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THE NEW DATA EXCHANGE FACILITIES WITH CAN-FD

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Abstract

The modern vehicles demand more and more data exchange to coordinate, control and monitor functions of on board system. The variety of networks applied in these systems is featured mainly by the bandwidth and time determinism. The development electronic information and network sciences find its reflection in the new and new automotive implementations. The last significant step towards the increase the throughout put of the on board network channels are works on CAN-FD. CAN is now the most common network present on board. It helps to manage the maintenance with the numerous subassemblies of the modern car. Next to the many features making CAN so useful and popular, there is a bandwidth limitation, which slows down further implementation of it. The new CAN-FD specification adds new properties that extend the possibilities of CAN as automotive network protocol. These are: different speed transmission in the arbitration phase and in the data phase during the message transmission as well as the extending the maximum size of data filed of the frame from 8 (CAN) to 64 (CAN-FD). In the paper there have been presented the limitations of existing CAN protocol usage, the explanation of the basics of the arbitration mechanisms and the response of the scientist and engineers to cope with it, as well as the formal result outlined in the CAN-FD specification.

Keywords: *automotive, communication networks, CAN, CAN-FD, transmission bandwidth*

1. Introduction

The contemporary data exchange systems in means of transport including motor vehicles are subject to continuous evolution resulting from the growing share of electronic components in the vehicle operation control and monitor units. This is facilitated by the increasing scale of integration of integrated circuits and memory resources of microcontrollers. The most significant factor forcing modifications of existing networking solutions is a necessity to transfer ever-greater amounts of data, often demanding the high degree of time determinism. This is directly related to the security of the vehicle elements, as both individual objects and the system under which they interacts. Ways of classifying network presented in [5, 15, 16, 18], although they are not always uniform because of the rapid development in this area, they reflect the requirements on the network protocol arising from the operation of the communicating devices. While in case of systems known as “comfort” or “body” the cost of implementing the solution is the main criterion implying development, for the systems powertrain or security the most important is the reliability of transmission and high bandwidth networks. Per example, the protocol with extensive self-checking properties and a very high degree of time determinism is Flex Ray, described in more detail in [4, 5, 17]. The range of measures to maintain the level of reliability available to the Flex

Ray results from the intended areas of the application of this network for X-by wire systems. It makes Flex Ray extremely complicated and thus difficult for fast implementation or modification. The final decision on of the optimal network solution selection for a given object is usually the result of a compromise between the conflicting requirements. The typical example of conflicting alternatives is the use the double line of Flex Ray network for the redundant transmission featuring higher reliability, or a doubling of bandwidth through the establishment of two independent channels of data flow. Nowadays Controller Area Network (CAN) is the most commonly used network in motor vehicles. Its advantages: bandwidth reliability and application flexibility is also appreciated by aviation (ARINC), vessels (NMEA200), heavy duty machines (ISOBUS), industrial installations (CAN OPEN, Device Net) etc. The use of CAN in a modern car covers wide area of applications, from simplest equipment elements control to complex control and propulsion systems security. The position of CAN in the automotive industry is also driven by the development of workshops and service stations back-end in the form of a large group of software and devices cooperating with this protocol. CAN, described in [2, 10], assumes further protocol development. The evidence is the introduction of the message "bits reserves" to frame. The need for increase of the bandwidth of the network has been implemented at the level of the Protocol relating, as in the earlier version, to the data layer in the form of CAN-FD specification [3].

2. The limitation and the evolution of CAN

One of the most important properties of CAN, affecting the high throughput and the possibility of use in real time systems, is the access to the bus mechanism, described in the specification CAN 2.0. The possibility to transmit messages always appears when the bus is free. In the case of bus access conflict – when simultaneously more than one node starts transmission, the arbitration mechanism is used. Arbitration does not eliminate all of the communication nodes, allowing one of them to continue its operation. Although the other senders are forced to re-start the sending, the time when the conflict happened is not lost, because it used to transmit the information provided by one of nodes. In contrary to such protocols, where conflict causes the necessity of retransmission of all messages, the gain on the network bandwidth it is obvious. The arbitration mechanism facilitates also messages hierarchy setting, thus by raising, the degree of the system time determinism system. The figure 1 shows an example implementation of the arbitration. Nodes 1 and 2, starting simultaneously sending, send subsequent message bits. High state corresponds to the so-called recessive bit of while low state represents the so-called dominant bit. Bus status is determined by the presence of at least one bit dominant. As shown in Fig. 1 the example situation of conflict is caused by a node 1 sending the recessive bit and node 2 sending dominant bit. According to the rule stated above, the bus has the state of the dominant bit (low). Because the state set by the node 2 is compliant with the state of the bus, the Nnode 2 continues transmissions while the node 1 is switched off.

