Service.

Self-Study Programme 238

Data Exchange On The CAN Bus I

Basics

The CAN bus system in a car interlinks the control units to form a network.
This produces new functions in the car and in diagnostics which span across control units.

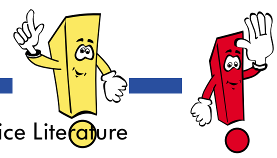
SSP 186 "The CAN Databus" gave an initial overview of the technology. SSP 238 will now describe the basic functions of the current CAN Bus system.

- **SSP 238:**
  Deals with basic functions of the current CAN system, e.g. the data exchange process

- **SSP 269:**
  Deals with special bus systems such as the Drive Train CAN bus and the Convenience CAN bus as used by VOLKSWAGEN and AUDI.

238_001

new



Important Note

Contents

Introduction

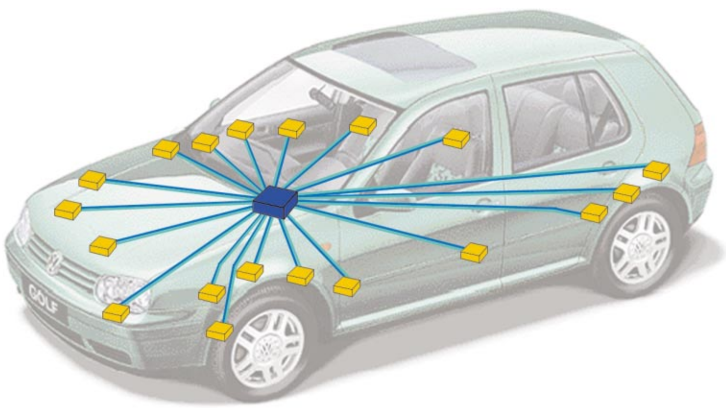
What is a bus system for?

The use of a CAN bus system in a car makes it possible to network electronic modules such as control units or intelligent sensors such as the wheel angle sensor.

The abbreviation "CAN" means Controller Area Network. The CAN bus system provides the following advantages for the car as an overall system:

- Data exchange between control units take place on a uniform platform.
  This platform is call a protocol. The CAN bus acts as a so-called data highway.
- Systems involving several control units, e.g. ESP, can be implemented efficiently.
- System expansions are easier to implement in the form of optional extras.
- The CAN bus is an open system which permits adaptation to various transmission media such as copper or optical fibre cables.
- Control units are diagnosed via the K-wire. Inside the car, diagnosis already takes place via the CAN bus in some cases (for example the airbag and the door control unit).
  In this context, this is called a "virtual K-wire" (see page 7). In future cars, there will be no K-wire.
- A cross-system diagnosis is possible across several control units.

From a central control unit to a networked system



Car with central control unit

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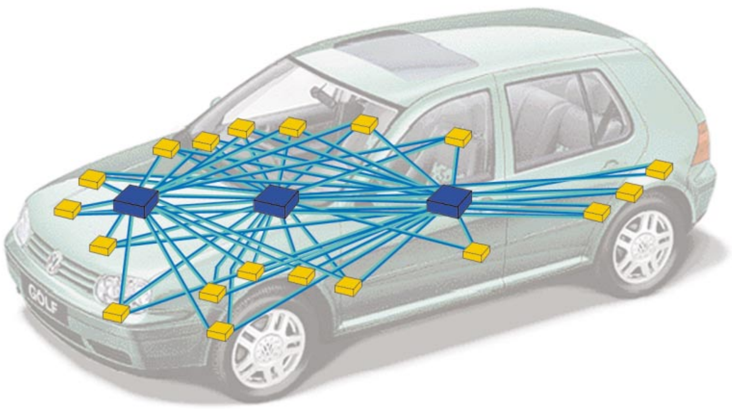

Car with 3 control units

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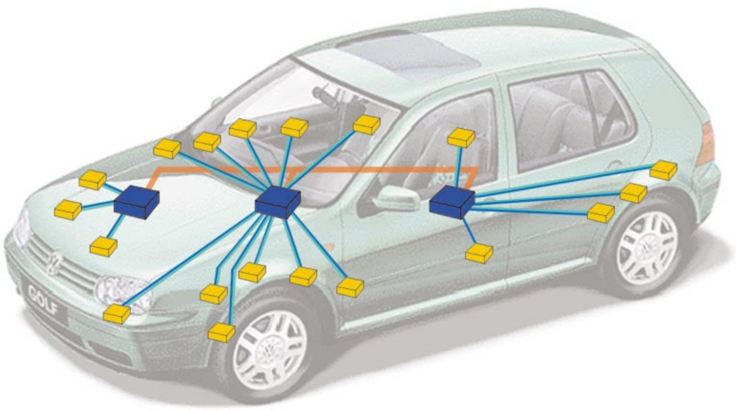

Car with 3 control units and bus system

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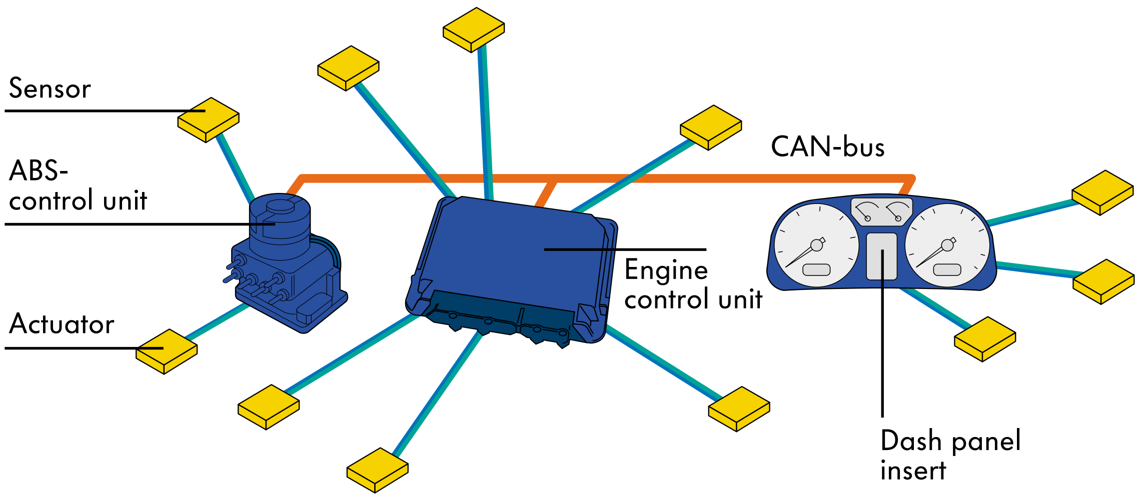


Drive train CAN network with 3 control units

238_005

Introduction

Design, main features

Many individual modules are connected in parallel to the CAN bus system.
This results in the following requirements for the design of the overall system:

- High level of error protection: transmission interference caused by internal or external sources must be detected with a high degree of certainty.

- High availability: if a control unit fails, the rest of the system must continue to be functional as far as possible in order to exchange information.

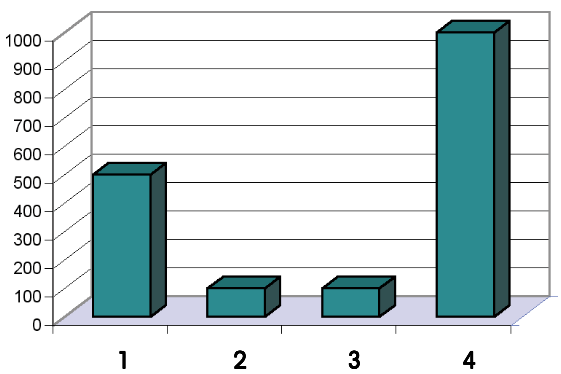
- High data density: all control units have the same information status at all times.
This means there is no difference in data between the control units.
In case of faults anywhere in the system, all the connected users can be informed with equal certainty.

- High data transmission rate: data exchange between networked users must be very fast in order to meet real time requirements.

Signals are sent over the CAN bus system digitally, at present over copper wires.
Secure transmission is possible at a maximum rate of 1000 kbps (1 Mbps).
The maximum data rate at VOLKSWAGEN and AUDI has been fixed at 500 kbps.

