CAN - Wiring

Notes on the Wiring of CAN-Bus Systems and the Cable Selection

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Changes in the Chapters

The changes in the user's manual listed below affect changes in the **hardware**, as well as changes in the **description** of the facts only.

Chapter	Changes versus previous version
1.3.4	Chapter revised.
2.1	New graphic inserted.
2.3	Pin assignment of Combicon-style connector inserted.
4.	List of available accessory extended.

Further technical changes are subject to change without notice.

NOTE

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1. Selecting Cables

1.1 Minimum Requirements

The boards and modules developed by esd use a differential two-wire system as a physical layer. The lines used, must have at least two wires for the differential signals (CAN_H, CAN_L) and one wire for the reference potential CAN_GND. If a shielded line is used, the shield should be assigned to CAN_GND.

1.2 Factors for the Selection of the Cable

Line length

Short lines (l < 0.3 m), such as T-connectors, can be designed as flat ribbon cable, if the external disturbances are low. Generally, a shielded data-transfer line with twisted wires for the differential signals is safer. Such lines should always be used for cable lengths of more than 0.3 m.

Bit rate

Depending on the group delay times of the line, the possible total line length of a CAN network increases with a decreasing bit rate (see chapter 1.4).

External disturbances

External disturbances, such as electromagnetic fields which are generated by other electric loads, must be considered. Critical are for instance powerful electric motors or other machines which can cause voltage variations in the supply lines when being switched on or off.
If it cannot be avoided, for instance, to run the CAN line parallel to supply lines which have strong voltage variations, the use of double shielded lines for the CAN is advisable.

Characteristic impedance

The characteristic impedance of the line used should be about 120 Ω. By connecting CAN participants, the characteristic impedance might change, though. Therefore, the characteristic impedance of the line used, should not be overvalued.

Effective resistance

The resistor of the line used must be low enough to avoid that the voltage-operating point of the receive component at the end of the line is being fallen below. For determining the voltage drop at the receiver the connected terminating impedance is used.

1.3 Limit Values for Cable Selection

1.3.1 Cable Geometry

In order to eliminate external disturbances, data-transfer cables should generally be used which have two twisted signal wires and at least one shield for the reference potential.

