CAN-Wiring

Guide to Wiring of CAN-Bus Systems and Cable Selection

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Notes

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This manual contains important information and instructions on safe and efficient wiring of CAN networks. Carefully read this manual before commencing any work and follow the instructions.

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Document History

The changes in the document listed below affect changes in the hardware as well as changes in the description of the facts, only.

Revision	Chapter	Changes versus previous version	Date
4.0	-	Text imported in OpenOffice and completely revised	2012-09-19
		"Correct Wiring" and "Troubleshooting Guide" text segments inserted	
4.1	1.5	Wiring length for bit rate 83,3 kbit/s inserted and editorially revising	2013-11-20
4.2	1.1	Chapter "1.1 Standards concerning CAN wiring" inserted.	2014-12-04
	-	New CAN termination connector "CAN-Termination-DSUB9" inserted.	
	1.8	Chapter "1.7 Effective Resistance of the Cable" deleted because effect of cable effective resistance is negligible in practical applications.	
4.3	-	Classification of Warning Messages and Safety Instructions inserted	2016-05-06
	1.3.3, 1.4.3, 3.	"(Gender Changer)" deleted	
	1.6	Reference to CiA 303-1 inserted in note and CiA recommendations of cable cross-section inserted in table 1	
4.4	1.3.3	New chapter "Branching"	2018-01-16
	1.4.2	Notes on T-Connector moved to chapter 1.4.3 "Branching"	
	1.4.3	New chapter "Branching"	
4.5	1.	Note on CAN FD inserted	2018-05-08
4.6	all	Text imported in Word and revised	2022-06-14
	-	Notes on page 4 inserted	
	1.6	Description to bus length taken from the website. Note to CiA 106 inserted	
	2.	Complete chapter revised, changes taken from the website, resistance value under "Expected Result" changed in chapter 2.5	

Technical details are subject to change without further notice.

Target Group of this Document
This document is directed exclusively towards personnel qualified in control and automation engineering. The installation and commissioning of the product may only be carried out by qualified personnel, which is authorized to put devices, systems, and electric circuits into operation according to the applicable national standards of safety engineering.

Conformity
The accessories for CAN wiring (CAN cables and connectors, see ordering information) are industrial products and comply with the respective directives and standards specified in their EU declarations of conformity.

Intended Use
The intended use of the CAN cables and connectors is the use for setting up the CAN wiring.
The guarantee given by esd does not cover damages which result from improper use, usage not in accordance with regulations or disregard of safety instructions and warnings.

- The accessories for the CAN wiring are intended for indoor use only.
- The operation of the accessories for the CAN-Wiring in hazardous areas, or areas exposed to potentially explosive materials is not permitted.
- Usage for medical purposes is prohibited.

Service Note
The accessories for the CAN-Wiring do not contain any parts that require maintenance by the user and they do not require any manual configuration. Unauthorized intervention in the accessories voids warranty claims

Disposal


Products marked with a crossed-out dustbin must not be disposed of with household waste. Devices which have become defective in the long run must be disposed in an appropriate way or must be returned to the manufacturer for proper disposal. Please, contribute to environmental protection.

Classification of Warning Messages and Safety Instructions
This manual contains noticeable descriptions, warning messages and safety instructions, which you must follow to avoid personal injuries and property damage.

NOTICE
Notice statements are used to notify people on hazards that could result in things other than personal injury, like property damage.

NOTICE
This NOTICE statement contains the general mandatory sign and gives information that must be heeded and complied with for a safe use.

INFORMATION

INFORMATION
Notes to point out something important or useful.

Table of Contents

1 Correct Wiring of Electrically Isolated CAN Networks

NOTICE
This chapter applies to CAN networks with bit rates up to 1 Mbit/s.
If you work with higher bit rates, as for example used for CAN FD, the information given in this chapter must be examined for applicability in each individual case.
For further information refer to the CiA® CAN FD guidelines and recommendations (https://www.can-cia.org/).

For the CAN wiring all applicable rules and regulations (EU, DIN), such as regarding electromagnetic compatibility, security distances, cable cross-section or material, must be observed.

1.1 CAN Wiring Standards

The flexibility in CAN network design is a major strength of the various extensions based on the original CAN standard ISO 11898-2, such as CANopen®, ARINC825, DeviceNet® and NMEA2000. However, taking advantage of this flexibility absolutely requires a network design that considers the interactions of all network parameters.

In some cases, the CAN organizations have adapted the scope of CAN in their specifications to enable applications outside the ISO 11898 standard. They have imposed system-level restrictions on data rate, line length and parasitic bus loads.