The CAN bus system is divided into 3 special systems due to the different requirements regarding signal repetition rate and the large data volume:

- Drive train CAN bus (high-speed) at 500 kbps with almost real time requirements
- Convenience CAN bus (low-speed) at 100 kbps with low time requirements
- Infotainment CAN bus (low-speed) at 100 kbps with low time requirements



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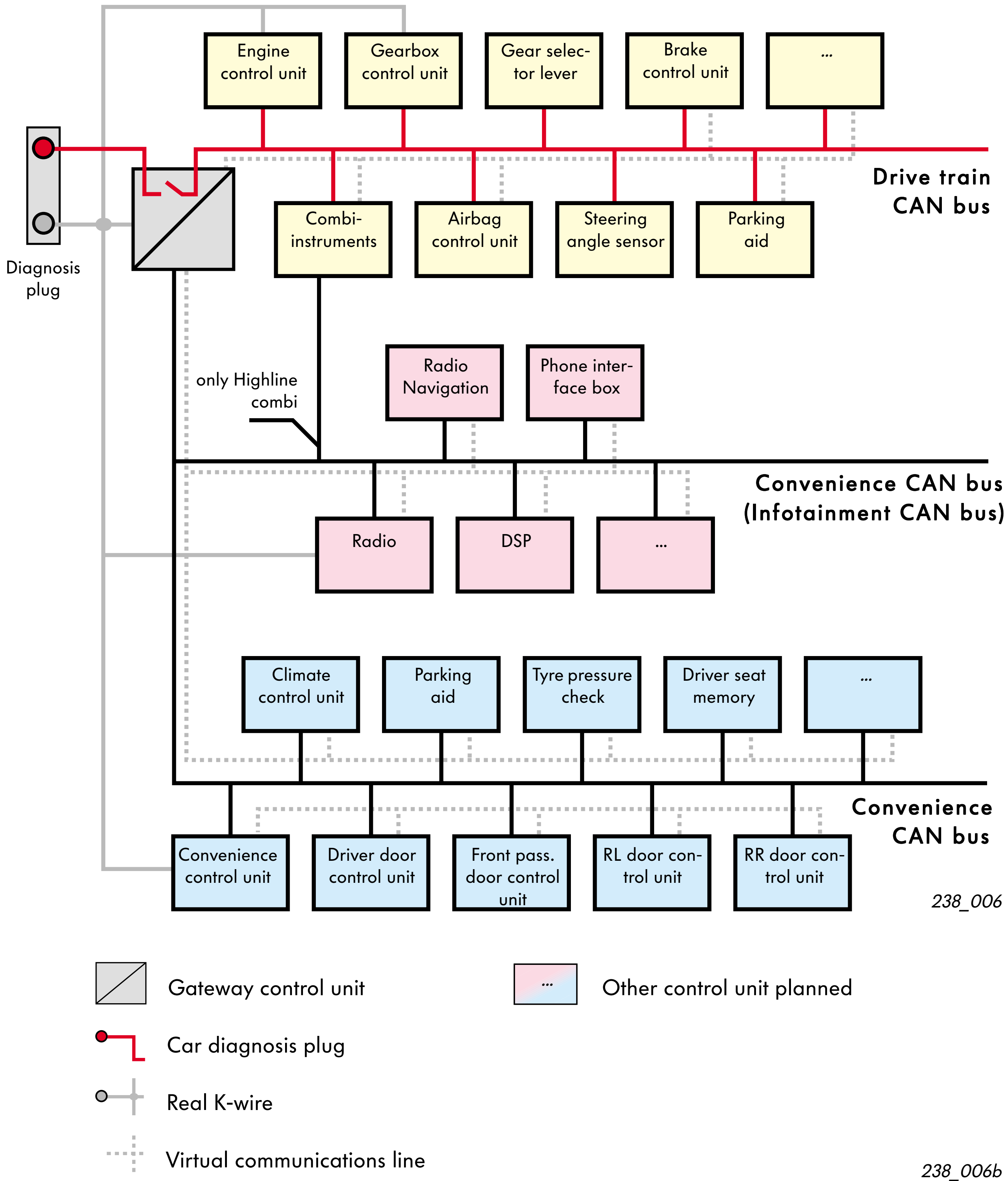
1	= 500 kbps	= Drive train CAN bus
2	= 100 kbps	= Convenience CAN bus
3	= 100 kbps	= Infotainment CAN bus
4	= 1000 kbps	= Maximum data transmission rate

Data transmission rates on the CAN bus system



CAN bus system (example: Polo MY 2002)

Introduction

Production launch and development statuses

The first production launch at Volkswagen took place in MY 97 with the 62.5 kbps convenience system in the Passat.

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Other development stages include:

MY 98 Drive train CAN bus in Golf and Passat, 500 kbps

238_008

MY 00 Gateway K-wire on CAN in Golf and Passat

238_009

MY 00 Convenience CAN bus 100 kbps standard in Group, e.g. in SKÔDA Fabia
Gateway drive train CAN bus / convenience CAN bus in SKÔDA Fabia

238_010

MY 01 Convenience CAN bus 100 kbps standard in Group, for example in Passat

238_011

Handling the CAN bus

The CAN bus is an independent system with the car's electronics systems and acts as a data line to exchange information between control units.

Due to its design and construction, the system works with a high degree of intrinsic safety.

If faults still occur, they are mainly stored in the fault memory of the related control unit and are accessible by the Diagnostic Testing and Information System.

- The control units contain self-diagnosis functions from which the system can detect CAN-related faults.

- After reading out the CAN fault entries with the Diagnostic Testing and Information System (for example VAS 5051, 5052), this information is available for specific fault-finding processes.

- The entries in the fault memory of the control units are suitable for initial fault detection. Beyond this, it provides you with confirmation that there are no more faults present after fault remedial action. The engine must be restarted to update the fault memory.

- A key requirement for a car with the status "CAN bus OK" is that there should be no CAN fault entry in any vehicle operating state.

To start an analysis which may lead to fault detection or fault remedy, a basic knowledge is required about data exchange on the CAN bus.

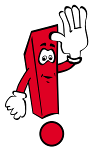
Notes

The networking principle

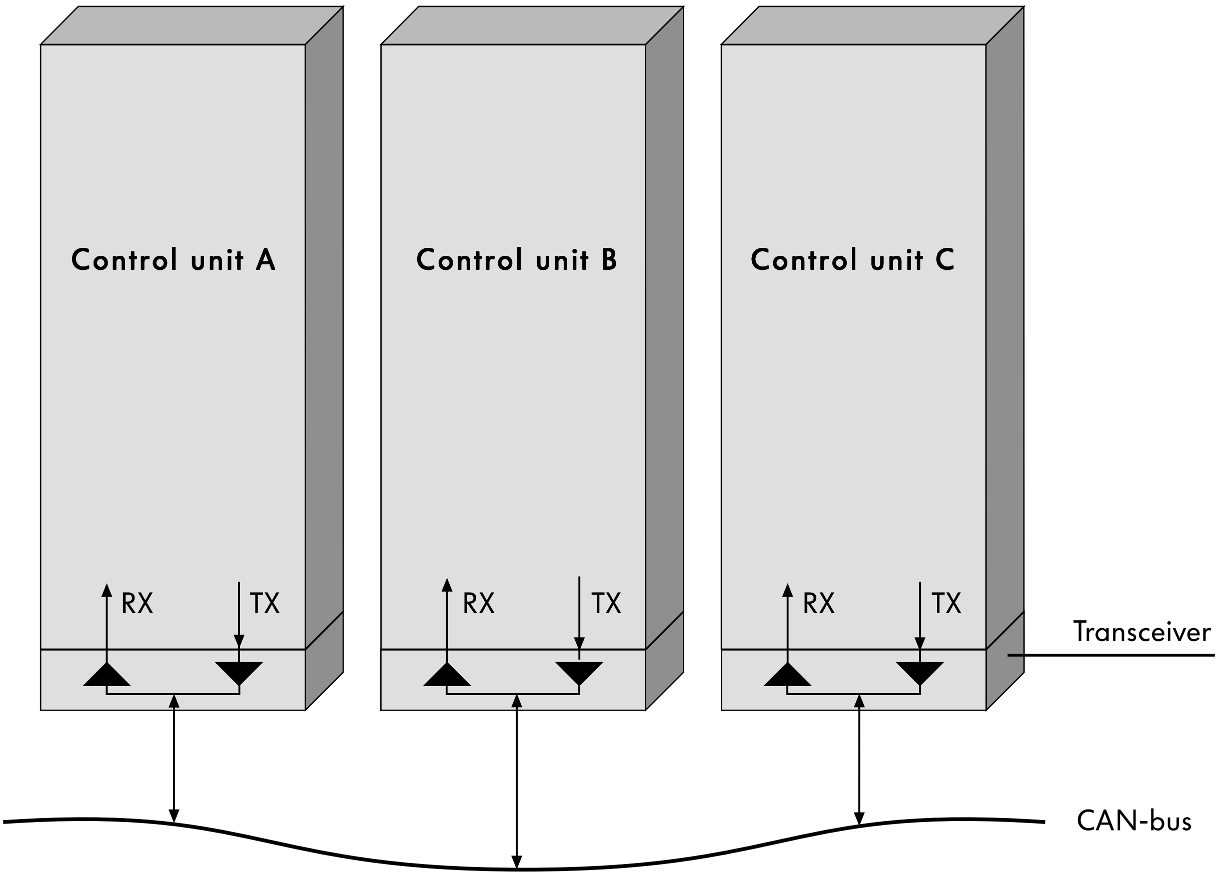
The basic system consists of several control units. They are connected in parallel to the bus line by transceivers. This means that the same conditions apply to all stations. In other words, all the control units are handled equally, none has any preference. In this context, this is called a multimaster architecture.

