Ringing suppression technology to achieve higher data rates using CAN FD

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ABSTRACT – As the number of electronic control units (ECUs) in an automobile steadily increases, the demand significantly rises for achieving higher data rates, and for connecting more ECUs into Controller Area Network (CAN). As a method to achieve higher data rates up to 10 Mbps without change in the existing CAN system, CAN FD (CAN with Flexible Data-rate) is proposed. However, it is difficult to establish a CAN FD communication under the network which has much signal ringing, because the bit decision timing is shortened while the ringing convergence time is same as in conventional CAN. As a result, it has to limit network size, and this means potential of CAN FD is not enough pilled out.

In this paper, we propose ringing suppression technology to boost CAN FD world which shortens the ringing convergence time, and which enables CAN FD communication with higher data rates. Typical network configurations are considered, and showed the effect of the technology up to 2 Mbps.

Introduction

Recently, the rapid computerization of the vehicle control system has boosted the increase of the quantity of communication data and the number of electronic control units (ECUs) mounted in a vehicle. These ECUs are connected to in-vehicle networks such as the Controller Area Network (CAN) [1], which is an international standard for the control domain, to realize a high-level system. It is expected that the quantity of communication data and the number of ECUs connected to in-vehicle networks will surely increase in near future.

A higher data rate is necessary to increase quantity of communication data. However, it will induce higher probability of communication error because the bit decision timing of the bit width is to be shortened. The data rate of CAN is typically up to 1 Mbps, however considering signal ringing, it is usually used for actual implementation on vehicles under following limitations; the number of ECUs is less than 16 ECUs [2], data rate as 500 kbps or 250 kbps. As a method to achieve higher data rates up to 1 Mbps or higher, excluding the arbitration of the transmission rights and changing the reply method of ACK are suggested [3].

However, these suggestions limit the topology as P to P (Peer to Peer), and require the modification of the controllers, which significantly differ from the conventional CAN. From the compatibility point of view, suppressing signal ringing is promising to achieve higher data rates in CAN communication without drastically changing the existing controlling hardware and software.

However, the increase in the number of connected ECUs enlarges the signal ringing, as well as the probability of communication errors [4] – [6]. Therefore network size is limited to establish communications, also in CAN. In case that the network size grows beyond this limit, it has to be divided and connected using broadcast devices such as gateway (GW) ECUs. However, using GW ECUs often leads to cost increase and communication delays [7] [8]. Therefore, a technology is needed to suppress the signal ringing which enables to expand the network size. For suppressing the signal ringing, introducing filter circuits [9] and ferrite [10] [11] are usually taken. However, these dampen not only the ringing but also the signal itself depending on the position and the number installed. As a result, the signal rounding might increase communication delays.

Recently, as a method to achieve higher data rates up to 10 Mbps without change in the existing CAN system, CAN FD (CAN with Flexible Data-rate) is proposed [12] - [15]. The main improvement is the boost of speed in the data frames by shortening the bit duration when just one node is allowed to transmit. However, the signal ringing might occur, which makes the network size limit to establish communications, because physical layers are the same as CAN. Therefore, a technology is needed to achieve higher data rates under the conventional network size and the number of connected ECUs. In our previous study, the ringing suppression circuit applying into conventional CAN [16] was proposed. In this paper, the technology, ringing suppression technology is applied into CAN FD. This suppression effect on higher data rates up to 2 Mbps is shown under the conventional network configuration with using prototype chip.

Physical layer of CAN FD

CAN FD is developed based on physical layer of CAN. Therefore conventional CAN transceiver is usable in CAN FD and the communication method is the same as CAN. In addition, various topologies can be adopted for CAN FD network, such as bus, star or these mixtures. Figure 3 shows frame format of CAN FD. The frame of CAN FD is constructed in an arbitration phase and a data phase. Due to the arbitration phase is the same as conventional CAN, the transmission rate is less than 1 Mbps. In the data phase, only one ECU which wins the arbitration can communicate and the transmission rate up to 10 Mbps is possible. The dominant and recessive periods are determined by the value of the differential voltage at the sampling point set in the latter half of the bit (Figure 4). The position of the sampling point in a data phase is different from one in an arbitration phase. The nominal bit has Prop_Seg to absorb the propagation delay of a bit other nodes transmitted in the arbitration phase. Because a transmission node is only 1 node, in the data phase, the nominal bit does not have Prop_Seg.

