare the response for sending.
· RSP (2bits) represents the response area.
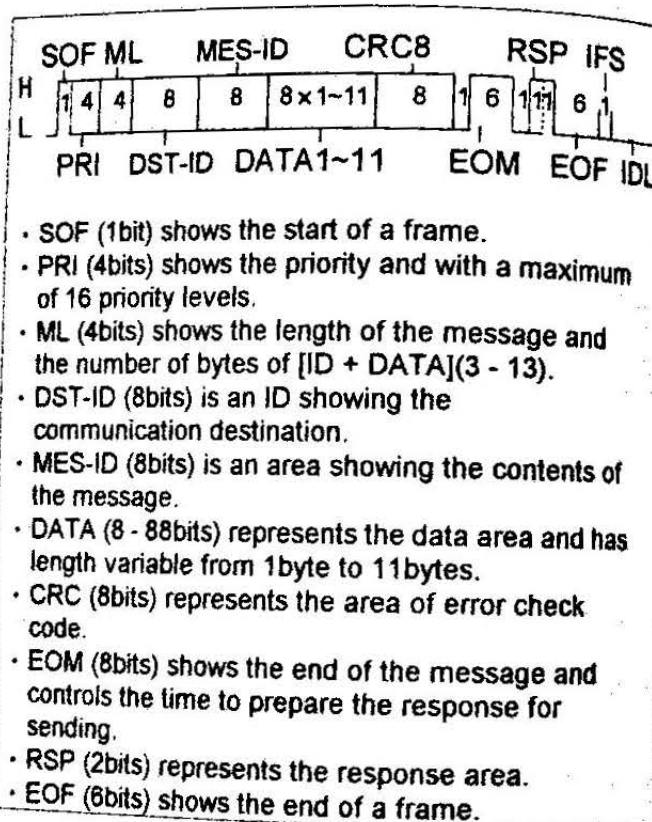· EOF (6bits) shows the end of a frame.

Figure 9: Frame Format

The bit stuffing rule is employed - an inverted bit is inserted when 5 consecutive bits have the same value in the period from SOF to CRC. Broadcast type

messages are available in addition to the point-to-point type messages, and the communication method is switched by the DST-ID. When the DST-ID is FFH, the communication is set to the broadcasting method. If the DST-ID contains a value other than FFH, that value represents the destination ID. The length of the data area is variable up to 11bytes which allows the packaging of other protocol messages into the data area. (It is possible to include 3bytes of header and 8bytes of data.)

Wake-up/Sleep Control - Some ECUs of the body control system are required to function even when the ignition key is set at OFF. To prevent draining the battery, a function to enter the power saving mode when operation of the ECU is not needed and to return the normal operation by detecting voltage changes on the transmission line is provided.

EXAMPLE OF BEAN DEVICE

This section describes a communication device (data link controller) which enables communication with the BEAN protocol explained in the previous sections.

EXAMPLE USING GENERAL MCU - Using a general single chip microprocessor, all communication is controlled by the software. This is applicable for small scale ECUs and is a small load on control programs.
Advantages of this system are shortened development time and ease of modification for changes in the protocol. For example, the load on the MCU is 61% on average using assembly language when BEAN is built using a Hitachi H8 MCU. (Where the clock frequency is 8MHz.)

EXAMPLE USING CUSTOM
COMMUNICATION IC - Wired logic circuits are achieved by using the custom communication IC independent of the MCU. This system can be used by any MCU without limitation. The advantage of this system is that the system reduces the load on the host MCU. Figure 10 shows a photo of the IC chip. Table 2 shows the primary specifications.

Figure 10: Photo of the chip

Table 2: Primary specification

ITEM	SPECIFICATION
Chip size	4mm x 2mm
Design rule	1.2um rule
Circuit scale	4000 gates

EXAMPLE USING ORIGINAL MCU FOR BODY CONTROL - The body control microcomputer (B05-microcomputer) used for BEAN is an 8-bit high speed, low power microcomputer designed for in-vehicle use, with built-in communication hardware that implements the BEAN protocol using customized communication software.

Using an original dual-task MCU, each task functions alternately based on the time sharing, and processes 2 instructions at $0.5 \mu s$ intervals when the external frequency is set at 8 MHz (internal frequency is 4 MHz). This enables high speed processing because 96% of the available 48 instructions are executed in 1 cycle. The communication software is processed only in the A task (one task of the dual-task) and the L task (the other task) is not influenced by the communication. Therefore, the L task can be programmed for the I/O controller such as the input/output process or error process, without worrying about the communication process overhead(Figure 11). Features are as follows:

1. The application program can be created easily, independent of the BEAN protocol
2. Simplification of peripheral circuits (Figure 12)
3. Built-in malfunction prevention (i.e. watch dog timer)
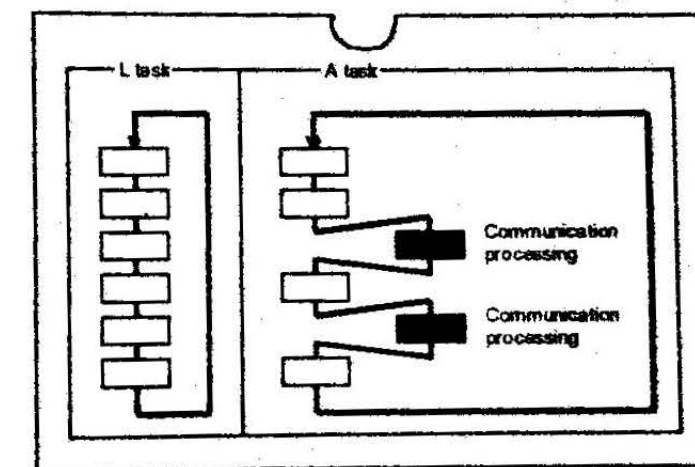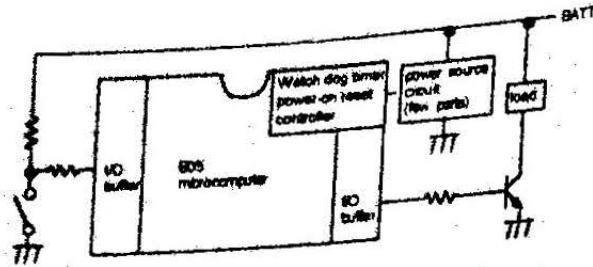4. Low power consumption

Figure 11: Images of L and A tasks.