Information is exchanged serially (in series).

Basically, the CAN bus is already fully functional with a single line!
The system can also be equipped with a second bus line.
The second line is used for signals travelling in the reverse order.
It is possible to suppress external interference more effectively by reversing the signals.



To explain the basic principle of data transmission in a simpler way, we will assume a single bus line in the following examples.



The networking principle

238_012

Information exchange

Exchange information is referred to as messages. Any control unit can send or receive messages.

A message contains physical values such as the engine speed (rpm).
The engine speed In this case, is represented as a binary value (a string of ones and zeroes).
For example: (The engine speed of 1800 rpm is represented as 00010101 in binary notation.)

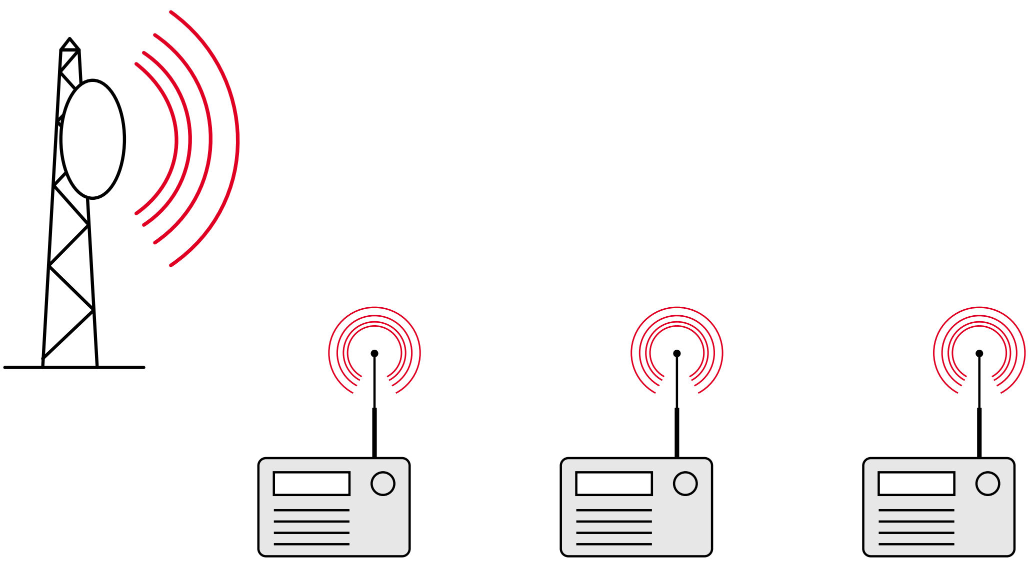
Before sending, the binary value is converted into a serial bit stream.
The bit stream is sent over the TX line (transmit line) to the transceiver (amplifier).
The transceiver converts the bit stream into voltage values which are then sent over the bus line one by one.

In the reception process, voltage values are converted back into a bit stream by the transceiver and sent over the RX line (receive line) to the control units.
The control units then convert the serial binary values back into messages.
For example: (the value 00010101 is converted back to the engine speed 1800 rpm)

A message sent can be received by any control unit.

This principle is also called a broadcast message. The idea is derived from a transmitter which broadcasts a programme which any tuner (receiver) can receive.

The broadcasting process ensures that all control units connected to the bus have the same information status.



The broadcasting principle: one sends, everyone receives.

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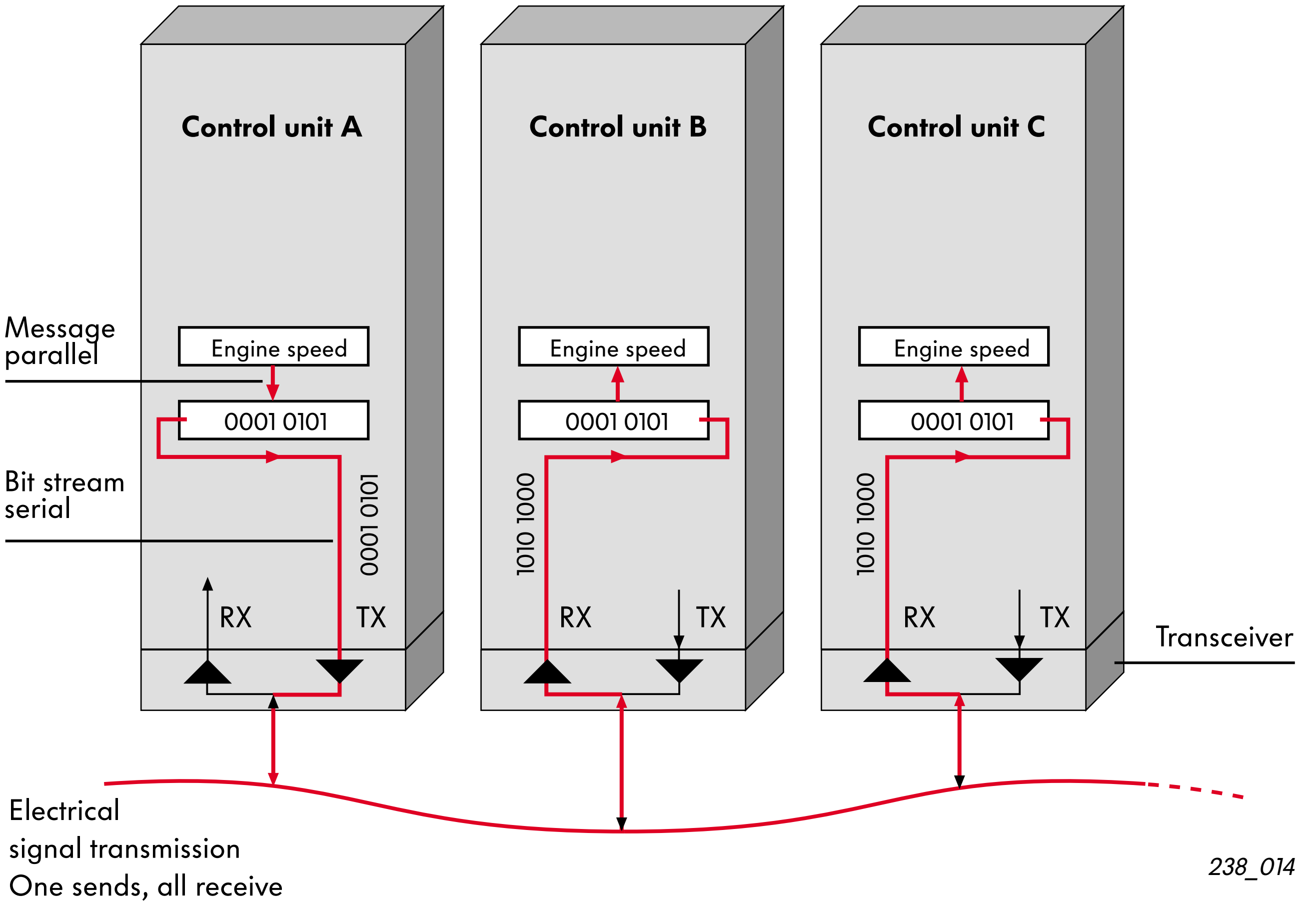
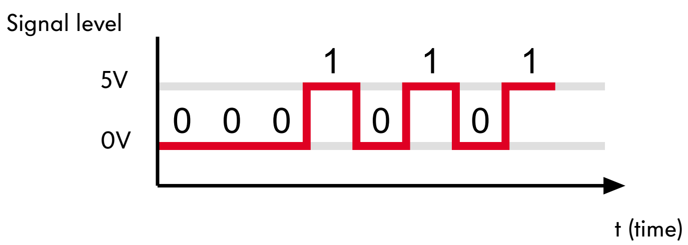


Information exchange of a message on the CAN bus (broadcast principle)



Electrical signal transmission in chronological sequence

Functional units

K wire

The K-wire is provided for connection to a VAS tester for vehicle diagnosis when servicing.