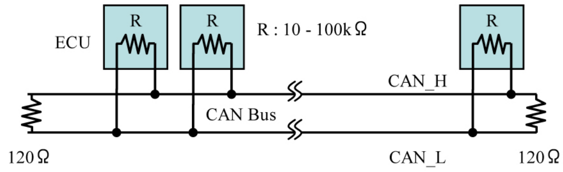

Figure 1: Physical layer of CAN FD

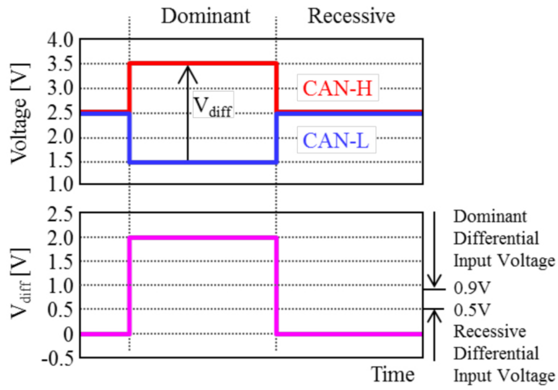

Figure 2:CAN FD typical voltage waveform

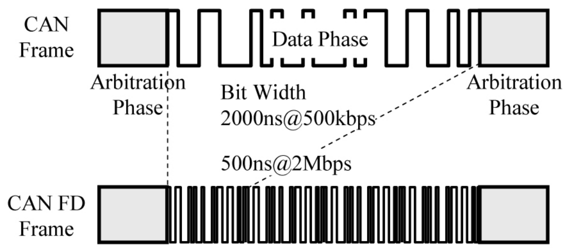

Figure 3 : CAN FD frame

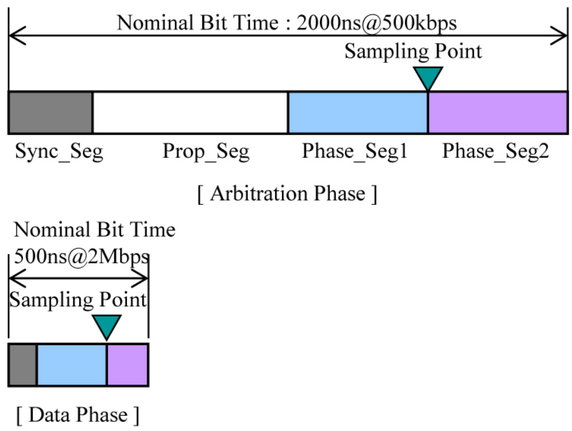

Figure 4 : Sampling point

Issues for higher data rates with CAN FD

Because the physical layer of CAN FD is the same as CAN, a ringing is generated by the reflections of communication voltage wave which occur because of impedance mismatches in a network at the signal transition frequencies [16]. The impedance mismatches occur mainly non-terminal ECUs and the junction.

When a transmitter outputs recessive state, the output of the transmitter becomes the high impedance. Therefore large signal ringing occurs in the transition from recessive to dominant in particular. In addition, a negative reflection occurs at a junction because the impedance decreases at a junction which means lower than the characteristic impedance. When ringing does not converge below predetermined voltage by the sampling point, a bit malfunction occurs. Therefore the network size is limited to establish communications.

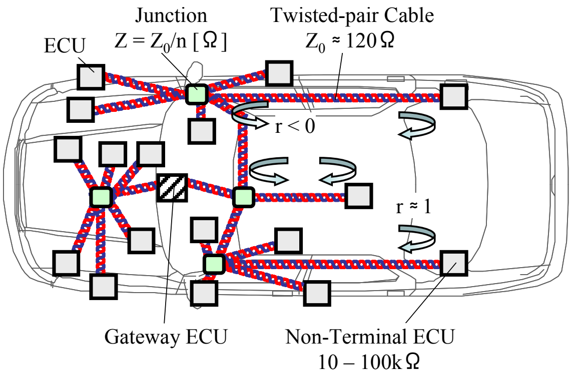

Figure 5 : Ringing generation mechanism

Because ringing does not depend on the transmission rate, the ringing in a high-speed data phase is the same as that in a low speed arbitration phase. However, bit width shortens when the transmission rate becomes higher. Therefore the time from bit transition to the sampling point is shortened. The ringing is to be converged earlier in a data phase than in an arbitration phase.

