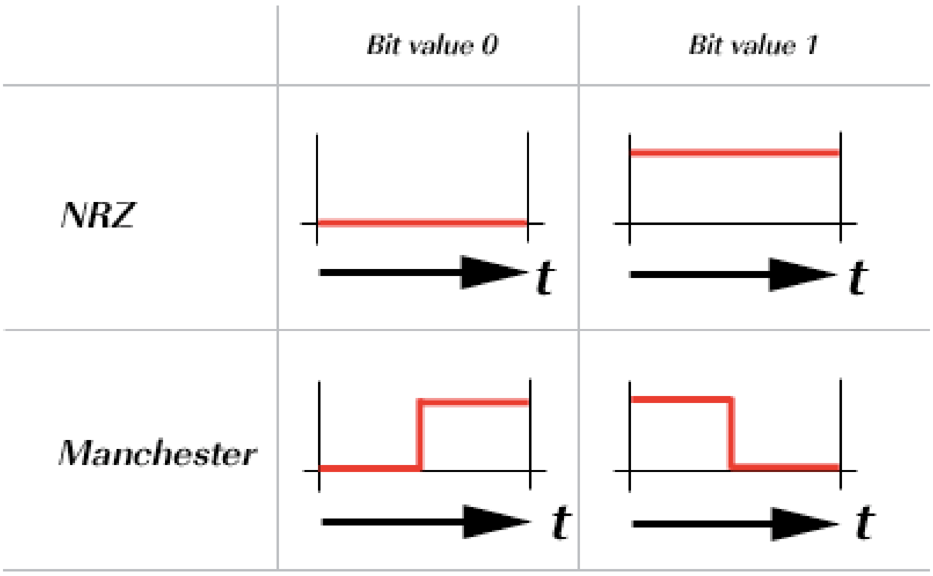
The CAN physical layer

The Controller Area Network (CAN) protocol defines the data link layer and part of the physical layer in the OSI model (picture of the OSI model), which consists of seven layers. The International Standards Organization (ISO) defined a standard, which incorporates the CAN specifications as well as a part of physical layer: the physical signaling, which comprises bit encoding and decoding (Non-Return-to-Zero, NRZ) as well as bit timing and synchronization.

Bit encoding

In chosen Non-Return-to-Zero (NRZ) bit coding the signal level remains constant over the bit time and thus just one time slot is required for the representation of a bit (other methods of bit encoding are e. g. Manchester or Pulse-width-modulation). The signal level can remain constant over a longer period of time; therefore measures must be taken to ensure that the maximum permissible interval between two signal edges is not exceeded. This is important for synchronization purposes. Bit stuffing is applied by inserting a complementary bit after five bits of equal value. Of course the receiver has to un-stuff the stuff-bits so that the original data content is processed.

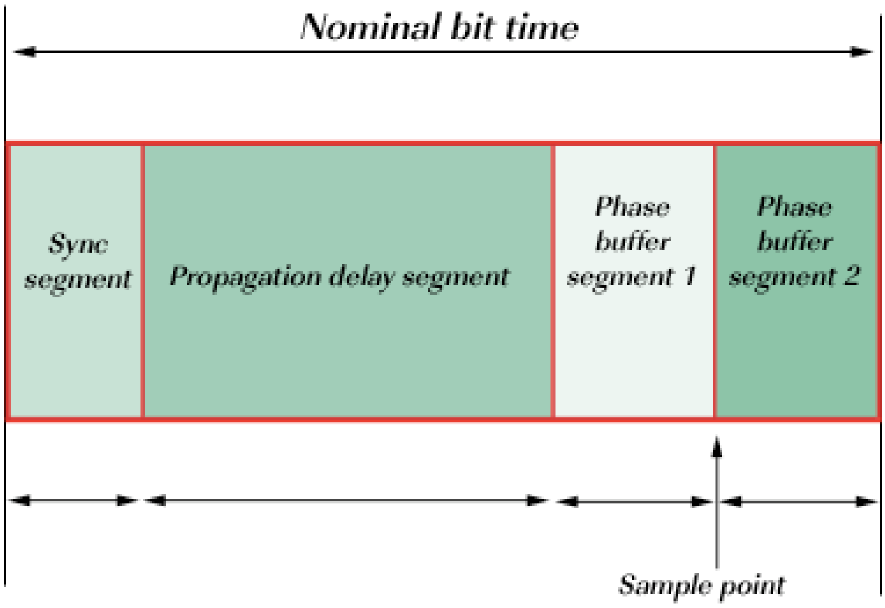


NRZ compared with Manchester bit representation

Am Weichselgarten 26 | Tel. +49-9131-69086-0 | headquarters@can-cia.org | CEO: Holger Zeltwanger
D-91058 Erlangen | Fax +49-9131-69086-79 | www.can-cia.org | Erlangen HRB 7780

Bit-timing and synchronization

On the bit-level (OSI level one, physical layer) CAN uses synchronous bit transmission. This enhances the transmitting capacity but also means that a sophisticated method of bit synchronization is required. While bit synchronization in a character-oriented transmission (asynchronous) is performed upon the reception of the start bit available with each character, a synchronous transmission protocol there is just one start bit available at the beginning of a frame. To enable the reveiver to correctly read the messages, continuous resynchronization is required. Phase buffer segments are therefore inserted before and after the nominal sample point within a bit interval.
The CAN protocol regulates bus access by bit-wise arbitration. The signal propagation from sender to receiver and back to the sender must be completed within one bit-time. For synchronization purposes a further time segment, the propagation delay segment, is needed in addition to the time reserved for synchronization, the phase buffer segments. The propagation delay segment takes into account the signal propagation on the bus as well as signal delays caused by transmitting and receiving nodes.