Control unit

The control unit receives signals from the sensors, processes them and passes them on to the actuators.
The main components of a control unit are: a microcontroller with input and output memories and a program memory.
The sensor values received by the control, e.g. engine temperature or engine speed, are interrogated at regular intervals and stored in the input memory in their order of occurrence.
This process corresponds to the principle of a mechanical step-by-step system with a rotating input selector switch (see figure).
The microcontroller links the input values based on the program configuration. The results of this process are stored in each output memory and from there, they are sent to each of the actuators.
In order to process CAN messages, each control unit has an additional CAN memory area for received and sent messages.

CAN module

The CAN module controls the data transfer process for CAN messages.
It is divided into two sections, the receive section and the send section.

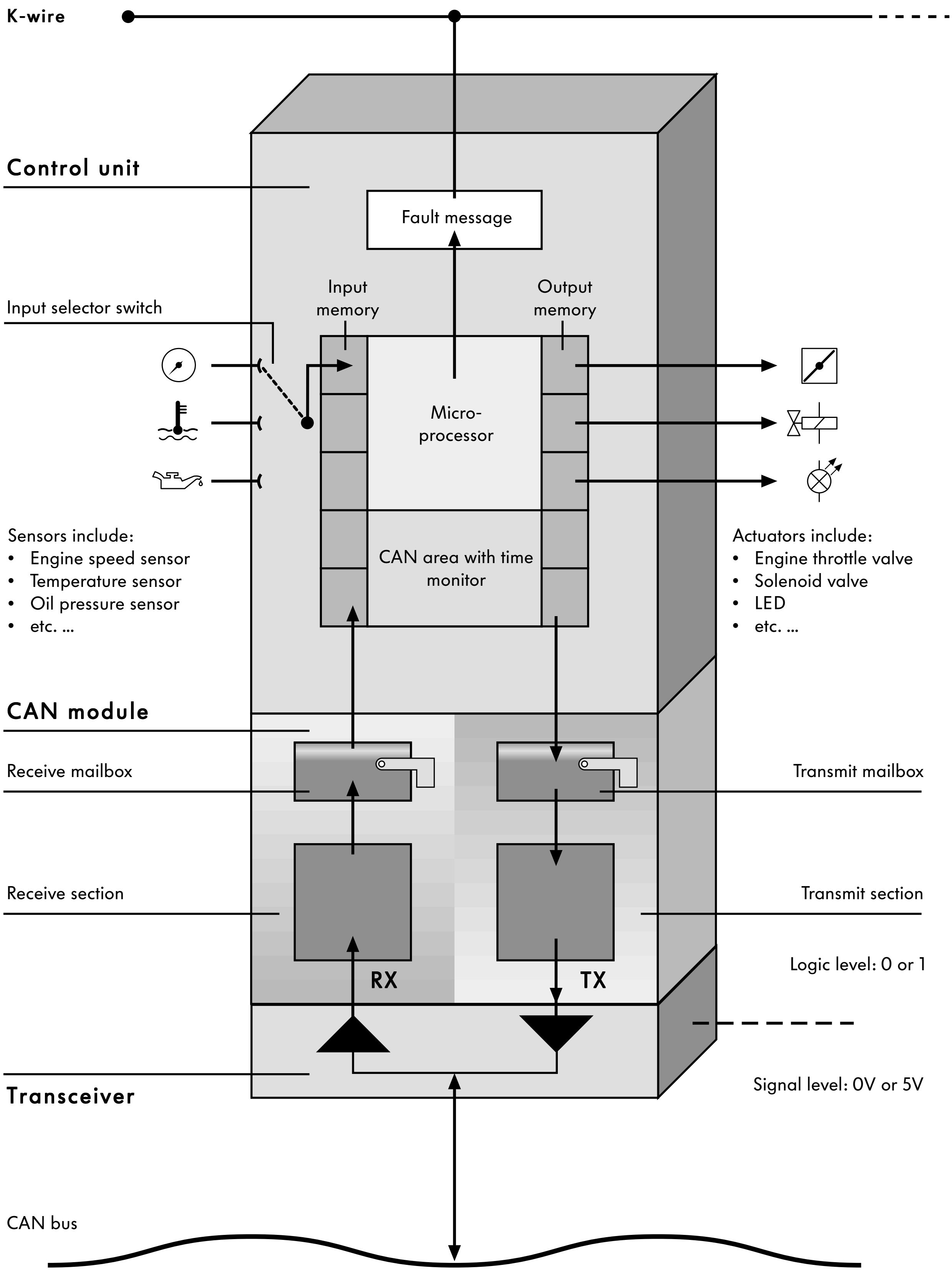
The CAN module is connected to the control unit via the receive mailbox or the send mailbox. It is normally integrated in the chip of the control unit microcontroller.

Transceiver

The transceiver is a transmitter and receiver amplifier. It converts the serial bit stream (logic level) of the CAN module into electrical voltage values (line level) and vice versa.
The electrical voltage values are designed for sending over copper wires.

The transceiver is connected to the CAN module via the TX line (transmit line) or via the RX line (receive line).

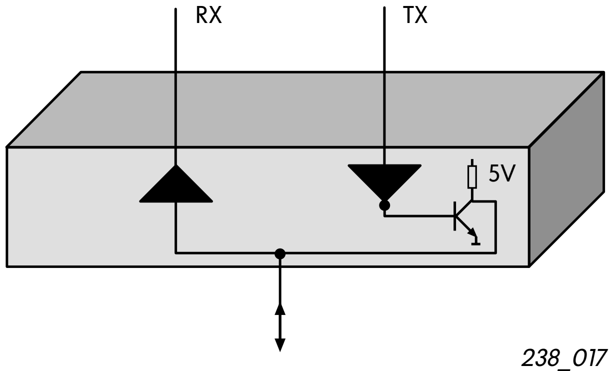
The RX line is directly connected to the CAN bus and permits continuous monitoring of bus signals.



Functional unit: control unit, CAN module and transceiver

238_016

Special features of transceiver



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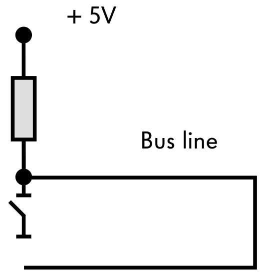
Transceiver with connection to TX line



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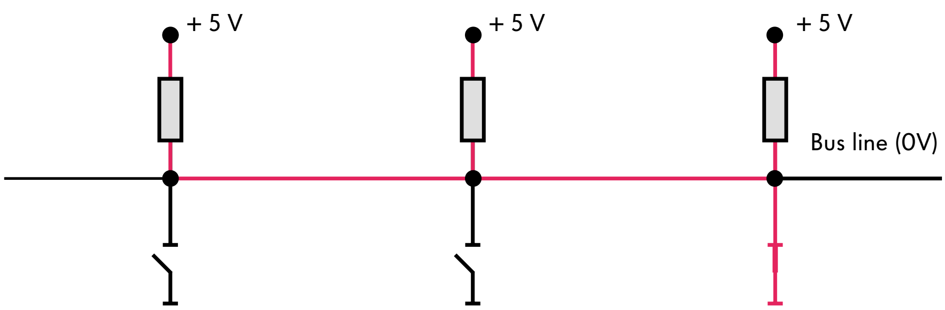
Block diagram with one switch

A special feature is the connection of the TX line to the bus. It is normally connected via an open collector.

This results in two different states on the bus line.

State 1:	inhibited state, transistor inhibited, (switch open)
Passive:	bus level=1, high-resistant via resistor
State 0:	switch-through state, transistor switched through (switch closed)
Active:	bus level=0, low-resistant without resistor

Three transceivers connected to a bus line



Connection of 3 transceivers to bus line (principle), transceiver C active

238_019

Switch open means 1 (passive) Switch closed means 0 (active)

The previous example (three transceivers connected to bus line) results in the following switch positions:

Transceiver A	Transceiver B	Transceiver C	Bus-Leitung
1	1	1	1 (5V)
1	1	0	0 (0V)
1	0	1	0 (0V)
1	0	0	0 (0V)
0	1	1	0 (0V)
0	1	0	0 (0V)
0	0	1	0 (0V)
0	0	0	0 (0V)

Possible switch positions with 3 transceivers connected to a bus line, transceiver C active

Response:

- If any switch is closed, current flows across the resistors. A voltage of 0V is generated on the bus line.
- If all switches are open, no current flows. No voltage drops across the resistor. A voltage of 5V is generated on the bus line.