Criteria to establish communication

In CAN FD, when a bit inversion occurs in the reception waveform, an error is detected by various error detection functions in the receiver. After that, the communication is maintained by requesting a re-transmission to the transmission ECU. However, constant ringing may occur depending on the network configuration which overrides this re-transmission method. So, the criteria is set for establishing communication as the longest ringing convergence time by the received voltage level gives valid state of dominant/recessive at the receiver.

The dominant / recessive state is determined by the level of the differential voltage at the sample point. Because the threshold defined for the recessive is less than 0.5 V, the ringing voltage at the transition from dominant to recessive must converge to less than 0.5 V at the sample point.

In this study, the transmission rate of the arbitration phase is set to 500kbps and the transmission rate of the data phase to 2 Mbps. At first the process in the arbitration phase is same as CAN, so it is necessary to consider a propagation delay from a transmission node to a reception node. Considering the above, the ringing convergence time at state transition from dominant to recessive is set less than 841 ns as the criterion for establishing communication.

Secondly, in the data phase, the time from the bit transition to the sampling point is set as criterion for establishing communication because the propagation delay of the bit which other nodes transmitted is unnecessary to be considered. In this study, a sampling point is set as 80 % of nominal bit width. Because the bit width is 500 ns, in the case of 2 Mbps, the ringing convergence time at state transition from dominant to recessive is set less than 400 ns as the criterion for establishing communication of the data phase.

Method of ringing suppression

Principle

Using low-pass filters (LPFs) is a common method of ringing suppression, but the attenuation of the high frequency band causes increase of the waveform rounding. As a result, communication delays might increase as well, which is not desirable.

Ringing is suppressed if the impedances at junctions are increased or the impedances of non-terminal ECUs are decreased at the signal transition frequencies. However, the impedance at a junction split into n branches drops to Z0 / n Ω as mentioned before, which is inevitable without introducing LPFs. Therefore, in this paper, a method of ringing suppression by reducing the impedances of non-terminal ECUs is examined.

As for the signal frequency band, CAN network has 60 Ω impedance for transmitters because usually two split terminations as total 120 Ω are installed and non-terminal ECUs have high impedance. The CAN transceiver is designed so that the dominant voltage is 2 V with 60 Ω load connected. Therefore, the impedance of non-terminal ECUs must be high during the dominant period to avoid the dominant voltage drop. In addition, high impedance is also necessary because other ECUs might start dominant output in the latter half of a bit in recessive period and lowering the impedance interrupts them. However, the drop in impedance does not influence CAN communication during the first half of the recessive period, which enables the operation to the impedance of non-terminal ECUs to suppress the ringing using this period. We propose a method which ECU itself detects the transition from dominant to recessive states based on the received voltage and reduces its impedance for a certain period while suppressing the ringing.

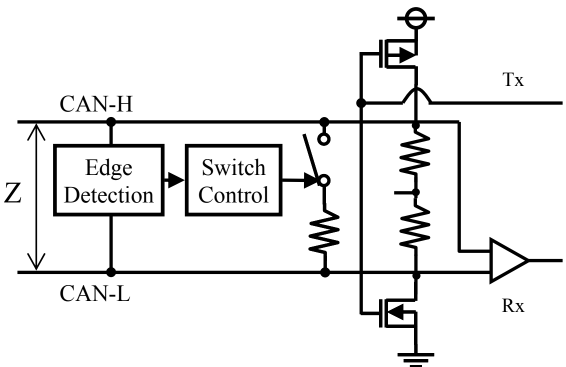

Figure 6 : Concept of ringing suppression circuitry

Circuit structure and behaviour

Figure 7 shows an explanatory example circuit implementation of the proposed method. The ringing suppression circuit is composed of four MOSs and a delay circuit. NMOS0 has the role to suppress the ringing and it is equivalent to the series circuit comprising a resistor and a switch described in Figure 6. The ON resistance of NMOS0 has a value that is almost equivalent to the characteristic impedance of the twisted pair cable. So, NMOS0 absorbs the incoming voltage wave of ringing frequency, and which suppresses the ringing. NMOS0 is applied with a gate voltage when both NMOS1 and NMOS2 connected between its gate and source in parallel turn OFF. The gate voltage is in the range between the voltages of the voltage source and CAN_L.