In order to allow the arbitration, CAN transceiver must be able to write and read the bus simultaneously. CAN transceiver block scheme is shown on Fig. 2.

Arbitration in the CAN protocol takes place at the stage of reading an message identifier. In accordance with the arbitration principle described above, messages with lower identifiers win the conflict, what allows prioritization of access to the bus. The ability of concurrent transmission and tracking the state of the bus, and the use of recessive and dominant bits, is used also to acknowledge receiving the message by one of the other nodes that are not currently sending the messages. For this purpose, each frame contains the so-called ACK bit, set as recessive by sender. Any node, which received successfully the message frame, sets the dominant bit on the bus. The change of the ACK bit in the frame sent, observed by the sender, is considered as the receipt acknowledgement. The Fig. 3 shows an example of the ACK bit control.

In the presented example, the sender sets the bit AK state as a recessive. The sum check CRC, calculated by the receiver 1 on the basis of the received message bits, is consistent with the CRC

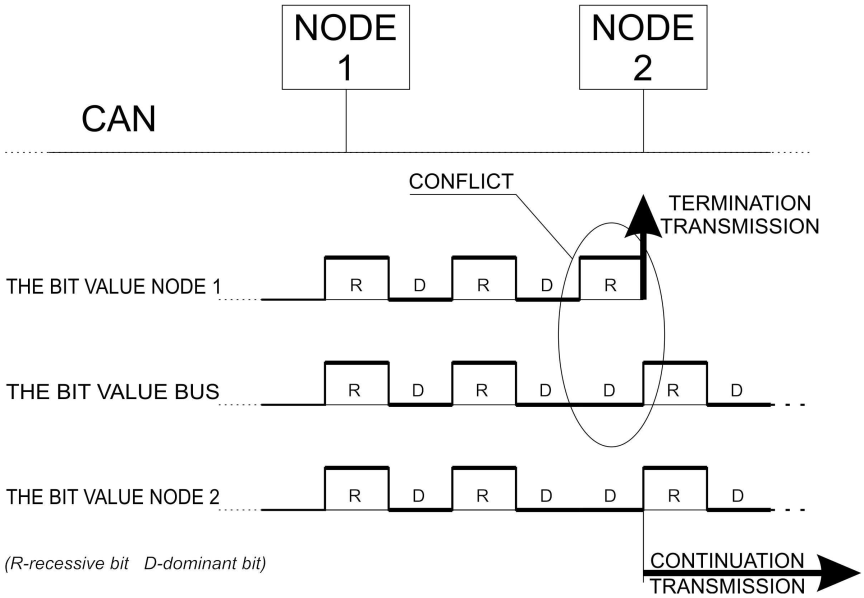

Fig. 1. example of CAN arbitration

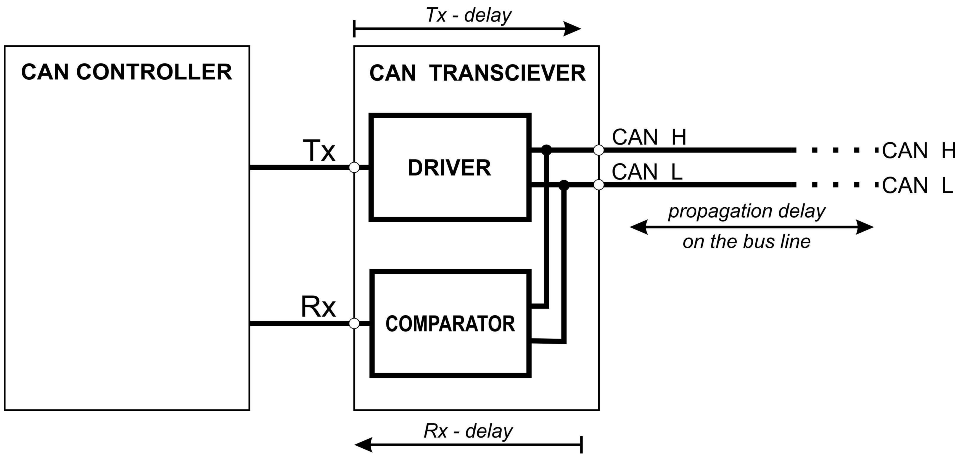

Fig. 2. Scheme of CAN transceiver

attached to the message by the transmitter. Receiver 1 sets state dominant of the ACK bit on the bus. Because a simple comparison carried out by the receiver 2 was not successful, the receiver 2 does not change the status of ACK bit. Bit issued by the receiver 1 determines bus state corresponding to bit dominant. The state of ACK bit read by the transmitter confirms that the message is received.