This achieves the following:

If the bus is in state 1 (passive), any other station can overwrite this state with state 0 (active).

The passive bus level is called recessive. The active bus level is called dominant.

This relationship is important in the following situations:

a) For signalling transmission faults (fault messages about error frames).
b) Collision detection (if several stations want to send simultaneously).

Data transmission process

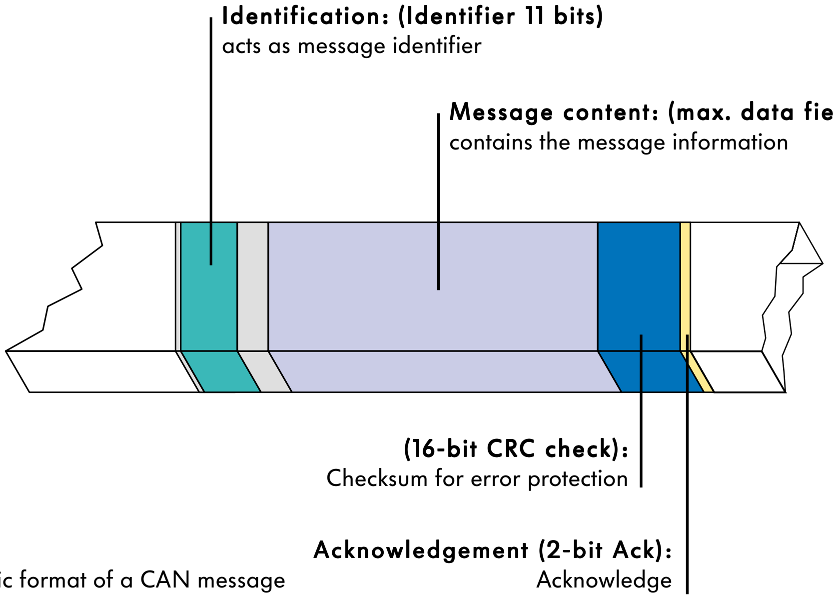
Data transmission using the example of engine speed detection > transmission > display

The following example describes the complete process for exchanging engine speed information from detection through to display in the rev counter. It explains the chronological sequence of the data transmission process and the interaction between the CAN modules and the control units.

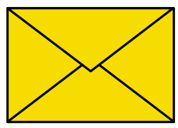
First the engine control unit sensor detects the engine speed value.
This value is stored in the microcontroller input memory at regular intervals (cyclically).
Since the present engine speed value is also required for other control unit, e.g. the dash panel insert, it has to be sent over the CAN bus.
The engine speed value is first copied to the transmit memory of the engine control unit.

From there the information goes to the transmit mailbox of the CAN module.
If a current value is located in the transmit mailbox, it is indicated by the transmit flag (the flag is raised).
Once the message is sent to the CAN module, the engine control unit has completed its task for this process.

The engine speed value is first converted into an engine message with a CAN-specific form in accordance with the protocol. The main components of a protocol are:



Basic format of a CAN message



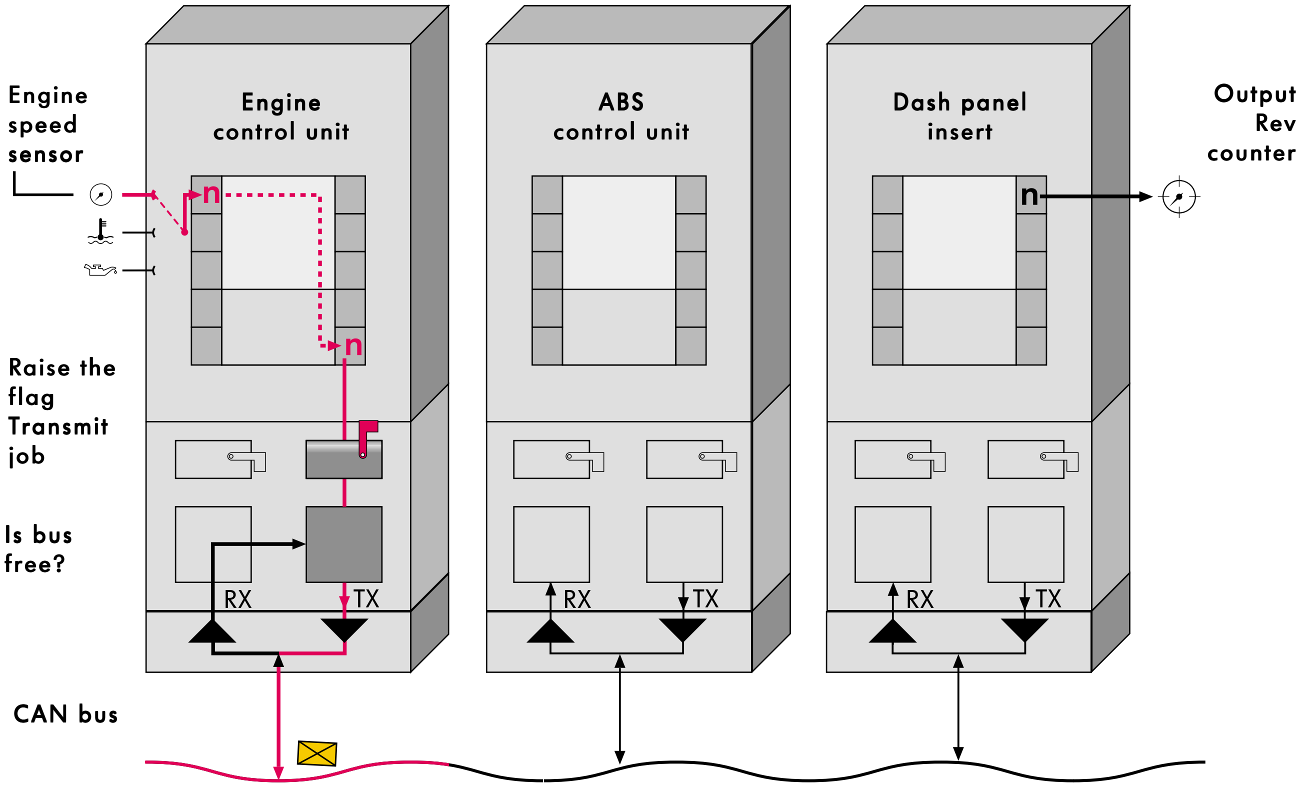
In the following diagrams, the CAN message is represented as a letter icon.

238_020

The components of an engine message would therefore include: identifier=engine_1, content= rpm.
The engine message also contains other values, e.g. idling speed, torque etc.

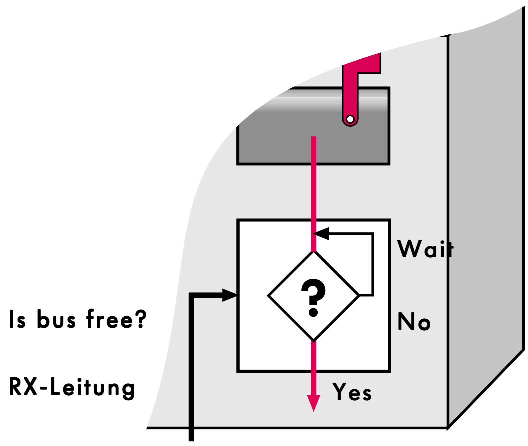
The CAN module then checks via the RX line whether the bus is active (whether information is in the process of being exchanged). If necessary, it waits until the bus is free.
(Level 1 (passive) for a specific period). If the bus is free, the engine message is sent.