NMOS1 has a role to detect the falling edge of the bus voltage at the time of transition from dominant to recessive states, and start the ringing suppression function. The gate voltage of NMOS1 is the differential voltage between CAN_H and CAN_L. Therefore, it is applied with approximately 2 V at the dominant, which turns NMOS1 ON. On the other hand, the gate voltage of NMOS1 becomes approximately 0 V at the recessive, which turns NMOS1 OFF. In this way, NMOS1 becomes OFF only at the recessive state.

NMOS2 and NMOS3 in a pair have a role to end the ringing suppression function after a certain period since the state transition from dominant to recessive states. NMOS2 is required to invert the ON-OFF state of NMOS3. The gate voltage of NMOS3 is applied with the bus voltage passing through a delay circuit. Therefore NMOS3 is in ON state during the dominant state. The state is maintained right after transition from dominant to recessive states during a certain period defined by the delay circuit. Because both NMOS1 and NMOS2 are in OFF state during this period, NMOS0 is ON and suppresses the ringing. After that when NMOS3 turns OFF, NMOS0 turns OFF and the ringing suppression is ended. In this way, a simple circuit composed of only four MOSs can suppress the ringing.

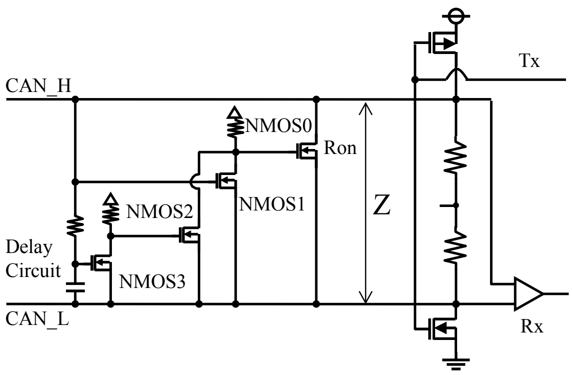

Figure 7 : Ringing suppression circuitry for explanatory example

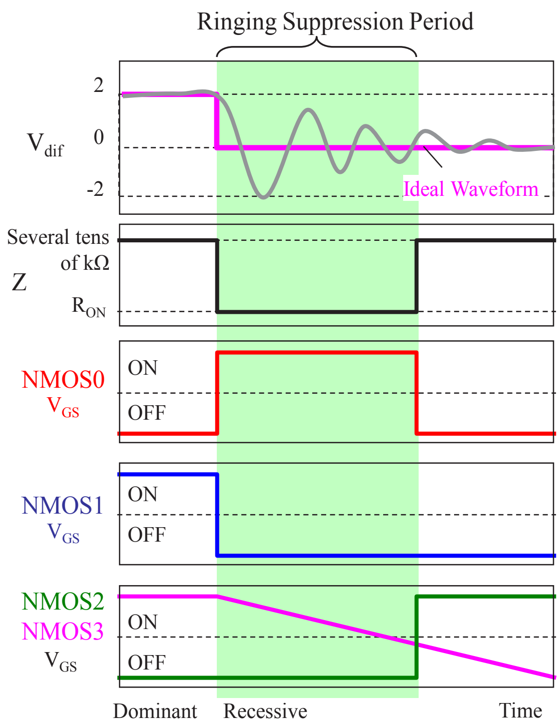

Figure 8 : Operating principle on proposed circuitry

Verification network configuration

In this study, the criterion for the bus differential voltage was set as less than 841 ns for its convergence time. Therefore, the worst case is when the amplitude of the reflected wave is the largest and its period is the longest. The maximum amplitude occurs when the reflectance at junctions is the highest and a reflection wave arrives at the reception ECU comprising multiple reflection waves arriving all at once. Furthermore, the maximum period occurs when the length of the transmission path is the longest. Figure 9 shows verification network configuration designed in consideration of these three essential conditions, where 'Tx' means the transmission ECU and 'Rx' means the reception ECU. In this verification network configuration, all ECUs except those for transmission and reception are connected to the junctions of both ends to assure maximum reflectance at the junctions and the junctions are located at isometric and farthest positions from the reception ECU to receive reflection waves latest at the same time. If the communication is not established in the 8-ECU network configuration, the ECUs connected at the junction of both ends are reduced until the communication is established.