Nominal bit time

Two types of synchronization are distinguished: hard synchronization at the start of a frame and resynchronization within a frame.

- After a hard synchronization the bit time is restarted at the end of the sync segment. Therefore the edge, which caused the hard synchronization, lies within the sync segment of the restarted bit time.
- Resynchronization shortens or lengthens the bit time so that the sample point is shifted according to the detected edge.

Interdependency of data rate and bus length

Depending on the size of the propagation delay segment the maximum possible bus length at a specific data rate (or the maximum possible data rate at a specific bus length) can be determined. The signal propagation is determined by the two nodes within the system that are farthest apart from each other. It is the time that it takes a signal to travel from one node to the one farthest apart (taking into account the delay caused by the transmitting and receiving node), synchronization and the signal from the second node to travel back to the first one. Only then can the first node decide whether its own signal level (recessive in this case) is the actual level on the bus or whether it has been replaced by the dominant level by another node. This fact is important for bus arbitration.

Physical media

The basis for transmitting CAN messages and for competing for bus access is the ability to represent a dominant and a recessive bit value. This is possible for electrical and optical media so far. Also powerline and wireless transmission is possible.
For electrical media the differential output bus voltages are defined in ISO 11898-2 and ISO 11898-3, in SAE J2411, and ISO 11992 (see below).
With optical media the recessive level is represented by "dark" and the dominant level by "light".
The physical media most commonly used to implement CAN networks is a differentially driven pair of wired with common return. For vehicle body electronics

single wire bus lines are also used. Some efforts have been made to develop a solution for the transmission of CAN signals on the same line as the power supply.

The parameters of the electrical medium become important when the bus length is increased. Signal propagation, the line resistance and wire cross sections are factors when dimensioning a network. In order to achieve the highest possible bit rate at a given length, a high signal speed is required. For long bus lines the voltage drops over the length of the bus line. The wire cross section necessary is calculated by the permissible voltage drop of the signal level between the two nodes farthest apart in the system and the overall input resistance of all connected receivers. The permissible voltage drop must be such that the signal level can be reliably interpreted at any receiving node.

Specific signal propagation time (ns/m)	Maximum bit rate (kbit/s)
5.0	80
5.5	73
6.0	67
6.5	62
7.0	58

* assumed line length 100 m

Am Weichselgarten 26 | Tel. +49-9131-69086-0 | headquarters@can-cia.org | CEO: Holger Zeltwanger
D-91058 Erlangen | Fax +49-9131-69086-79 | www.can-cia.org | Erlangen HRB 7780

Network topology

Electrical signals on the bus are reflected at the ends of the electrical line unless measures against that have been taken. For the node to read the bus level correctly it is important that signal reflections are avoided. This is done by terminating the bus line with a termination resistor at both ends of the bus and by avoiding unnecessarily long stubs lines of the bus. The highest possible product of transmission rate and bus length line is achieved by keeping as close as possible to a single line structure and by terminating both ends of the line. Specific recommendations for this can be found in the according standards (i.e. ISO 11898-2 and -3).
It is possible to overcome the limitations of the basic line topology by using repeaters, bridges or gateways. A repeater transfers an electrical signal from one physical bus segment to another segment. The signal is only refreshed and the repeater can be regarded as a passive component comparable to a cable. The repeater divides a bus into two physically independent segments. This causes an additional signal propagation time. However, it is logically just one bus system.
A bridge connects two logically separated networks on the data link layer (OSI layer 2). This is so that the CAN identifiers are unique in each of the two bus systems Bridges implement a storage function and can forward messages or parts thereof in an independent time-delayed transmission. Bridges differ from repeaters since they forward messages, which are not local, while repeaters forward all electrical signals including the CAN identifier.
A gateway provides the connection of networks with different higher-layer protocols. It therefore performs the translation of protocol data between two communication systems. This translation takes place on the application layer (OSI layer 7).