Transmit process



Start of a transmit process

238_021



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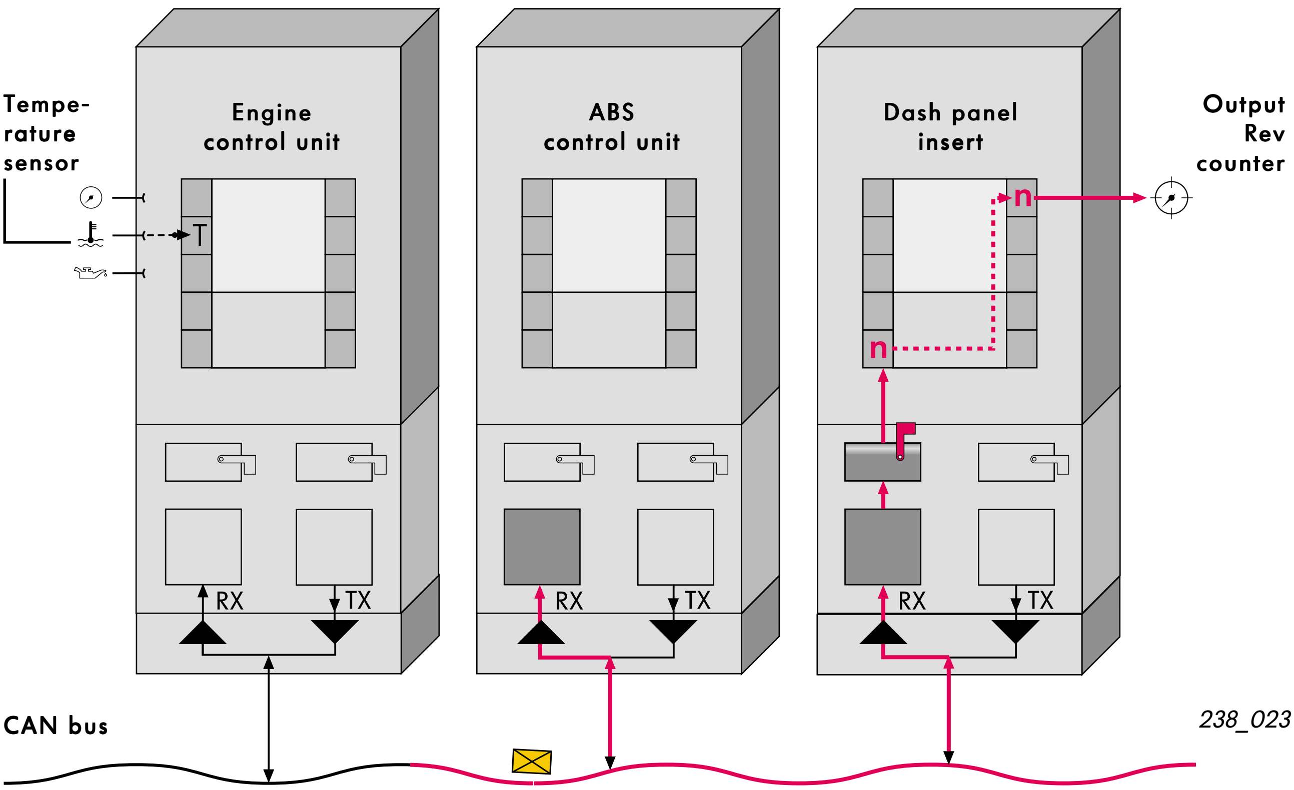
Detail: Interrogation format for 'Is bus free?'

Data transmission process

Receive process

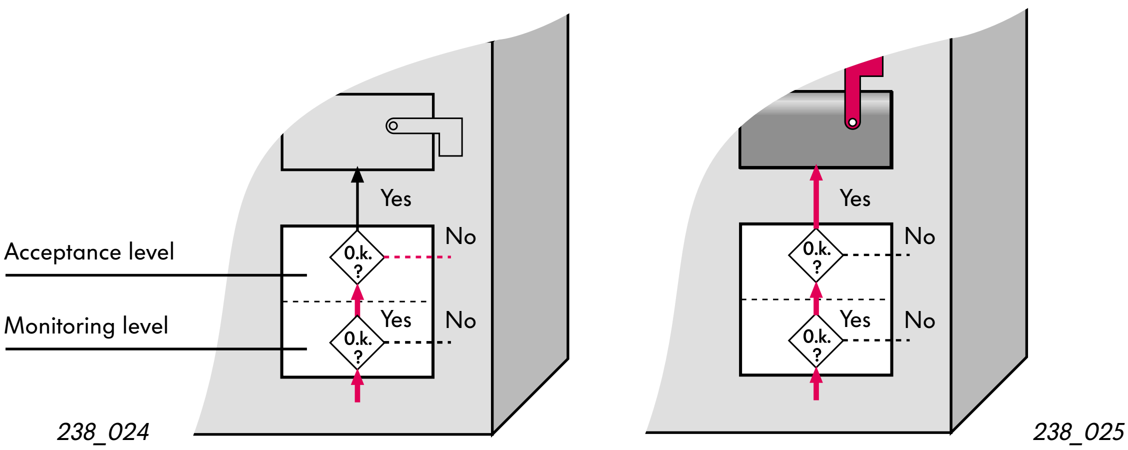
The receive process consists of two steps:

- Step 1 = check message for errors (at monitor level)
- Step 2 = check message for usability (at acceptance level)



Receive process

All connected stations receive the message sent by the engine control unit.
It travels over the RX lines to the receive areas of the CAN modules.

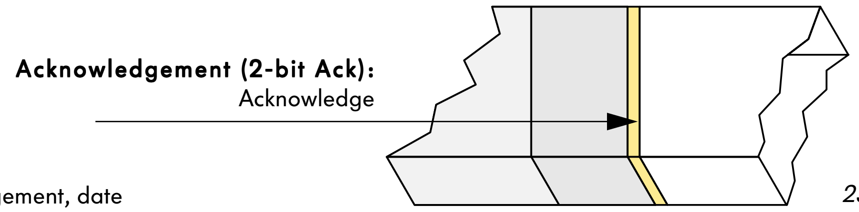


Detail: receive area, monitoring and acceptance levels

The receivers have all received the engine message and have checked them for correctnesss at the associated monitoring level. This helps to detect local faults which may occur only in one control unit under certain circumstances. This results in the high data density mentioned before (also refer to the sections on "Transmission protection, fault response“).

All connected stations receive the message sent by the engine control unit (broadcast). Using the CRC checksum, they can detect whether any errors have occurred in transmission. CRC is an acronym for Cyclic Redundancy Check. When a message is sent, a 16-bit checksum is generated from all the bits and included in the transmission.
The receivers calculate the checksum from all the bits received using the same protocol.
Then the received checksum is compared with the calculated checksum.

If no error is found, all the stations send an acknowledgement to the transmitter (called the Acknowledge) confirming correct reception.



Information flow, acknowledgement, date

238_026

Finally the correctly received message goes to the acceptance section of the associated CAN modules.

- There a decision is made whether the message is necessary for the function of the related control unit.
- If not the message is discarded.
- If so, the message is placed in the receive mailbox.

When the "receive flag" is raised, the connected combi-instrument knows that a current message, e.g. engine speed, has arrived for processing.
The combi-instrument calls the message and copies the value to its input memory.

This concludes the sending and receiving of a message via the CAN modules.

- After the microcontroller in the dash panel insert processes the engine speed value, the value is sent to the actuator and then to the rev counter.
- Data exchange of a message is repeated depending on the cycle time setting (for example, every 10 ms).

Data transmission process

Simultaneous send attempt by several control units

If several control units attempt to send at the same time, there would be a data collision on the bus line. To avoid this, the CAN system uses the following strategy:

every active control unit starts its transmit process by sending an identifier.

All the control units monitor the bus traffic by monitoring the bus on their RX line.