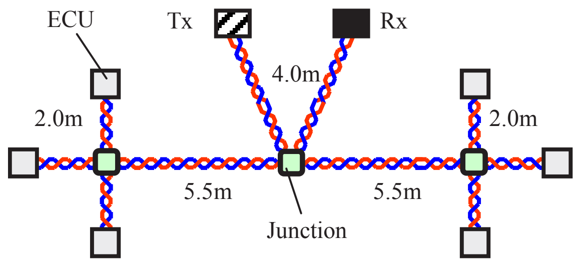

Figure 9 : Verification network configuration with 8 ECUs

Prototype verification

A prototype CAN transceiver was developed embedding the proposing ringing suppression circuitry and an evaluation board equipped with CAN FD controller (Figure 10). It was applied to a transmission ECU and a reception ECU of verification network, and verified the communication establishment under the number of connectable ECUs.

Figure 11 shows waveform under 8 ECUs configuration (Figure 9). These are reception waveforms in the arbitration phase at the reception ECU. In case using conventional CAN transceivers without the ringing suppression circuit, the ringing convergence time is 770 ns, so it satisfies the criterion of the arbitration phase. On the other hand, when the prototype CAN transceivers with the embedded ringing suppression circuit are applied to the same network configuration, the ringing convergence time is 297 ns, which means it is reduced as 473 ns.

Figure 12 shows the reception waveform of the data phase. In case using conventional CAN transceivers, ringing does not converge by the criterion time, and it interferes to the next dominant bit. As a result, the evaluation board detected a communication error and output an error frame. Therefore, it is impossible to have communication establish in the network of 8 ECUs using conventional CAN transceivers. On the other hand, in case using prototype CAN transceivers embedded ringing suppression circuitry, the ringing convergence time is 300 ns. As a result, the ringing convergence time satisfies criterion and enables communication under the network configuration with 8 connected ECUs.

Figure 13 shows the largest network configuration using conventional CAN transceivers. Figure 14 shows the reception wave pattern of the data phase. In case using conventional CAN transceivers, because the ringing convergence tine is 392ns, CAN FD communications are established. However there are not enough margins to increase the number of the connected ECUs.

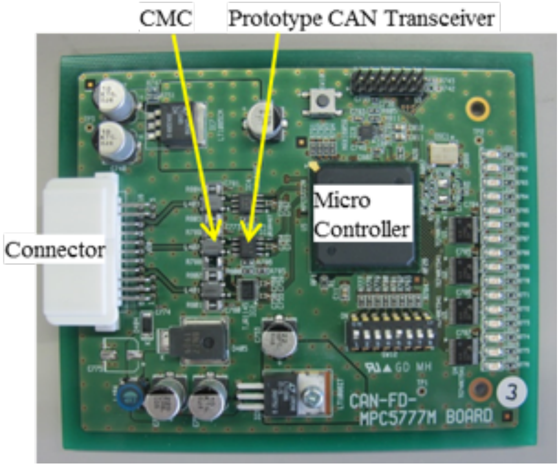

Figure 10 : Prototype CAN FD evaluation board

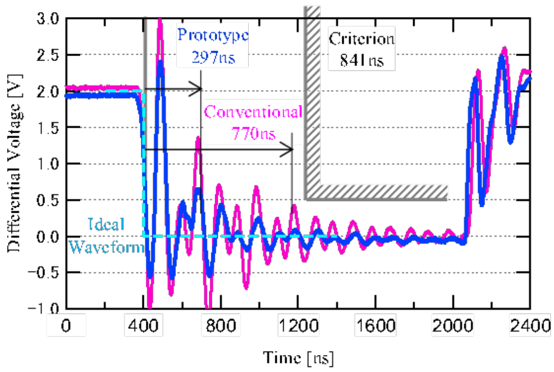

Figure 11 : Waveform on 8-ECU configuration (BRS bit)

