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CAN bus diagnostics

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The paper contains information on the CAN bus, which is a data transmission network for communication between vehicle steering systems. Its structure is outlined, and the ways of message sending discussed. Methods of detecting faults when the CAN bus is physically damaged are presented. Signal changes are shown for typical faults.

KEYWORDS: data bus, diagnostics, vehicle electronics

1. Introduction

The development of electronics made it an object of interest for engineers employed by automotive concerns. Equipped with complicated electronic systems, vehicles provide improved comfort and safety of driving, as well as having a less adverse effect on the environment. Especially worth noticing are computer communication networks, which became basic data exchange systems within a very short time. They made it possible to reduce the kerb weight of a vehicle and, by using digital signals, to improve transmission quality. Currently, the most popular network used by vehicle manufacturers is the CAN bus (Controller Area Network). Though the bus was used for the first time in 1992 by the Mercedes concern, it was not later than at the beginning of the 21st century that every car was commonly equipped with it [1]. The CAN in Automation organisation developed standards for the bus. It introduced the ISO 11898 European standard, which corresponded the SAE J1939 American standard, and defined the physical layer of the CAN system and the physical layer [4, 5, 10].

Due to the multiplicity of systems that cars were provided with, data interchange was hindered, hence subassemblies were grouped, for example into lighting, bodywork, and drive systems, and the like. Vehicles feature more than one CAN bus, with data often transferred between particular systems. In addition to data interchange between nodes, a network of this type allows effective fault diagnostics. Electronic controllers of particular systems monitor their work, and each irregularity is recorded in the memory as a code denoting a corresponding fault. By connecting a diagnostics interface to the OBD connector, it is possible to read and then decode faults [3, 4].

2. CAN bus structure

The physical layer of the CAN bus consists of a two-wire twisted pair connecting all transmitters and receivers. Linear topology is commonly used, ensuring continuity of data interchange despite a damaged node. Resistors, called terminating resistors, are installed at both ends of the twisted pair to prevent electromagnetic wave reflection. Data is transmitted in the form of a differential signal [9, 10]. The principle of its generation is presented by Figure 1.

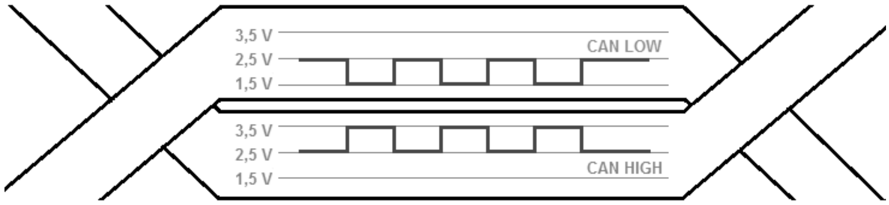

Fig. 1. Signal transmission in the CAN twisted pair [9, 10]

The bus twisted pair consists of two wires, CAN_L (low-speed CAN) and CAN_H (high speed CAN). When there is a recessive bit, the value of voltage is the same in both cases, namely 2.5 V. The dominant state is represented by potential values: CAN_L – 1.5 V; and CAN_H – 3.5 V. In the dominant state, voltage difference is at a level of 2Vapproximately (Fig. 1). Possible interference acting on the twisted pair is cancelled out, which ensures a high level of data transmission.

The length of the bus wires is of significance and affects the quality of data transmission. When the bus is designed, its maximum length l_{max} is determined by means of relation 1 [4].

$$l_{max} = \frac{C_{Cu}}{V_t} \quad (1)$$

where: V_t– transmission speed, C_{Cu}– signal propagation in copper ($C_{Cu}= 2\cdot 10^8$ m/s).

According the ISO 11898 standard, it is recommended that the length of the bus not exceed 40 m (in view of vehicle structure and dimensions, this makes sense) [6, 7, 8].

The data link layer is responsible for attaching addresses to devices so that messages can be received in the form of data frames (Fig. 2).

A message consists of [2, 5, 10]:

- start-of-frame field (SOF) – starts a frame transmitted; its value is always a dominant one,
- status field(message identifier) – defines the priority of a message and may consist of 11 bits (CAN2.0A) or 29 bits (CAN2.0B), depending on the CAN standard adopted,

- control field (data length field – DLC) – informs about the CAN standard adopted and the length of the next frame field (data field),
- date field a maximum of 8 bytes containing the main information in the message transmitted,
- security field – responsible for detecting transmission interference on the basis of the check sum value (CRC), which is created by the transmitter and stored in that place; when receiving a frame, the receiver creates another sum and compares it with that of the security field,
- acknowledgement field (ACK) – a two-bit field containing feedback information sent by the receiver to confirm that a frame was received,
- end-of-frame (EOF) seven bits of a recessive value, ending the data frame.

