Ringing suppression in CAN FD networks

In star and hybrid topology networks, the ringing needs to be suppressed in particular at higher bit-rates. This can be achieved by the method described in the CiA 601-4 specification.

When using line topology with a proper termination and connecting just two nodes, there is no significant ringing on the bus. Connecting more than two nodes, the ringing becomes an issue. With unterminated stub-lines the ringing becomes serious. In star topologies and hybrid topologies, the ringing can corrupt the communication. This means, it is necessary to suppress the ringing. 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.

The increase in the number of connected ECUs enlarges the signal ringing, as well as the probability of communication errors. Therefore network size is limited to establish communications, also in Classical CAN networks. This is even more critical in CAN FD networks running at higher bit-rates (e.g. 2 Mbit/s). Of course, you can reduce the number of nodes in a network segment and introduce a second segment interconnected by means of a gateway ECU. However, using gateway ECUs leads to cost increase and communication delays. Therefore, a technology is needed to suppress the signal ringing, which enables expanding the network size. For suppressing the signal ringing, introducing filter circuits and ferrite are usually taken. However, this dampens 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.

The CAN FD physical layer

CAN FD networks use transceivers compliant with ISO 11898-2 qualified for the chosen data-phase bit-rate



Figure 2: Evaluation board using CAN transceivers compliant with ISO 11898-2:2016 integrating the ringing suppression circuitry (RSC) as specified in CiA 601-4 (Photo: Denso)

(e.g. 2 Mbit/s or 5 Mbit/s). The topology is not internationally standardized. Depending on the used topology, the system designer specifies the sample-point of the bit-timings for the data-phase and the arbitration phase. Due to the inbit-time detection in the arbitration phase, the maximum speed is limited to 1 Mbit/s. In the data phase, when only one node transmits data, it is possible to send at higher speeds. The dominant and recessive periods are determined by the value of the differential voltage at the samplepoint set in the second half of the bit. The position of the sample-point in the data-phase is independent of the sample-point in the arbitration phase.



Figure 1: Principle of the ringing suppression circuitry (RSC) (Photo: Denso)



Figure 3: RSC implementation used in Denso's study (Photo: Denso)



Figure 4: Operating principle on proposed circuitry (Photo: Denso)

In CAN FD networks with more than two nodes, 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. The impedance mismatches occur mainly at not-terminated nodes and the junction. When a transmitter outputs recessive state, the output of the transmitter has a high resistance. 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.

Because ringing does not depend on the transmission rate, the ringing in the "high-speed" data-phase is the same as 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 the data-phase than in an arbitration phase.

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 transmitting node. 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 level of the differential voltage at the sample-point determines if the bit is regarded as dominant or recessive. \triangleright

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Figure 5: CAN FD network configuration with eight nodes used in Denso's study (Photo: Denso)

Because the threshold defined for the recessive state 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.

Experimental study and its results

In our study, the transmission rate of the arbitration phase was set to 500 kbit/s and the transmission rate of the data phase to 2 Mbit/s. At first, the process in the arbitration phase is the same as in Classical 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 was set less than 841 ns as the criterion for establishing communication.



Figure 6: Waveform on 8-nodes configuration at BRS bit (Photo: Denso)



Figure 7: Waveform on 8-nodes configuration at DLC3 bit (Photo: Denso)



Figure 8: Possible largest network using conventional CAN transceiver without RSC (Photo: Denso)

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 our study, a sample-point was set as 80 % of the nominal bit-time. Because the bit width is 500 ns, in the case of 2 Mbit/s, the ringing convergence time at state transition from dominant-to-recessive was set less than 400 ns as the criterion for establishing communication of the data phase.

We used in our study a method of ringing suppression by reducing the impedances of unterminated nodes. As for the signal frequency band, CAN network has a $60-\Omega$ impedance for transmitters because usually two split terminations as total 120 Ω are installed and unterminated nodes have a higher impedance. The CAN transceiver is designed so that the dominant voltage is 2 V with $60-\Omega$ load connected. Therefore, the impedance of unterminated nodes must be higher during the dominant period to avoid a voltage drop. In addition, higher impedance is also necessary because other nodes might start dominant output in the second half of a bit in recessive period and lowering the impedance interrupts. 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-terminated nodes to suppress the ringing using this period. We developed a ringing suppression circuitry (RSC) compliant to CiA 601-4 that 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 9: Waveform on 4-nodes configuration at DLC3 bit (Photo: Denso)

The proposed RSC is composed of four MOS components 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. 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, 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 state, which turns NMOS1 ON. On the other hand, the gate voltage of NMOS1 becomes approximately 0 V at the recessive state, 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 NMOS2areinOFFstateduringthisperiod, NMOS0isONand 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 MOS components can suppress the ringing.

In our 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 receiving nodes comprising multiple reflection waves arriving all at once. Furthermore, the maximum period occurs when the length of the transmission path is the longest. In the network used for our study, all nodes 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 receiving node to receive reflection waves latest at the same time. If the communication is not established in the 8-nodes network configuration, the nodes connected at the junction of both ends are reduced until the communication is established.

A prototype CAN transceiver was developed embedding RSC as specified in CiA 601-4. Additionally, we designed an evaluation board equipped with a CAN FD \triangleright



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controller. It was applied to a transmitting node and a receiving node, and verified the communication establishment under the number of connectable nodes.

When using CAN transceivers without RSC, 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 are used with integrated RSC are applied to the same network configuration, the ringing convergence time is 297 ns, which means it is reduced by 473 ns. When 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 detects a communication error and outputs an error frame. Therefore, it is impossible to have an errorfree communication. On the other hand, when using prototype CAN transceivers with RSC, the ringing convergence time is 300 ns. As a result, the ringing convergence time satisfies criterion and enables communication under the network configuration with eight connected nodes.

Figure 8 shows the largest network configuration using conventional CAN transceivers. Figure 9 shows the reception wave pattern of the data phase. When using conventional CAN transceivers, because the ringing convergence time is 392 ns, CAN FD communication is established. However there are not enough margins to increase the number of the connected nodes.

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