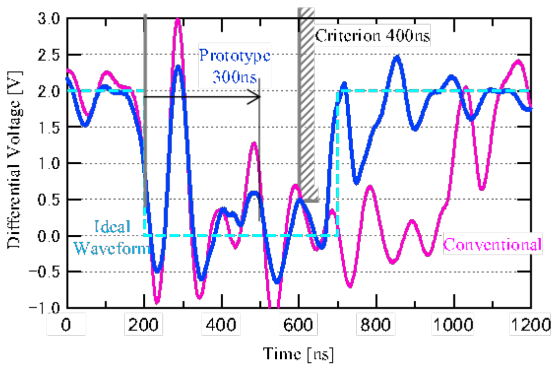

Figure 12 : Waveform on 8-ECU configuration (DLC3 bit)

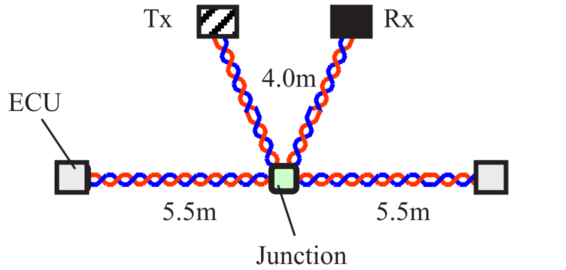

Figure 13 : Possible largest network using conventional CAN transceiver

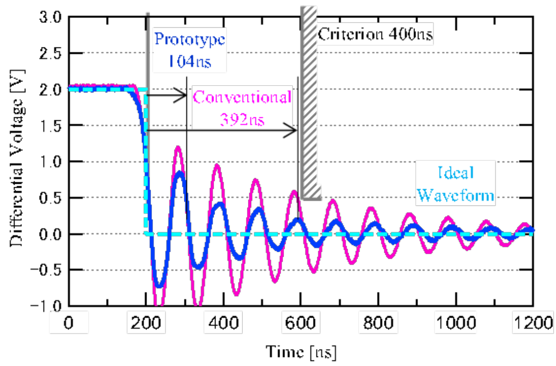

Figure 14 : Waveform on 4-ECU configuration (DLC3 bit)

Conclusions

In this paper, we proposed an application of the ringing suppression circuitry into CAN FD. The effect on higher data rates up to 2 Mbps was demonstrated under the conventional network configuration using the prototype transceivers and the evaluation boards.

Ideally CAN FD is able to achieve higher data rates up to 10 Mbps without change in the existing CAN system. CAN FD is developed based on physical layer of CAN. Therefore, signal ringing occurs in particular at the time of transition from dominant to recessive states. The criterion was set for the communication signal of the arbitration phase and the data phase to establish CAN FD communications. The signal ringing does not depend on a transmission data rate but is decided by the network configuration. In this paper, it was assumed that transmission data rate with 500 kbps in the arbitration phase and 2 Mbps in the data phase. Because the criterion for the data phase was severer than that for the arbitration phase, the ringing suppression period was adjusted to fit the data phase. The effect of signal ringing suppression was demonstrated using prototype CAN transceivers embedded the ringing suppression circuitry and evaluation boards. It was shown that it could establish the communication even for a network configuration with 8 ECUs while the network configuration using conventional CAN transceivers was limited up to 4 ECUs. That means it is possible to reduce the number of GW ECUs in large CAN FD network configurations. As a result, costs and communication delays of CAN FD networks can be reduced. The results suggest that this ringing suppression technology can be applied to communication ICs for use in future high-speed communications, too.

For future studies, the further confirmation of ringing suppression effects and functional robustness will be proceeded using the transceivers which were already developed.

On the other hand, this technology was submitted to CiA for standardization and submission to ISO, and it is described in CiA 601-4. The further preparation for the standardization will be conducted.

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