The physical implementation of the network system, which has the ability to simultaneously transmit and read bus status, however, has significant limitations. Due to the need to compare the synchronous transceiver line Tx state, and bus status at the output of the transceiver output Rx, the finding of Tx state and bus status may not exceed specified values on the timeline. Actual signal transmitted by and read from the bus by the CAN controller have the phase error. The source of the error phase may be, for example, differences in the CAN controllers' clocks, errors in the bit rate configuration, quantization errors related to discrete signal sampling, as described in [11].

A significant source of error phase is also physical layer device indicated in Fig. 2 as Tx delay, Rx delay, propagation on the bus line delay. These unwanted signals slopes offsets, reflecting a bit state, are mainly related to the physical parameters of the transceiver and bus lines. Additional signals distortions are also caused by the line load as described in [9]. Acceptable latency values set by standard ISO 11898-2, ISO 11898-5 are respectively 280 ns and 255 ns [6]. Signal propagation time on the bus line is linked to its physical length. In trucks or buses it reaches

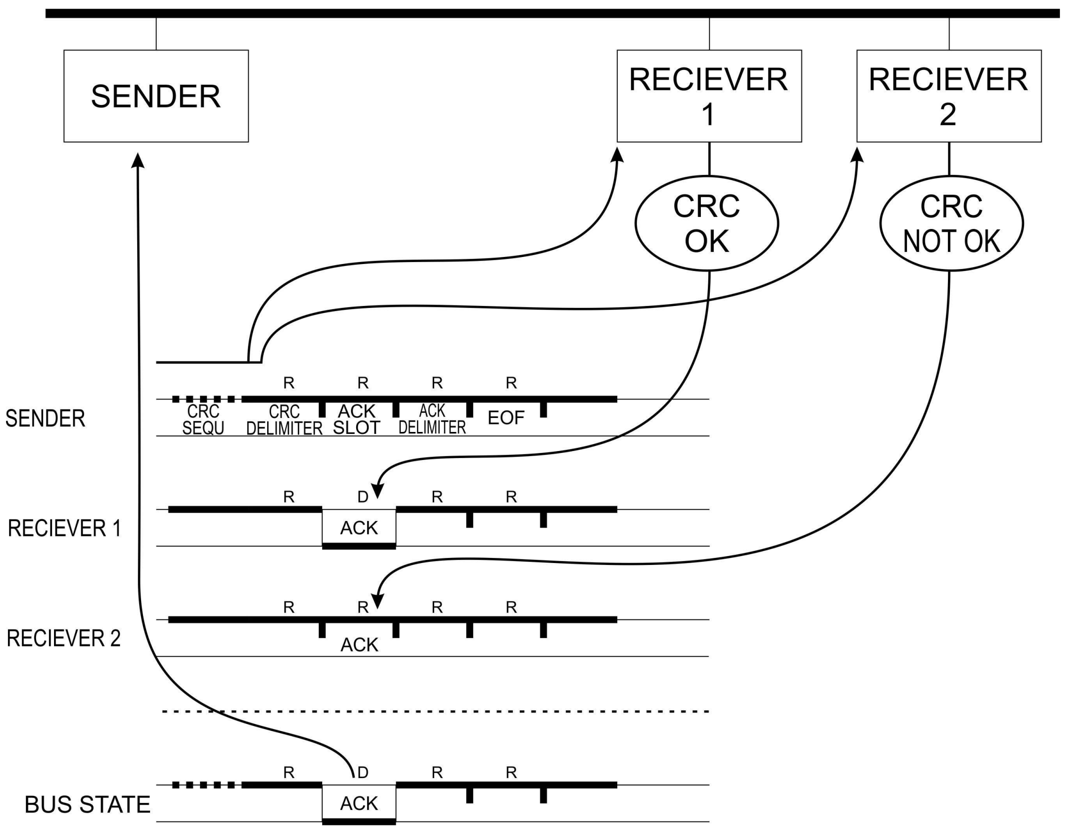

Fig. 3. CAN acknowledge bit check

dozens of meters [13].The transmission speed of 1 Mbit/s, provided for in the CAN specification 2.0, results in the single bit duration of 1 us. In practice, using presently available transceivers and with distances between network nodes in vehicles, the proper functioning of the mechanisms described above can be granted. The increase of the speed transmission, that may be increase the network bandwidth, may result in an improper operation of the arbitration mechanism and ACK control. The arbitration errors, resulted from excessive increase of the speed of transmission are shown on the Fig. 4.

