CAN

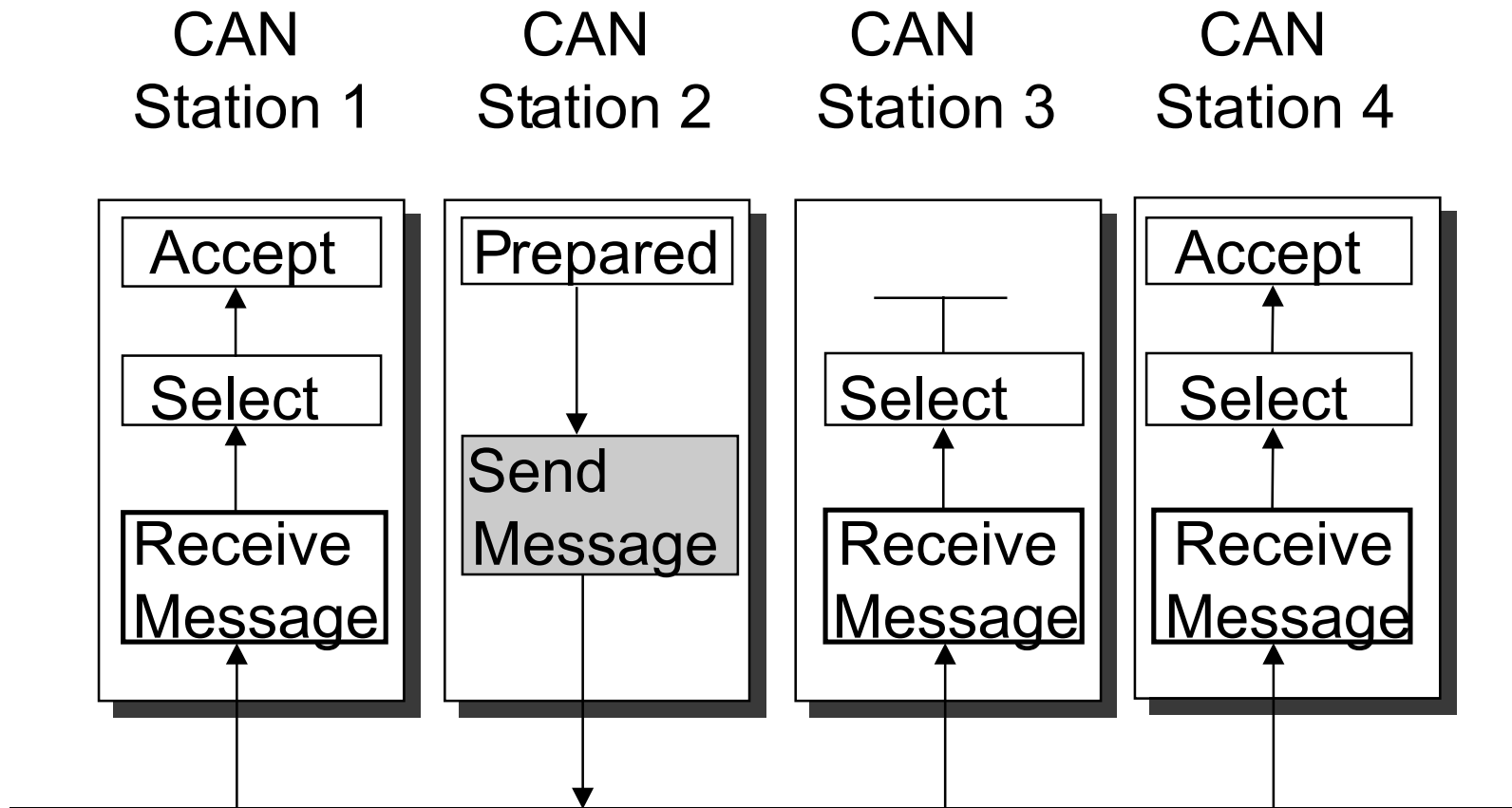# Data Link Layer

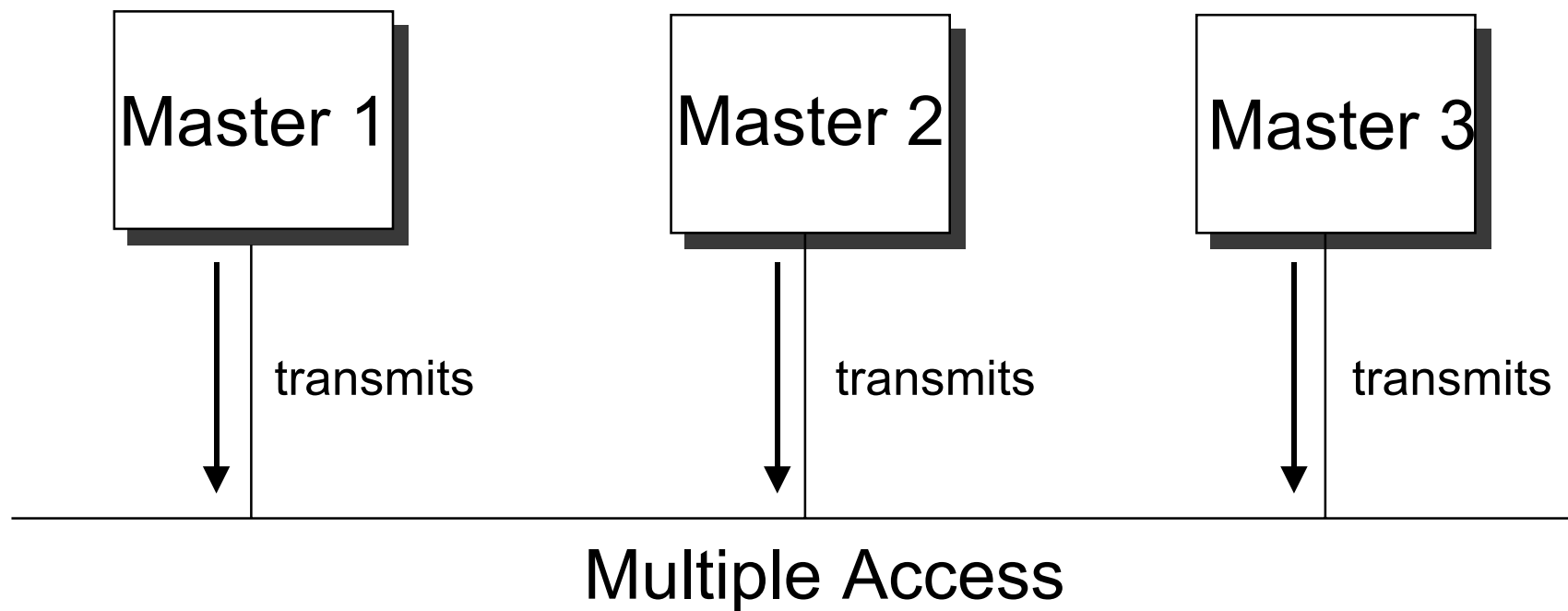## Communication Models

Bus Arbitration

Frame Formats

Error Detection

Error Handling

Implementation

CAN Broadcast Communication

CAN Station 1	CAN Station 2	CAN Station 3	CAN Station 4

CAN Multi-Master Communication

Master 1	Master 2	Master 3

transmits   transmits   transmits

Multiple Access

Data Link Layer

CAN

Communication Models

ẞus Arbitration

Frame Formats

Error Detection

Error Handling

Implementation

Dominant and Recessive Level

V+

V+ -> 1
⊥ -> 0

bus-line

S1 device 1

S2 device 2

S3 device 3
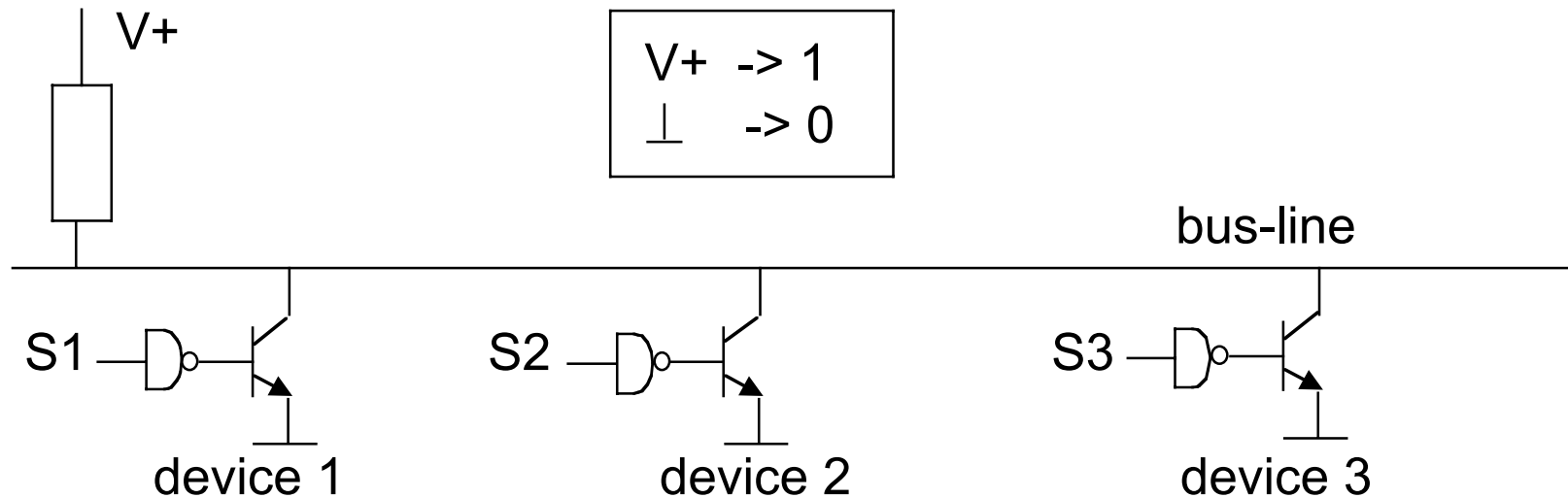
State Table

S1	0	1	0	1	0	1	0	1
S2	0	0	1	1	0	0	1	1
S3	0	0	0	0	1	1	1	1
Bus Level	0	0	0	0	0	0	0	1

0 - level is dominant

1 - level is recessive

CAN Bus Arbitration with CSMA/CA

Node 3 wins arbitration and transmits his data.

© CiA

Data Link Layer

Communication Models

Bus Arbitration

Frame Formats

Error Detection

Error Handling

Implementation

CAN

CAN Frame Formats
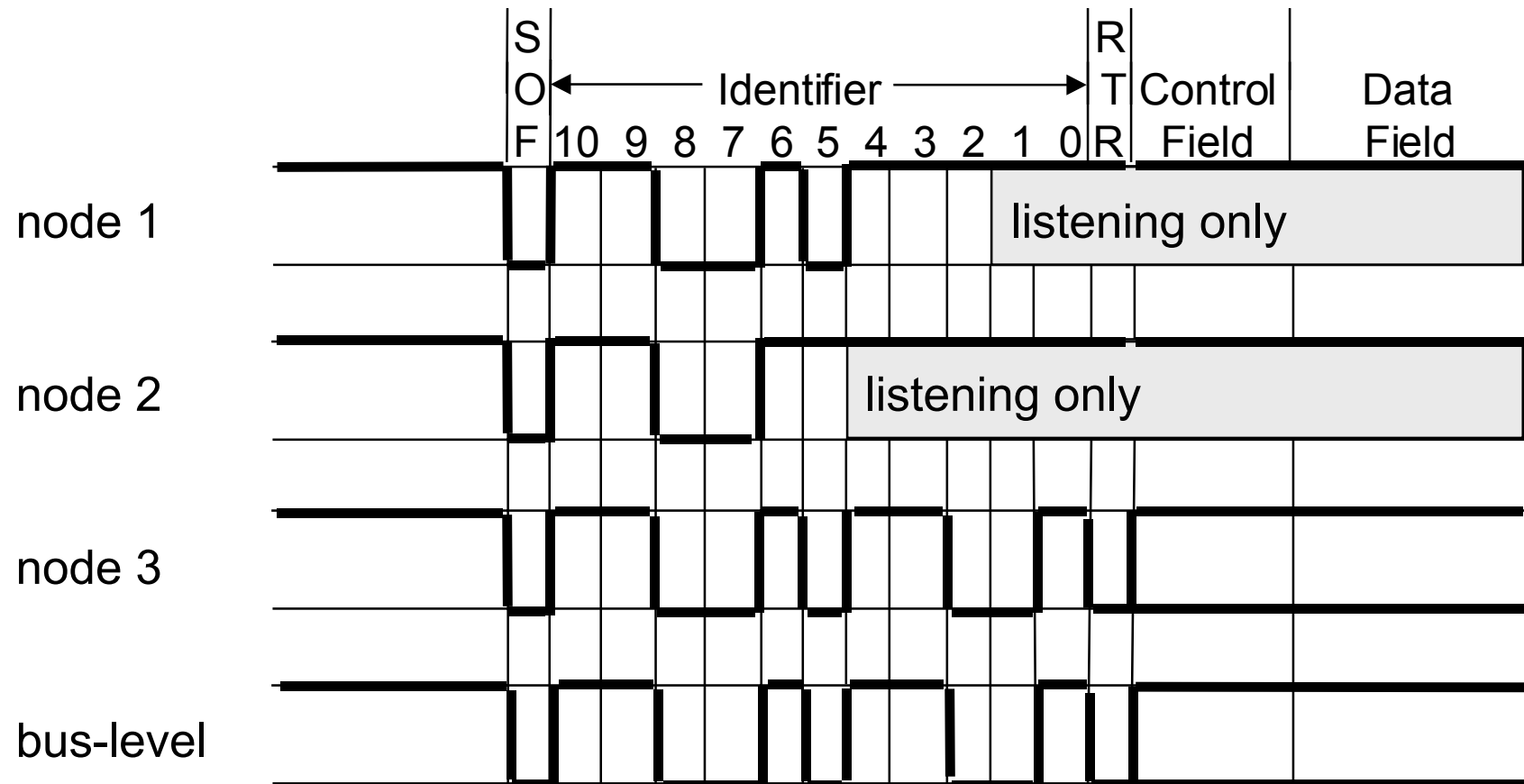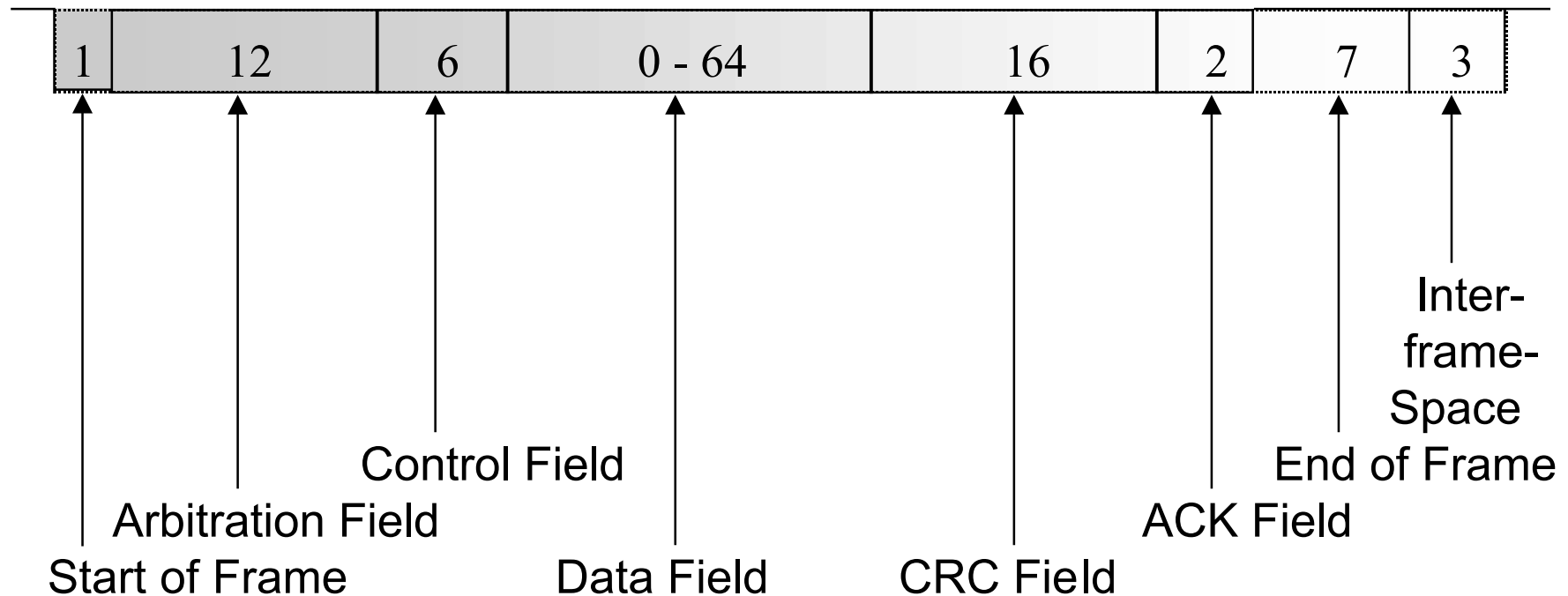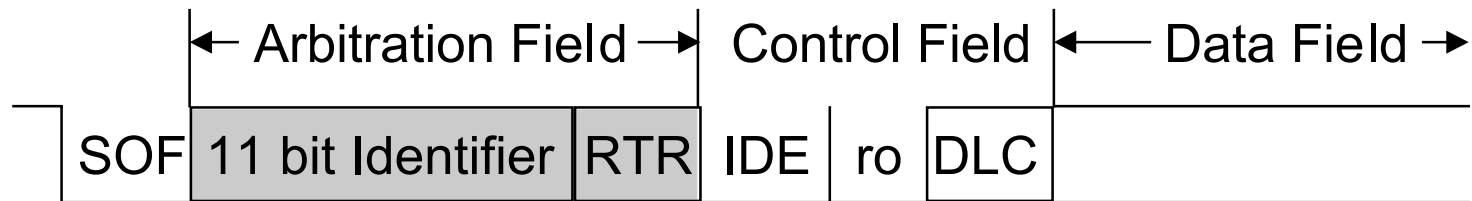
- Data Frame - Used for data transfer on transmitter´s initiative
- Remote Frame - Used for initiating a data transfer by a receiver
- Error Frame - Used for signalling a detected error
- Overload Frame - Used for initiating a time delay between two frames