However, when designing CAN networks, a margin must always be planned for signal losses over the entire system and cabling, parasitic loads, network imbalances, potential differences against earth potential, and signal integrities. **Therefore, the maximum achievable number of nodes, bus lengths and stub lengths may differ from the theoretically possible number!**

esd has limited its recommendations for CAN wiring to the specifications of ISO 11898-2. A description of the special features of the derived specifications CANopen, ARINC825, DeviceNet and NMEA2000 is omitted here

The consistent compliance with the ISO 11898-2 specification offers significant advantages:

- Reliable operation due to proven design specifications
- Minimization of error sources due to sufficient distance to the physical limits.
- Easy maintenance because there are no "special cases" to consider for future network modifications and troubleshooting.

Of course, reliable networks can be designed according to the specifications of CANopen, ARINC825, DeviceNet and NMEA2000, **however it must be observed that it is strictly not recommended to mix the wiring guidelines of the various specifications!**

1.2 Selecting Cables

The following properties should be considered for the selection of the CAN lines:

Characteristic impedance

The characteristic impedance of the cable used should be about 120 Ω.

Effective resistance

The ohmic resistance of the cable must be so low that the voltage-switching threshold of the receiver component at the end of the line is met. The connected termination resistor and the number of nodes must be considered for determining the voltage drop at the receiver.

EU Conformity

NOTICE

esd grants the EU Conformity of the product, if the CAN wiring is carried out with the CAN cables that are required for this particular product.

Depending on the product at least single shielded two- or four-wire twisted pair cables must be used, that meet the requirements of ISO 118982-2 standard.

For information on whether the usage of two-wire or four-wire cables is required for a product, please refer to the manual of the respective product.

For instructions about wiring of single shielded two-wire twisted pair cables, please read chapter 1.3.

For instructions about wiring of single shielded four-wire twisted pair cables, please read chapter 1.4

Bit rate / cable length

Depending on the signal propagation times of the line, the achievable total line length of a CAN network increases with a decreasing bit rate (see chapter 1.6).

1.3 Light industrial Environment (single twisted Pair Cable)

1.3.1 General Rules

The following **general rules** for CAN wiring with single shielded *single* twisted pair cable should be followed:

1	A suitable cable type with a wave impedance of about 120 Ω ±10% with an adequate conductor cross-section (≥ 0.22 mm²) must be used. The voltage drop over the wire must be considered.
2	For light industrial environment use at least a two-wire CAN cable, the wires of which must be assigned as follows: • Two twisted wires must be assigned to the data signals (CAN_H, CAN_L). • The cable shield must be connected to the reference potential (CAN_GND).
3	The reference potential CAN_GND must be connected to the functional earth (FE) at exactly **one** point.
4	A CAN bus line must not branch (exception: short cable stubs) and must be terminated with the characteristic impedance of the line (generally 120 Ω ±10%) at both ends (between the signals CAN_L and CAN_H and **not** at CAN_GND).
5	Keep cable stubs as short as possible (l < 0.3 m).
6	Select a working combination of bit rate and cable length.
7	Keep away cables from disturbing sources. If this cannot be avoided, double shielded wires are recommended.

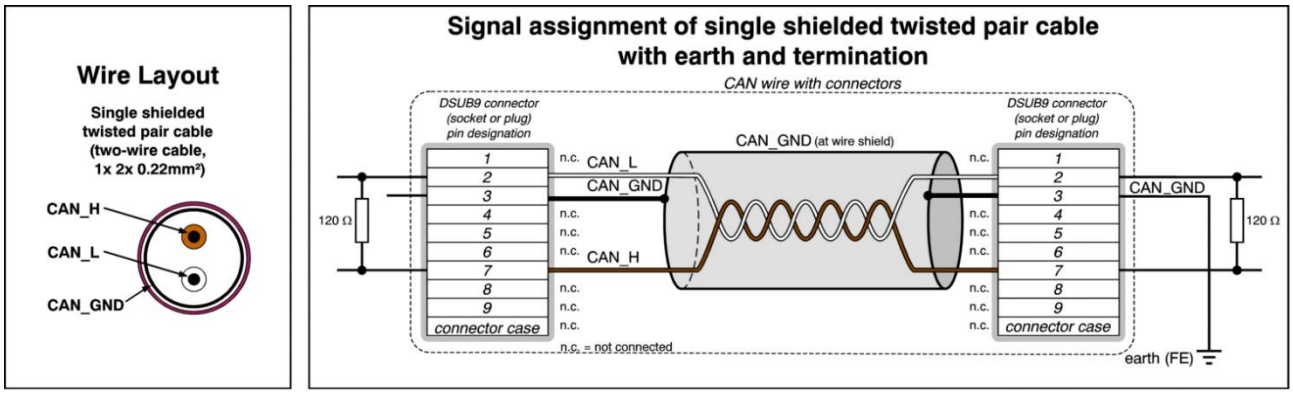


Figure 1: CAN wiring for light industrial environment

1.3.2 Cabling

- To connect CAN devices with just one CAN connector per net use a short stub (< 0.3 m) and a T-connector (available as accessory). If these devices are located at the end of the CAN network, the CAN terminator “CAN-Termination-DSUB9” can be used.