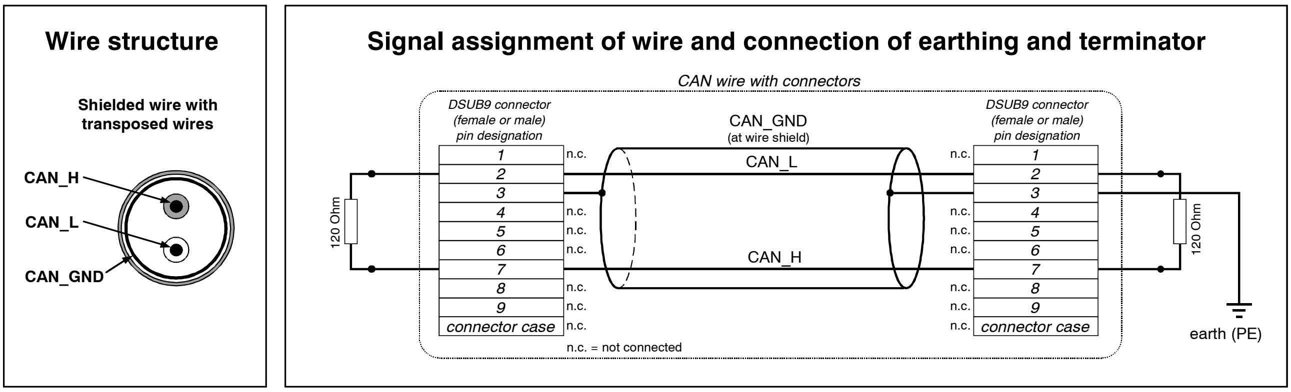


Fig. 1.3.1: Geometry and connection of the single shielded CAN cable

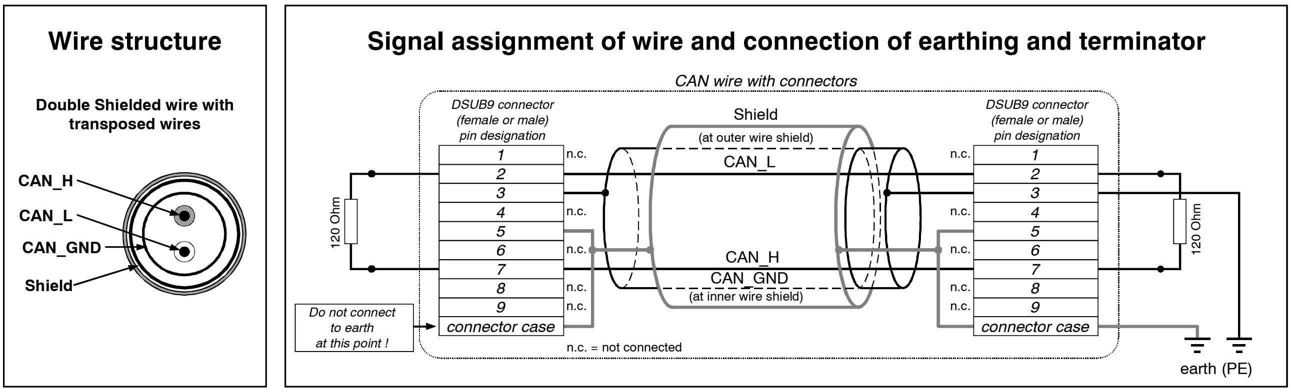


Fig. 1.3.2: Geometry and connection of the double shielded CAN cable

At the double shielded line the user has to take special care that the outer shield is connected with the earth potential only via *one* connector housing. Due to the connection of the connector housing to grounded front panels, the connection of pin5/connector housing to the outer shield has to realised at only one point of the net (see above shown figure).
This should be carried out at the same device at which the inner shield is also grounded.

1.3.2 Effective Resistance of the Cable

The ISO/DIS 11898 has the following recommendations for the DC voltage parameters, the terminating impedances and approximate values for the bit rate:

Bus length	Cable 1*)		Terminating impedance	Maximum bit rate
	Resistivity per meter	Cross section of line		
0...40 m	70 mΩ/m	0.25 mm², 0.34 mm² AWG23, AWG22	124 Ω / 1%	1 Mbit/s at 40 m
40 m ... 300 m	< 60 mΩ/m	0.34 mm²... 0.6 mm² AWG22, AWG20	127 Ω / 1% 2*)	> 500 kbit/s at 100 m
300 m ... 600 m	< 40 mΩ/m	0.5 mm², 0.6 mm² AWG20	127 Ω / 1% 2*)	> 100 kbit/s at 500 m
600 m ...1 km	< 26 mΩ/m	0.75 mm², 0.8 mm² AWG18	127 Ω / 1% 2*)	> 50 kbit/s at 1 km

1*) Recommendation for AC parameters of the cable: - 120 Ω characteristic impedance
- 5 ns/m delay time

2*) It order to minimize the voltage losses caused by the effective resistance of the cable, a larger value for the terminating impedance (such as 150 Ω ...300 Ω, disregarding the norm ISO/DIS 11898, which here provides '118 Ω < R_T < 130 Ω') might be helpful for longer cables.

Table 1.3.1: Recommended DC voltage parameters depending on line length

1.3.3 Effective Resistance of the DSUB-Connectors

When determining the voltage loss of the cable, the transfer resistance of the connectors have to be considered in addition to the cable resistance. According to manufacturer specifications, the volume resistances of e.g. DSUB-connectors are between 2.5 mΩ and 10 mΩ per contact, i.e. that the effective resistance increases by 5 mΩ to 20 mΩ with every plug.

1.3.4 Examples for Suitable Types of Cable

The following table shows some CAN cable types. The list is to be seen as an advice and does not have a claim to completeness. The user has to decide for himself, which cable he wants to use for his field of application.

We recommend requesting the technical data of the cables from the manufacturers before deciding on a cable.

