

CAN *made easy*

Basic information on the CAN physical and data link layer by CAN in Automation (CiA)

Controller Area Network (CAN) is a data link layer protocol internationally standardized as ISO 11898-1. When data is transmitted, no stations are addressed, but instead, an identifier that has to be unique throughout the network designates the content of the message. The identifier content but also the priority of the

message. This is important for the bus arbitration procedure when several stations are competing for bus access. Bus access conflicts are resolved by bit-wise arbitration on the identifier bits involved by each station observing the bus level bit for bit. In accordance with the 'wired- and' mechanism, by which the dominant state

(logical 0) overwrites the recessive state (logical 1), the competition for bus allocation is lost by all those stations with recessive transmission and dominant observation. All 'losers' automatically become receivers of the message with the highest priority and do not re-attempt transmission until the bus is available again.

Message frame formats

The CAN protocol supports two message frame formats, the only essential difference is the identifier (ID) length. In standard format the length of the ID is 11 bit and in extended format the length is 29 bit. As the two formats have to co-exist on one physical bus line it is laid down, which message has higher priority: the standard message always has higher priority to the extended message.

All new CAN implementations must be able to receive and send messages in standard format. In addition, they must be able to recognize messages in extended format. However, they may be not

able to store received messages and to send received messages in extended format. There are some trade-off using message in extended format: higher bandwidth requirements, longer bus latency times, and less powerful error detection capability.

A standard frame message begins with the 'Start of Frame (SoF)' bit, which is followed by the arbitration field including the 11-bit ID and the 'Remote Transmission Request (RTR)' bit. The RTR bit indicates whether it is a data frame or a request frame without any

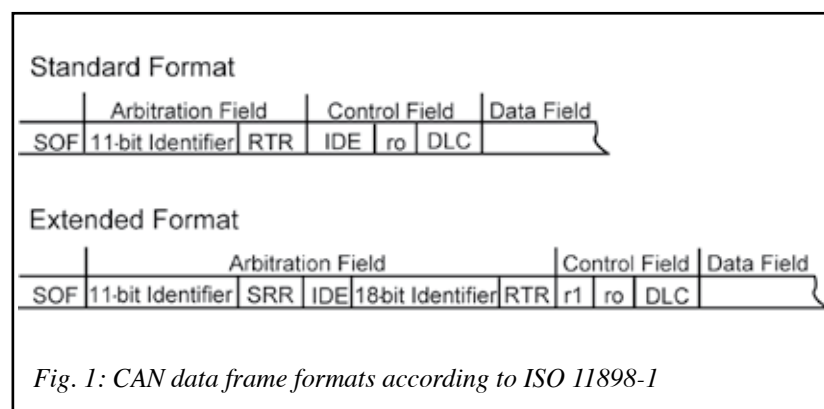


Fig. 1: CAN data frame formats according to ISO 11898-1

data bytes (remote frame). The 'Control Field' contains 'Identifier Extension (IDE)' bit, which indicates either standard format or extended format, one reserved bit, and at least 4 bits – a count of data bytes in 'Data Field'. (Note: In remote frame 'Data Length Code (DLC)' corresponds to the length of the requested data!).

'Data Field' ranges from 0 to 8 bytes in length and is followed by 'Cyclic Redundancy Checksum (CRC) Field', which is used as frame security check for detecting bit errors. 'Acknowledge (ACK) Field' comprises ACK slot (1 bit) and ACK delimiter (1 recessive bit). The ACK slot bit is sent as a recessive bit and is overwritten as a dominant bit by those receivers that have not detected any CRC failure at this time.

Correct messages are acknowledged positively regardless of the result of the acceptance filtering. The end of the message is indicated by 'End of Frame (EoF)' field (7 recessive bits). 'Intermission' is the minimum number of bit periods separating consecutive messages. If there is no following bus access by any station, the bus remains idle (recessive state).

Detecting and signaling errors

Unlike other bus systems, the CAN protocol does not use acknowledgement messages but instead signals any errors that occur. For error detection the CAN protocol implements three mechanisms at the message level:

◆ **Cyclic redundancy check**

The CRC safeguards the information in the frame by adding redundant check bits at the transmission end. At the receiver end these bits are re-computed and tested against the received bits. If they do not agree, there has been a CRC error.