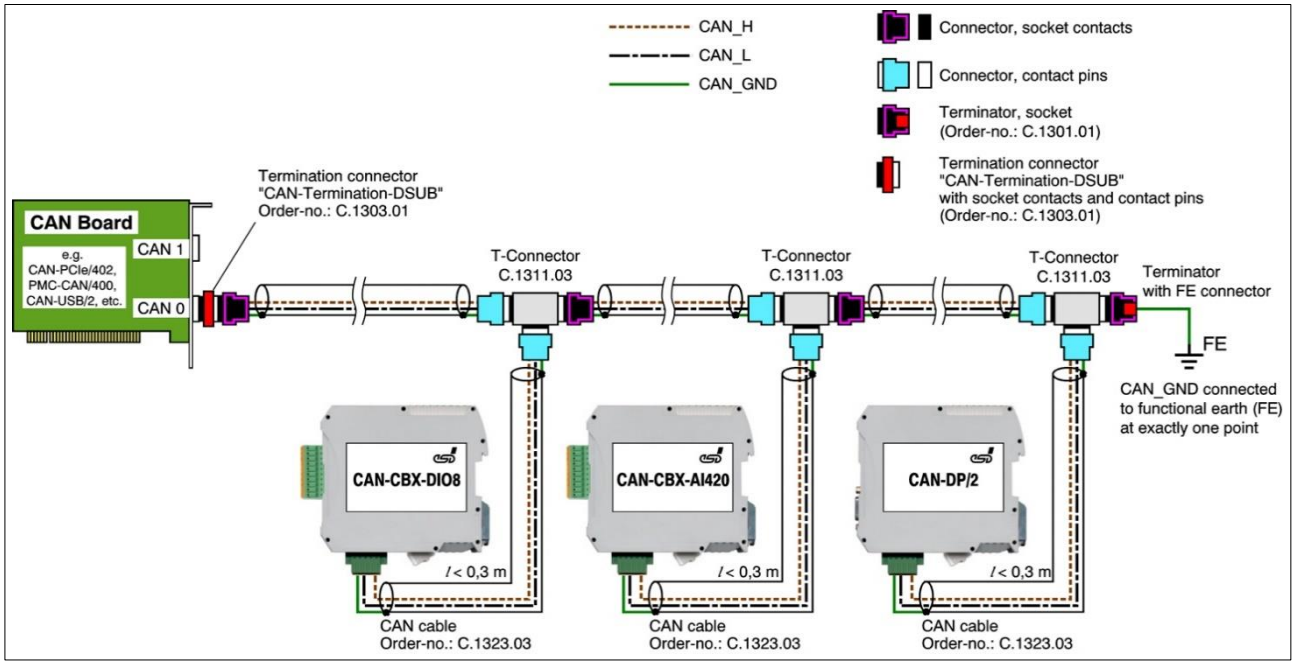


Figure 2: Example for proper wiring with single shielded single twisted pair wires

1.3.3 Branching

- In principle the CAN bus must be realized in a line. The nodes are connected to the main CAN bus line via short cable stubs. This is normally realised by so called T-connectors. esd offers the CAN-T-Connector (Order No.: C.1311.03)
- If a mixed application of single twisted and double twisted cables cannot be avoided, ensure that the CAN_GND line is not interrupted!
- Deviations from the bus structure can be realized by using repeaters.

1.3.4 Termination Resistor

- A termination resistor must be connected at both ends of the CAN bus.
  If an integrated CAN termination resistor is connected to the CAN interface at the end of the CAN bus, this integrated termination must be used instead of an external CAN termination resistor.
- 9-pole DSUB-termination connectors with integrated termination resistor and pin contacts and socket contacts are available from esd (order no. C.1303.01).
- For termination of the CAN bus and grounding of the CAN_GND, DSUB terminators with pin contacts (order no. C.1302.01) or socket contacts (order no. C.1301.01) and with additional functional earth contact are available.

INFORMATION
A selection of CAN cables, T-connectors and termination resistor plugs that are available from esd is printed in chapter “Order Information” on page 17.