Figure 12: Example of peripheral circuits.

BEAN DEVELOPMENT TOOLS

The multiplex transmission protocol has the advantages of simplified wire harnesses. However, as the scale of the system becomes larger, development and evaluation becomes more difficult. The development tools corresponding to each development phase -- such as the simulation prior to development, prototype modeling of each ECU, functional checks of all ECUs, and confirmation of functions an actual vehicle -- are needed. For these purposes, development tools called "LAN testers" are available.

The primary functions of the development tools are explained below:

1. Collection, recording, and display of communication bus data.
2. Detection and display of errors.
3. Specified data sent at a specified timing.
4. Specified collection data such as switch data output from ports in real time.
5. Analog signals (i.e. the vehicle speed, water temperature) output in real time.

Functions 3 to 5 are useful for the functional check of a single ECU or used as an alternative ECU. Functions 4 and 5 are useful for monitoring the signal of sensors and switches on an actual vehicle. Figure 13 shows a custom LAN tester. Figure 14 shows the PC card(PCMCIA type2) type development tool.
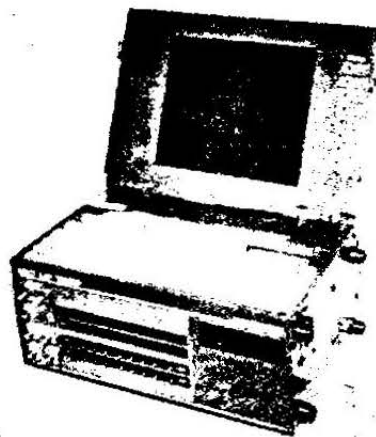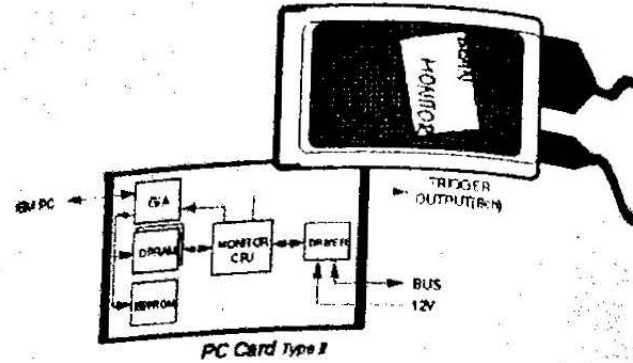

Figure 13: Custom LAN Tester.

Figure 14: PC card type development tool.

CASE STUDY USING LS400

This section describes the BEAN case study using the LEXUS LS400 which has a complex large scale body electronic system. Figure 2 shows the configuration of the system. The number of nodes connected to the body control network is 15.

STRUCTURE OF THE NETWORK - First, the structure of the network is shown. Functions restricted by the protocol, such as fault tolerance are performed within the respective application taking fail-safe into consideration.

Multiplex Transmission Signals - Multiplex transmission signals are selected as follows by taking into consideration the reliability of the communication:

Signals necessary for the control of a node, even during bus failure, are inputted directly by the node and then transmitted to the other nodes. For example, the vehicle speed signal is calculated by the combination meter ECU and the ignition key start position is detected by the engine ECU and then both signals are transmitted through the network by the respective ECU.

In the body system, there are many signals suitable for asynchronous event triggering. If an error occurs in the message, some of the data will be lost. To solve this problem, signals like the warning signal to the combination meter ECU is not only sent by event transmission, but also by periodical transmission.

Communication Method - Each node uses messages corresponding to the vehicle mode -- the ignition key is set at OFF, Accessory, ON, or Diagnosis. Each node basically sends the data received from sensors and switches to the network. For example, when all sensor data necessary for control is read by an ECU, (i.e. engine ECU), Data

such as the RPM of the engine and water temperature is sent to the network during the periodical transmission only when the ignition key is set in the ON position even though the amount of the data received from the body control system is small. To efficiently design the wire harness system, signals around the nodes are inputted to the ECU to send them to the network, even though they may not be needed for control. For example, the engine ECU reads the hydraulic pressure switch of the engine and sends the data to the instrument cluster ECU.

Bus Reliability - Since this protocol's goal is reduce the cost of the physical layer, the following is taken into consideration on the vehicle side to improve the bus reliability. The bus is connected In daisy chain configuration to ensure safe communication even if a wire in the system is broken. Multiple bus terminating circuits are mounted in the network to prevent the entire system from malfunctioning even if a terminating circuit fails.

Gateway For Diagnosis Data - In Figure 2, the engine ECU and body ECU are nodes that use the ISO9141 interface for communicating with diagnostic tools. The other nodes are connected to the diagnostic tools through BEAN. The messages specially designed for diagnosis is set on each node beforehand and is sent only when In the diagnosis mode.

The diagnostic message is placed into the DATA area of BEAN by the body ECU. Since this message is sent via the broadcast method, other ECUs automatically read the message and confirm that the diagnosis request has been sent. If there is diagnostic data, the ECU returns to the body ECU a message to transmit the diagnostic data to the tool. When the body ECU determines that the MES-ID is for diagnostic data, the body ECU puts the DATA area into a diagnostic message to be sent to the tool. Thus, the body ECU is able to transmit the diagnosis message from other nodes without reading its contents, resulting in a reduction in the load on the body ECU.

COMMUNICATION CAPACITY AND SIMULATION - Using the model shown in Figure 2, the volume of communication data shown in Table 3 is needed.

Table 3: Communication data volume.