Standard Data Frame
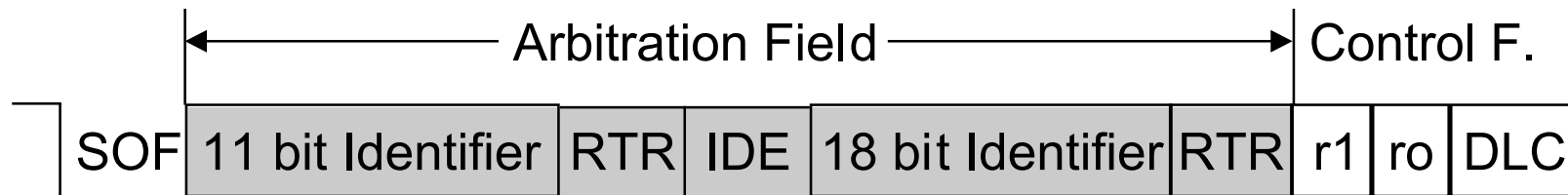
| 1 | 12 | 6 | 0 - 64 | 16 | 2 | 7 | 3 |

Start of Frame

Arbitration Field

Control Field

Data Field

CRC Field

ACK Field

End of Frame

Inter-frame-Space

© CiA

3.1.

Arbitration Field

Standard Format

Extended Format

3.1.2.

CAN Remote Frame

| 1 | 11/29 | 1 | 6 | 16 | 2 | 7 | 3 |

Inter-
frame-
Space

Control Field

RTR-Bit

End of Frame

ACK Field

Identifier

CRC Field

Start of Frame

© CiA

3.2.

CAN Active Error Frame

	6 Bit	0...6 Bit	8 Bit	3 Bit	

Error Flag

Superposition of
Error Flags

Error
Delimiter

Interframe Space
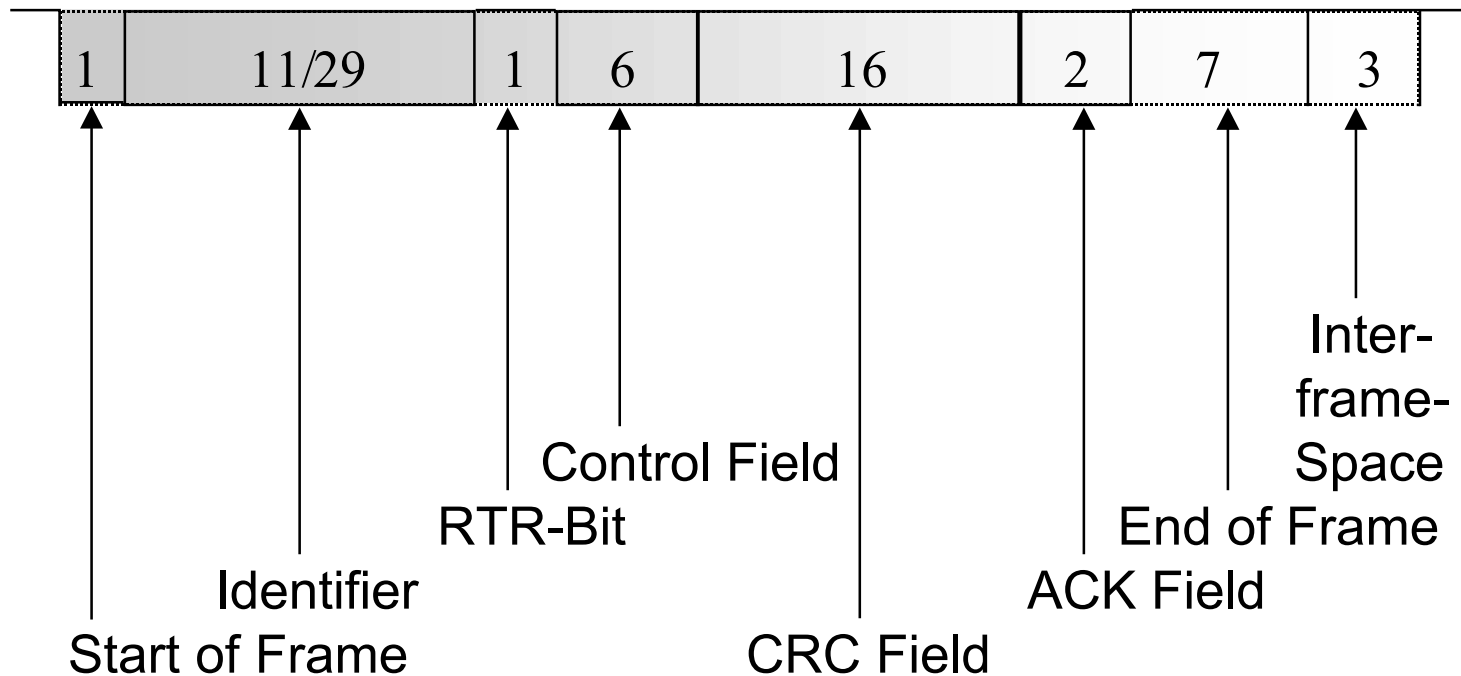
Data Frame ← Error Frame →

CAN Overload Frame
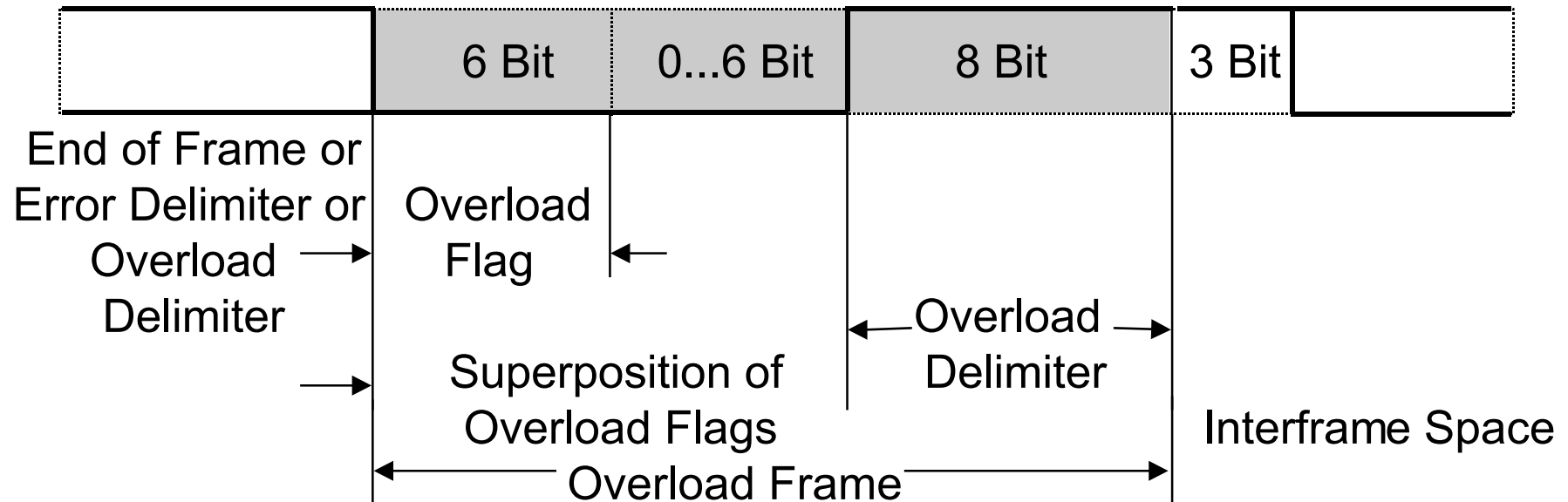
	6 Bit	0...6 Bit	8 Bit	3 Bit	

End of Frame or
Error Delimiter or
Overload
Delimiter

Overload
Flag

Superposition of
Overload Flags

Overload Frame

Overload
Delimiter

Interframe Space

3.4.

Data Link Layer

CAN

Communication Models

Bus Arbitration

Frame Formats

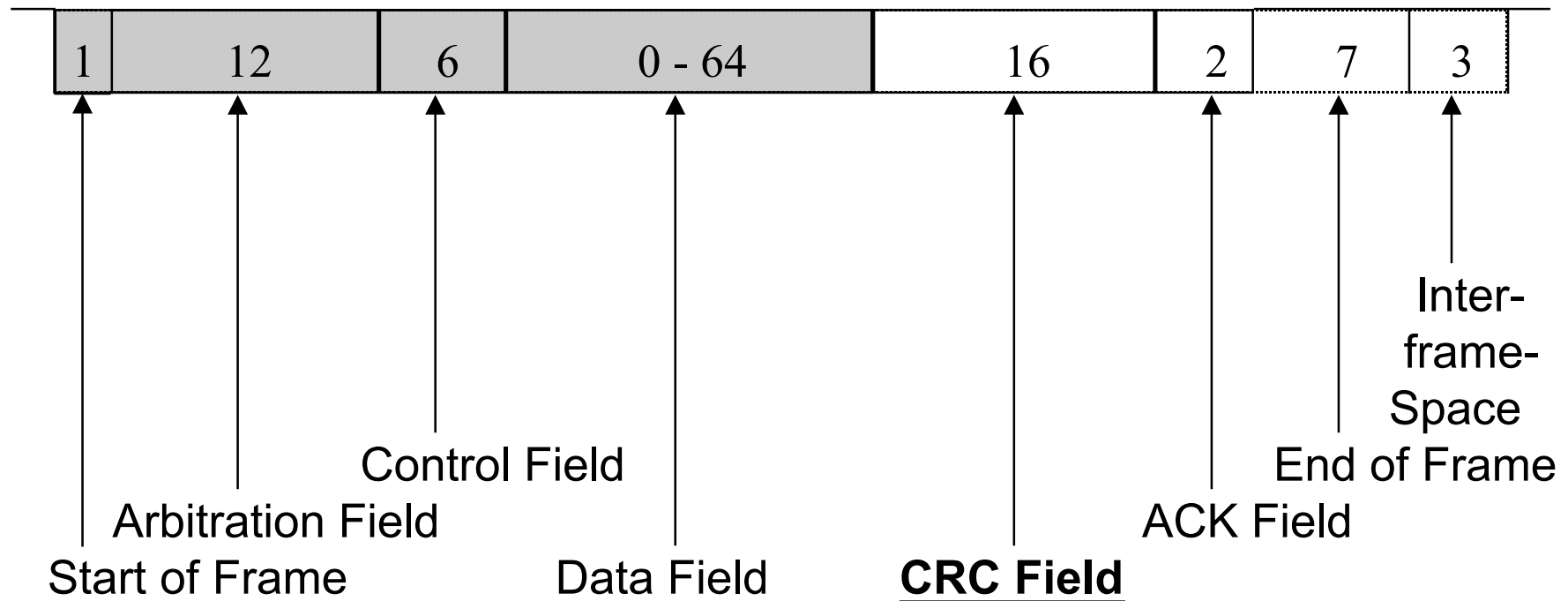**Error Detection**

Error Handling
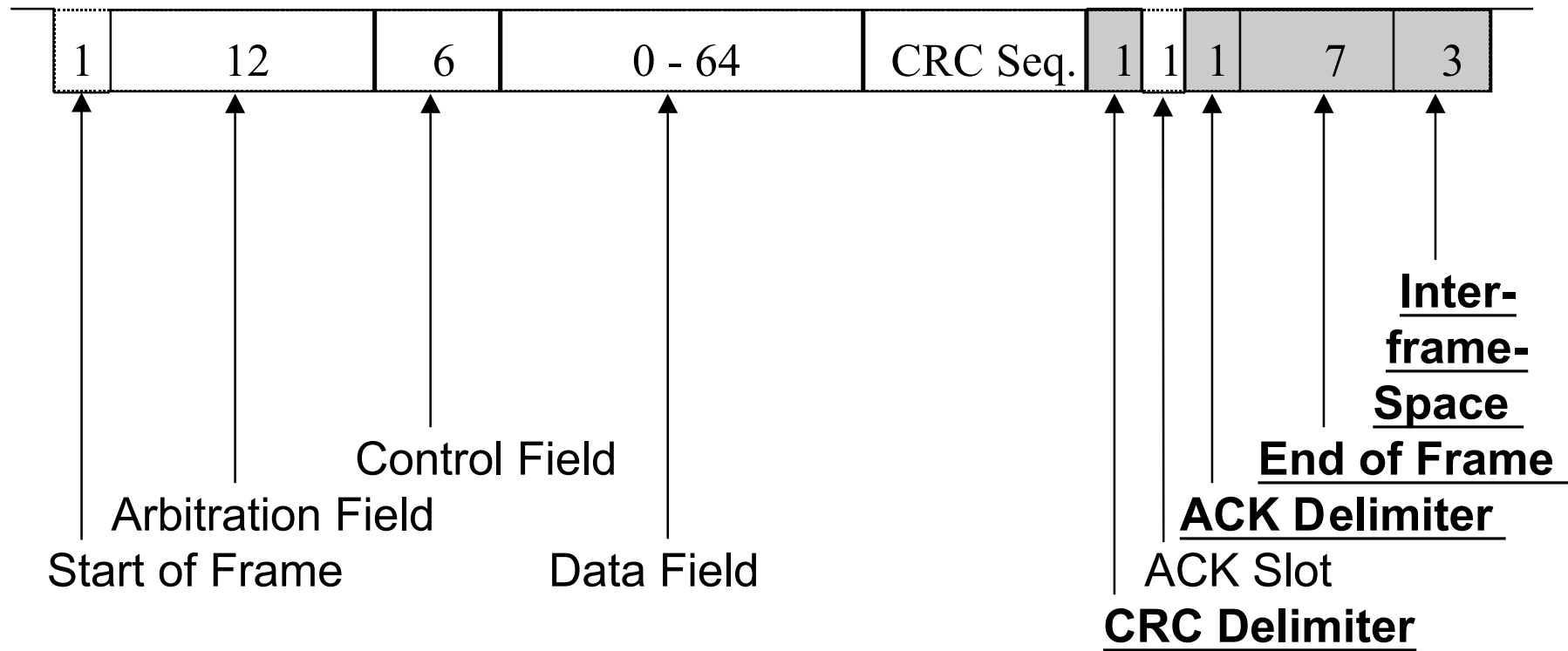
Implementation

© CiA

4.