1.4 Heavy industrial Environment (double twisted Pair Cable)

1.4.1 General Rules

The following **general rules** for the CAN wiring with single shielded *double* twisted pair cable should be followed:

1	A suitable cable type with a wave impedance of about 120 Ω ±10% with an adequate conductor cross-section (≥ 0.22 mm²) must be used. The voltage drop over the wire must be considered.
2	For heavy industrial environment use a four-wire CAN cable, the wires of which must be assigned as follows: • Two twisted wires must be assigned to the data signals (CAN_H, CAN_L) and • The other two twisted wires must be assigned to the reference potential (CAN_GND). • The cable shield must be connected to functional earth (FE) at least at one point.
3	The reference potential CAN_GND must be connected to the functional earth (FE) at exactly **one** point.
4	A CAN bus line must not branch (exception: short cable stubs) and must be terminated with the characteristic impedance of the line (generally 120 Ω ±10%) at both ends (between the signals CAN_L and CAN_H and **not** to CAN_GND).
5	Keep cable stubs as short as possible (l < 0.3 m).
6	Select a working combination of bit rate and cable length.
7	Keep away CAN cables from disturbing sources. If this cannot be avoided, double shielded cables are recommended.

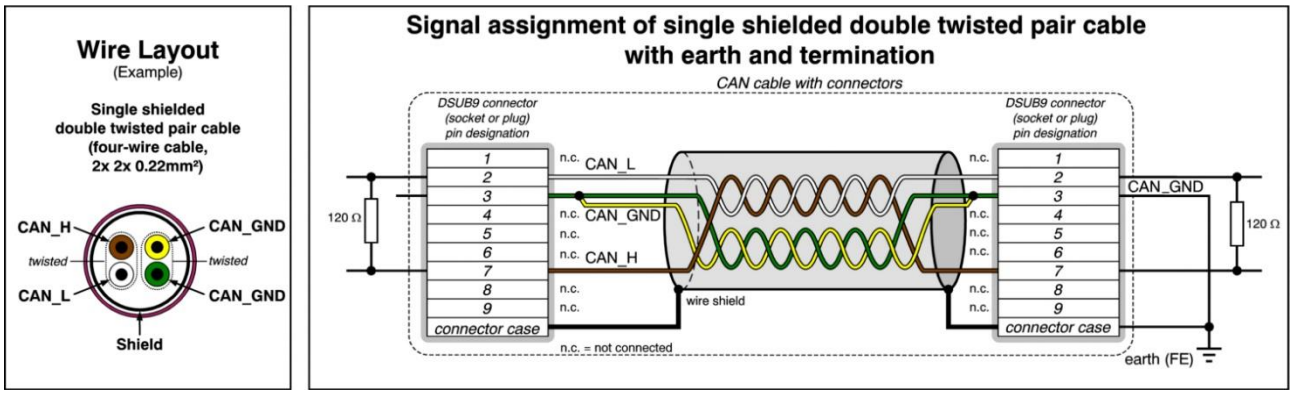


Figure 3: CAN wiring for heavy industrial environment

1.4.2 Device Cabling

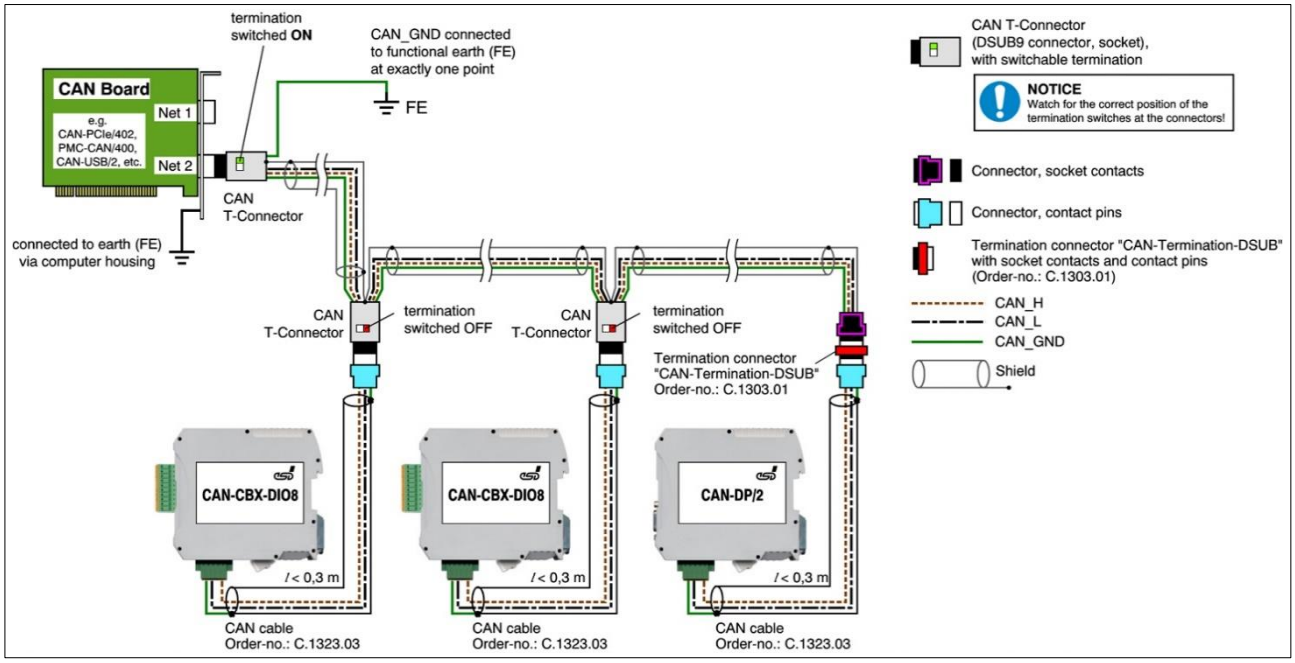


Figure 4: Example of proper wiring with single shielded double twisted pair cables

1.4.3 Branching

- In principle, the CAN bus must be realized in a line. The nodes are connected to the main CAN bus line via short cable stubs. This is usually realised via so called T-connectors. When using esd's CAN-T-Connector (order no.: C.1311.03) in heavy industrial environment and with four-wire twisted cables, it must be noted that the shield potential of the conductive DSUB housing is not looped through this type of T-connector. This interrupts the shielding. Therefore, you must take appropriate measures to connect the shield potentials, as described in the manual of the CAN-T-Connector. For further information on this, please refer to the CAN-T-Connector Manual (order no.: C.1311.21).
  Alternatively, a T-connector can be used, in which the shield potential is looped through, for example the DSUB9 connector from ERNI (ERBIC CAN BUS MAX, order no.:154039).
- If a mixed application of single twisted and double twisted cables cannot be avoided, ensure that the CAN_GND line is not interrupted!
- Deviations from the bus structure can be realized by using repeaters.

1.4.4 Termination Resistor

- A termination resistor must be connected at both ends of the CAN bus.