Manufacturer	Wire Type	
U.I. LAPP GmbH Schulze-Delitzsch-Straße 25 70565 Stuttgart Germany Tel.: 0711/7838-01 Fax: 0711/7838-264 www.lappkabel.de	e.g. UNITRONIC ®-BUS CAN UL/CSA UNITRONIC ®-BUS-FD P CAN UL/CSA (different wire gauges available)	 (UL/CSA approved) (UL/CSA approved)
ConCab GmbH Äußerer Eichwald 74535 Mainhardt Germany Tel.: 07903/9155-0 Fax: 07903/9155-88 www.concab.de	e.g. BUS-PVC-C (1 x 2 x 0,22 mm²) BUS-Schleppflex-PUR-C (1 x 2 x 0,25 mm²)	 Order-no.: 93 022 016 (UL appr.) Order-no.: 94 025 016 (UL appr.)
SAB Bröckskes GmbH&Co. KG Grefrather Straße 204-212b 41749 Viersen Germany Tel.: 02162/898-0 Fax: 02162/898-101 www.sab-brockskes.de	e.g. SABIX® CB 620 (1 x 2 x 0,25 mm²) CB 627 (1 x 2 x 0,25 mm²) (bigger wire gauges available as well)	 Order-no.: 56202251 Order-no.: 06272251 (UL appr.)

Table 1.3.2: Recommended cable types

Ready-Made Cables
Ready-made cables can be ordered from esd (see chapter 3).

1.4 Bit Rate Depending on the Cable Lengths

1.4.1 CiA Recommendation for Bit Timing (07/1995)

The following table represents the bit rates determined by the CiA with bit timing and the controller registers of the SJA1000, 82C200, 82527 and 8xC592. These specifications of the reachable bus length differ especially in the area of higher bit rates (> 500 kbit/s) from experience at esd. The reason for this can be found in the tough worst-case conditions at timing the interface used as a basis. Experience shows that normally larger distances can be reached with the interface used by esd (see the following chapter).

You are on the safe side, of course, if you do not exceed the bit rates recommended by the CiA. This applies especially, if bus modules by other manufacturers are also connected.

Bit rate Bus length	nominal bit time t_B	Number of time quanta per bit	Length of time quantum t_q	Location of sample point	BTR 0 Setting at 16 MHz, i.e. 82C200 [HEX]	BTR 1 Setting at 16 MHz, i.e. 82C200 [HEX]
1 Mbit/s 25 m	1 µs	8	125 ns	6 tq (750 ns)	00	14
800 kbit/s 50 m	1.25 µs	10	125 ns	8 tq (1 µs)	00	16
500 kbit/s 100 m	2 µs	16	125 ns	14 tq (1.75 µs)	00	1C
250 kbit/s 250 m	4 µs	16	250 ns	14 tq (3.5 µs)	01	1C
125 kbit/s 500 m	8 µs	16	500 ns	14 tq (7 µs)	03	1C
100 kbit/s 650 m	10 µs	16	625 ns	14 tq (8.75 µs)	04	1C
50 kbit/s 1 km	20 µs	16	1.25 µs	14 tq (17.5 µs)	09	1C
20 kbit/s 2.5 km	50 µs	16	3.125 µs	14 tq (43.75 µs)	18	1C
10 kbit/s 5 km	100 µs	16	6.25 µs	14 tq (87.5 µs)	31	1C

Table 1.4.1: Bit-timing standard for CAN-networks (CiA-recommendation)

The rounded values of the bus length are based on a delay time of the cable of 5 ns/m and an internal delay time which is assumed depending on the bit rate: 1 M...800 kbit/s: 210 ns; 500k...250 kbit/s: 300 ns; 125k...100 kbit/s: 450 ns; 50 k...10 kbit/s: 1.5 t_q. Further information can be taken from the CiA-publications.