Error Detection Mechanisms

Data Link Layer

Cyclic Redundancy Check

Frame Check

Acknowledge Error Check

Bit-Monitoring

Bit-Stuffing

Cyclic Redundancy Check

| 1 | 12 | 6 | 0 - 64 | 16 | 2 | 7 | 3 |

Start of Frame

Arbitration Field

Control Field

Data Field

CRC Field

ACK Field

End of Frame

Inter-frame-Space

4.1.

CAN Frame Check

| 1 | 12 | 6 | 0 - 64 | CRC Seq. | 1 | 1 | 1 | 7 | 3 |

Start of Frame

Arbitration Field

Control Field

Data Field

CRC Delimiter

ACK Slot

ACK Delimiter

End of Frame

Inter-frame-Space

© CiA

4.2.

Acknowledge Error Check

1	12	6	0 - 64	16	1	1	7	3

Inter-
frame-
Space

Control Field

End of Frame

Arbitration Field

ACK Delimiter

Start of Frame

Data Field

ACK Slot

CRC Field

© CiA

4.3.

Bit-Monitoring

Bit-Stuffing and De-Stuffing

Bit Sequence to be transmitted

1
0

1 2 1 2 3 4 5 6 7 8 9 1 2 3 4 5 1 2 1 2

Stuffed **(S)** Bit-Sequence

1
0

1 2 1 2 3 4 5 **S** 6 7 8 9 1 2 3 4 5 **S** 1 2

De-Stuffed Bit Sequence

1
0

1 2 1 2 3 4 5 6 7 8 9 1 2 3 4 5 1 2 1 2
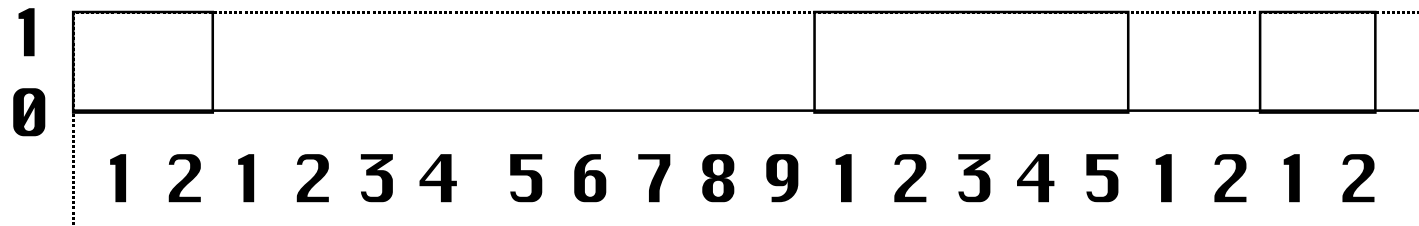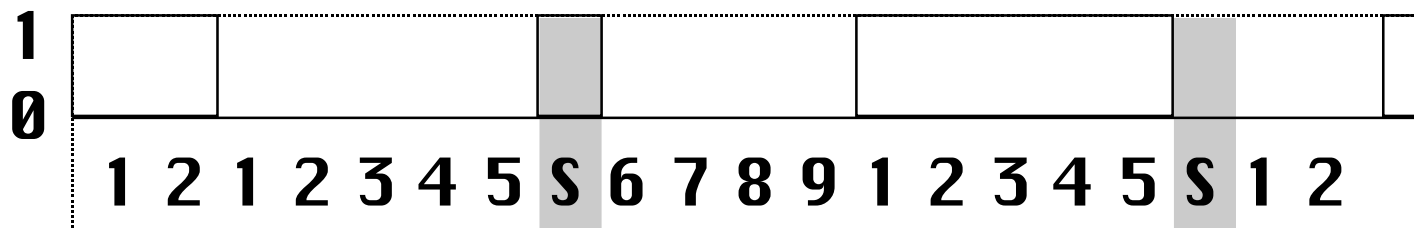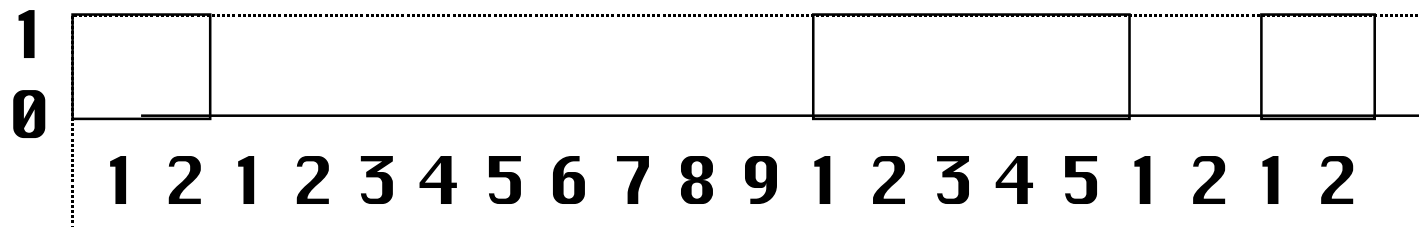
Error-Detection Analysis

Probability of Non-detected Faulty CAN Messages:

$$\rho < 4.7 \times 10^{-11} \times \text{error rate}$$

example: 1 error each 0.7 s, 500 kbps,
8h / day, 365 days / year
statistical average:
1 undetected error in 1000 years

Data Link Layer

CAN

Communication Models

Bus Arbitration

Frame Formats

Error Detection

Error Handling

Implementation

© CiA

5.

Globalisation of Local Errors

transmitter	data	data			8 bit	3	repetition
receiver 1			6 bit				
receiver 2		6 bit					
bus-level							
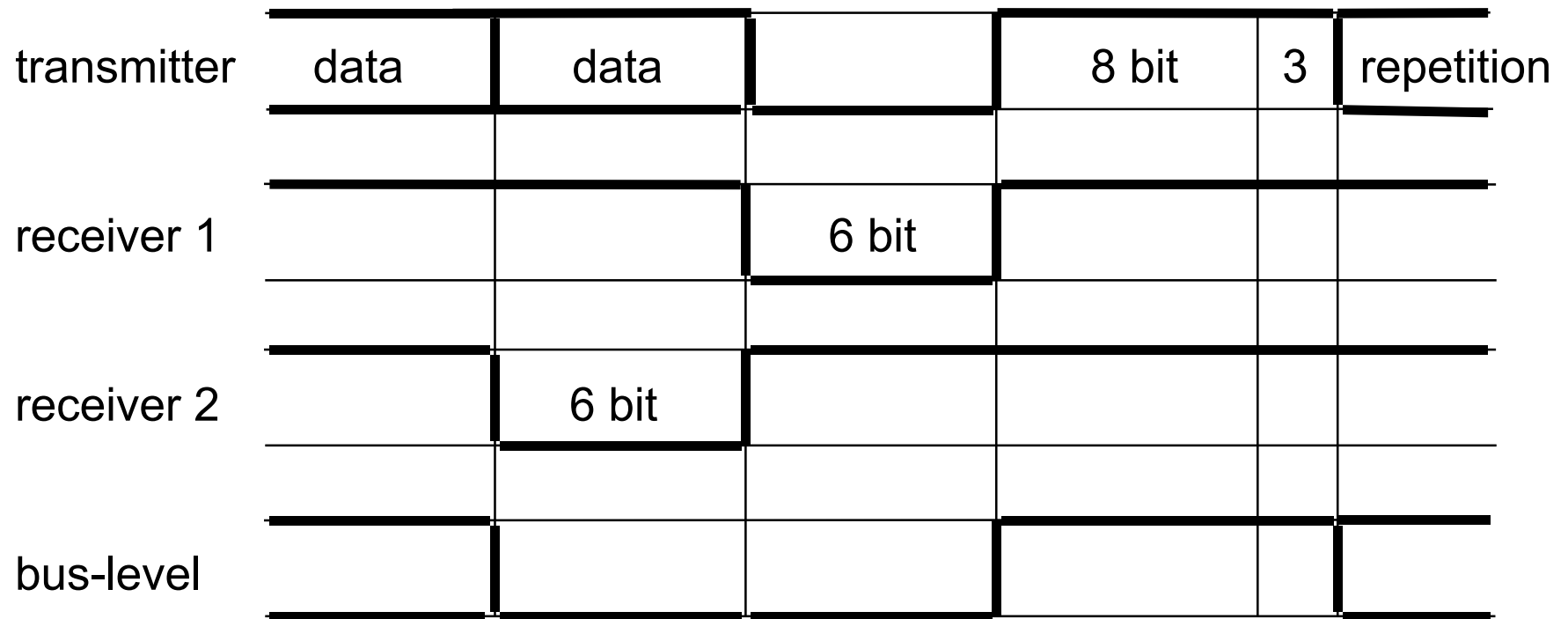
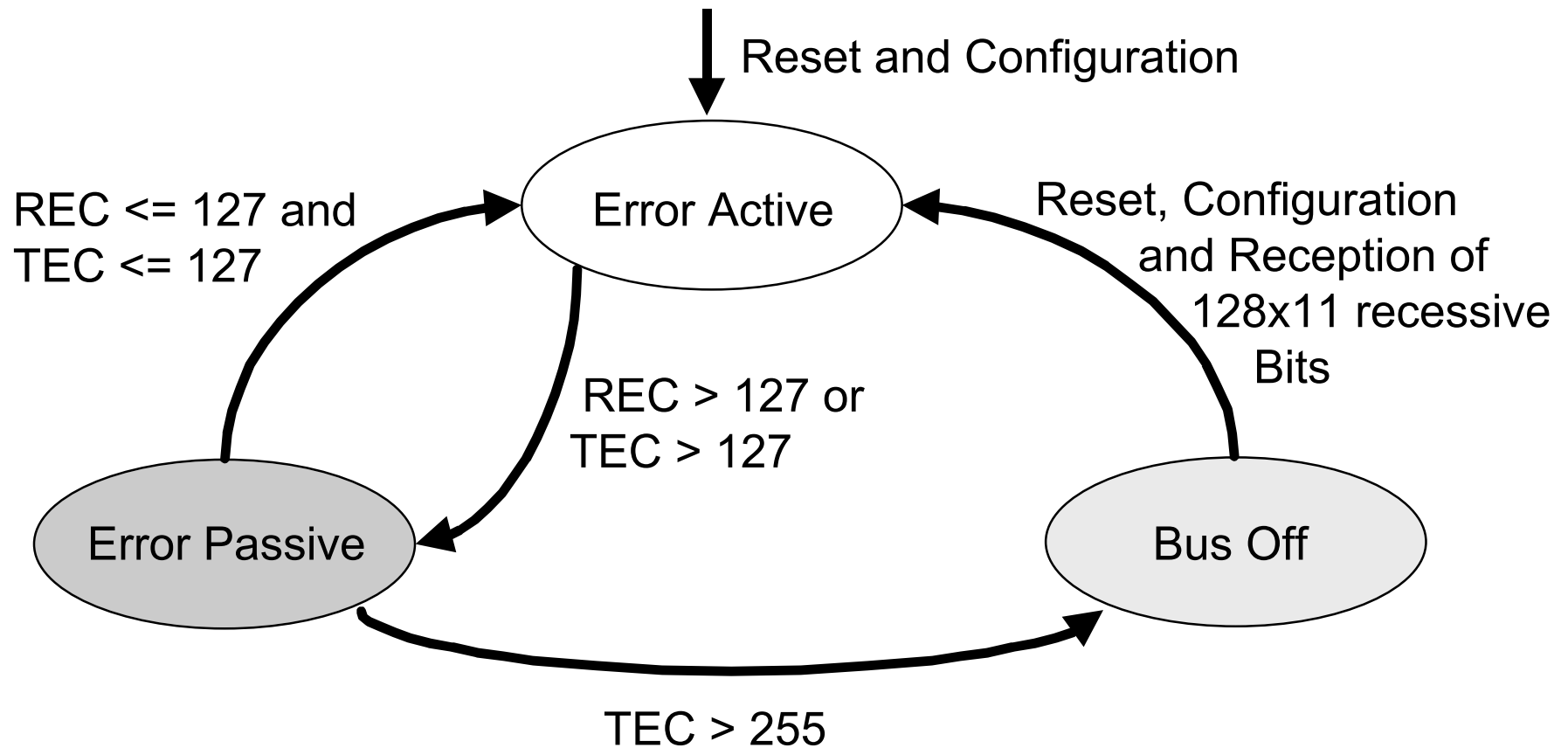The receiver 2 detects an error and makes it public to the other nodes.

Message Doubling

The CAN protocol assures with an extreme high probability that no messages are falsified or lost. But it is possible that a message is doubled by a single bit error near the end of End of Frame (EOF)!

Therefore, if CAN is used in a disturbed environment:

- don't use toggle messages

- don't transmit messages carrying relative data

   (like angle increments or delta counts)

- use protected protocols or sequence numbers

   for data or program segmentation

Error States of a CAN Node

Reset and Configuration

Error Active

REC <= 127 and
TEC <= 127

Reset, Configuration
and Reception of
128x11 recessive
Bits

REC > 127 or
TEC > 127

Error Passive

Bus Off

TEC > 255

REC: Receive Error Counter
TEC: Transmit Error Counter
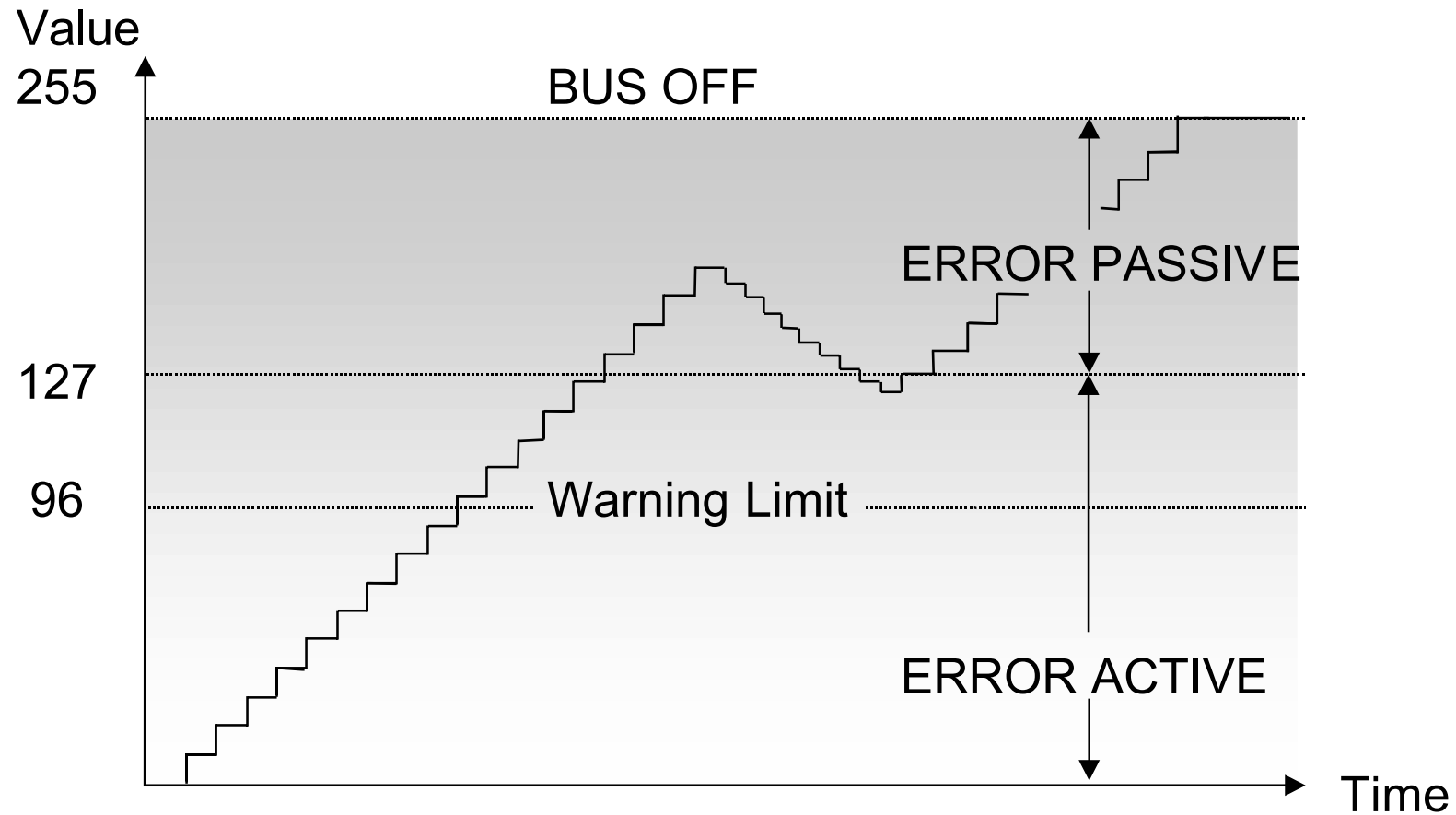
© CiA

5.3.1.