  If an integrated CAN termination resistor is connected to the CAN interface at the end of the CAN bus, this integrated termination must be used instead of an external CAN termination resistor.
- 9-pole DSUB-termination connectors with integrated termination resistor and pin contacts and socket contacts are available from esd (order no. C.1303.01).
- 9-pole DSUB-connectors with integrated switchable termination resistor can be ordered for example from ERNI (ERBIC CAN BUS MAX, socket contacts, order no.:154039).

1.5 Electrical Grounding

- For CAN devices with electrical isolation the CAN_GND must be connected between the CAN devices.
- CAN_GND should be connected to the earth potential (FE) at **exactly one** point of the network.
- Each *CAN interface with electrical connection to earth potential* acts as a grounding point. For this reason, it is recommended not to connect more than one *CAN device with electrical connection to earth potential.*
- Grounding can be done for example at a termination connector (e.g. order no. C.1302.01 or C.1301.01).

1.6 Bus Length

The bus length of a CAN network must be adapted to the set bit rate. The maximum values result from the fact that the time required for a bit to be transmitted in the bus system is shorter the higher the transmission rate is. However, as the line length increases, so does the time it takes for a bit to reach the other end of the bus. It should be noted that the signal is not only transmitted, but the receiver must also respond to the transmitter within a certain time. The transmitter, in turn, must detect any change in bus level from the receiver(s). Delay times on the line, the transceiver, the controller, oscillator tolerances and the set sampling time must be considered.
In the following table you will find guide values for the achievable bus lengths at certain bit rates.

Bit Rate [kbit/s]	Theoretical values of reachable wire length **with esd interface** l_{max} [m]	**CiA recommendations** (07/95) for reachable wire lengths l_{min} [m]	Standard values of the cross-section according to CiA 303-1 [mm²]
1000	37	25	0.25 to 0.34
800	59	50	0.34 to 0.6
666.$\overline{6}$	80	-	
500	130	100	
333.$\overline{3}$	180	-	
250	270	250	
166	420	-	0.5 to 0.6
125	570	500	
100	710	650	0.75 to 0.8
83.$\overline{3}$	850	-	
66.$\overline{6}$	1000	-	
50	1400	1000	
33.$\overline{3}$	2000	-	not defined in CiA 303-1
20	3600	2500	
12.5	5400	-	
10	7300	5000	

Table 1: Recommended cable lengths at typical bit rates (with esd-CAN interfaces)

Optical couplers are delaying the CAN signals. esd modules typically achieve a wire length of 37 m at 1 Mbit/s within a proper terminated CAN network without impedance disturbances, such as those caused by cable stubs > 0.3 m.