1.4.2 Reachable Line Lengths Via the esd-CAN-Interface

The line length which can be reached by means of the esd-CAN-interface can be determined by means of the following equations:

$$l_{MAX} = \frac{t_x \,/\, \text{cable delay}}{2}$$

(t_x = residual delay $t_{SAMPLING} - t_{DELAY}$)

$$\boxed{l_{MAX} = \frac{t_{S1} - 2\cdot(t_{rxdel} + t_{txdel} + 2\cdot t_{opto})}{2\cdot\text{cable delay}}}$$

with

$$\boxed{t_{S1} = T_0\cdot T_{brp}\cdot(T_{seg1} - T_{sjw} + 1)}$$

(t_{S1} = sampling point)

$T_0 = 2/16\ \text{MHz} = 125\ \text{ns}$ (for SJA1000 and 8xC592)

$T_{brp} = \text{BTR0x} + 1$ (BTR0x = contents of register BTR0 of the CAN-controller masked by \$3F (-> bits 6...0 of register BTR0))

$T_{seg1} = \text{BTR1x} + 1$ (BTR1x = contents of register BTR1 of the CAN-controller masked by \$0F (-> bits 3...0 of register BTR1))

$T_{sjw} = \text{sjw} + 1$ (sampling point jump width; sjw = contents of register BTR1 masked by \$C0 (-> bits 7 and 6 of register BTR1), value range 0..3)

t_{rxdel} =	max. 62 ns		(delay of the CAN-controller)
	50 ns		(experimental value)
t_{txdel} =	max. 40 ns	(Tx)	(delays of CAN-transceiver 82C250)
	max. 80 ns	(Rx)	
	30 ns		(typical delay in connection with HCPL710x)
t_{opto} =	max. 40 ns		(Delays of optocoupler HCPL710x)
	typ. 28 ns		
	15 ns		(typical delays in connection with 82C250)

Cable delay = 5.5 ns/m (typical value for twisted pair (effective length), manufacturer specifications, see also CiA (previous table 1.4.2))

Therefore, for CAN-controllers SJA1000, 82527 and 8xC592 the following equation results (at a cable delay of 5.5 ns/m):

$$\boxed{l_{MAX} = \frac{[125\text{ns}\cdot(\text{BTR0x}+1)\cdot\{(\text{BTR1x}+1)-(\text{sjw}+1)+1\}] - [2\cdot(t_{rxdel}+t_{txdel}+2\cdot t_{opto})]}{11\text{ns/m}}}$$

(all times in ns)

The following table represents typically reachable line lengths and the minimum reachable line lengths for some bit rates.

The typically reachable line lengths correspond to experience by esd and have been corroborated by measurements. esd-CAN-units are standardly tested and checked on keeping to the specified values for 1 Mbit/s.
The minimum reachable line lengths have been determined from manufacturer specifications for worst-case delays. These line lengths could not be corroborated by measurements, because the delays of the components are normally much better than stated in the worst-case specifications.

Significant changes in the delays caused by temperature can be ruled out. The large dispersions in the delays are generally caused by production tolerances of the components rather than by temperature.

Please note that a network with terminating impedances forms the basis of these specifications! Each impedance disturbance in the line (such as longer dead-end feeders) can cause a reduction of the reachable line length!

typical values of the reachable line length l_{max} [m] 1*)	minimum reachable line length l_{min} [m] 2*)	bit rate [kbit/s]	8xC592, or SJA1000 register	
			BTR0 [HEX]	BTR1 [HEX]
37	20	1000	00	14
59	42	800	00	16
80	65	666.6	00	18
130	110	500	00	1C
180	160	333.3	01	18
270	250	250	01	1C
420	400	166	02	1C
570	550	125	03	1C
710	700	100	43	2F
1000	980	66.6	45	2F
1400	1400	50	47	2F
2000	2000	33.3	4B	2F
3600	3600	20	53	2F
5400	5400	12.5	5F	2F
7300	7300	10	67	2F

1*) Delays:
t_{rxdel} = 50 ns
t_{txdel} = 30 ns
t_{opto} = 15 ns
$\sum T_{DEL}$ = 110 ns

2*) Delays:
t_{rxdel} = 62 ns
t_{txdel} = 60 ns
t_{opto} = 40 ns
$\sum T_{DEL}$ = 202 ns

Table 1.4.2: Reachable bit rates depending on the line lengths when using the esd-CAN-interface

2. Wiring the Devices

2.1 Wiring and Connection

The topology of the CAN-network is ‘bus-shaped’, i.e. in contrast to a star-shaped or ring-shaped wiring the network has two ‘ends’. At both ends, a terminating impedance of about 120 Ω has to be connected between the signals CAN_H and CAN-L.