Transmit data	Transmit mode	Data volume
Switch signal	Periodical	272bit
	Not periodical	136bit
Control data	Periodical	41byte
	Not periodical	176byte

Since short interval periodic data may greatly affect the communication capacity, to insure the

performance of the CSMA/CD system, the interval of transmission is optimized based on a average bus utilization target of 40% or less. In order to verify the performance of the network, the following simulations were performed.

Simulation System - The configuration of the simulation system is shown in Figure 15. The details of the simulation system are contained in the SAE paper 910463 and will not be described in this paper. The simulation system was designed to be capable of evaluating both the entire communication line as well as processing of individual signals. Items which can be evaluated by the system are as follows:

1. Signal base evaluation: Number of data originally produced, number of collisions, number of data discarded, delay time.
2. Node base evaluation: Number of data sent, Amount of data sent, Average data sending time.
3. Communication system base evaluation: Total size of messages, Total data discarded.
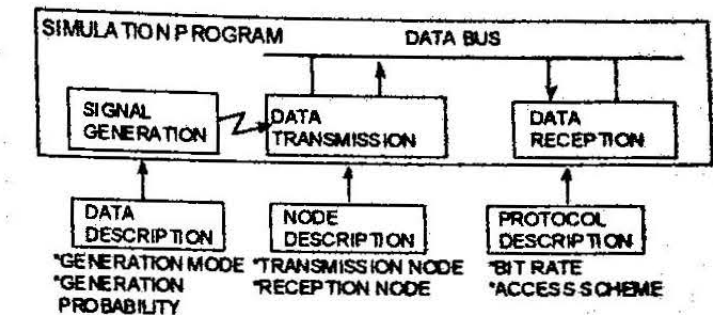

Figure 15: Configuration of the simulation system.

Result Of Evaluation - According to the results of the evaluation and simulation, the performance of the communication protocol was verified as follows:

1. Delay time: Fig. 16 shows the delay time distribution of all passenger seat window UP/DOWN signals which have the highest priority and the vehicle status signal which has the lowest priority. The delay time refers to the interval between occurrence of the transmission data and the completion of its reception. For the highest priority, the delay time is 20 ms or less.

2. Bus utilization: The bus utilization is an index representing the rate of time when a message (including headers and error check codes) is on the communication line. The bus utilization is calculated based on the formula below:

Bus utilization = (Frame length) × (Number of transmission frames) / (Measurement time)

Table4 shows the results of the communication line evaluation, including bus utilization. According to this table, BEAN has sufficient performance for the body communication system even at a transmission rate of 10 kbps.

Table 4	Result of simulation.
Total transmission volume	19930325bit
Bus utilization	41.52147%
Average delay time	7.775ms
Maximum delay time	191.263ms

Verification - As explained above, according to the simulation, we confirmed that the proposed communication protocol satisfies the requirements for the body communications system and shows sufficient performance with regard to timing and reliability.
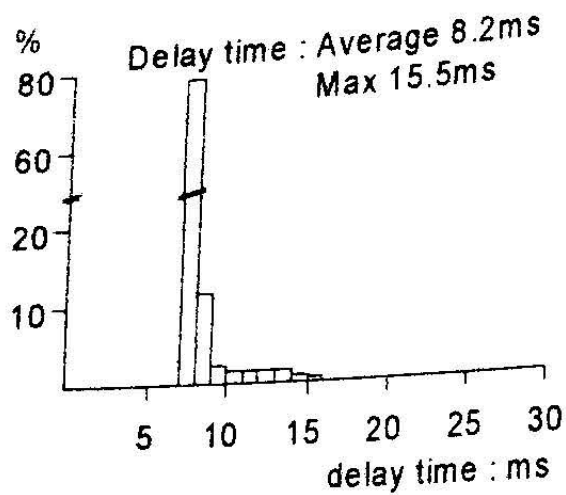
(a) The highest priority
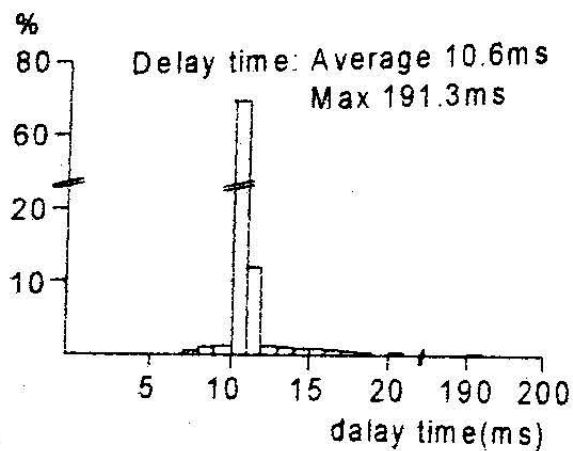
(b) The lowest priority

Figure 16: Delay time distribution.

FUTURE ISSUE OF THE BODY CONTROL NETWORK

The following subjects will arise as the use of in-vehicle body control network increases in the future.

EXPANSION OF COMMUNICATION CAPACITY - It will be necessary to consider the expansion of the communication capacity as the communication items and communication frequency increase. One method to meet this is to increase the transmission rate. However, to achieve this, it will be necessary to develop faster communication devices to avoid increasing the cost of the ECU. Another method is to reduce the amount of transmission data for each block by dividing the bus. For this case, it will be necessary to reduce the burden on the gateway by dividing the bus at points where the amount of transmission data is small.

IMPROVEMENT OF FAILSAFE - Currently, the body control system network handles only signals that do not affect control even if communication were to fail. As the number of systems increases, the signal communication range is enlarged while improving the redundancy of the communication lines. Additionally, depending on the type of vehicle, the wire harnesses may need to be run through an area where it may be exposed to a higher noise level. To solve this, it may be necessary to use wire harnesses which have a higher noise resistance. As a result, various physical layers, including a faster transmission rate, will be needed in the future.

CONNECTION TO OTHER LAN - In the near future, several types of LAN will be implemented in vehicles. Examples are shown below:

1. High speed control system bus for the power train and chassis control.
2. Low cost, low speed, flexible body control system bus .
3. High speed, large capacity multimedia system bus to transmit visual images and voice data.
4. Standard diagnostic bus for use with service tools.