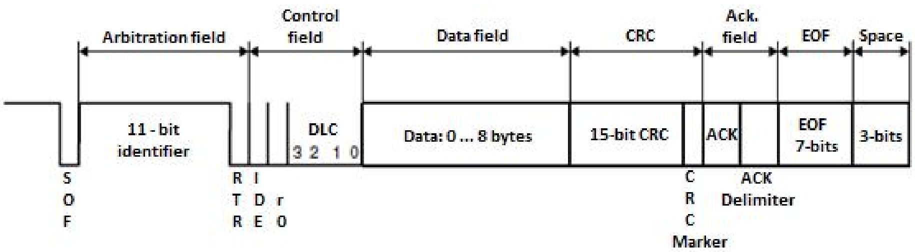

Fig. 2. CAN standard frame structure CAN [1]

Each message contains also 3-4 interframe space bits, which called Stuff bits. They separate particular frames. A correctly transmitted frame should not contain six successive bits of the same logical value. When the controller sends a sequence of equal bits, the transceiver adds an additional bit after the same five values. The receiver skips this bit, when decoding the message. A sequence of bits of this type is called an interframe space [3, 10]. Figure 3 presents part of the frame as divided into bits. The bits shaded orange are added ones.

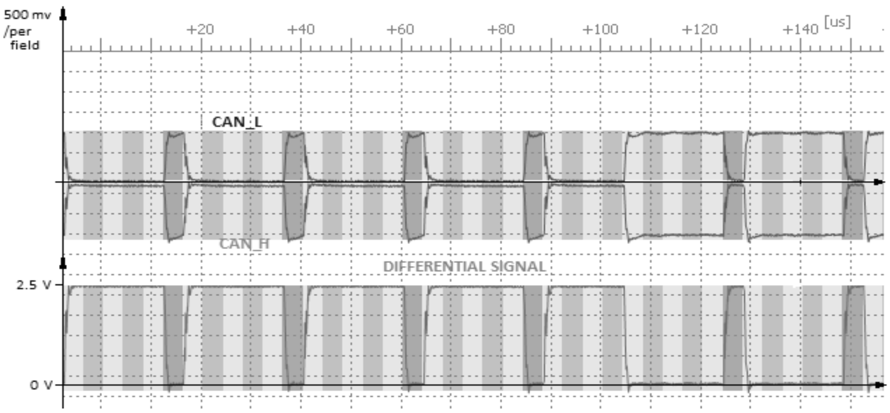

Fig. 3. Bit sequence with interframe space bits marked (Stuff bits)

The last layer of the CAN standard is the application layer, which was not defined in any legal documents. No limitations being imposed on this part, automotive concerns developed their own protocols which are kept secret on account of privacy policy. These can be exemplified, amongst others, by control protocols of modern vehicles.

3. CAN bus communication

Controllers and actuators cannot be directly connected to the CAN bus, since they are not adapted to receive and send data. Two additional electronic systems make data interchange possible, including such subassemblies as a microcontroller, CAN processor and transceiver.

The microcontroller receives a signal and passes it on in the form of data to the CAN controller. A typical CAN frame is created, containing data. It is sent by the transceiver, which is a system that transmits or receives messages. The receiving systems of the remaining controllers take data from the bus and pass it on to the CAN controllers, where, using the identifier, it is verified whether a given massages addressed to a particular node. If the message is accepted, it is processed further. The bit of the acknowledgement field is changed from a dominant value to a recessive one and sent back as a type of report to the sender. When the identifier is not accepted, the data stops being received [2, 5, 6].

The basic bus access method is the CSMA/CA multiple access one. Information is transmitted as long as it is consistent with the sequence of the bits present in the bus. If a recessive bit is sent, and the main signal is at that time equal to logical zero (dominant bit), a given node stops the transmission and starts to receive information.

It is the arbitration process that is responsible for the proper functioning of transmission, consisting of transmitting a message priority based on the frame identifier. This process uses the so-called „Wired-And" logical operation of recessive bits being overwritten by dominant ones. Arbitration ensures that no bit is lost and the time of message transmission is not extended [4, 10].