NOTICE
Please note that the cables, connectors, and termination resistors used in CANopen networks shall meet the requirements defined in ISO 11898-2.
In addition, further recommendations of the CiA, like standard values of the cross section, depending on the cable length, are described in the CiA recommendation CiA 303-1 (see CiA 303 CANopen Recommendation - Part 1: “Cabling and connector pin assignment,” Version 1.9.0, Table 2). Recommendations for pin-assignment of the connectors are described in CiA 106: “Connector pin-assignment recommendations ”.

1.7 Examples for CAN Cables

esd recommends the following two-wire and four-wire cable types for CAN network design. These cable types are used by esd for ready-made CAN cables, too.

1.7.1 Cable for Light Industrial Environment Applications (Two-Wire)

Manufacturer	Cable Type
U.I. LAPP GmbH Schulze-Delitzsch-Straße 25 70565 Stuttgart Germany www.lappkabel.com	e.g. UNITRONIC ®-BUS CAN UL/CSA (1x 2x 0.22) (UL/CSA approved) Part No.: 2170260 UNITRONIC ®-BUS-FD P CAN UL/CSA (1x 2x 0.25) (UL/CSA approved) Part No.: 2170272
ConCab GmbH Äußerer Eichwald 74535 Mainhardt Germany www.concab.de	e. g. BUS-PVC-C (1x 2x 0.22 mm²) Order No.: 93 022 016 (UL appr.) BUS-Schleppflex-PUR-C (1x 2x 0.25 mm²) Order No.: 94 025 016 (UL appr.)

1.7.2 Cable for Heavy Industrial Environment Applications (Four-Wire)

Manufacturer	Cable Type
U.I. LAPP GmbH Schulze-Delitzsch-Straße 25 70565 Stuttgart Germany www.lappkabel.com	e.g. UNITRONIC ®-BUS CAN UL/CSA (2x 2x 0.22) (UL/CSA approved) Part No.: 2170261 UNITRONIC ®-BUS-FD P CAN UL/CSA (2x 2x 0.25) (UL/CSA approved) Part No.: 2170273
ConCab GmbH Äußerer Eichwald 74535 Mainhardt Germany www.concab.de	e. g. BUS-PVC-C (2x 2x 0.22 mm²) Order No.: 93 022 026 (UL appr.) BUS-Schleppflex-PUR-C (2x 2x 0.25 mm²) Order No.: 94 025 026 (UL appr.)

INFORMATION
Ready-made CAN cables with standard or custom length can be ordered from **esd**.

2 CAN Troubleshooting Guide

The CAN Troubleshooting Guide is a guide to finding and eliminating the most common problems and errors when setting up CAN bus networks and CAN-based systems

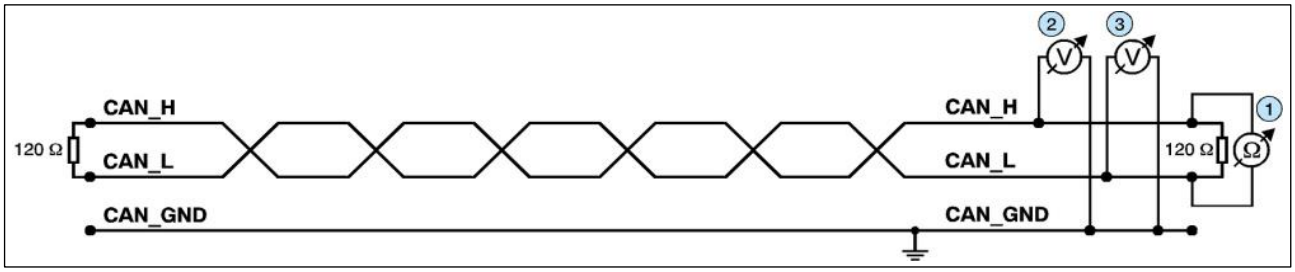


Figure 5: Simplified diagram of a CAN network

2.1 Termination

The bus termination is used to match impedance of a node to the impedance of the bus line used. If the impedance is mismatched, the transmitted signal is not completely absorbed by the load and will be partially reflected back into the transmission line.
If the impedances of the sources, transmission lines and loads are equal, the reflections are avoided. This test measures the total resistance of the two CAN data lines and the connected terminating resistors.