Since each LAN has different features and each vehicle has different equipment, we don't believe it is a good idea to integrated all in-vehicle LANs into a single LAN. The in-vehicle network will be built by using several LANs that take advantage of the benefits of each LAN.

CONCLUSION

We have developed a new protocol that is applicable for large scale network systems, that can be implemented by the software program of a general single chip microprocessor. So engineers are free to select communication devices according to their specific applications. We also developed the physical layer for a high data transmission rate and low radiation noise. Case studies using the LS400 were conducted and excellent results concerning the bus utilization and data delay time were obtained. Additionally, the effect of wire harness reduction was calculated, and we found that approximately 15% of the wire harness could be reduced. As the body control system continues to change and evolve , while there is increasing pressure to reduce cost , the ability to select an optimal system that can meet all our design needs will be a vital issue to be tackled in the future.

ACKNOWLEDGMENTS

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Gateway Application for Automotive Network System "BEAN"

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ABSTRACT

In applying a LAN to automotive electronics systems, an optimal protocol has been adopted for each system so far, such as body electronics system, entertainment system, service system and power train system. As low cost communication protocol "BEAN" (Body Electronics Area Network; SAE paper 970297) adopted to wider range of functions on vehicle, ECU's numbers are increased which have BEAN communication and that is branched to plural communication networks. We have succeeded in rationalization of those network systems with the gateway function on a delegated ECU for each LAN system on vehicle. And this system also realized the connection to after market products by data exchange through the gateway function, while securing vehicle fail-safe.

INTRODUCTION

In applying a LAN to automotive electronics systems, these have been developed independently in several technical fields. We have introduced total control network, which is J1850 type of protocol since 1991. Since then, we are now developing the standard communication protocol that is suitable for high speed and periodically timing communication. That aims to simplify the optional connection and harmonized control in between power train system and chassis control system and so on. For entertainment system, its communication technology has been developed in order to be common connection method with the combination by components such as audio and navigation, communication and also after market product connection since 1994. For service system, its development has originally started with the legal requirement on diagnostics. Then it has been improved since 1994 in order to become common connection to tester tools and enhance diagnostic contents.

For body control system, single way communication to the driver's door ECU from body ECU has been adopted since 1992 in order to reduce wire harness to the door and function enhancement by information sharing between ECUs. After that plural ECUs have adopted

bilateral communication in 1994. BEAN has been developed and launched in 1997. BEAN is communication protocol that is low cost, low quiescent drain to drive and secure response characteristics for less frequent data transmission.

By the expansion of BEAN application to automotive electronics systems, ECU's numbers are increased which are connect to BEAN communication lines that is branched to plural communication networks. It is also required for after market products to connect to that communication network.

RATIONALITY OF VEHICLE LAN MOUNTED GATEWAY FUNCTION

GATEWAY BETWEEN ENTERTAINMENT LAN AND BODY CONTROL SYSTEM LAN – It's difficult to combine entertainment LAN had registration function for adding dealer-installed options to body control system LAN was required hi-response and had different operating power supply. The following to the vehicle control functions are connected with these two LANs.

- Operation of air-conditioner on multi-display
- Interactive control of navigation system and engine
- Integration of body control switches and audio control switches

To mount the gateway function on representative ECU that communicated between each LANs enables to reduce communication circuit parts and to decrease communication software load.
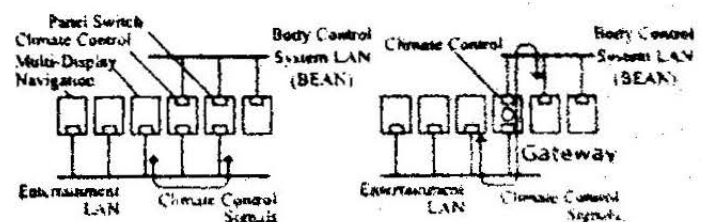

Figure 1. An Example of Construction between Entertainment LAN and Body Control System LAN

GATEWAY BETWEEN SERVICE LAN AND BODY CONTROL SYSTEM LAN – To enhance serviceability, it is essential to improve the diagnostic function. Conventionally, there are many cases in which a diagnostic tool cannot be used for diagnosing body control ECUs, because of a relatively small system size and cost restrictions. The matter is as good as after introduction of in-vehicle LAN. Since it's difficult to combine body control system LAN was required hi-response to service LAN was required standard, it's necessary for connecting a diagnostic tool to mount communication circuit and wiring. In this case, diagnostic tool is connected with many LANs. By mounting gateway function on representative ECU can be connected diagnostic tool enables communication of diagnostic frame format between the body control system LAN and diagnostic tool, resulting in the following advantages:

- Only one ECU has to be connected to the diagnostic tool. It is not necessary, therefore, to install additional hardware for diagnosis result outputs for multiple ECUs.
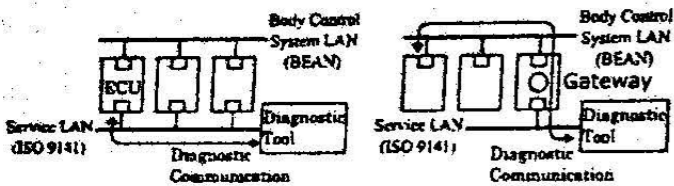- Service LAN communication software is not required for each LAN.

Figure 2. An Example of Construction between Service LAN and Body Control System LAN

GATEWAY BETWEEN BODY CONTROL SYSTEM LAN AND DEALER-INSTALLED OPTION LAN – Connection of dealer-installed options is indispensable to satisfy the diversifying needs of automobile users. For wiring to each optional ECU, it is necessary to connect joints to the cables of existing switches and actuators. If an in-vehicle LAN is introduced, it is possible to obtain various signals through the LAN. In connection of dealer-installed options, adverse influence of defective wiring of the vehicle is considered. It can be avoided by connecting gateway function ECU isolated each bus electrically.

DESIGN OF GATEWAY FUNCTIONS

Each of the above-mentioned three gateway functions have been designed as follows.