The CAN bus is a highly infallible computer network. However, in order to control connections and data interchange when required, error detection and correction systems are used. Information on an error is sent at the latest at the end of a message so that the transmitting system can send a data frame again. Error detection methods are as follows [1, 4, 9, 10]:

- cyclic redundancy check CRC – error detection by comparing the check sum at the end of transmission in the system receiving the message with the initial value in the sending system,
- checking the frame format – checking particular message fields that their logical values are for sure consistent with those of the CAN protocol; the message structure is controlled,

- acknowledgement error – lack of a feedback message from the receiving system to inform the sending one that the transmission proceeded correctly,
- data synchronization error monitoring the frame code to ensure that five successive bits can have the same logical value.

Having detected an error, the CAN controller stops sending the data frame, transmitting a so-called error frame. This is six successive dominant bits (active error flag) or recessive ones (passive error flag). Figure 4 shows this situation where the transmission was stopped at 0.83 and replaced by the error frame.

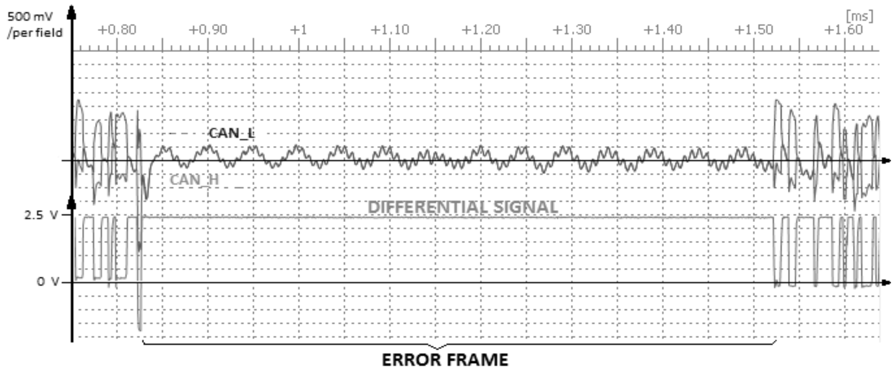

Fig. 4. CAN bus signal changes of an error frame

With the sending of the frame interrupted, the transmitter attempts to resume the transmission process later so that other nodes of the bus will not accidentally receive wrong information. Eight dominant bits are followed by eight recessive bits seen as an interframe space after the error frame.

4. CAN bus diagnostics

The CAN bus is used not only to interchange information between devices connected thereto, but also to enable an OBD standard connector to be used so that that parameters of particular systems and information on errors can be read by means of external diagnostics interfaces.

In order for the system to operate properly, the bus may not have any mechanical damage. The ISO 11898 standard defines, amongst other things, mechanical defects of the CAN bus that can appear when vehicles are used:

- broken CAN_H or CAN_L wire,
- CAN_H or CAN_L short to power source,
- CAN_H or CAN_L short to earth,
- a short between the CAN_H and CAN_L bus wires
- any wire of the bus broken,
- bus terminating resistor damaged.

Special interfaces with appropriate software are used to diagnose one of the above faults. After interfaces have been connected to the bus, the signals of the frames are read to determine a fault type. The following procedure should be adhered [3, 9]:

1) Testing the data transmission bus by means of a tester or computer interface.
2) Becoming acquainted with the structure of the whole system of the car serviced, and measuring the network with a multimeter or oscilloscope.
3) Repairing the wire damaged, or replacing the controller comprising a faulty connector; when the working condition of the bus has been restored, cancelling the error in the register memory and checking the system.

The paper covers research on a bus responsible for engine and drive systems (throughput 250 kb/s). Solaris Urbino U18 with the CNG gas engine was the vehicle that was used for the experiments. ThePicoScope 3200 oscilloscope was used as diagnostic equipment, featuring two analogue channels and sixteen digital ones.

Figure 5 shows examples of signal changes of a bus in a good working condition.

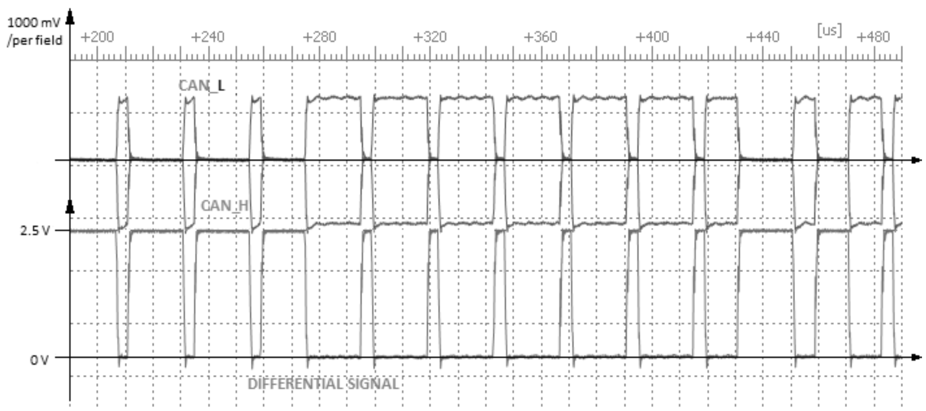

Fig. 5. Data transmission within the CAN bus in good working condition

For the purpose of the research, the following faults were simulated:

a) Lack of a matching resistor

The oscillogram in Figure 6 shows large oscillations on the leading edge of the high signal and on the trailing edge of the low one. This is a reflection of the differential signal disturbance. The sequence of the low state bits in the particular wires deviates from a straight line.

b) CAN_L wire short to earth

In this case the voltage of the CAN_L wire is 0 V. The signal in the bus comes from the CAN_H wire, and the bus does not stop working, but proceeds to a single-wire mode (Fig. 7).

Fig. 6. Data transmission within the CAN bus with a terminating resistor disconnected

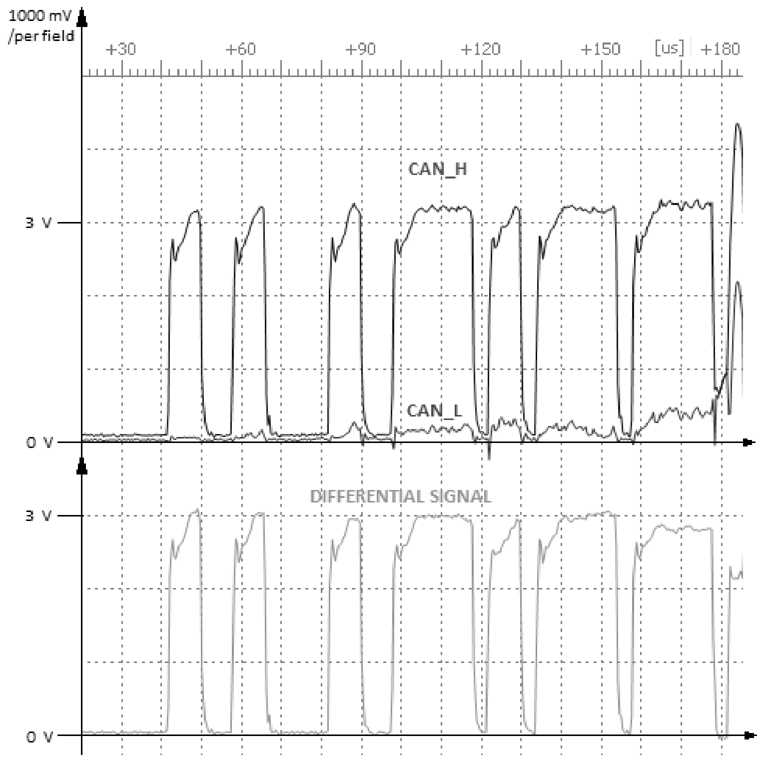

Fig. 7. Signal change in the CAN bus in the state ofthe CAN_L wireshorted to earth

c) the CAN_H wire shorted to earth

When a short occurs, the signal in the CAN_H wire disappears, falling down to 0 V. In the CAN_L wire, single peaks appear, indicating an attempt to start transmission (Fig. 8). Data transfer in this case is not possible, and the CAN network ceases to work properly. Single-wire operation in this case is impossible. This is a system protection feature so that the differential signal ($U_{CAN\_H} - U_{CAN\_L}$) will not have negative values.