Transmit Error Counter

Data Link Layer

CAN

Communication Models

Bus Arbitration

Frame Formats

Error Detection

Error Handling

Implementation

© CiA

CAN Object-Filtering and -Storage

CAN Protocol Controller

Microcontroller

TX

RX

object storage

acceptance filtering by hardware (simple or advanced)

object storage

acceptance filtering by software (optional)

Appli-cation

Priority Inversion

CAN Protocol Controller   Microcontroller

Single Transmit-Buffer

message of low priority   message of high priority

waiting loop
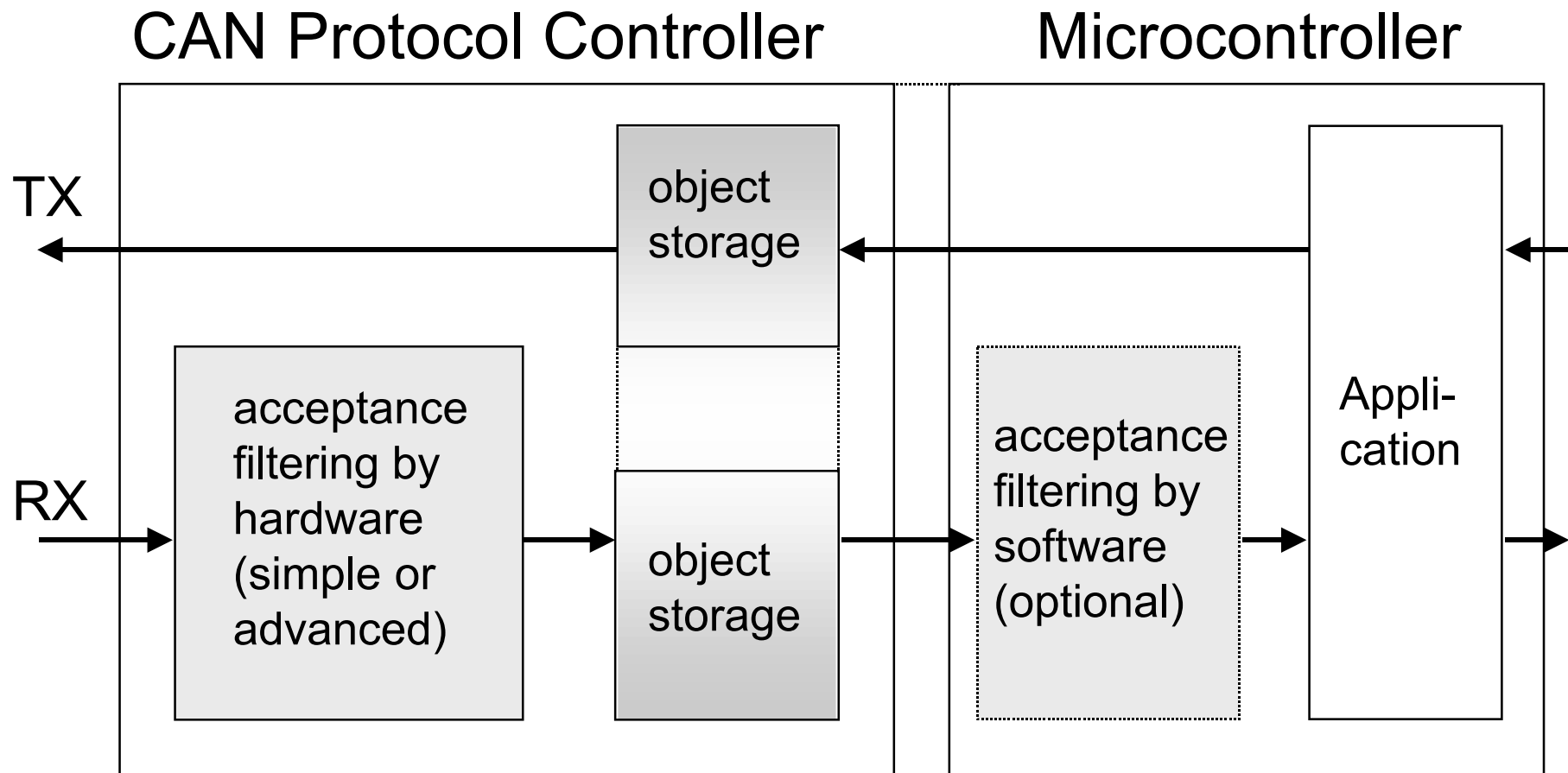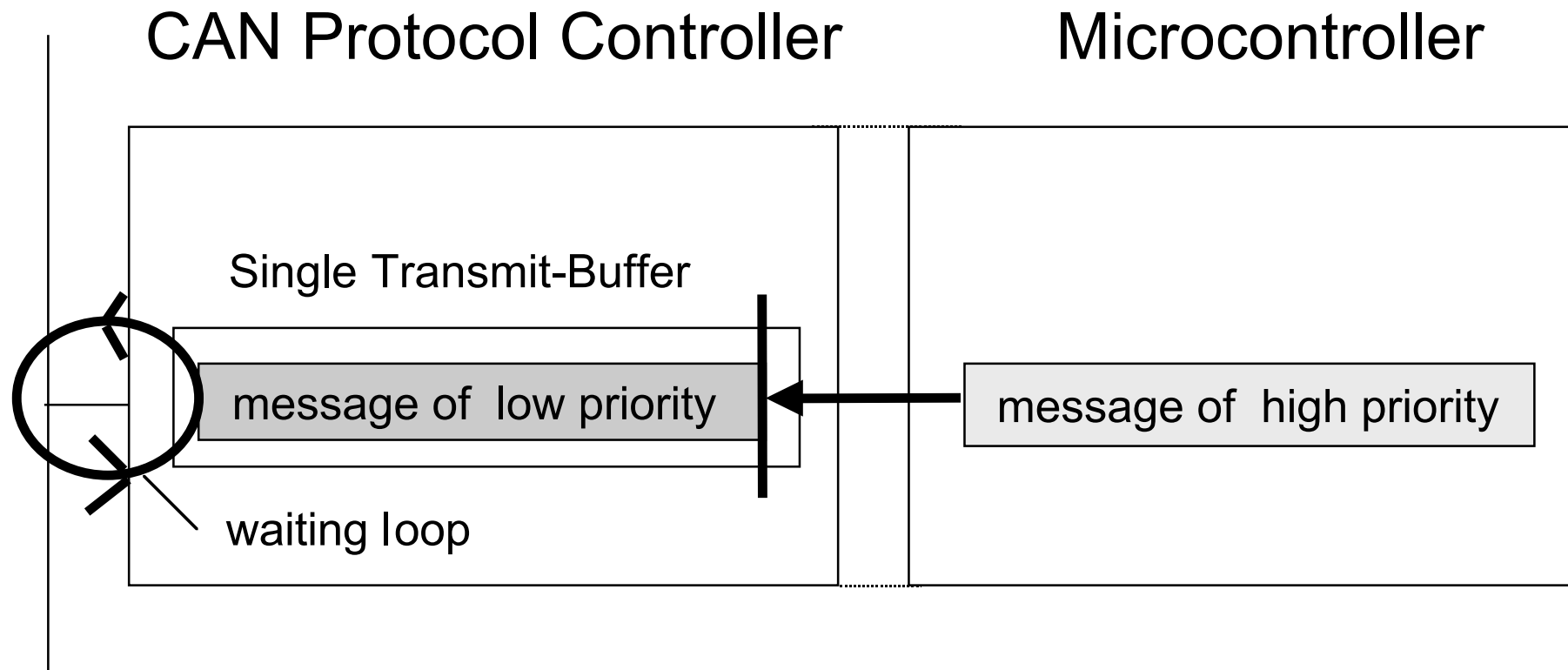
Overwriting of Received Message

CAN Protocol Controller   **Microcontroller**

Dual Receive-Buffer as FIFO

RX

third received message
first received message

first message-interrupt
not performed

second received message
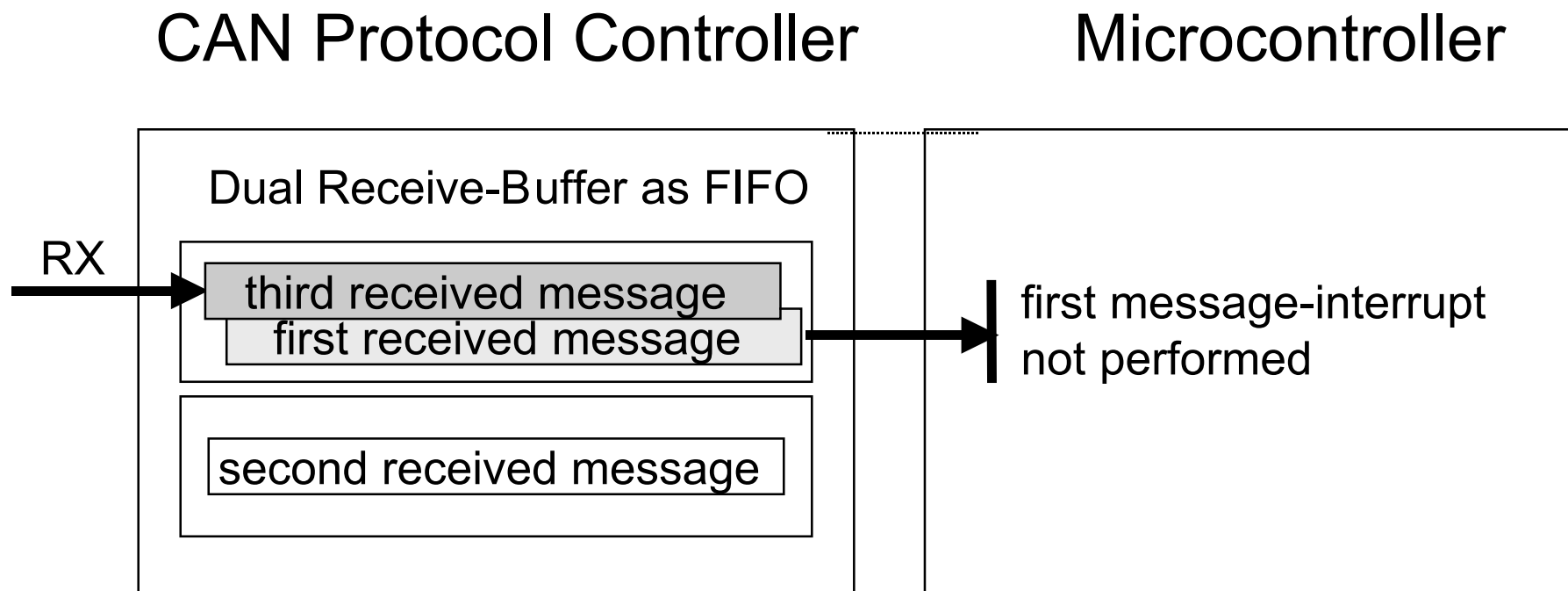
Updating of Received Data

CAN Protocol Controller   Microcontroller

Receive-Buffer as Dual-Ported RAM

| data of message 1 |
| data of message 2 |
| data of message 3 |

RX → | data of message 4 | → message-interrupt not performed

⋮

| data of message n |

Physical Layer

- ◆ Bit-Encoding/Decoding
- ◆ Bit-Timing
- ◆ Soft Synchronization
- ◆ Media Attachment
- ◆ Transceiver Characteristics
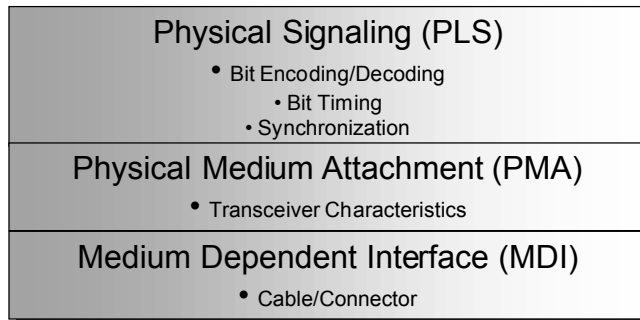- ◆ Bus Cable Characteristics