SPECIFICATION OF GATEWAY BETWEEN ENTERTAINMENT LAN AND BODY CONTROL SYSTEM LAN

Position of the gateway function – The gateway function should be implemented in an ECU that requires data from both entertainment LAN and body control system

LAN. The following points should be taken into consideration in selecting such an ECU:

- Allowance for gateway processing software load
- Reduced traffic in each communication line

In the above-mentioned application example, data is concentrated in the display. We have therefore decided to mount the gateway function in the display. An example construction is shown below.
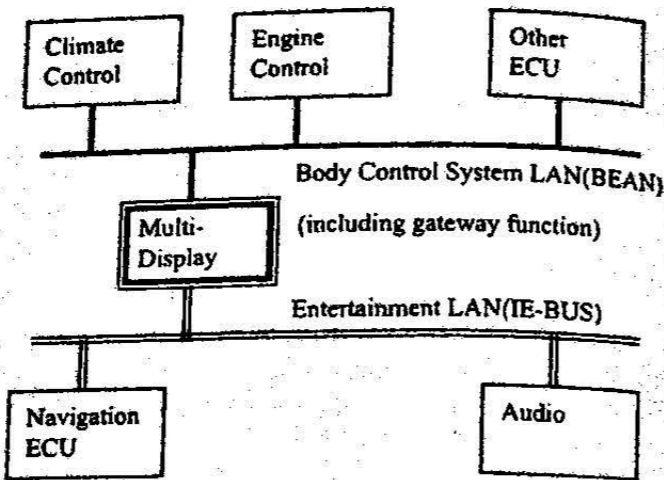

Figure 3. An Example of Construction between BEAN and Entertainment LAN

Protocol conversion – An example frame conversion is presented below.

The entertainment LAN uses IE-BUS protocol. Since the IE-BUS can handle longer data blocks than BEAN, the BEAN frame format is inserted in the data block of the IE-BUS frame format as shown in Figure 4, to enable the gateway ECU to process all data regardless of content.
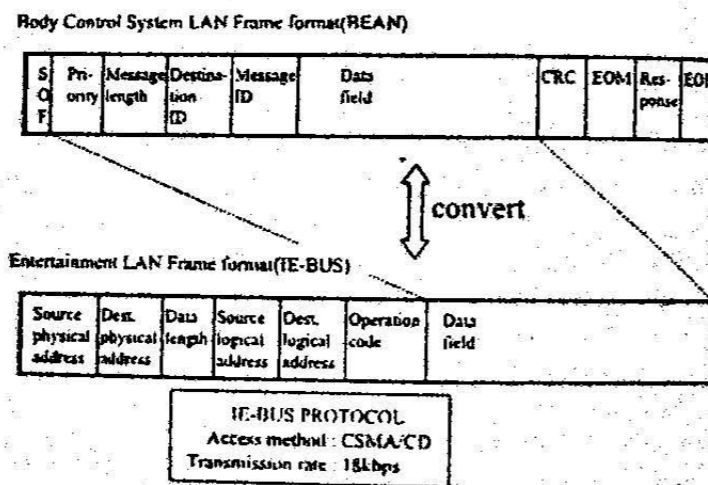

Figure 4. An Example of Frame Conversion

This type of gateway function has been achieved simply: both LANs access data using the CSMA/CD system, both provide close communication speeds, and both are required to handle a relatively small amount of gateway data.

SPECIFICATION OF GATEWAY BETWEEN SERVICE LAN AND BODY CONTROL SYSTEM LAN – This section describes the method of transmitting data from a diagnostic tool to a gateway ECU connected to the body control system LAN.

Method of connecting diagnostic tool – Figure 5 shows an example construction in which a diagnostic tool is connected via the body control ECU.
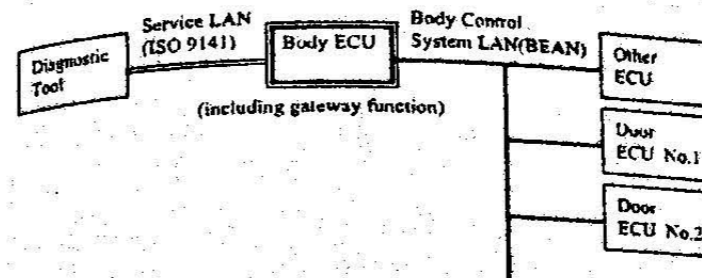

Figure 5. An Example of Construction between BEAN and ISO 9141

Basic operations are as follows:

1. Request frame for a target ECU is transmitted from the diagnostic tool to the body control ECU.
2. The body control ECU converts ISO 9141 frame format to BEAN frame format.
3. The target ECU transmits data in response to the request from the diagnostic tool.
4. The body control ECU converts BEAN frame format to ISO 9141 frame format.
5. The diagnostic tool receives the response sent by the target ECU via the body control ECU.

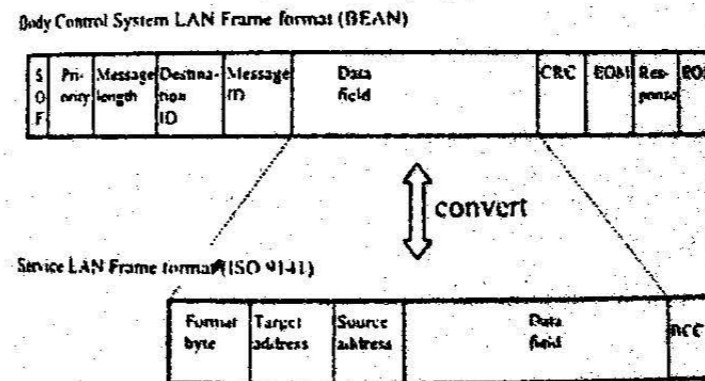An example conversion between ISO 9141 and BEAN frame formats is shown below.