Bus access

The connection between a CAN controller chip and a two-wire differential bus a variety of CAN transceiver chips according to different physical layer standards are available (see below ISO 11898-2 and –3, etc.).
This interface basically consists of a transmitting amplifier and a receiving amplifier transceiver = transmit and receive). Aside from the adaptation of the signal representation between chip and bus medium the transceiver has to meet a series of additional requirements. As a transmitter it provides sufficient driver output capacity

Am Weichselgarten 26 Tel. +49-9131-69086-0 headquarters@can-cia.org CEO: Holger Zeltwanger

D-91058 Erlangen Fax +49-9131-69086-79 www.can-cia.org Erlangen HRB 7780

and protects the on-controller-chip driver against overloading. It also reduces electromagnetical radiation. As a receiver the CAN transceiver provides a defined recessive signal level and protects the on-controller-chip input comparator against over-voltages on the bus lines. It also extends the common mode range of the input comparator in the CAN controller and provides sufficient input sensitivity. Furthermore it detects bus errors such as line breakage, short circuits, shorts to ground, etc. A further function of the transceiver can also be the galvanic isolation of a CAN node and the bus line.

Physical layer standards

ISO 11898-2 high speed

ISO 11898-2 is the most used physical layer standard for CAN networks. It describes the bus access unit (implemented as CAN high-speed transceiver) functions as well as some medium-dependent interface features.
In this standard the data rate is defined up to 1 Mbit/s with a theoretically possible bus length of 40 m at 1 Mbit/s. The high-speed standard specifies a two-wire differential bus whereby the number of nodes is limited by the electrical busload. The characteristic line impedance is 120 Ohm, the common mode voltage ranges from -2 V on CAN_L to +7 V on CAN_H. The nominal specific propagation delay of the two-wire bus line is specified at 5ns/m. All these figures are valid only for a 1 Mbit/s transfer rate and a maximum network length of 40 m.
In order to achieve physical compatibility all nodes in the network must use the same or a similar bit-timing. For automotive applications the SAE published the SAE J2284 specification. For industrial and other non-automotive applications the system designer may use the CiA 102 recommendation. This specification defines the bit-timing for rates of 10 kbit/s to 1 Mbit/s. It also provides recommendations for bus lines and for connectors and pin assignment.

ISO 11898-3 fault-tolerant

An alternative form of bus interfacing and arrangement of bus lines is specified in ISO 1898-3 (fault-tolerant CAN). This standard is mainly used for body electronics in the automotive industry. Since for this specification a short network was assumed,

the problem of signal reflection is not as important as for long bus lines. This enables the use of an open bus line possible.
This means low bus drivers can be used for networks with very low power consumption and the bus topology is no longer limited to a linear structure. It is possible to transmit data asymmetrically over just one bus line in case of an electrical failure of one of the bus lines.
ISO 11898-3 defines data rates up to 125 kbit/s with the maximum bus length depending on the data rate used and the busload. Up to 32 nodes per network are specified. The common mode voltage ranges between -2 V and +7 V. The power supply is defined at 5 V.
Transceiver chips, which support this standard, are available from several companies. The fault-tolerant transceivers support the complete error management including the detection of bus errors and automatic switching to asymmetrical signal transmission.

SAE J2411 single wire

The single-wire standard SAE J2411 is also for CAN network applications with low requirements regarding bit rate and bus length. The communication takes place via just one bus line with a nominal data rate of 33,3 kbit/s (83,3 kbit/s in high-speed mode for diagnostics). The standard defines up to 32 nodes per network. The main application area of this standard is in comfort electronics networks in motor vehicles. An unshielded single wire is defined as the bus medium. A linear bus topology structure is not necessary. The standard includes selective node sleep capability, which allows regular communication to take place among several nodes while others are left in a sleep state. Transceivers for this standard are available, too.

ISO 11992 point-to-point

An additional approach to using CAN low-speed networks with fault-tolerant functionality is specified in the ISO 11992 standard. It defines a point-to-point connection for use in e.g. towing vehicles and their trailers. For one vehicle with one trailer, a point-to-point connection is defined. For one vehicle with two trailers, a daisy-chain connection is defined. The nominal data rate is 125 kbit/s with a maximum bus line length of 40 m. The standard defines the bus error management and the supply voltage (12 V or 24 V). An unshielded twisted pair of wires is defined as the bus medium.

Am Weichselgarten 26 | Tel. +49-9131-69086-0 | headquarters@can-cia.org | CEO: Holger Zeltwanger
D-91058 Erlangen | Fax +49-9131-69086-79 | www.can-cia.org | Erlangen HRB 7780

Others

Not standardized are fiber-optical transmissions of CAN signals. Due to the directed coupling into the optical media, the transmitting and receiving lines must be provided separately. Also, each receiving line must be externally coupled with each transmitting line in order to ensure bit monitoring. A star coupler can implement this. The use of a passive star coupler is possible with a small number of nodes, thus this kind of network is limited in size. The extension of a CAN network with optical media is limited by the light power, the power attenuation along the line and the star coupler rather than the signal propagation as in electrical lines.
Advantages of optical media are emission- and immission-free transmission and complete galvanic decoupling. The electrically neutral behavior is important for applications in explosive or electromagnetically disturbed environments.

Am Weichselgarten 26 *Tel. +49-9131-69086-0* *headquarters@can-cia.org* *CEO: Holger Zeltwanger*

D-91058 Erlangen *Fax +49-9131-69086-79* *www.can-cia.org* *Erlangen HRB 7780*