© CiA
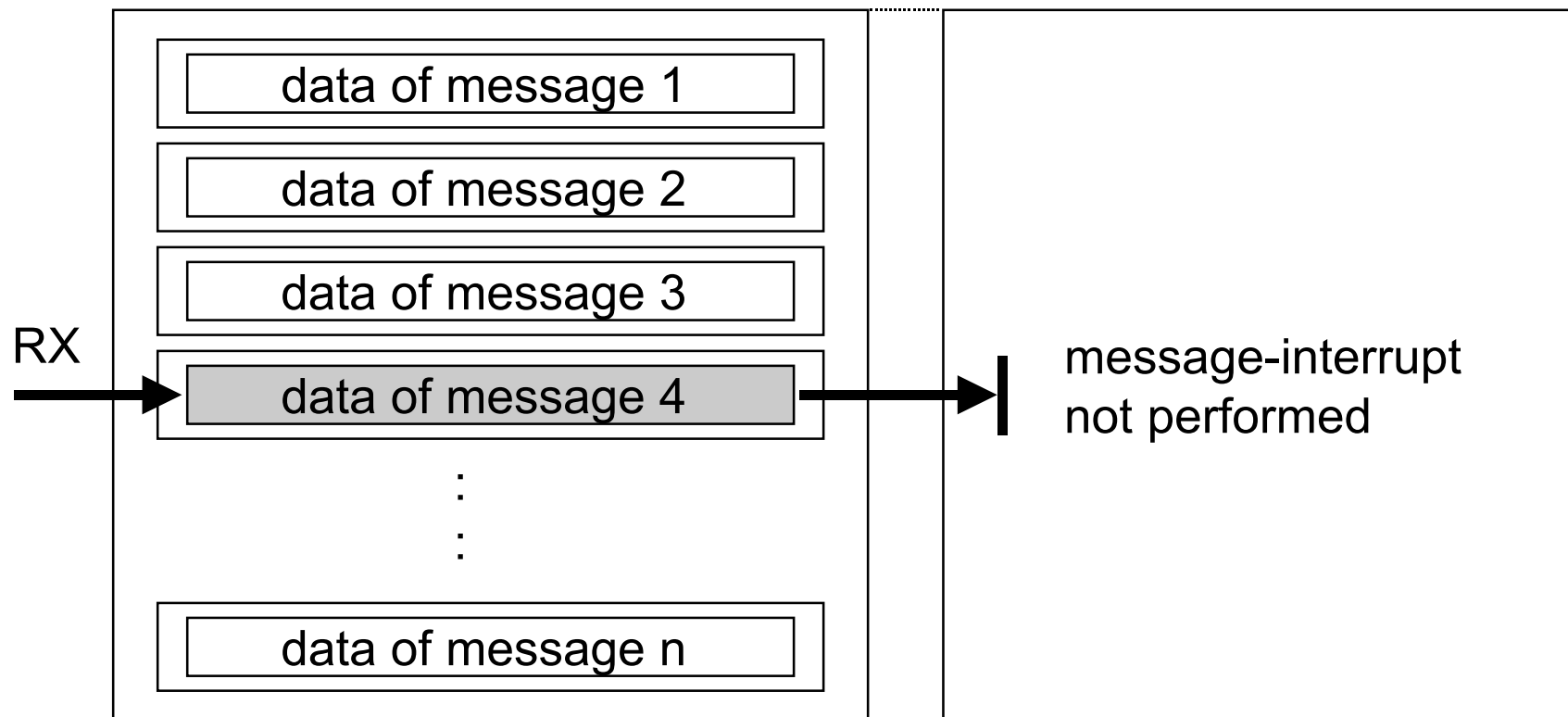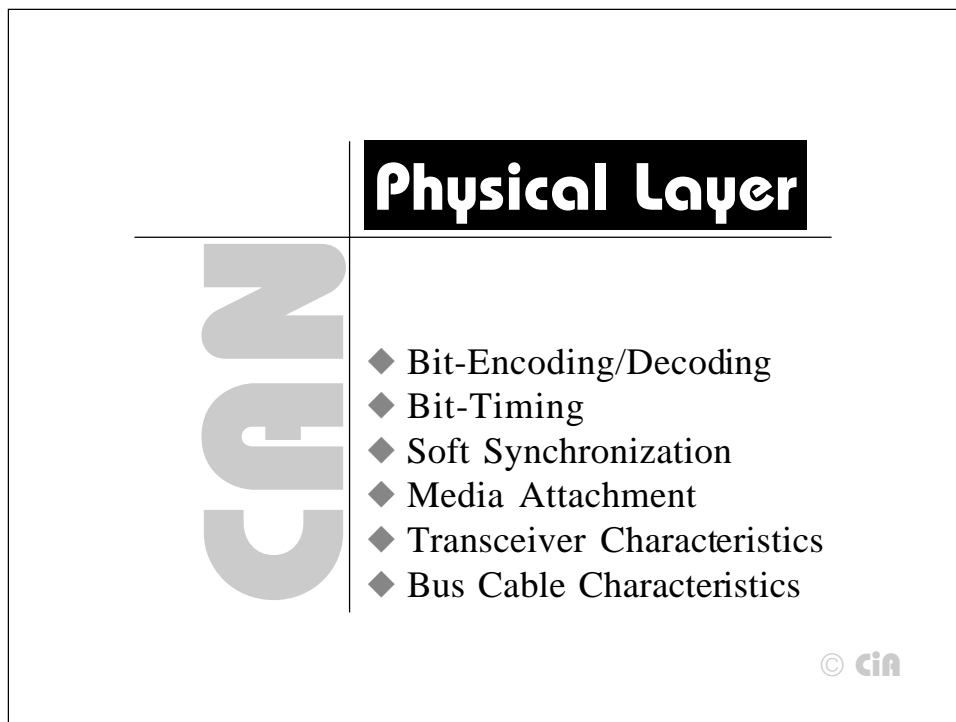
The physical layer of a communication link covers the aspects of physical data transmission between the nodes of a network. In this presentation, the requirements of CAN physical layers and some existing concepts are discussed.

The MAC (Medium Access Control) layer of the CAN protocol defines the non-destructive bit-wise arbitration, so that the message with highest prior identifier will get the bus. Therefore, any CAN physical layer has to support the representation of a recessive and a dominant state on the transmission medium. The transmission shall be in the recessive state if no bus node transmit a dominant bit. If one or multiple bus nodes transmit a dominant bit, then the transmission medium shall enter the dominant state, thus overwriting the recessive state.

Physical Interface Layer

| Physical Signaling (PLS) |
| • Bit Encoding/Decoding |
| • Bit Timing |
| • Synchronization |

Physical Medium Attachment (PMA)
• Transceiver Characteristics

Medium Dependent Interface (MDI)
• Cable/Connector

© CiA

The CAN physical layer can be divided in three sub-layers. The PLS layer is implement in the CAN controller chips. The PMA layer describes the transceiver characteristics. The MDI layer specifies the cable and connector characteristics.

The PMA and MDI layers are subject of different international, national and industry standards as well as proprietary specifications. Most common is the ISO 11898 standard specifying a high-speed transceiver for CAN-based networks.
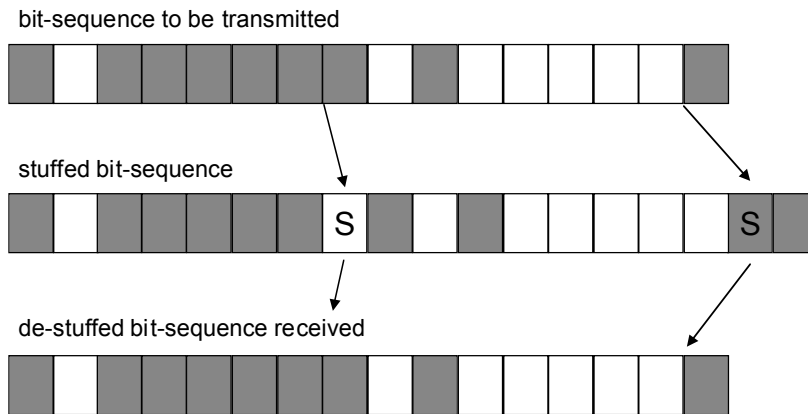
Non-Return-to-Zero Coding

5V — recessive bit-level

| Bit 1 | Bit 2 | Bit 3 | Bit 3 | Bit 4 | Bit 5 |

0V
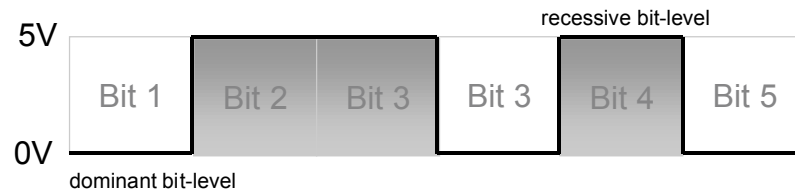
dominant bit-level

Remark: *There is not in each bit a falling or rising edge*

© CiA

The bit stream in a CAN message is coded according to the Non-Return-to-Zero (NRZ) method. This means that during the total bit time the generated bit level is either 'dominant' or 'recessive'. The alternative method, the Manchester coding, requires in each bit a falling or rising edge, which leads to higher frequency.

Bit-Stuffing Rule

bit-sequence to be transmitted

stuffed bit-sequence

de-stuffed bit-sequence received

© CiA

One characteristic of Non-Return-to-Zero code is that the signal provides no edges that can be used for resynchronization if transmitting a large number of consecutive bits with the same polarity. Therefore bit-stuffing is used to ensure synchronization of all bus nodes. This means that during the transmission of a message, a maximum of five consecutive bits may have the same polarity.
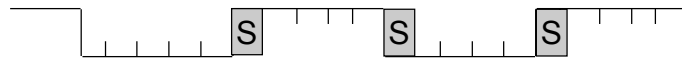
The bit-stuff area in a CAN frame includes the SOF, Arbitration field, Control field, Data field and CRC field.

User-Bit to Stuff-Bit Ratio

Unstuffed bit-sequence
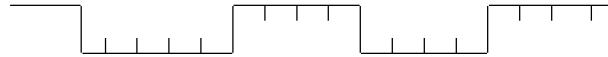
stuffed bit-sequence

worst-case calculation for frames in standard format:

$$s\_max = (34 + 8\ dlc - 1) : 4 = 8 + 2\ dlc$$

© CiA

At a first glance the user-bit to stuff-bit ratio may be estimated as 5:1. But in worst-case the maximum number of stuff-bits is calculated as:

$$s\_max = (n-1) : 4$$

n is number of data-bits

Stuff-Bit Estimation

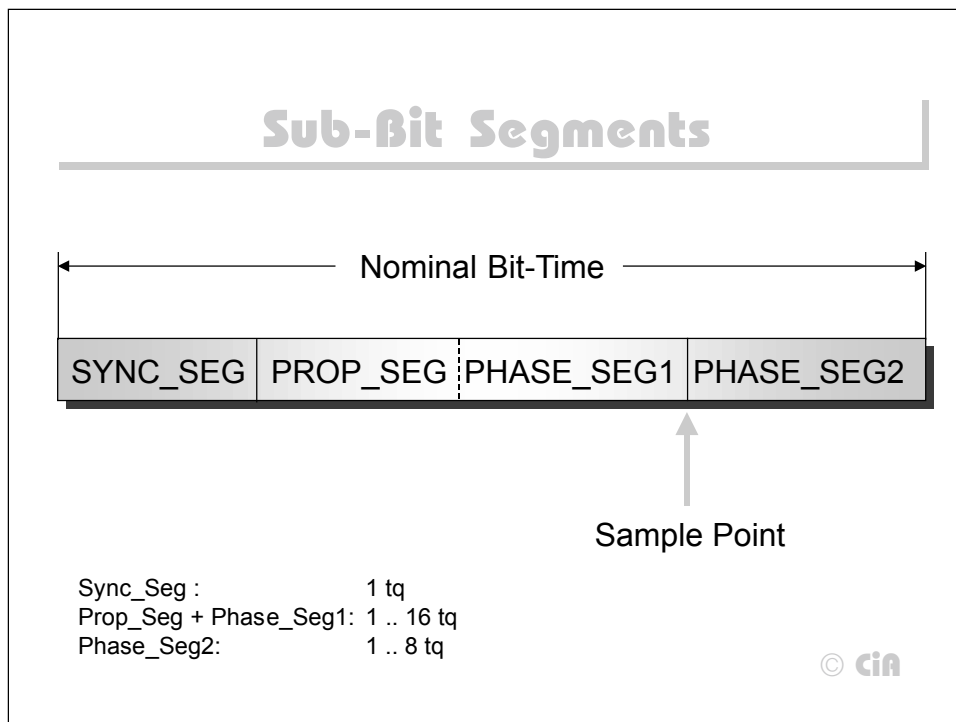| data length code	estimated maximum	number of existing CAN messages with:			
dlc	s_max	s_max	s_max-1	s_max-2	s_max-3
0	8	0	0	1	13
1	10	0	0	0	30
2	12	0	0	0	32
3	14	0	0	5	444
4	16	0	0	2	>171
5	18	0	0	0	>82
6	20	0	0	1	>175
7	22	0	1	124	>15205
8	24	0	0	21	>2660

© CiA

Because the Control Field of the CAN Data Frame contains two reserved bits of dominant value and the Data Length Code the practical maximum number of stuff-bits is not the same as theoretically calculated.

The shown table is the result of simulation for all possible CAN Standard Frames. There is no frame with the maximum number of stuff-bits existing. CAN frames with a Data Length Code of 7 contain more stuff-bits in average than the others. This is why the DLC has the value of 0111 (0 = dominant, 1 = recessive).

Bit-Timing

Oscillator

↓

Baudrate-Prescaler

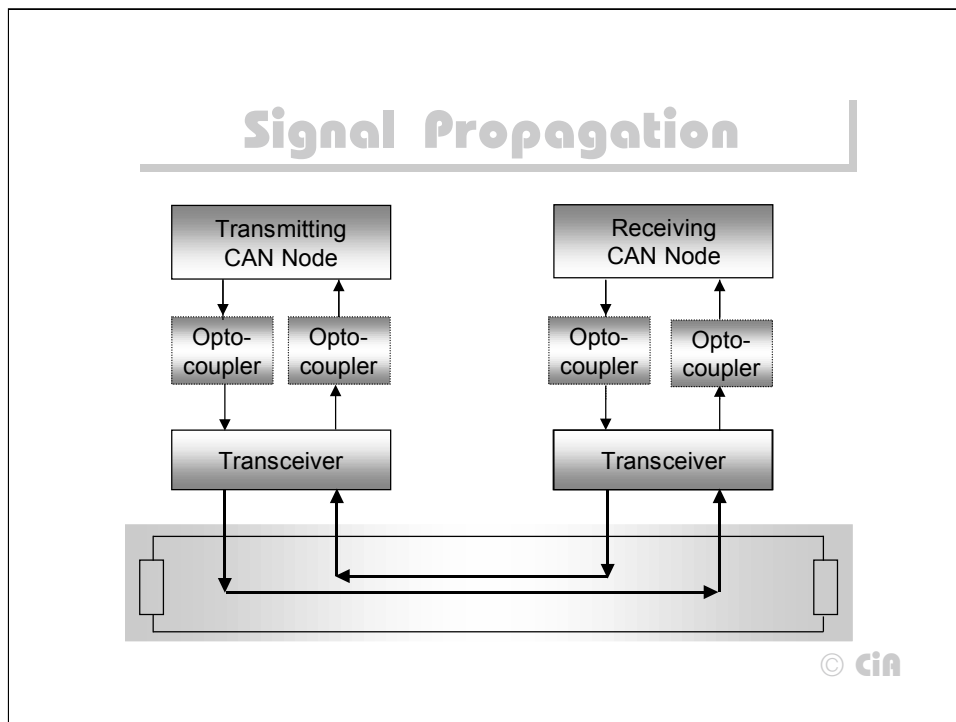Time Quantum

↓

Bit-Time

© CiA
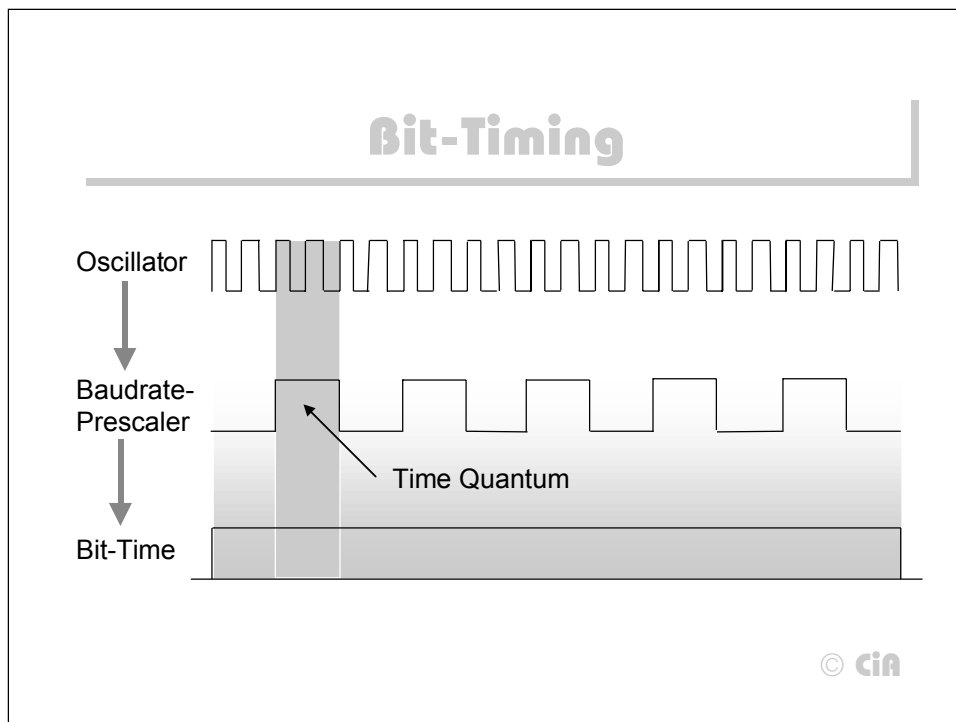
One bit time is specified as four non-overlapping time segments (see next slide). Each segment is constructed from an integer multiple of the Time Quantum (tq). The Time Quantum is the smallest discrete timing resolution used by a CAN node. Its length is generated by a programmable divide of the CAN node's oscillator frequency. There is a minimum of 8 and a maximum of 25 Time Quanta per bit. The bit time is selected by programming the width of the Time Quantum and the number of Time Quanta in the various segments. This has to be done in the CAN controllers.

Sub-Bit Segments

Nominal Bit-Time

| SYNC_SEG | PROP_SEG | PHASE_SEG1 | PHASE_SEG2 |

Sample Point

Sync_Seg :   1 tq
Prop_Seg + Phase_Seg1: 1 .. 16 tq
Phase_Seg2:   1 .. 8 tq

© CiA

Basically the CAN bit period can be subdivided into four time segments. Each time segment consists of a number of Time Quanta.