To test this, please proceed as follows:

1. Switch off the supply voltages of all connected CAN nodes.
2. Measure the DC resistance between CAN_H and CAN_L at one end of the network, measuring point ① (see figure above).

Expected result:
The measured value should be between 50 Ω and 70 Ω.

Possible causes of error:

- If the determined value is below 50 Ω, please make sure that:
  - There is no **short circuit** between CAN_H and CAN_L wiring.
  - **No more than two** terminating resistors are connected.
  - The transceivers of the individual nodes are not defective.

- If the determined value is higher than 70 Ω, please make sure that:
  - All CAN_H and CAN_L lines are correctly connected.
  - Two terminating resistors of 120 Ω each are connected to your CAN network (one at each end).

2.2 Electrical Grounding

The CAN_GND of the CAN network should be connected to the functional earth potential (FE) at only **one** point. This test indicates whether the CAN_GND is grounded at one or more points.

Please note that this test can only be performed with electrically isolated CAN nodes.

To test this, please proceed as follows:

1. Disconnect the CAN_GND from the earth potential (FE).
2. Measure the DC resistance between CAN_GND and earth potential (see figure on the right).

Do not forget to reconnect CAN_GND to earth potential after the test!

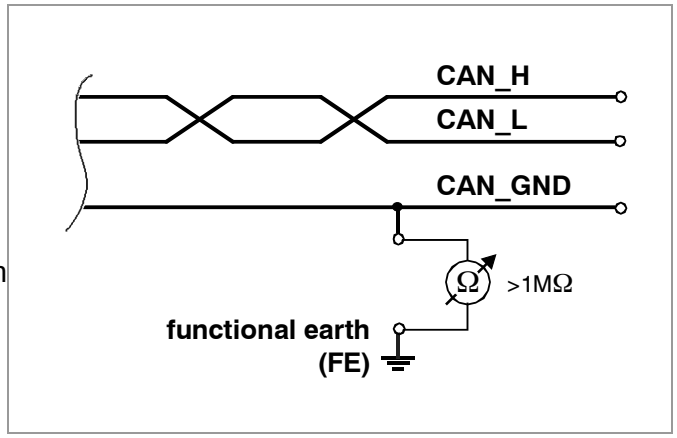


Figure 6: Simplified schematic diagram of ground test measurement

Expected result:
The measured resistance should be greater than 1 MΩ. If it is smaller, please search for additional grounding of the CAN_GND wires.

2.3 Short Circuit in CAN Wiring

A CAN bus might possibly still be able to transmit data even if CAN_GND and CAN_L are short-circuited. However, this will usually cause the error rate to rise sharply.
Ensure that there is no short circuit between CAN_GND and CAN_L!

2.4 Correct Voltage Levels on CAN_H and CAN_L

Each node contains a CAN transceiver that outputs differential signals. When the network communication is idle the CAN_H and CAN_L voltages are approximately 2.5 V measured to CAN_GND. Faulty transceivers can cause the idle voltages to vary and disrupt network communication.

To test for defective transceivers, please proceed as follows:

1. Switch on all supply voltages.
2. Terminate all network communication.
3. Measure the DC voltage between CAN_H and CAN_GND, measuring point ②.
   (See “Simplified diagram of a CAN network” on previous page).
4. Measure the DC voltage between CAN_L and CAN_GND, measuring point ③.
   (See “Simplified diagram of a CAN network” on previous page).

Expected result:
The measured voltage should be between 2.0 V and 3.0 V.

Possible causes of error:

- If the voltage is lower than 2.0 V or higher than 3.0 V, it is possible that one or more nodes have defective transceivers.
    - If the voltage is lower than 2.0 V, please check the connections of the CAN_H and CAN_L lines.
- To find a node with a defective transceiver within a network, please check individually the resistances of the CAN transceivers of the nodes (see next section).

2.5 CAN Transceiver Resistance Test

CAN transceivers have circuits that control CAN_H and CAN_L. Experience shows that electrical damage can increase the leakage current in these circuits.

To measure the current leakage through the CAN circuits, please use an ohmmeter and proceed as follows:

1. Switch **off** the node ④ and **disconnect** it from the CAN network.
   (See figure below.)
2. Measure the DC resistance between CAN_H and CAN_GND, measuring point ⑤
   (See figure below.)
3. Measure the DC resistance between CAN_L and CAN_GND, measuring point ⑥
   (See figure below.)