In this example it is assumed the use the same physical layer devices, and therefore the phase error as the same delay (L) and the same bit timing settings for two networks with different transmission rates.

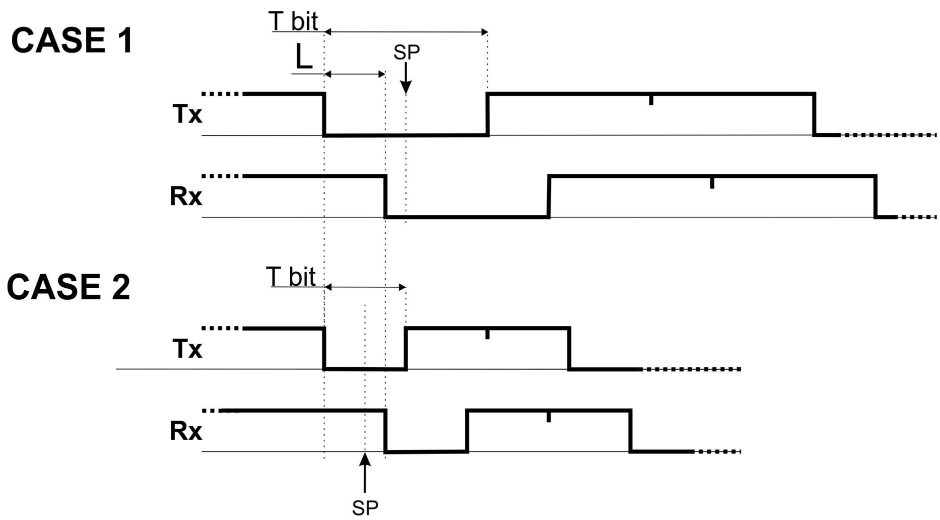

Fig. 4. The scheme of error caused by to high bandwidth

Cases − case 1, and − case 2 demonstrate the effect of the time shift of the signal transmitted on the transceiver Tx input with respect to the Rx signal, resulting from the state of the bus at different one bit times duration. In the case 1, the phase error does not change the result of Tx and Rx lines reading comparison. In the case 2, shorter duration of bit and phase errors occurring at the same time makes the comparison incorrect. The issue of the CAN controller configuration, associated with the sampling time is described in [9]. The phase delay between the signals on the CAN controller input and output for long lines using network transceivers is inevitable, which is the main cause of transmission speed limitation to 1 Mbit/s, specified in the CAN specification. Due to the CAN networks common use, the evolutionary approach to its modification has been adopted. New version of the specification assumed the backward compatibility of the new product with the possibility of its implementation in systems, where previous versions had been used, also taking into account issues such as the use of existing cabling and/or existing software structure. For this reason, among others, rejected part of proposing solutions, e.g. the use of the star topologies with the arbitration inside the active star or doubling the amount of lines [3]. The specification, finally adopted by the Bosch, provides for transmission of a single frame with different bandwidths. An official document under the name "CAN with flexible data rate" can be considered as CAN 2.0 extension [7]. Primary assumptions about the protocol scalability in the form of, p. ex. Reserve bits, allowed the backward compatibility and similar user interface.

The main change applied in CAN-FD, compared to its previous version CAN v. 2.0, is the increase of allowed speed transmission in so called the data phase. The allowed speeds transmissions in phases using comparison of data transmitted and received by the CAN controller are left unchanged in order to maintain the arbitration properties described above. Acceptable transmission speeds, used to transfer parts of a frame including data, are not specified in official documents. The published work, describing the research on the application of CAN-FD [6], refers to the transmission speed of 2 Mbit/s, 5/Mbit/s up to even 12 Mbit/s. Such transmission speeds make CAN network comparable with Flex Ray, however, it should be emphasized, that Flex Ray has many other mechanisms related to security. CAN-FD frame description and its comparison to CAN is shown on Fig. 5.