• SYNC_SEG is 1 Time Quantum long. It is used to synchronize the various bus nodes.
• PROP_SEG is programmable to be 1, 2,... 8 Time Quanta long. It is used to compensate for signal delays across the network.
• PHASE_SEG1 is programmable to be 1,2, ... 8 Time Quanta long. It is used to compensate for edge phase errors and may be lengthened during resynchronization.
• PHASE_SEG2 is the maximum of PHASE_SEG1 and the Information Processing Time long. It is also used to compensate edge phase errors and may be shortened during resynchronization.
• Information Processing Time is less than or equal to 2 Time Quanta long.
• The total number of Time Quanta has to be from 8 to 25.

Programming of the Sample Point allows optimizing the Bit Timing: A late sampling for example allows a maximum bus length; an early sampling allows slower rising and falling edges.

Signal Propagation

Transmitting CAN Node — Opto-coupler — Opto-coupler — Transceiver

Receiving CAN Node — Opto-coupler — Opto-coupler — Transceiver

© CiA

It is necessary to compensate for signal propagation delays on the bus line and through the electronic interface circuits of the bus nodes. The sum of the propagation delay times of controller, optional galvanic isolation, transceiver and bus line has to be less than the length of the Propagation Time Segment (Prop_Seg) within one Bit.

You have to add up the following delays depending on the selected components: CAN controller (50 ns to 62 ns), optocoupler (40 ns to 140 ns), transceiver (120 ns to 250 ns), and cable (about 5 ns/m). These delays have to be considered twice, because after hard synchronization the most far away node is expect switching edges with delay of the propagation time, and the bit of the transmitter has to wait another propagation time to guarantee that the identifier bit or the Acknowledge slot bit of the Receiver is valid. Using ISO 11898 compliant transceiver and high-speed optocoupler you can reach a maximum bus length of 9 meters at 1 Mbit/s.

$$t_{propagation} = 2 \, (t_{cable} + t_{controller} + t_{optocoupler} + t_{transceiver})$$

Data-Rate/Bus-Length Ratio
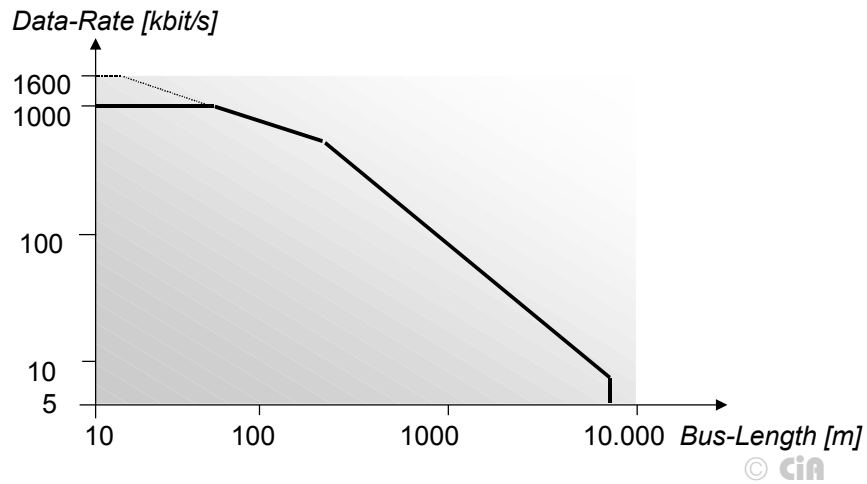
At bit rates lower than 1 Mbit/s the bus length may be lengthened significantly. A data rate of 50 kbit/s allows a bus length of 1 km. ISO 11898 compliant transceivers specify max. bus length of about 1 km. But it is allowed to use bridge-devices or repeaters to increase the allowed distance between ISO 11898 compliant nodes to more than 1 km.
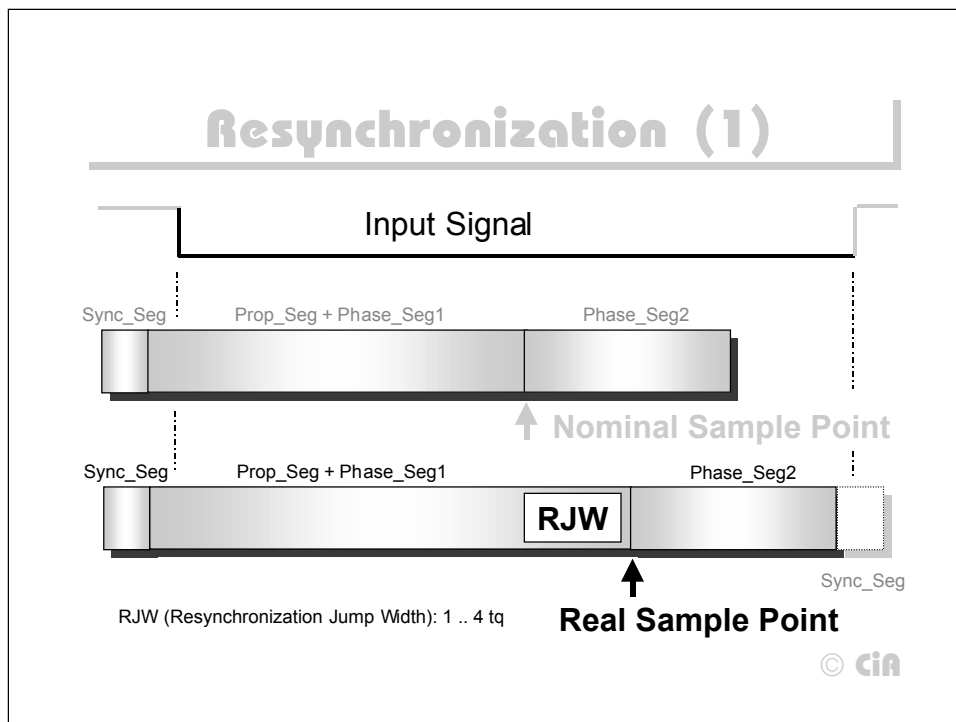
Practical Bus Length

Bit Rate	Bus Length	Nominal Bit-Time
1 Mbit/s	30 m	1 µs
800 kbit/s	50 m	1,25 µs
500 kbit/s	100 m	2 µs
250 kbit/s	250 m	4 µs
125 kbit/s	500 m	8 µs
62,5 kbit/s	1000 m	20 µs
20 kbit/s	2500 m	50 µs
10 kbit/s	5000 m	100 µs

© CiA

The maximum achievable bus line length in a CAN network is determined essentially by the following physical effects:
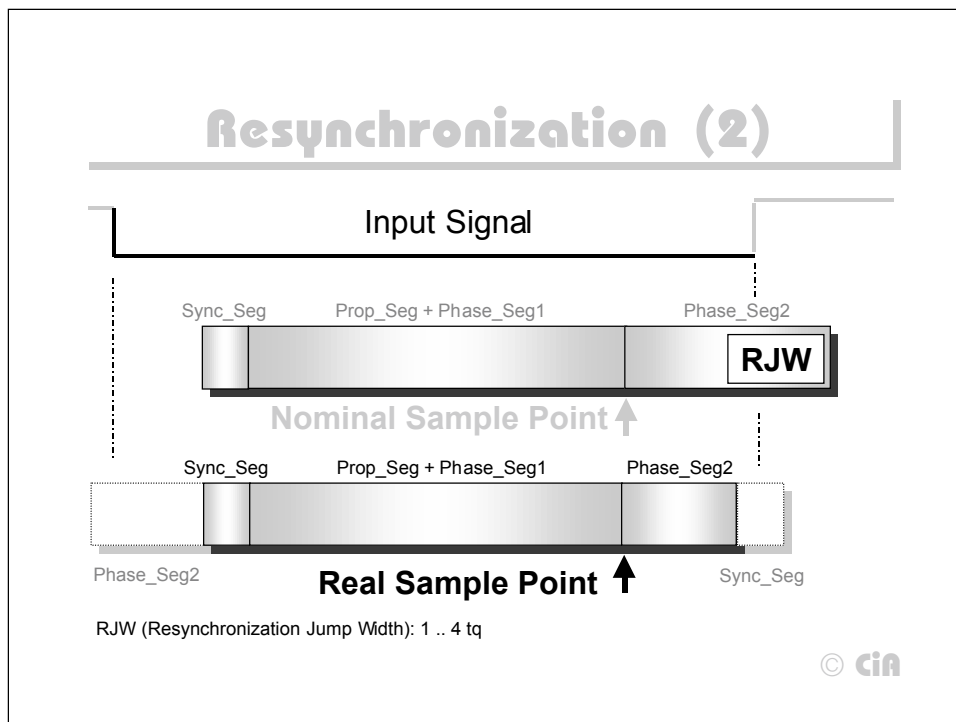
• the loop delays of the connected bus nodes and the delay of the bus lines

• the differences in bit time quantum length due to the relative oscillator tolerance between nodes

• the signal amplitude drop due to the series resistance of the bus cable and the input resistance of bus nodes

The shown practical bus length can be reached with ISO 11898 compliant transceivers and standard bus line cables. Note, there are no optocouplers considered.

Resynchronization (1)

Input Signal

| Sync_Seg | Prop_Seg + Phase_Seg1 | Phase_Seg2 |

↑ Nominal Sample Point

| Sync_Seg | Prop_Seg + Phase_Seg1 | RJW | Phase_Seg2 | Sync_Seg |

↑ **Real Sample Point**

RJW (Resynchronization Jump Width): 1 .. 4 tq

© CiA

A CAN network consists of several nodes, each clocked with its individual oscillator. Because of this, phase shifts can occur in different nodes. Each CAN controller provides a resynchronization (soft synchronization) mechanism to compensate phase shifts while receiving a CAN frame.

An edge is expected in the Sync_Seg. In the case of a slower transmitter meaning the edge is detected in the Prop_Seg, the receiver lengthens the Phase_Seg1 with a maximum of the programmed value of the Resynchronization Jump Width (RJW = 1 .. 4 tq).

Resynchronization (2)

Input Signal

Sync_Seg	Prop_Seg + Phase_Seg1	Phase_Seg2

RJW

Nominal Sample Point

Sync_Seg	Prop_Seg + Phase_Seg1	Phase_Seg2

Phase_Seg2   **Real Sample Point**   Sync_Seg

RJW (Resynchronization Jump Width): 1 .. 4 tq

© CiA

In the case of a faster transmitter meaning the edge is detected in the previous Phase_Seg2, the receiver shortens the Phase_Seg2 with a maximum of the programmed value of the Resynchronization Jump Width (RJW = 1 .. 4 tq).

There is only one resynchronization allowed within one bit time.

Medium Attachment

- CAN High-Speed (ISO 11898)
- CAN Low-Speed (ISO 11519-1)
- Fault-Toler ant Transceivers
- Truck/Trailer Transceiver (ISO 11992)
- Single-Wire (SAE 2411)
- Fiber Optical Transmission
- Wire-Less Transmission
- Power-Sup ply Transmission

© CiA

There are several official and industry standards dealing with CAN medium attachment.

Most important for general purpose applications is the CAN high-speed standard ISO 11898.

The ISO 11519-1 specification will be withdrawn in the near future, and is only used by the German LBS standard (DIN 9684) for agriculture machines.

Fault-tolerant transceivers used in car body electronics will be standardized by the ISO TC22 SC3 WG1.

The ISO 11992 standard was originally developed for truck/trailer connections, and provides also fault-tolerant capability.

A SAE task force is working on a single-wire transmission specification.

Proprietary fiber-optical solutions as well as wire-less transmission are available.

A power-supply transmission is possible but not commercially available due to the high price of the transceiver.

ISO 11898 Basic Network Setup

node 1 . . . . node n

CAN_H

120 Ω   CAN Bus Line   120 Ω

CAN_L
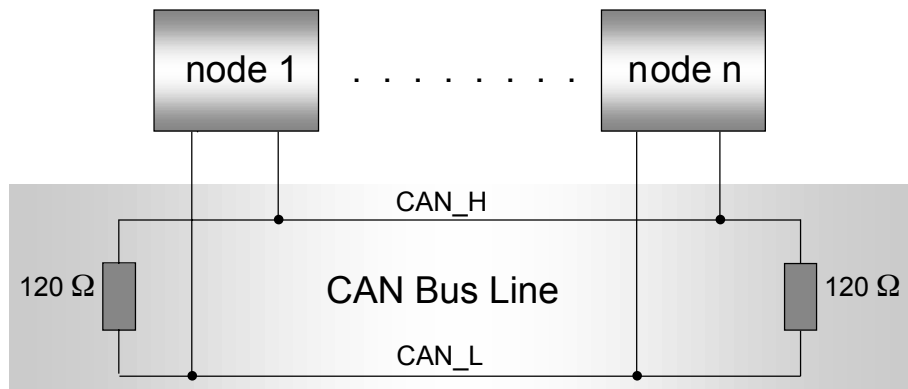
© CiA

The ISO 11898 standard assumes the network wiring technology to be close to a single line structure in order to minimize reflection effects on the bus line. The bus lines have to be terminated by resistors at both ends.

ISO 11898 Node
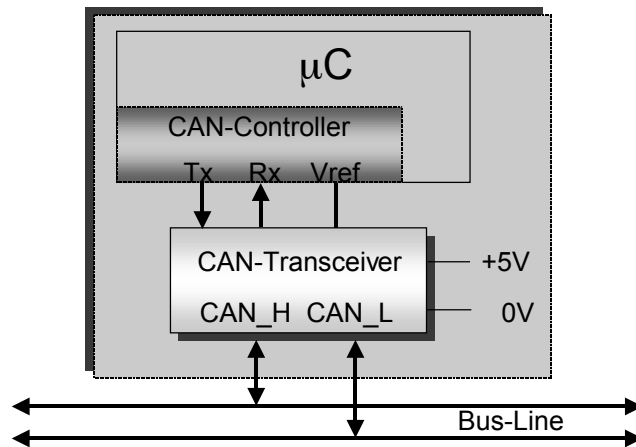
AN ISO 111898 compliant bus node requires a microcontroller and a CAN controller, which is connected to the transceiver via a serial data output line (Tx) and a serial data input line (Rx). The reference voltage output Vref provides an output voltage of 0.5 X Vcc nominal. The transceiver has to be powered with a nominal supply voltage of +5 V.

At static conditions the differential input voltage at a bus node is determined by the current flowing through the differential input resistance of that node. In case of a dominant bit the output transistors of the transmitting node are switched on, causing a current flow, whereas the transistors are switched off for a recessive bit.