◆ **Frame check**

This mechanism verifies the structure of the transmitted frame by checking the bit fields against the fixed format and the frame size. Errors detected by frame checks are designated „format errors“.

◆ **ACK errors**

Frames received are acknowledged by all recipients through positive acknowledgement. If no acknowledgement is received by the transmitter of the message (ACK error) this may mean that there is a transmission error which has been detected only by the recipients, that the ACK field has been corrupted or that there are no receivers.

The CAN protocol also implements two mechanisms for error detection at the bit level.

◆ **Bit stuffing**

The coding of the individual bits is tested at bit level. The bit

representation used by CAN is NRZ (non-return-to-zero) coding, which guarantees maximum efficiency in bit coding. The synchronization edges are generated by means of bit stuffing, i.e. after five consecutive equal bits the sender inserts into the bit stream a stuff bit with the complementary value, which is removed by the receivers. The code check is limited to checking adherence to the stuffing rule.

◆ **Monitoring**

The ability of the transmitter to detect errors is based on the monitoring of bus signals: each node which transmits also observes the bus level and thus detects differences between the bit sent and the bit received. This permits reliable detection of all global errors and errors local to the transmitter.

If one or more errors are discovered by at least one station (any station) using the above mechanisms, the current transmission is aborted by sending an „error flag“. This prevents other stations from accepting the message and thus ensures the consistency of data throughout the network.

After transmission of an erroneous message has been aborted, the sender automatically re-attempts transmission (automatic repeat request). There may again be competition for bus allocation. As a rule, retransmission will be begun within 23-bit periods after error detection; in special cases the system recovery time is 31-bit periods. However, as effective and efficient the method de-

scribed may be, in the event of a defective station it might lead to all messages (including correct ones) being aborted, thus blocking the bus system if no measures for self-monitoring were taken. The CAN protocol therefore provides a mechanism for distinguishing sporadic errors from permanent errors and localizing station failures (fault confinement). This is done by statistical assessment of station error situations with the aim of recognizing a station's own defects and possibly entering an operating mode, in which the rest of the CAN network is not negatively affected. This may go as far as the station switching itself off to prevent messages erroneously recognized as incorrect from being aborted.

CAN high-speed physical layer

The specified data rates (up to 1 Mbit/s) necessitate a sufficiently steep pulse slope, which can be implemented only by using power elements. A number of physical connections are basically possible. However, the international users and manufacturers group CAN in Automation (CiA) recommends the use of driver circuits in accordance with ISO 11898-2 for general purpose applications. Integrated driver chips in accordance with ISO 11898-2 are available from several companies. CiA also recommends mechanical connections (CiA DS-102). For industrial applications there are different additional physical layer specifications included in CANopen and DeviceNet standards.

The CAN high-speed physical layer as specified in ISO 11898-2 determines a bus line which has to be terminated at

each end with a resistor to suppress reflections. The location of this resistor within a device should be avoided because the bus lines loose termination if one of these devices is disconnected from the bus line. The termination resistor used shall comply within the following limits: minimum 118 Ω , nominal 120 Ω , maximum 130 Ω .

The physical medium is two-wire bus line with common return terminated at both ends by resistors representing the characteristic impedance of the line. The wiring topology of a CAN network should be as close as possible to a single line structure in order to avoid cable-reflected waves. In practice short stubs are necessary to connect devices to the bus line. They should be as short as possible, especially at high bit rates. At 1 Mbit/s, the length of the cable stubs should not exceed 0.3 m.

The theoretical maximum bus length is 40 m at a data rate of 1 Mbit/s. At bit rates lower than 1 Mbit/s the bus length may be lengthened significantly. The maximum bus length is 1 km allowing a maximum data rate of 50 kbit/s). It is possible to use bridge-devices or repeaters to increase the number of nodes which may be connected, or to increase the allowed distance between the bus nodes (to e. g. more than 1 km), or to provide galvanic isolation (a bridge device contains at least two CAN controllers and two transceivers).