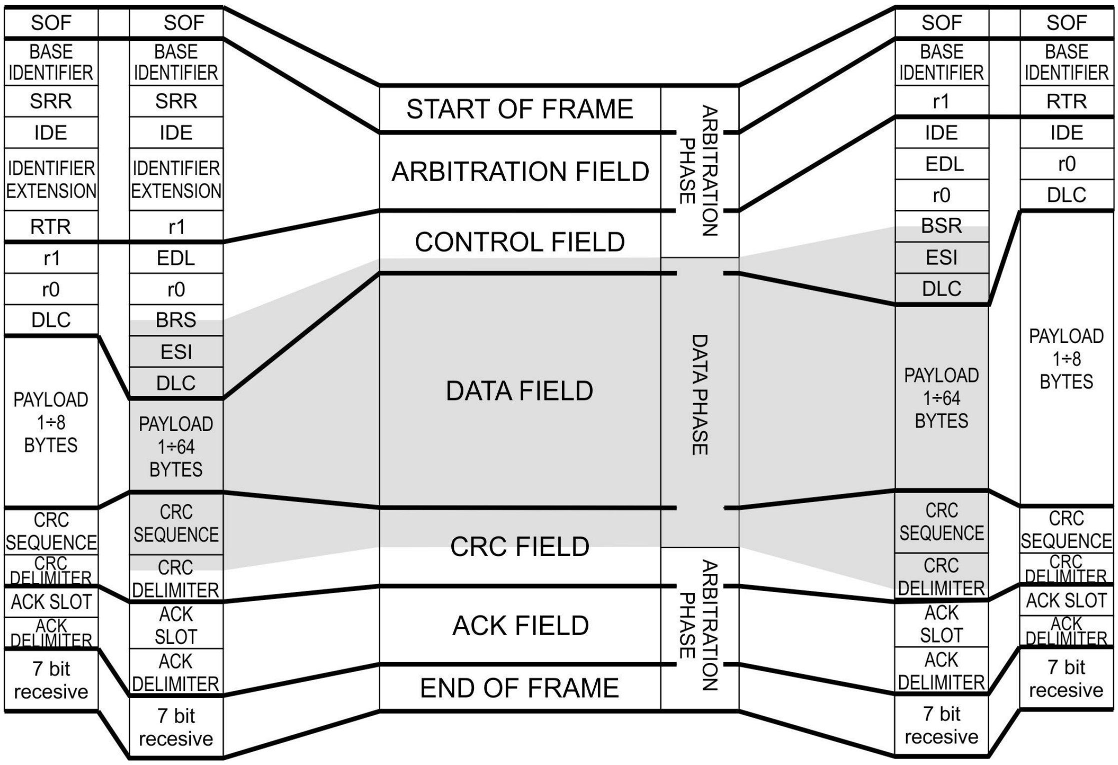

Fig. 5. The scheme of CAN-FD message frame

Frame CAN-FD, just like CAN, consists of 7-bit fields. The information contained in the bit fields has similar functions in CAN and CAN-FD: SOF start of frame, Arbitration Field, Control Field, Data Field, CRC Fied, ACK Field, EOF End of frame.

Another extremely important modification contained in the CAN-FD specification compared to version CAN v2.0 , apart from the different transmissions in the arbitration and data phase, is the net transfer increase, achieved by expanding the data field from 8 bytes (CAN) to 64 bytes(CAN-FD). The issues of the network load, resulted from the transmission of additional information not directly related to the transmission of data, are described in [1]. The number of data bytes in the data field is indicated by the DLC (Data Length Code). The first 8 DLC values in binary code correspond to the number of data in the data field. The values of the DLC above 8 apply only to CAN-FD and correspond to, consecutively 8, 12, 16, 20, 24, 32, 48, 64 of bytes of data in the data field. The length of the data fields stored in the DLC, limited to 8 fixed values, can in many cases reduce netto/brutto transfer ration, what should be taken into account when designing a network for a particular object [14]. Consequence of the lengthening of the data fields with the assumption of maintaining the level transmission reliability level is a modification of the CRC sequence providing a Hamming distance of HD = 6. CAN FD specification mandates the use three different generator-polynomials depending on the data field length: CRC_15 (CAN frames), CRC17 (CAN-FD frames with data field up to 16 Bytes), CRC_21 (data field longer than 16 Bytes) [3, 8]. The distinction between formats of frames is done by bits in the frame

3. Summary

The protocol CAN-FD, presented in the article, significantly expands the features of commonly used protocol CAN. Although the official version of the specification was presented by Bosch in 2014, the works on its inclusion in the standard ISO are still running. At the time of publication there are already on the market integrated circuits containing controllers that fulfil tasks in the data layer in accordance with CAN-FD (e.g. Atmel Atsamc21). Given that the CAN-FD controller can work as CAN controller, it is expected, that this element in the first phase will be introduced into existing communications systems to work as CAN protocol, to use in next steps expanded possibilities of CAN-FD. The so far positive experience with CAN gives perspective on equally large propagation of the CAN-FD, despite the growing popularity of the automotive networks such as Ethernet [12] or Flex Ray [4]. Taking into account the dynamics of the systems on board based communication networks development, the many issues found in the context of the CAN-FD such as data streams forming, interoperability with other on-boards networks or, gaining significant importance, of data security issues, will be addressed in the closest time in the form of concrete application experience.

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