Nominal ISO 11898 Bus Levels
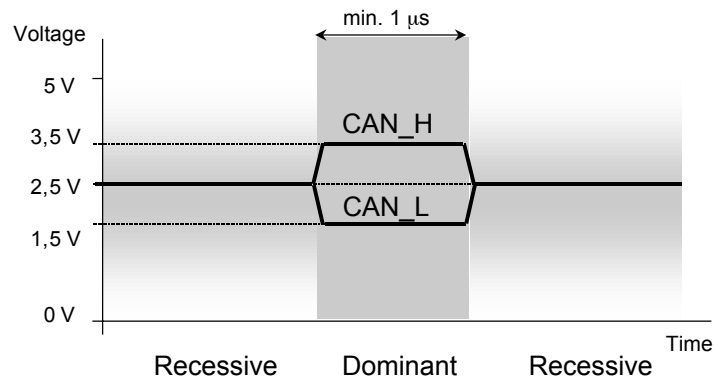
The bus nodes shall detect a recessive bus condition if the voltage of CAN_H is not higher than the voltage of CAN_L plus 0.5 V. If the voltage of CAN_H is at least 0.9 V higher than CAN_L, then a dominant bus condition shall be detected. The nominal voltage in the dominant state is 3.5 V for the CAN_H line and 1.5 V for the CAN_L line.
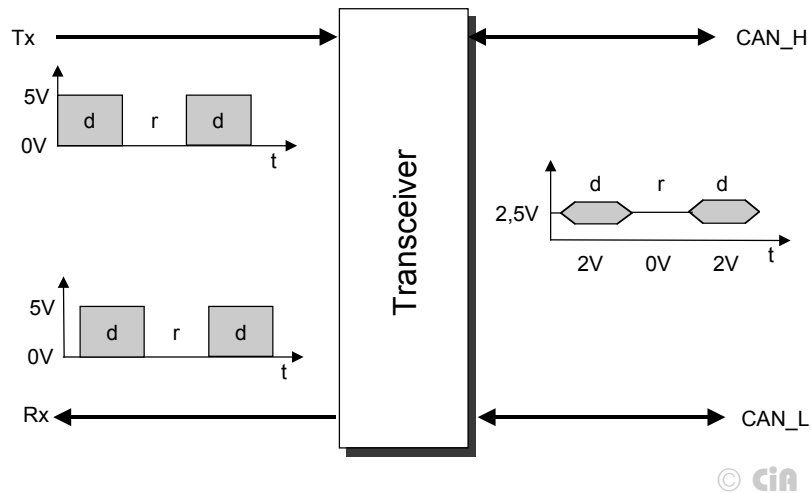
Electromagnetic Interference

EMI

CAN Bus Line

120 Ω   120 Ω

CAN_H

CAN_L
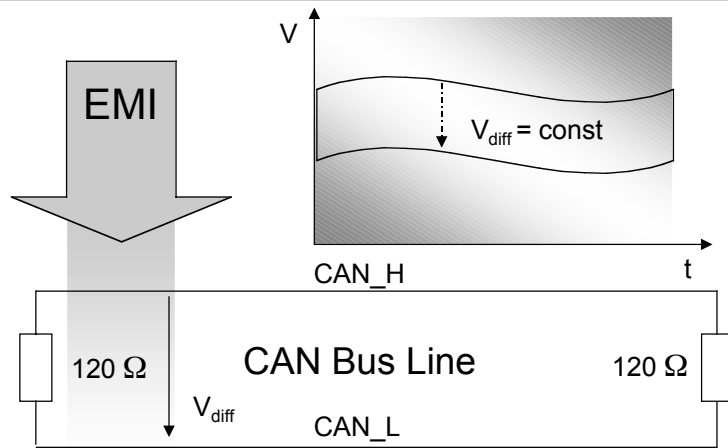
V_{diff} = const

V_{diff}

© CiA

Due to the differential nature of the transmission signal CAN is insensitive to electromagnetic interference, because both bus lines are affected in the same way which leaves the differential signal unaffected (Vdiff = constant).

ISO 11898 Signal Levels

A CAN controller is connected to the ISO 11898 compliant transceiver via the Tx serial data output line and the Rx serial input line. The transceiver is attached to the bus line via its two bus terminals CAN-H and CAN_L., which provide differential receive and transmit capability. Tx and Rx are direction-related signals. The differential signal between CAN_H and CAN_L is undirected.

Each transmitting CAN node reads the output back; but there is delay between the bits transmitted and the according received bits to be consider.

ISO 11898 Transceivers

Manufacturer	Bosch	Mietec	Philips Semiconductors	Philips Semiconductors	SGS-Thomson	Temic (Siliconix)	Texas Instruments	Unitrode
type no.	CF150B	MTC-3054	82C250	82C251	L9615	Si9200EY	SN75LBC031	UC5350
data rate max. [Mbd]	0.5	1	1	1	0.5	1	0.5	1
short circuit [V]	-5...+36	-3...+65	-8...+18	-36...+36	-5...+36	GND...+16	-2...+20	-8...+36
transient [V]	-200...+200	-200...+200	-150...+100	-200...+200	-200...+200	-60...+60	-150...+100	-150...+100
ESD [kV]	2	2	2	2.5	2	2	2	2
thermal shutdown	(1,2)	n.a.	yes	yes	(1, 2)	yes	yes	yes
slope control	on/off	variable	variable	variable	on/off	none	fast/slow	variable
CMR [V]	-2...+7 (3)	-7...+12	-7...+12	-7...+12	-2...+7 (3)	-2...+7	-2...+7	-25...+18
delay [ns]	230	100	170	170	230	120 (4)	280	100 (4)
fan out (5)	32	32	64 (110)	110	32	32	32 (5)	n.a. (6)
supply current [mA]	<80	110	<70	<80	<80	70	<80	70
stand-by current [μA]	n.a.	300	<170	<250	n.a.	n.a.	n.a.	1000
packaging	SOIC-8	SOP-16	SO-8, DIP-8	SO-8, DIP-8	SO-8	SO-8	SO-8, DIL-8	SOIC-8,DIL-8

(1) short circuit detection and shutdown   (2) overvoltage detection and shutdown   (3) measured CMR: -12...+18V

(4) 50 ns for transmit   (5) higher fan out possible, depends on application   (6) under specific circumstances more than 128

n.a.: data not available

Remarks: 82C250 and UC5350 are pin compatible; L9615 is licenced by Bosch

© CiA

There are several ISO compliant transceiver chips available from different manufacturers. They differ in some characteristics, such as internal delay time and output resistance that lead to different values for maximum bus length resp. for maximum number of nodes.

CiA DS-102 Baudrates

Bit rate / Bus length [1]	Nominal bit time t_b	Number of time quanta per bit	Length of time quantum t_q	Location of sample point	BTR 0 at 16 MHz (82C200)	BTR 1 at 16 MHz (82C200)
1 Mbit/s / 25 m	1 µs	8	125 ns	6 t_q (750ns)	00h	14h
800 kbit/s / 50 m	1.25 µs	10	125 ns	8 t_q (1 µs)	00h	16h
500 kbit/s / 100 m	2 µs	16	125 ns	14 t_q (1.75 µs)	00h	1Ch
250 kbit/s / 250 m [2]	4 µs	16	250 ns	14 t_q (3.5 µs)	01h	1Ch
125 kbit/s / 500 m [2]	8 µs	16	500 ns	14 t_q (7 µs)	03h	1Ch
50 kbit/s / 1000 m [3]	20 µs	16	1.25 µs	14 t_q (17.5 µs)	09h	1Ch
20 kbit/s / 2500 m [3]	50 µs	16	3.125 µs	14 t_q (43.75 µs)	18h	1Ch
10 kbit/s / 5000 m [3]	100 µs	16	6.25 µs	14 t_q (87.5 µs)	31h	1Ch

© CiA

The CAN in Automation (CiA) international users and manufacturers group has recommended some baud rates to be used in general purpose CAN networks as well as the maximum bus length for a given baud rate. In addition, the bit-timing is recommended, so that nodes from different manufacturers can be connected to one CAN network without calculating the bit-timing parameters.

CiA DS-102 Bit-Timing
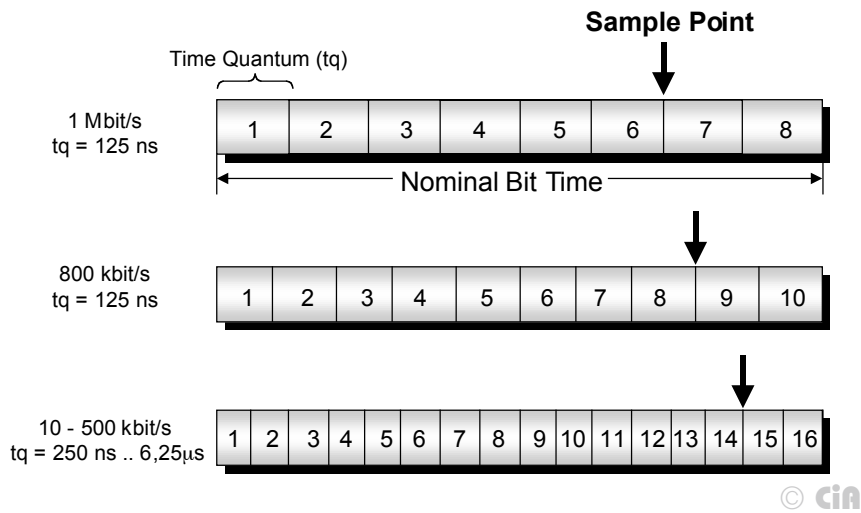
The bit timing recommended by CiA defines the time quantum as well as the position of the sample point.

CiA DS-102 Design Hints

- Every module should support a bit rate of 20 kbit/s and as many of the recommended bit-rates as possible.

- For bus-length greater than about 200 m the use of optocouplers is recommended.

- For bus length greater than about 1 km bridge or repeater devices may be needed.

© CiA

CiA DS-102 Pin Assignment
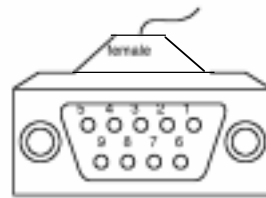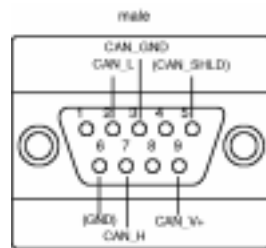
9-pin D-Sub: DIN 41652

Pin	Signal	Description
1	-	Reserved
2	CAN_L	CAN_L bus line dominant low
3	CAN_GND	CAN Ground
4	-	Reserved
5	(CAN_SHLD)	Optional CAN Shield
6	GND	Optional Ground
7	CAN_H	CAN_H bus line dominant high
8	-	Reserved
9	(CAN_V+)	Optional CAN external supply

© CiA

The CiA DS-102 standard includes a pin assignment for 9-pole Sub-D connectors for the connection of nodes to the CAN bus lines. This pin assignment is also used by some higher-layer protocol specifications (e.g. CANopen, Smart Distributed System).

ISO 11898 Parameters

DC Parameter
- **Length-Related Resistance (r):**
  70 m Ω /m
- **Termination Resistor (Rt):**
  nominal 120 Ω (min. 108 Ω, max. 132 Ω)

AC Parameter
- **Impedance (Z):**
  nominal 120 Ω (min. 108 Ω, max. 132 Ω)
- **Specific Line Delay:**
  5 ns/m

© CiA

According to the ISO 11898 standard, cables to be chosen for CAN bus lines should have a nominal impedance of 120 Ohm, and a specific line delay of nominal 5 ns/m. Line termination has to be provided through termination resistors of 120 Ohm located at both ends of the line. The length related resistance should have 70 mOhm/m. All these mentioned AC and DC parameters are suitable for a 1 Mbit/s transmission rate.

DC Characteristics

| Bus Length | Bus Cable | | Termination Resistance | Max. Baudrate |
	Length-Related Resistance	Bus-Line Cross-Section		
0 .. 40 m	70 mΩ/m	0.25 mm² .. 0.34 mm² AWG23, AWG22	124 Ω (1%)	1 Mbit/s at 40 m
40 .. 300 m	<60 mΩ/m	0.34 mm² .. 0.6 mm² AWG22, AWG20	127 Ω (1%)	500 Kbit/s at 100 m
300 .. 600 m	<40 mΩ/m	0.5 mm² .. 0.6 mm² AWG20	150 Ω το 300 Ω	100 Kbit/s at 500 m
600 m .. 1 km	<26 mΩ/m	0.75 mm² .. 0.8 mm² AWG 18	150 Ω το 300 Ω	50 Kbit/s at 1k m

© CiA

These recommended DC parameters for bus line cables are suitable for ISO 11898 based networks. To minimize the voltage drop on long distances the termination resistor should be higher than in the ISO 11898 standard.

The system integrator has to consider the DC parameters for the connectors as well. To calculate the voltage drop, he has to add for each node with 9-pin D-Sub connector about 5 m Ω to 20 m Ω to the total transmission resistance.

CAN Bus-Line Cross-Sections

Length	32 nodes	64 nodes	100 nodes
100 m	0,25 mm^2	0,25 mm^2	0,25 mm^2
250 m	0,34 mm^2	0,50 mm^2	0,50 mm^2
500 m	0,75 mm^2	0,75 mm^2	1,00 mm^2

Wire resistance Rw < 21 Ω (32 nodes), < 18,5 Ω (64 nodes), 16 Ω (100 nodes),

© CiA

The table provides a first indication on which kind of wire cross section should be considered for the signal pair of the bus trunk cable (Philips Application Note AN96116 for the PCA82C250/1 CAN Transceiver). The table bases on the following assumptions:

• 32 nodes: Rw < 21 Ω

• 64 nodes: Rw < 18.5 Ω,

• 100 nodes: Rw < 16 Ω.

Ground potential shifts should not lead to a fall of voltage of more than 2 V.

SAE J2284 Proposal

- CAN 2.0 B compliant CAN controller
- Standard 11-bit identifiers
- ISO 11898 compliant transceiver chips
- max. data rate: 500 Kbit/s
- max. number of nodes: 16 ECUs
- bus cable: unshielded twisted pair
- max. stub length: 1 m
- min./max. ECU distance: 0.1/40 m

© CiA

The Society of Automotive Engineers (SAE) proposes for powerengine applications the J2284 specification, which will be submitted to the ISO for international standardization.

SAE J2284 Bit Timing

	min. [ns]	nom. [ns]	max. [ns]
Nominal Bit Time*	1990	2000	2010
Media Delay	0	-	220
ECU Delay	100	-	390
Time Quantum	-	-	200
TSEG1	***	***	***

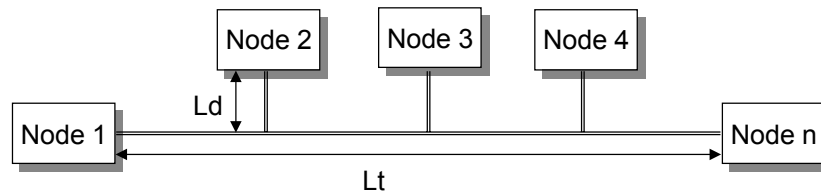* The nominal bit time must be a programmable, integer multiple of the system clock periods.
** Media delay one tip through 40 m
*** TSEG1 = Nominal Bit Time - 1 Time Quantum - TSEG2

© CiA

The SAE J2284 specification defines also the bit timing in CAN networks.

ISO 11898 Network Topology

Ld = Drop Length   Lt = Trunk Length

© CiA

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. Essentially it depends on the bit timing parameters, the trunk cable length Lt and the drop cable length Ld whether reflections will be tolerated. In practice short stubs Ld are necessary to connect devices to the bus line successfully. 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.

Calculation of Cable Drop Length

Rules of thumb for the maximum length of a unterminated cable drop Ld
and for for the cumulative drop length Ldi:

$$Ld < t_{PROPSEG} / (50 * t_P)$$

$$\sum_{i=1}^{n} Ldi < t_{PROPSEG} / (10 * t_P)$$

$t_{PROPSEG}$: length of the propagation segment of the bit period
t_P : specific line delay per length unit

Example: bit rate = 500 kbit/s: $t_{PROPSEG}$ = 12 * 125ns = 1500 ns; t_P = 5 ns/m

$$Ld < 1500 \text{ ns} / (50 * 5 \text{ ns/m}) = 6 \text{ m}; \sum_{i=1}^{n} Ldi < 1500 \text{ ns} /(10 * 5 \text{ ns/m}) = 30 \text{ m}$$

© CiA

Split Termination Concept

Topology option intended to provide enhanced EMC characteristics without changing the DC characteristics of the termination line.

CAN_H

Rt/2   Rt/2

Cg   Rt/2   Bus Line   Rt/2   Cg

CAN_L

$Rt/2 = 62\ \Omega$
$Cg = 10...100nF$

© CiA
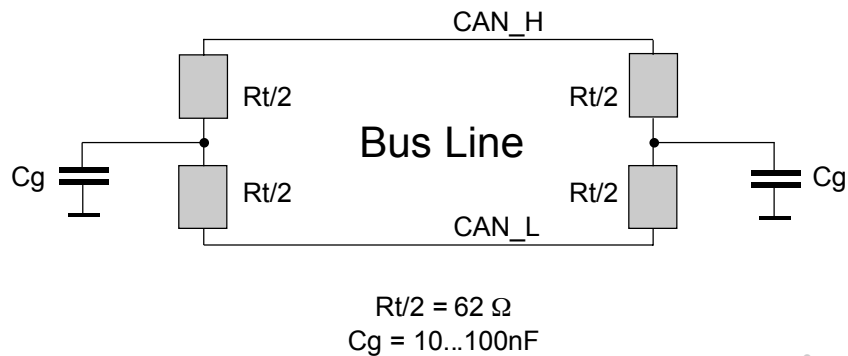
Basically each of the termination resistors is spit into two resistors of equal value, i.e. two resistors of 62 Ohm instead of one resistor of 124 Ohm. The special characteristic of this approach is that the so-called common-mode signal is available at the center tap to the termination. As the common-mode signal is simply a DC voltage in the ideal case, this center tap can be grounded via a capacitor. However it is obvious that the capacitor should be connected to a 'quit' ground level. For example a separate ground lead to the connector's ground pin is recommended, if termination is placed inside of bus nodes.