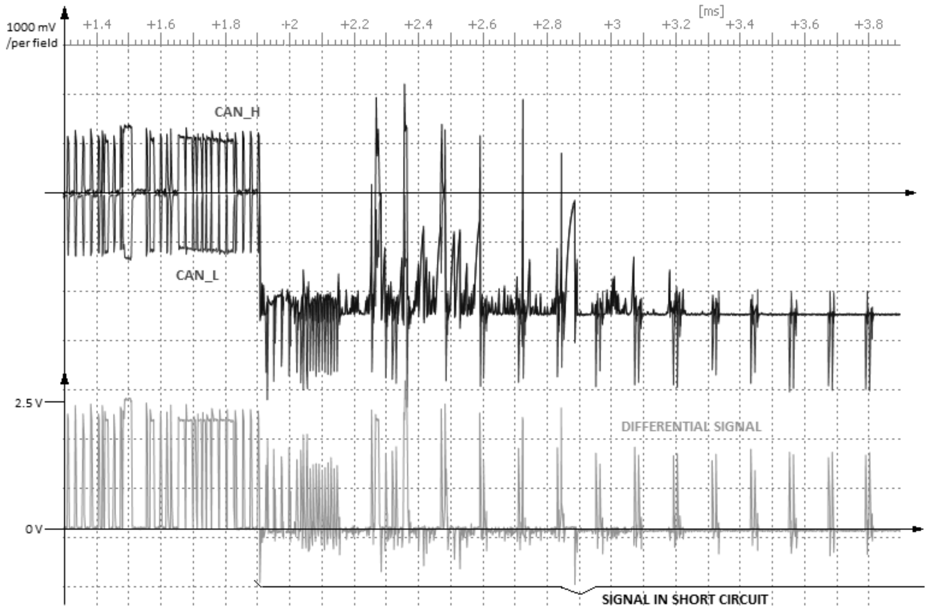

Fig. 8. Signal changes in the CAN bus with the CAN_H wire shortened to earth

d) CAN_H shortened to CAN_L

Initially, the CAN_H wire shortened to the CAN_L wire causes oscillations, followed by the voltages in the bus becoming steady at a level of 2.5 V. A series of oscillations appears, deforming the messages (Fig. 9).

At the beginning, an attempt is made to send a message, but from the moment of the short-circuit (45 ms),the signals of both wires coincide with each other. A differential signal does not appear, as indicated by its value, 0 V. In the case of this fault, the CAN bus stops working. Figure 9 shows bus with reverse polarity differential signal.

e) the CAN_L or CAN_H wire shorted to the plus value of the power supply

In the case of such faults, the CAN bus starts to operate in a single-wire mode. The voltage in the wire shortened to the power supply is 12 V or 5 V. This may damage electronic systems.

f) Any wire of the bus is broken

In this case there is an open circuit of one wire, which means that the CAN bus starts to operate a single-wire mode. The signal of the bus can be seen as coming from the undamaged twisted-pair wire. It does not require an advanced technology to detect this type of faults. Each manufacturer has a unique fault code to be read by a diagnostic tester.

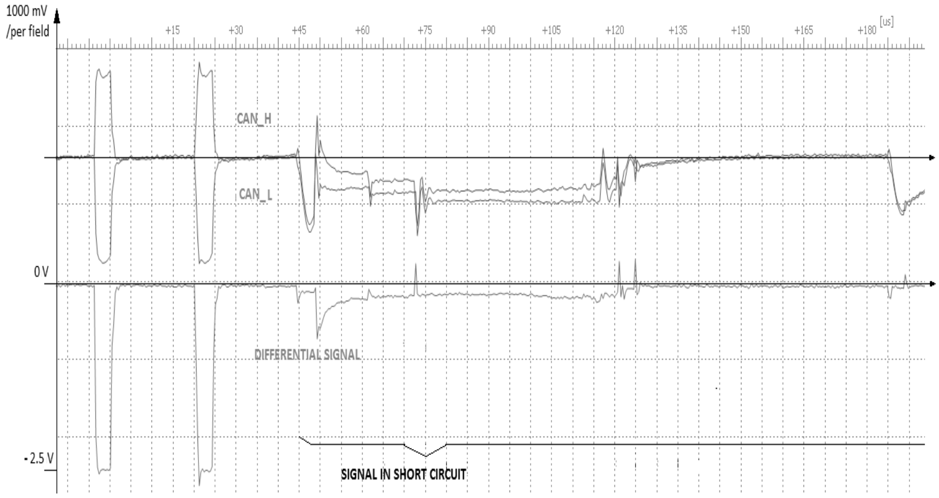

Fig. 9. A short between the CAN bus twisted-pair wires

5. Conclusions

The CAN bus is a versatile system to integrate many devices using a common transmission medium. A twisted pair and differential digital signal provide a high quality of transmission. It is important to become acquainted with the bus responses to mechanical damage. Since such faults are not precisely recognized by diagnostic testers, multimeters and oscilloscopes are used to pinpoint the spot where the CAN bus is damaged.

Simulated experiments were carried out to show voltage changes during a fault. A differential signal change always occurs when the bus operates in a two- or single-wire mode. The latter reflects a faulty state of the network, though enabling the transmission to continue. In designing a CAN bus, standards should be complied with and the arrangement of vehicle installations taken into account so as to avoid possible mechanical damage.

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