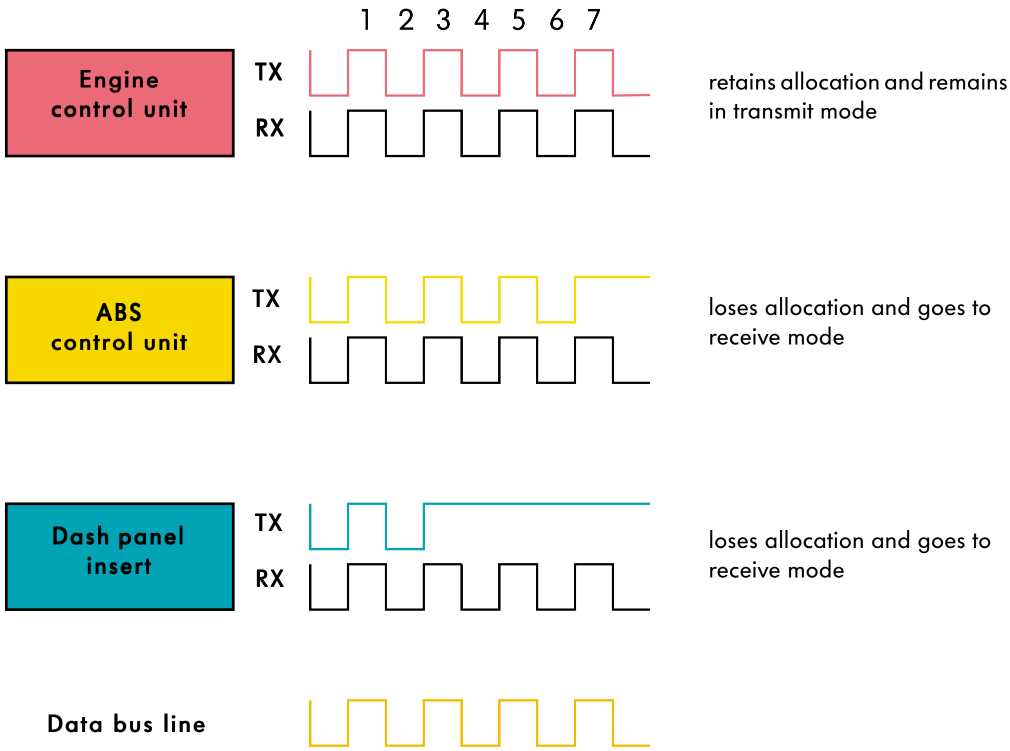
Every transmitter compares the state of the TX line bit-by-bit with the state of the RX line. The comparison may show differences.

The CAN strategy regulates this situation in the following way: the control unit whose TX signal was over-written by a zero must withdraw from the bus.

Message weighting is controlled by the number of leading zeroes in the identifier. This ensures that messages are sent in the order of their priority.

Rule: the lowers the number in the identifier, the more important the message.

This procedure is called arbitration. Association: arbiter = referee or judge



Arbitration process to avoid collisions

238_027

The next example shows that the wheel angle sensor has the highest priority when several control units attempt to transmit simultaneously. The wheel angle sensor's message is therefore sent first.

Explanation: the wheel angle sensor with the smallest number (mainly leading zeroes) asserts itself.

Identifier	Binär	Hex
Engine_1	010_1000_0000	280
Brake_1	010_1010_0000	1A0
Combi_1	011_0010_0000	320
Steeringangle_1	**000_1100_0000**	**0C2**
Gearbox_1	100_0100_0000	440

Possible identifiers in drive train CAN *238_027b*

Conclusion when transmitting sensor values (e.g. engine speed)

Due to the high transmission protection in CAN, all errors are detected reliably, e.g. electrical faults or interruptions in the CAN system.

- The engine speed of 1800rpm is correctly sent or not at all if a fault occurs (no display, rev counter shows "0").
- For example, if implausible engine speeds occur, the cause may not lie with the transmission (CAN) but with a defective sensor, display instrument or the supply line.

Transmission protection, interference response

Internal error management

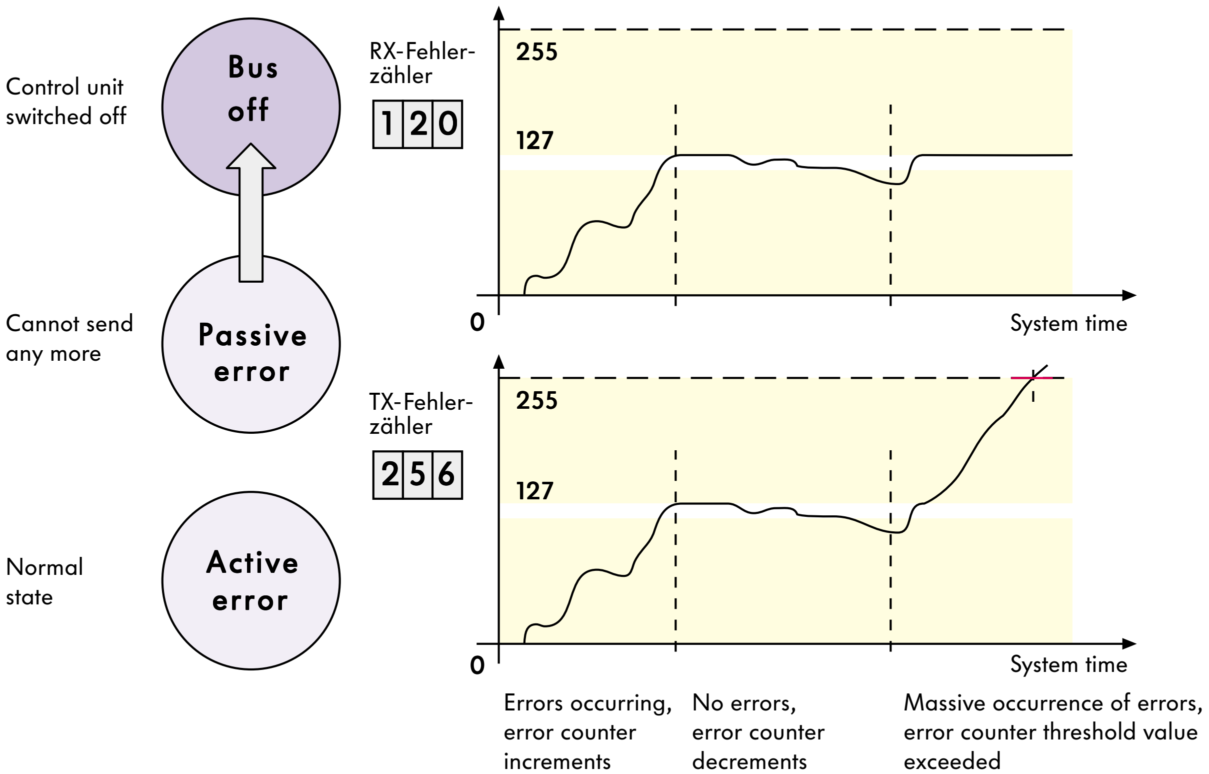
To ensure high data protection, the CAN has an extensive integrated error management system.

This is capable of detecting any transmission errors occurring with a high level of certainty. Corrective action can then be initiated.
The rate of undetected errors, what is known as residual error probability, is about < 10^{-12}.
This value is equivalent to 4 errors over the lifespan of the car.

Using the broadcast process (one sends, all receive and evaluate), any network user detecting an error immediately notifies all other users by sending an error message called an error frame.
The current message is then rejected by all users.

This is followed by an automatic transmission repetition. This process is completely normal and may be caused by major voltage fluctuations in the onboard power supply, e.g. on engine start or strong external interference.

What is more critical is if transmission repetitions become more frequent due to continuously detected errors.
In this case, every station has an integrated error counter which increments detected errors and decrements once the transmission repetition has been sent.



Interner Fehlerzähler

238_028

Transmission protection, interference response

The internal error counter is responsible for internal error management and cannot be read out.

If the preset threshold value is exceeded (equivalent to max. 32 transmission repetitions), the affected control unit is informed and is switched off by the CAN bus.
After the bus goes off-state twice (without any intermediate communication), an entry is made in the fault memory.

After a fixed waiting time (approx. 0.2s) the control unit attempts to access the bus again.

Message traffic is normally cyclical with prescribed cycle times.
This ensures that the messages are transmitted in good time.
If there are delays, it means that at least ten messages are not received and this triggers the message timeout.

This causes a entry in the fault memory of the receiving control unit.
This is the second element of the error management system. The following error messages are available for in-service diagnosis:

1. Data bus defective

Fatal errors were detected in the affected control unit.

The control unit disconnected at least twice from the bus (bus off).

2. Missing messages from .... or no communication with the affected control unit.

Messages are not received in good time. Timeout monitor responded.