Multiple Termination Concept

Topology option which targets at networks differing from a single line structure for example with cable drop lengths of a few meters. This topology can be used in combination with the split termination.

CAN_H

Rt   Rt

CAN_L

Rt = 180 Ω   Rt

© CiA
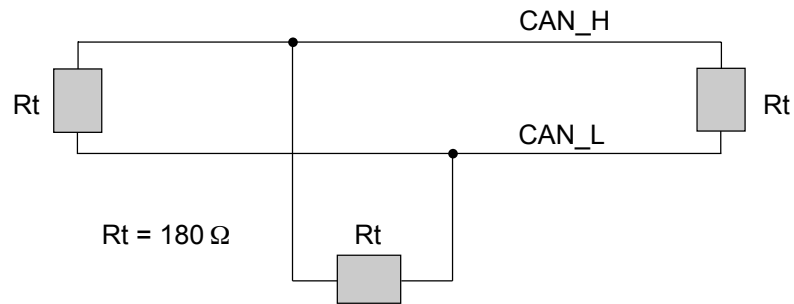
In some applications a topology different from a single line structure is needed, e.g. a star topology with three branches. To accommodate such a topology, the multiple termination concept may be considered. Essentially this approach suggests, that the total termination resistance is being distributed over more than two resistors. If for example a star topology is needed with three branches, then one may consider to terminate each branch with about three times the total termination resistance. With this approach it is essential that the total termination resistance does suit the transceiver's output drive capability.
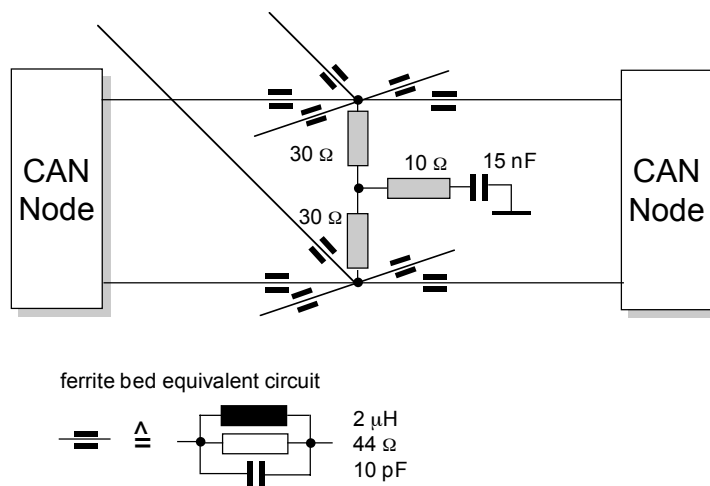
Daimler-Benz has patented a star topology with common termination in the star. This topology overcomes resonance problems and undesired harmonies and is insensitive to incoming disturbing signals.

To understand why there is only one termination, it should be noted that a one-side termination of a transmission line is sufficient to avoid resonance, because a wave traveling toward the termination point will be absorbed there and never reflected again.

Open and Short Failures

Node 1   Node 2   Node n

CAN_H

CAN_L

R_T R_T
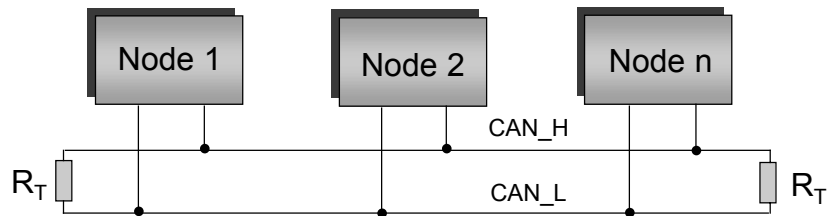
Case 1: CAN_H interrupted
Case 2: CAN_L interrupted
Case 3: CAN_H shorted to battery voltage
Case 4: CAN_L shorted to ground
Case 5: CAN_H shorted to ground
Case 6: CAN_L shorted to battery voltage
Case 7: CAN_L shorted to CAN_H
Case 8: CAN_H and CAN_L interrupted at the same Location
Case 9: Loss of one connection to termination network

© CiA

During normal operation several bus failures may occur that may influence the bus operation. In several applications, in particular in car body electronics, fault- tolerance capability is required.

Except in case 8 the transceiver will indicate the failure to the microcontroller via a dedicated error flag output. This signal can be used for diagnostic purposes.
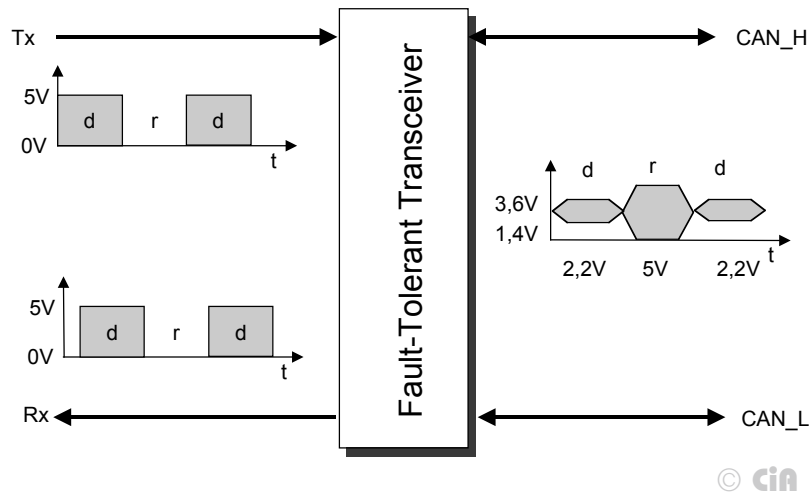
Fault-Tolerant Transceiver

Fault-tolerant Transceivers are primarily intended for low-speed applications, up to 125 kbit/s, in passenger cars. The device provides differential transmit capability but will switch in error conditions to a single-wire transmitter and/or receiver.

In the supported failure cases all nodes continue communication with reduced signal-to-nose ratio. Once the wire corruption is removed, the fault-tolerant transceiver automatically resumes differential signal transmission.

Fault-Tolerant Signal Levels

The fault-tolerant transceiver was originally specified by Daimler-Benz and other passenger car manufacturers. This approach will substitute the ISO 11519-1 standard.

The dominant bit is represented by 3.6 V (CAN_H) and 1.4 V (CAN_L) meaning there is difference voltage of 2.2 V; the recessive bit difference voltage is 5 V (CAN_H = 0 V and CAN_L = 5 V).

Fault-Tolerant Transceiver

| Product	PCA82C252	TJA1053	SN65LBC032
Company	Philips	Philips	Texas Instr.
Baudrate	125 Kbit/s	125 Kbit/s	125 Kbit/s
No. of Nodes	15	15	32
Protection	-10 to +27 V	-10 to +27V	-5 to +10V
Slew Rate	fixed	fixed	fixed
Sleep Mode	<75 μA	<75 μA	<200 μA
Others	automatic recovery from bus wiring failures, power fail flag	automatic recovery from bus wiring failures, power fail flag, transmit watch-dog timer	automatic recovery from bus wiring failures, power fail flag

© CiA

3.5

Nominal ISO 11992 Bus Levels
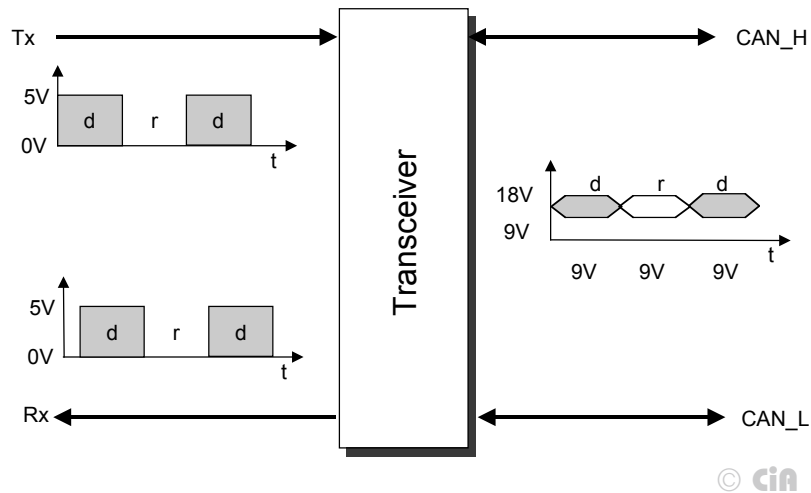
Transceiver compliant with ISO 11992 provide fault-tolerant capability on wiring failures. This standard was primarily developed for truck and van applications to withstand high common mode HF emission (more than 100 V) and high ground offsets (about 6 V). Some external circuitry is necessary to get this results, and also some current consumption must be accepted.

The dominant bit values are 18 V at CAN_H line and 9 V at CAN_L line (difference voltage = 9 V). The recessive bit has also a difference voltage of 9 V, but the CAN_H line is 9 V and the CAN_L line is 18 V.

ISO 11992 compliant transceivers are manufactured by Temic (B10011S).

Active Star Coupler Concept
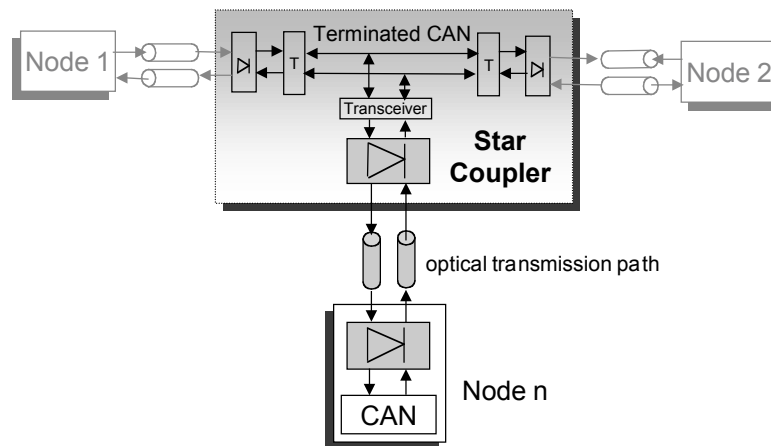
Due to the large coupling losses in passive starcoupler solutions it was not possible to carry data over a distance longer than 5 m to 10 m.

For the definition of the active starcoupler the bus structure was left and the fieldbus melded into one point, the starpoint device. The CAN bus is now limited to the star point and is only a few cm long, interconnecting the different optical links. The starcoupler is able to handle a number of links restricted only by the transceiver characteristics.

In this approach the optocoupler used in traditional control applications is substituted by the optical transmission path. The optical Transmitter/Receiver-Pair resides in the bus nodes and in the active starcoupler.

Power Line Transmission

Power Source — Power Circuit — Signal Circuit

CAN Node

© CiA
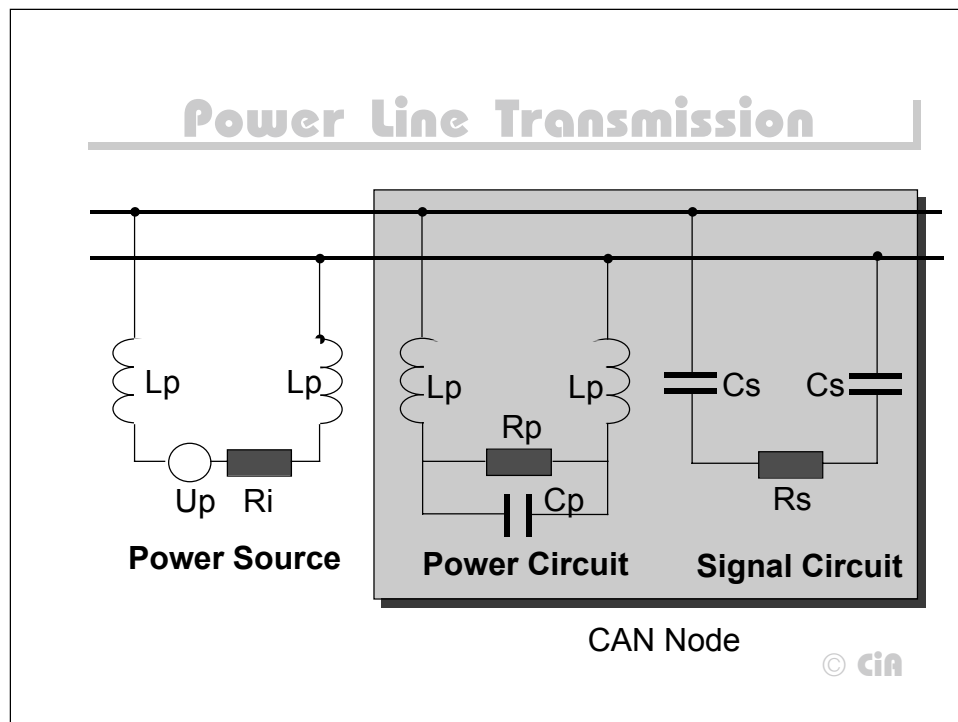
A central bus power source generates the direct current. The inductance prevent a short cut of the signal voltage.

There are two possible methods how to transmit data signals on the power lines: the base band transmission and the modulation.
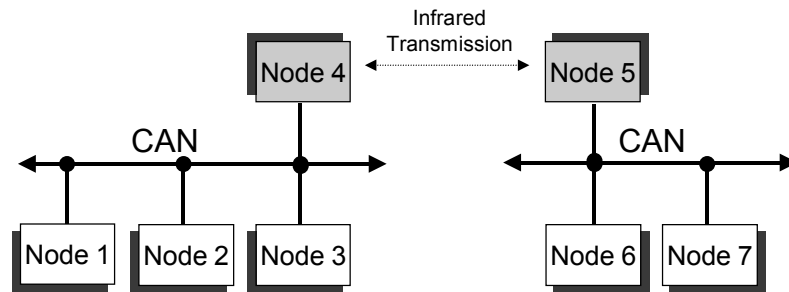
RF Transmission

Radio Transmission

Node 4 — Node 5

CAN — CAN

Node 1 — Node 2 — Node 3 — Node 6 — Node 7

© CiA
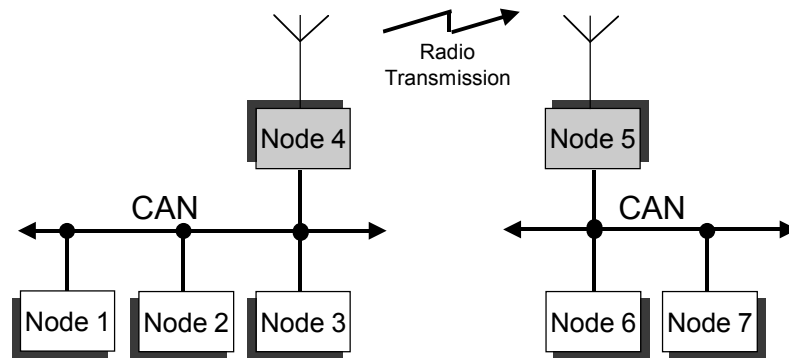
In some applications it is an advantage to control a system without using a wire-based transmission. A typical case is when two moving sub-systems have to communicate , e.g. in a crane or an excavator or in a tank.

The simplest application for a remote link is the point-to-point link: e.g. break open the existing CAN bus and throws in a pair of CAN RF gateway to accommodate a large distance, a moving target, or anything similar.

A radio frequency connection can be used as a transparent link between two or more CAN nets but can also be set up to pass only certain messages.

Infrared Transmission

Infrared Transmission

Node 4 ←·····→ Node 5

CAN   CAN

Node 1   Node 2   Node 3   Node 6   Node 7

© CiA

In some applications there is a infrared transmission between to CAN sub-networks required. The infrared double-bridge links to independent CAN networks like a double-bridge solutions with any other bus system (e.g. Arcnet) to achieve specific features (e.g. long distance transmission)