Figure 6. An Example of Frame Conversion

ISO 9141 frame format comprises 11 bytes: 3bytes of header and a maximum of 8 bytes of data. Since the BEAN data length is variable to a maximum of 11 bytes, the entire ISO 9141 frame format can be included as data in the BEAN frame format. Except at initialization, the ECU serving as a gateway between ISO 9141 and BEAN

only performs simple frame conversion as a relay, and does not process data according to the content, which is important in view of ensuring future expandability.

ISO 9141 protocol uses a master and slave, with a tool as the master, whereas BEAN uses the CSMA/CD system. These two protocols differ in basic characteristics. The ISO 9141 specifies the timing at which a slave (target ECU) responds to a request from the master (tool). For BEAN, on the other hand, it is difficult to specify an exact communication delay time, since it uses the CSMA/CD system to access data. To the request that an ISO 9141-based master transmits to a slave, the slave is required to respond within 50 ms. With the construction shown in Figure 5, however, there is a possibility that the slave cannot respond within the specified time, due to the time required for data transmission from the body control ECU to the target ECU, and from the target ECU to the body control ECU.
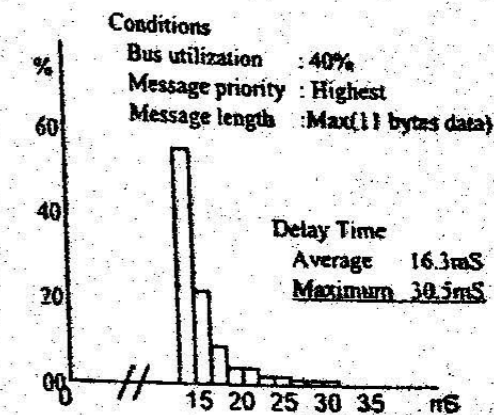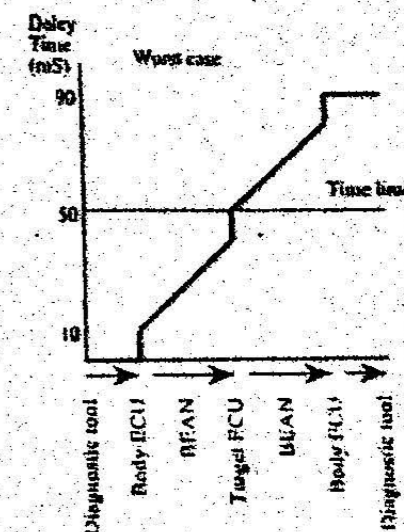

Figure 7. Message Latency

Figure 8. Operation Latency

Use of negative response – The service tool has the function of receiving negative response. Negative response provides the specification for extending the time-out value in cases where a response cannot be transmitted within the specified time.

An example of an operation sequence involving a negative response is shown below with reference to Figure 9.

1. Initialization of service bus
2. Connection request to target ECU
3. Response from body control ECU (for target ECU)
4. Communication request to target ECU
5. Gateway operation by body control ECU
6. Negative response from body control ECU
7. Response from target ECU
8. Gateway operation by body control ECU

Until a response is sent from the target ECU, the body control ECU continues to send a negative response to the service tool, enabling the tool to wait for a response from the target ECU. Time-out process has been added to each step of the procedure, to prevent locking in the case of failure of any equipment.
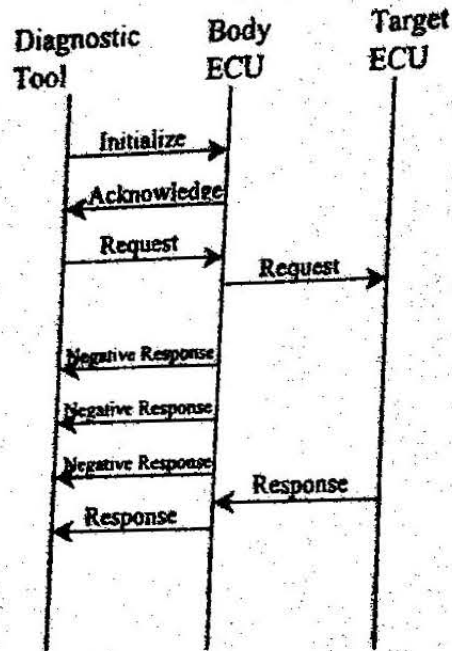

Figure 9. Operation Sequence

The gateway function for diagnostic tools has been realized by the above-mentioned method.

SPECIFICATION OF GATEWAY BETWEEN DEALER-INSTALLED OPTION LAN AND BODY CONTROL SYSTEM LAN

Method of connecting the bus of dealer-installed options – This section describes the method of connecting dealer-installed options to the in-vehicle LAN. Figure 10 shows the construction in-vehicle the dealer-installed option LAN connected with the body control system LAN via the gateway function. We call midget ECU that mounted gateway function for connecting dealer-installed options "bus buffer".
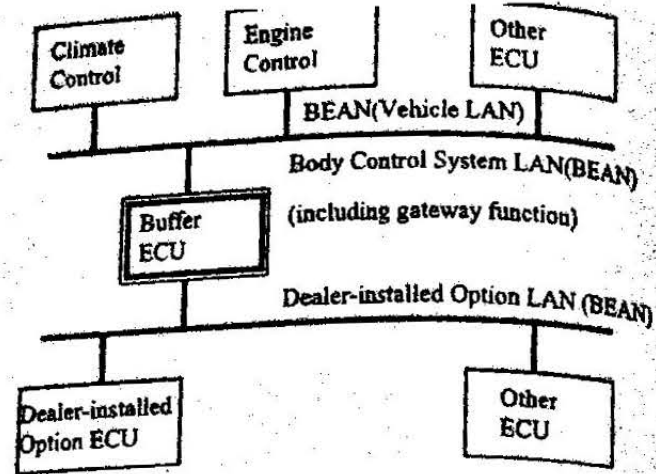

Figure 10. An Example of Construction between Vehicle and Dealer-installed Option LAN

BEAN has been adopted as the communication protocol for the dealer-installed option LAN, as well as for the body control system LAN. Basic gateway operation is as follows.