Transmission protection, interference response

Diagnosis information using defective engine speed transmission as an example

- The engine speed is transmitted correctly or not at all due to a fault (value not displayed).
  In this case, the Vehicle Diagnostic Testing and Information System VAS 5051 sends notification that there is a fault in the CAN system:

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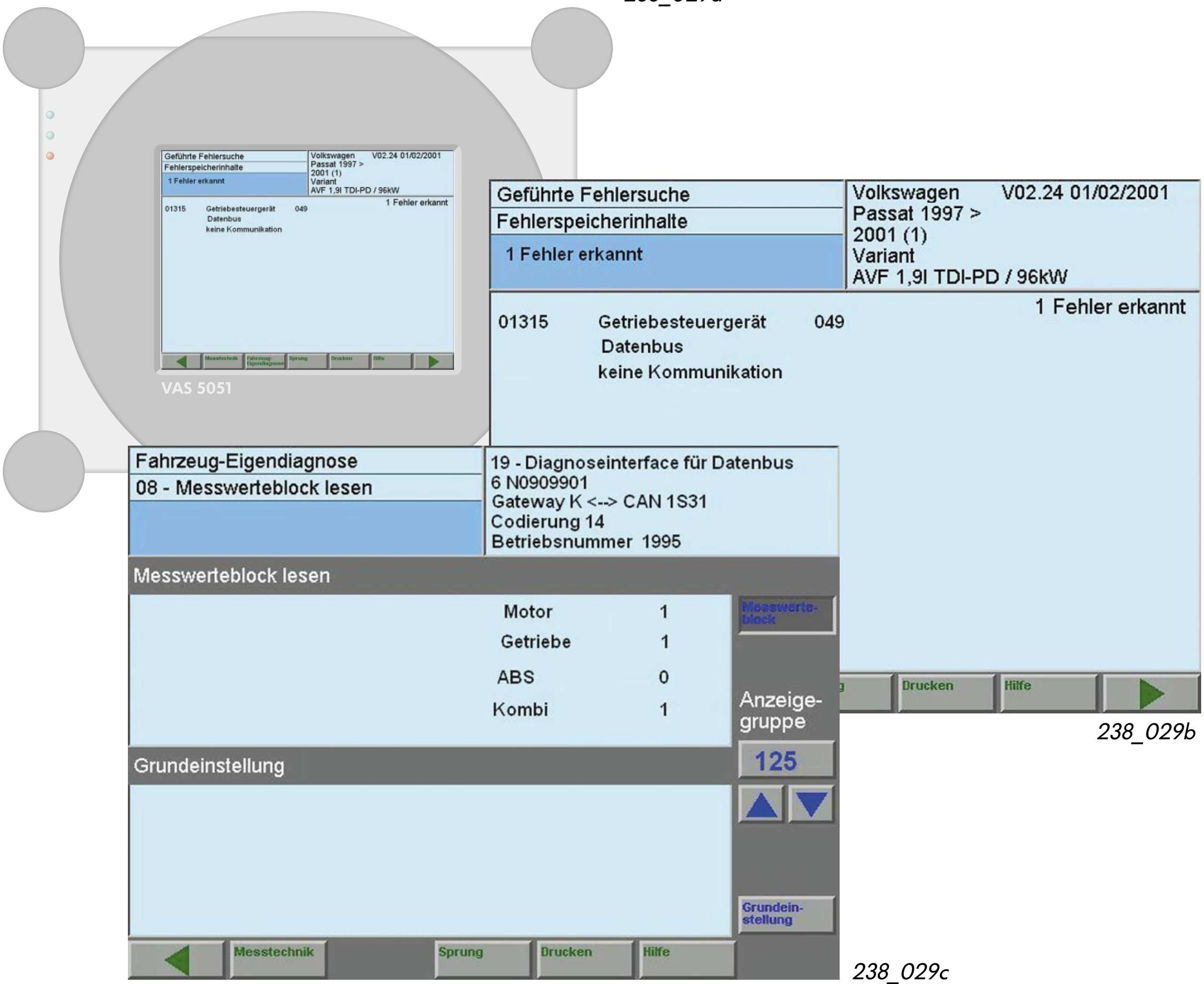

238_029b

238_029c

VAS 5051 display

- For example, if implausible engine speeds occur, the cause may not lie with the CAN transmission) but with a sensor or actuator (display instrument or rev counter).

If there is a fault in the CAN system, the Vehicle Diagnostic Testing and Information System VAS 5051 indicates a general fault message.

This message indicates which component is defective in the CAN system.

To localise errors, data blocks 125, 126 can be read out from the active state gateways of the control units connected to the CAN bus (1=active, 0=passive).

If necessary, further electrical measurements, for example, signal testing using the oscilloscope) may be required.

Outlook

This SSP 238 explains the basic functions of the CAN system.
SSP 269 "Data Exchange on CAN Bus II, Drive Train CAN Bus/Convenience CAN Bus“ describes the CAN bus system specially implemented in Volkswagen and Audi vehicles.
It describes in detail the special features with the Drive Train CAN bus and Convenience CAN bus with respect to function and diagnosis.

Finally, the entire system combining the Drive Train CAN bus and Convenience CAN bus via the Gateway is explained. The fault-finding procedure is also part of this SSP.

Test your knowledge

1. Why are bus systems used in cars?

A ☐ Increasing complexity in motor vehicle electronics

B ☐ System expansions in the form of optional extras are easily possible

C ☐ Prescribed by law

2. What is the data transmission rate on the Drive Train CAN bus?

A ☐ 10 kbps

B ☐ 100 kbps

C ☐ 500 kbps

3. The Diagnostic Testing and Information System VAS 5051 helps to detect ... ?

A ☐ CAN line errors

B ☐ CAN hardware errors

C ☐ Displays CAN messages

4. What messages are received and tested by control units?

A ☐ Only the messages meant for a particular control unit

B ☐ All messages sent

C ☐ Messages with the highest priority

5. 3 control units wait until the bus is free and then they attempt to send messages ...

A ☐ ... All can send messages immediately

B ☐ ... A data collision occurs

C ☐ ... Arbitration controls the order in which messages are sent

6. What does Bus OFF mean?

A ☐ All bus users switch off

B ☐ A bus user withdraws from bus traffic temporarily

C ☐ The bus is totally switched off

7. What is the function of the internal error counter?

A ☐ To count CAN messages

B ☐ To count errors in order to switch the control unit Bus OFF

C ☐ For statistical purposes

8. What does "high transmission protection" means on the bus?

A ☐ Almost no transmission errors occur

B ☐ Transmission errors are detected with certainty

C ☐ All bus users are informed when errors are detected

9. The identifier of a CAN message ...

A ☐ ... identifies the name and priority of a message

B ☐ ... indicates the destination address

C ☐ ... helps to control access rights

10. The function of the protocol is ...

A ☐ ... to protect data

B ☐ ... detect errors

C ☐ ... control access rights

Glossary

ACK:
Acknowledge, receive confirmation of a correct message. Occurs by setting a dominant bit from all bus users.

Actuators
Drive elements and displays in the vehicle.

Acceptance range
Filtering received messages which are relevant for the affected control unit.

Arbitration
Mechanism for avoiding collisions when several users want to send at the same time.
Arbitration makes sure that messages are sent in the order of their importance.

Message
A message is a data packet which is sent by a control unit.

Message timeout
Time monitor that monitors transmitted messages on receiver side.

Broadcast
Transmitting principle - one sends - all receive.

BUS line
Electrical connection made of copper in car, twisted wire pair. The bus line connects control unit together.

Bus OFF
Control unit is switched off from the bus when the internal error counter is exceeded.

Bus transceiver
Electronic transmitter-receiver amplifier to connect acontrol unit to the bus.

CAN
Controller Area Network, bus system to network control units.

Drive Train CAN bus
Subsystem for control units in drive train.

Convenience CAN bus
Subsystem for control units in the convenience system.

Infotainment CAN bus
Subsystem for control units in the radio and information system.

CAN module
Process data exchange for CAN messages.

CRC
Cyclic Redundancy Check, checksum (16 bits) for error detection.

Receive mailbox
Memory which stores messages received from the CAN module.

Error frame
Error message (>6 dominant bits) to indicate transmission errors on the bus.

Error memory
Memory area in control unit; readable by VAS Tester.

Identifier
Start of a message; used for identifying and distinguishing between message priorities.

K-wire
Customer Service line; connecting line between control unit and diagnostic plug in vehicle for connecting to the VAS Tester.

Logic level:
State 0 or 1 at a connection point in the system.

Microcontroller:
1-chip computer system, comprises CPU, memory and input/output modules

RX line
Receive-side connecting line between CAN module and transceiver

Transmit mailbox
Memory in the CAN module storing messages sent by control units.

Sensors
Electronic sensors in the car, for capturing operating states

Signal level
Electric voltage state on a wire

Transceiver
Electronic transmitter/receiver amplifier, for coupling the CAN module to the bus line.

TX line
Transmit-side connecting line between CAN module and transceiver

Answers to test questions:

1: AB / 2: C / 3: AB / 4: B / 5: C
6: B / 7: B / 8: BC / 9: AC / 10: ABC

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CAN

Controller-Area-Network

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