Please make sure that you always use a separate termination as a terminating impedance, because a resistor in a wired connector or on a PCB is difficult to find when you want to carry out some changes in future. 9-pole DSUB-connectors in male or female design are used as connectors.

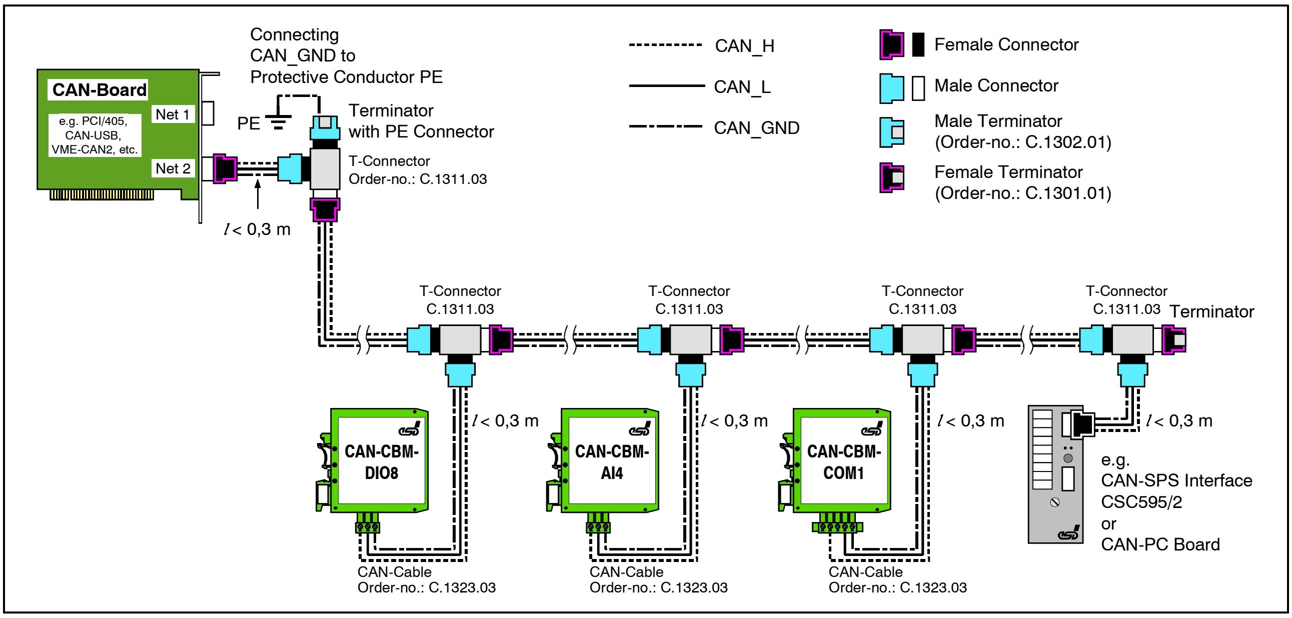


Fig. 2.1.1: Structure of the CAN-network
(example when using single shielded cables)

Many esd-modules support the bus structure because they have two female DSUB9: One for the input line, the other for the output line. If a module is removed from the chain, the CAN-lines can directly be connected to each other, because one has a female DSUB-connector and the other one a male DSUB-connector.

For devices which have only one CAN-connection a dead-end feeder is often unavoidable. It is connected by means of a T-connector (see list of accessories). The dead-end feeder is to be kept as short as possible! Generally, lengths of up to 0.3 m are acceptable.

The reference potential has to be carried in the CAN-line, because the individual modules are electrically insulated from each other. The reference potential has to be connected to the earth potential (PE) at *one* point in the network. Please make sure that only one earth connection is made, because otherwise disturbing equalizing currents might flow in the CAN_GND line.

If a CAN-participant without an electrically insulated interface is connected, it acts as an earth connection. Therefore, only a maximum of one participant without electrically insulated interface should be connected!