Gateway from the body control system LAN to the dealer-installed option LAN

1. Dealer-installed option bus buffer receives the BEAN frame format from the body control system LAN.
2. After changing the destination ID of the BEAN frame format, the bus buffer transmits the format to the dealer-installed option LAN.

Gateway from the dealer-installed option LAN to the body control system LAN

1. Dealer-installed option bus buffer receives the BEAN frame format from the dealer-installed option LAN.
2. The BEAN frame format undergoes a security check.
3. The frame is reorganized.
4. The reorganized frame is transmitted to the body control system LAN.

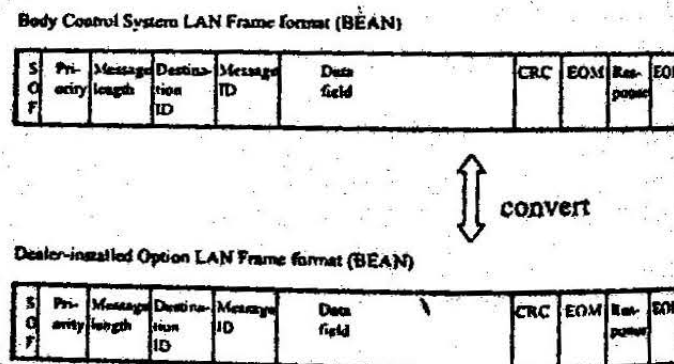Figure 11 shows an example frame conversion.

Figure 11. An Example of Frame Conversion

The gateway between the body control system LAN and the dealer-installed option LAN is designed such that it can deal with relatively high traffic volume, providing for

future expansion of dealer-installed options. When each LAN has heavy traffic, frames to be transmitted may remain in each bus buffer. A communication data buffer is necessary to prevent the remaining frames from being lost.

Adoption of communication data buffer – Investigation revealed that, in data transmission from the body control system LAN to the dealer-installed option LAN, the number of frames remaining in the bus buffer becomes the largest when a combination of successive long and short frames occurs as shown below.
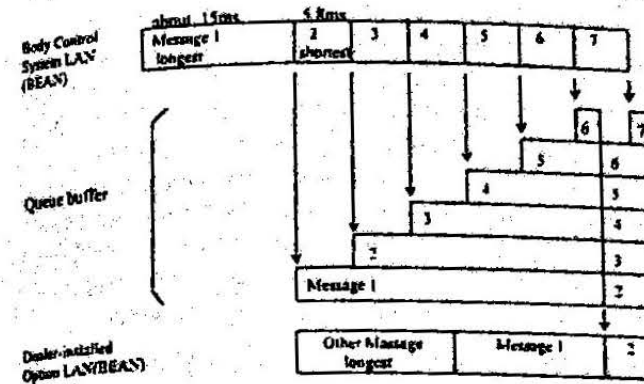

Figure 12. Data Flow in Bus-Buffer

Based on this finding, it has been determined that any dealer-installed option requires six stages of bus buffer.

EFFECT OF GATEWAY

VEHICLE SYSTEM CONFIGURATION – Figure 13 shows an example application of the above-mentioned gateway functions to an actual vehicle.
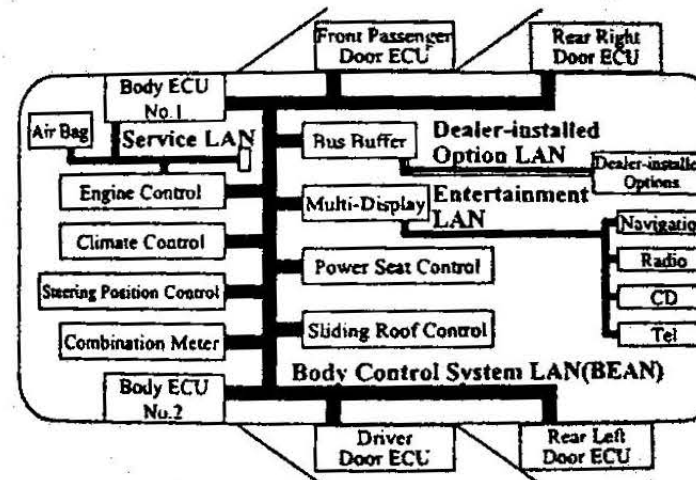

Figure 13. An Example of System Configuration

Gateway function between entertainment LAN and body control system LAN is mounted multi-display ECU. Gateway function between service LAN and body control system LAN is mounted body-ECU-No.1. Gateway function between dealer-installed option LAN and body control system LAN is mounted bus buffer.

EFFECT OF GATEWAY BETWEEN ENTERTAINMENT LAN AND BODY CONTROL SYSTEM LAN – The utility of gateway between entertainment LAN and body control system LAN, but in Figure 13 shows only one example of applying to multi-display, is expected expanding, for example, interactive control of navigation system and engine and using speed-data from instrument-panel-cluster to navigation system and audio control.

EFFECT OF GATEWAY BETWEEN SERVICE LAN AND BODY CONTROL SYSTEM LAN – Figure 14 shows the result of a number of ECU can be diagnosed, in which compared after introduction of gateway between service LAN and body control system LAN with before.
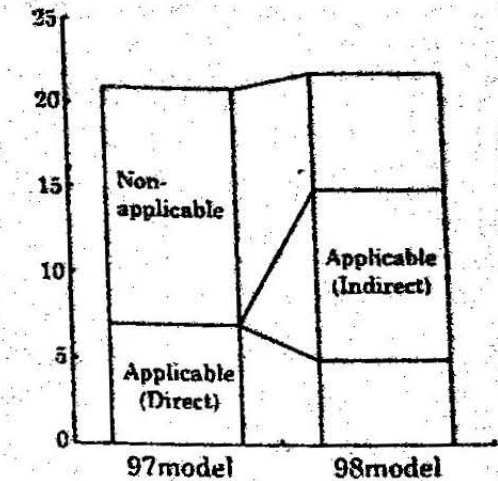

Figure 14. Number of ECUs Communicating with Diagnostic Tools

By the introduction of the gateway between ISO 9141-based LANs and the body control system LAN(BEAN), 10 ECUs can be indirectly connected to the diagnostic tool. As a result, the number of ECUs can be diagnosed has increased by 8.