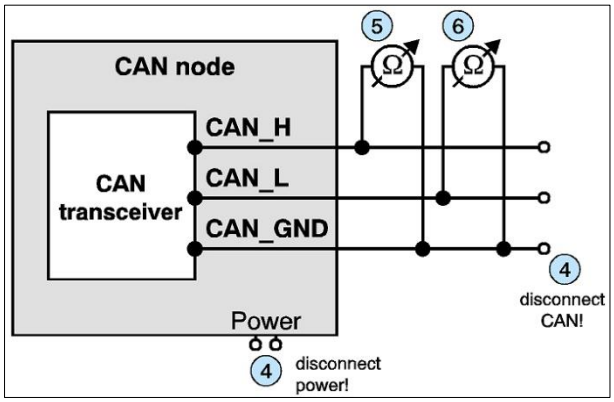


Figure 7: Measuring the internal resistance of CAN transceivers

Expected result:
The measured resistance should be greater than 10 kΩ for each measurement.

Possible causes of error:

- If the resistance is significantly lower, the CAN transceiver may be defective.
- Another indication of a defective CAN transceiver is a very high deviation of the two measured input resistances (>> 200 %).

2.6 Support by esd

If you have followed the troubleshooting steps in this troubleshooting guide and still cannot find a solution to your problem, our support team can help.
Please contact our support by email to support@esd.eu or by phone **+49-511-37298-130**.

3 Order Information

Type	Properties	Order No.
Accessories		
CAN-Termination-DSUB9 	Small termination connector, termination resistance of 120 Ω in a 9-pin DSUB-connector with pin contacts at one side and socket contacts at the other side	C.1303.01
CAN-Termination 	Terminating impedance in 9-pole DSUB-connector (socket contacts) with a 4.8 mm fast-on plug to ground the reference potential CAN_GND	C.1301.01
CAN-Termination 	Terminating impedance in 9-pole DSUB-connector (pin contacts) with a 4.8 mm fast-on plug to ground the reference potential CAN_GND	C.1302.01
CAN-T-Connector 	T-connector, 2 x DSUB9 with socket contacts and 1 x DSUB9 with pin contacts	C.1311.03
Cables		
CAN-Cable-SB, 0.3 m	CAN-cable with two DSUB9-connectors (Grade 3 quality), 1 x socket contact, 1 x pin contact, single twisted pair, dimension 2 x 0.22 mm²	C.1322.03
CAN-Cable-SB, 0.5 m		C.1322.05
CAN-Cable-SB, 1.0 m		C.1322.10
CAN-Cable-SB, 2.0 m		C.1322.20
CAN-Cable-SB, 3.0 m		C.1322.30
CAN-Cable-SB, 4.0 m		C.1322.40
CAN-Cable-SB, 5.0 m		C.1322.50
CAN-Cable-SB, 10.0 m		C.1322.99

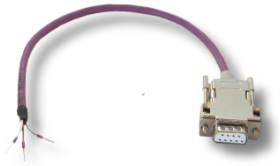
Type	Properties	Order No.
CAN-Cable-S, 0.3 m (male) 	CAN-cable with 1x DSUB9 plug (Grade 3 quality) and 3 wire end sleeves, single twisted pair, dimension 2 x 0.22 mm²	C.1323.03
CAN-Cable-B, 0.3 m (female) 	CAN-cable with 1x DSUB9 socket (Grade 3 quality) and 3 wire end sleeves, single twisted pair, dimension 2 x 0.22 mm²	C.1323.04
CAN-Cable-BB, customised length	CAN-cable with two DSUB9-connectors (Grade 3 quality), 2 x socket contacts, single twisted pair, dimension 2 x 0.22 mm²	C.1321.00
CAN-Cable-BB, 1.0 m		C.1321.10
CAN-Cable-BB, 2.0 m		C.1321.20
CAN-Cable-SS, customised length	CAN-cable with two DSUB9-connectors (Grade 3 quality), 2 x pin contacts, single twisted pair, dimension 2 x 0.22 mm²	C.1320.00
CAN-Cable-SS, 1.0 m		C.1320.10
CAN-Cable-SS, 2.0 m		C.1320.20

Table 2: Order information hardware

PDF Manuals
For the availability of the manuals see table below.
Please download the manuals as PDF documents from our esd website https://www.esd.eu for free.

Manuals		Order No.
CAN-Wiring-ME	Wiring Notes in English (this manual)	C.1300.02
CAN-Verdrahtungshinweise-MD	Wiring Notes in German	C.1300.01

Table 3: Available Manuals

Printed Manuals
If you need a printout of the manual additionally, please contact our sales team (sales@esd.eu) for a quotation. Printed manuals may be ordered for a fee.