A connector used to plug devices to the bus line shall have a nominal impedance of 120 Ω and a nominal transmission re-

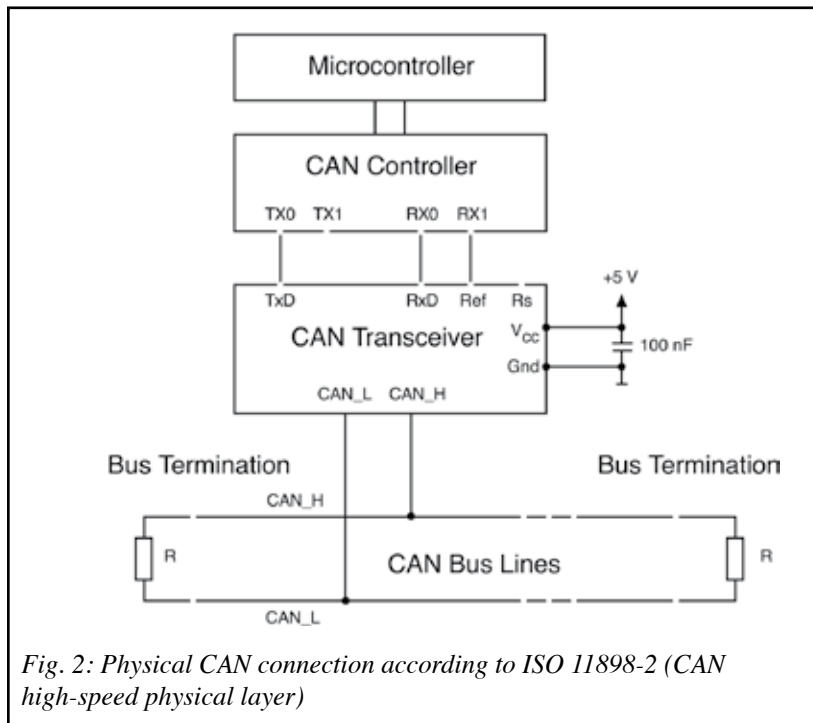


Fig. 2: Physical CAN connection according to ISO 11898-2 (CAN high-speed physical layer)

sistance of 70 mΩ. The cables chosen for the CAN bus lines shall have a nominal impedance of 120 Ω, a length-related resistance of 70 mΩ/m, and a specific line delay of nominal 5 ns/m. At bus line length greater than 40 m, the specific resistance of the bus cable should be lower. The aim of these specifications is to standardize the electrical characteristics and not to specify mechanical and material parameters of the connectors respectively cables. The bus wires may be routed parallel, twisted and/or shielded, depending on EMC requirements.

The ground inputs of all transceivers are interconnected. The parameters for specific resistance per length unit, network length, current, and location of the power supply input should be chosen in a way, that the difference between the ground potentials of the transceivers does not exceed 2 Volt. If necessary, galvanic isolation has to be applied, to reduce the current through the ground-line. In general, it is advantageous to locate the power supply input in the center of the bus line.

Some ISO 11898-2 compatible integrated transceiver circuits provide a slope-control function to reduce electromagnetic emission (i.e. to support unshielded bus wires) and to increase allowed stub cable length. But if the slope-control function is used the internal delay time increases, this corresponds to a reduction of the maximum bus length at a given bit rate. The thermal shutdown function is needed in particular if the bus line is short-circuited.

Higher layer protocols for CAN networks

The CAN protocol provides basic communication services. In any CAN network application, there is some additional functionality required. This may be implemented in software and, if it is separated from real application programs, is called higher-layer protocol. If open communication is required, the higher-layer protocol specification should be available publicly.

There are several standardized higher-layer protocols for CAN network applications. CiA supports all internationally standardized higher-layer protocols e.g. CANopen, DeviceNet, Isobus, as well as 'CAN Application Layer (CAL)', CANKingdom, and SAE J1939. They address different applications fields, and sometimes there may be a small overlapping of the fields. Many higher-layer protocols allow object-ori-

ented modeling of devices and network. They feature interoperability between devices, and when standardized device profiles are used even interchangeability of modules. Some higher-layer protocol definitions provide off-the-shelf plug-and-play capability.

However, more standardization leads to less communication flexibility meaning that is no longer possible to tailor communication to application requirements. Benefits of all standardized higher-layer protocols include off-the-shelf protocol stack implementations as well as configuration and analysis tools from different sources. Another important advantage of standardized protocols is the availability of independent conformance testing and certification as provided by ODVA for DeviceNet and by CiA for CANopen.

***CAN in Automation
Kontumazgarten 3
DE-90429 Nuremberg***

***Tel: +49-911-928819-0
Fax: +49-911-928819-79
headquarters@can-cia.org
www.can-cia.org***