By implementing the relay function between ISO 9141-based LANs and the body control system LAN (BEAN), the following functional enhancement has been achieved easily.

Changeable shipment information on-board – By using the diagnosis connector installed in a completely assembled vehicle, it is possible to set each ECU connected with the LAN memorizing shipment information, from the facility in the vehicle assembly line. This feature is useful to minimize parts numbers of ECUs.

According to this shipment information ECUs connected to the LAN can behave properly in accordance with destinations it has shipped.

Settings at dealers in accordance with customers' requests (Customize function) – With a service tool connected to a diagnosis connector linked to ISO 9141-based LANs, if ECUs are set memorizing customized information in accordance with customers' requests. As a

result it is possible to change the sound volume of the alarm buzzer, etc. and to add or remove optional functions.

These features can be added to all ECUs connected to the LAN if gateway functions are mounted.

EFFECT OF GATEWAY BETWEEN A DEALER-INSTALLED OPTION LAN AND BODY CONTROL SYSTEM LAN – By the gateway between dealer-installed option LAN and body control system LAN, we could reduce the wire-harness and wiring work for installation of a remote-engine-starter.

VARIATE OF GATEWAY DATA – The following diagram shows gateway data among entertainment LAN, dealer-installed option LAN and body control system LAN.
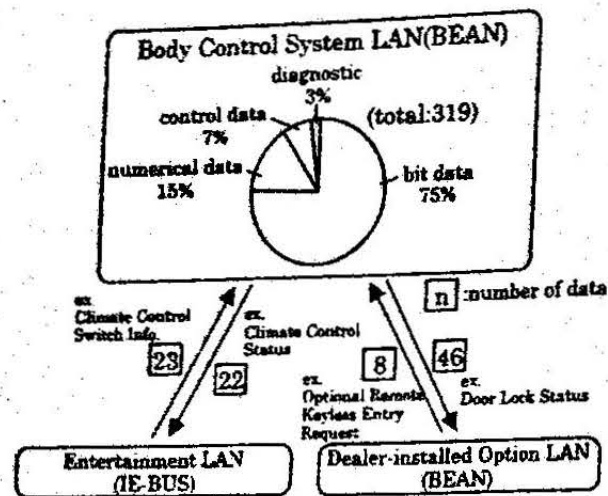

Figure 15. Gateway Data Volume

There are 319 kinds of data in body control system LAN. Gateway data are 45 kind of entertainment LAN data and 54 kind of dealer-installed option LAN data.

FUTURE TASKS

1. It is anticipated that gateway function handling ECUs number will be increased with LAN application expansion. And the processing load of ECU for communication becomes higher according to the increased communication data. It is predictable that an exclusive gateway function ECU could be required to develop to apply for valiant vehicles as it is possible to save software and hardware development cost on the conventional ECU to additionally add on. Thus exclusive ECU could be achieved both high reliability and cost reduction by the drastic IC customization.

2. Although vehicle manufacturers adopted their own protocols for LAN, these are standardizing step by step. It is recommended to improve the automotive electronics system architecture by degree with gateway function adoption to avoid the protocol modification in short term with enormous development expenditure.

3. It will be necessary to protect vehicle information leakage and improve fail-safe capability depend on outside bus connection, i.e. ITS bus, and enhancement of communication information. We will expand gateway function more in order to establish firewall function and security function.

CONCLUSION

Gateway functions that exchange data among three independent LAN which are body control, entertainment control and diagnostics system has been developed. This function makes easier for ECUs to adopt LAN communication with saving cost increase to avoid each ECU connects to plural communication bus, while ECU numbers are increased which are connect to different LAN system. The method for data communication on body control LAN to outside through gateway function has also been developed. This method has brought after market products to reduce installation workload at dealer with maintaining the same fail-safe capability as before installation.

These gateway function has realized whole vehicle network system which effectively applies the each network merit and adopt own strategy for each system.

ACKNOWLEDGMENTS

REFERENCES

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Real-Time Software for In-Vehicle Communication

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ABSTRACT

This paper describes the architecture and the implementation of a software for the communication between networked in-vehicle ECUs.

The communication software is based upon a real-time multitasking operating system. The operating system and the communication software form an application-independent platform for the implementation of distributed ECU software.

The software architecture consists of several communication layers and a station management module. The communication layers provide network driver, data transfer services and an application interface that is independent of the used network protocol. The station management module is responsible for configuration and initialization of the communication controller, error detection during operation and error handling.

The modular structure of the architecture supports the simple adaptation of the software to different bus systems and communication controllers. The network-independent application interface frees the programmer from knowing the details of the used communication network and supports the reuse of application software in diffferent projects. The software is part of the diesel engine management in production cars.

The paper presents the architecture of the communication software, the operating system, the services of the different communication layers, the station management module and the results from the implementation of the communication software.

1. Introduction

Serial data buses are increasingly being used for the networking of in-vehicle electronic control units. Protocols such as the Controller Area Network (CAN) and the Vehicle Area Network (VAN) have now been standardized and are supported by several semiconductor manufacturers. A wide variety of components is available today to implement the CAN protocol in hardware. Software support for networked ECUs, however, is still in its infancy. Harmonization of software interfaces and definition of additional communication functions (network management for example) has been done in the frame of the OSEK project (Open Systems and Interfaces for Electronics in Cars) [1]. Specifications of services and interfaces for real-time executives, communication and network management are now available [2] and will be used in various pilot projects.

This paper describes the results of a project which aimed to create reusable communication software. The work was based on the architecture model described in [3]. The software developed represents a concrete implementation of the architecture proposed in [3] and conforms with the OSEK specification.

2. Requirements and design goals

The aim of the project was the development of real-time communication software for data exchange between the components of distributed ECUs. The software platform used in these ECUs is a multitasking operating system. The operating system represents a programming and runtime environment on the basis of which the application software is implemented in the form of a modular-structured set