Nearly all esd-CAN-products have an electrically insulated interface. If a module is not electrically insulated, this fact will be especially mentioned in the manual of the module.

If a single shielded cable is used, the shield line, which is assigned with CAN_GND, must not be connected to the shield case of the DSUB-connectors, but only to pin 3 and/or pin 6. The shield has to be connected to earth potential (PE) at one point. For this matter special terminators with a connection for the earth line are available.

If a double shielded cable is used, the same applies for the inner shield as for the shield of the single shielded cable: It carries the CAN_GND signal and is connected to earth (PE) at one point.

The outer shield is also connected to earth (PE) at only one point. It should not be assigned with CAN_GND. Instead, it should always be connected to the shield case of the DSUB-connectors, if possible. The parallel connection of the outer shield to pin 5 guarantees the potential to be connected through, if connectors without connection at the shield case (such as flat-ribbon cable connectors) are used.

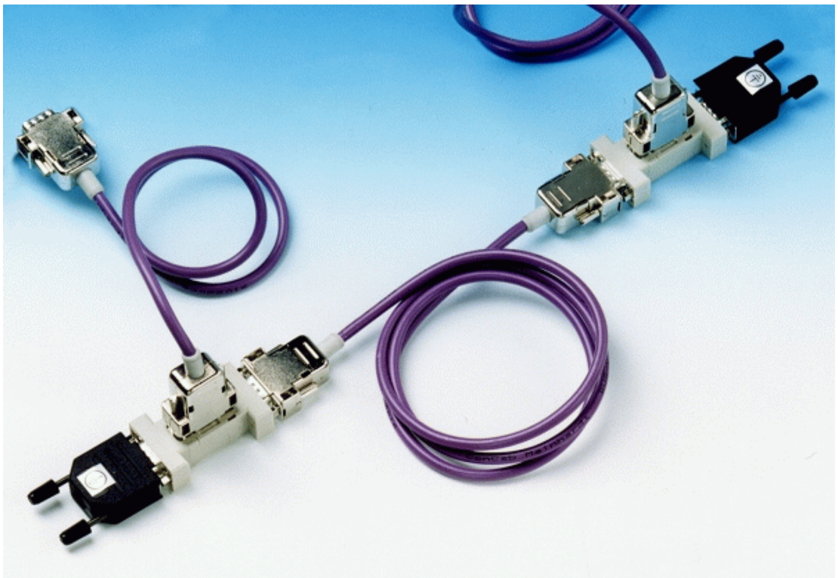


Fig. 2.1.2: T-Connectors and termination connectors from esd

Wiring the Devices

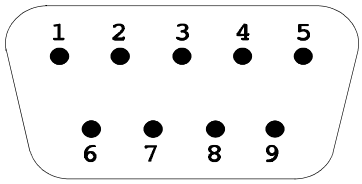
The following list shows rules which are to be followed when installing a CAN-network:

1.	The net must be terminated at both ends with a resistor in the range of '118 Ω < R_T < 130 Ω' (between the signals CAN_L and CAN_H)!
2.	The reference potential 'CAN_GND' has to be connected at *one* point to the earth potential (PE). There has to be exactly *one* connection to earth!
3.	When using double shielded cables, the outer shield has to be connected to the earth potential at *one* point. There must not be more than *one* connection to earth.
4.	Dead-end feeders must be kept as short as possible (l < 0.3 m)!
5.	A suitable cable type has to be used (see previous chapter)! Always remember the voltage loss in the cable!
6.	Make sure not to wire CAN-lines directly next to disturbance sources. If this cannot be avoided, always use double shielded cables.

2.2 Connecting the 9-Pole DSUB-Connectors

The following figure represents the assignment of a 9-pole DSUB-connector (male) with the CAN-signals in accordance with the guidelines of the CiA DRP303-1 from 12.12.2001. The CAN-modules and boards by esd normally only assign the signals CAN_H, CAN_L and CAN_GND. Therefore, the other signals are generally not assigned in connecting cables supplied by esd.

Pin Location:



Pin Assignment:

Signal	Pin	Pin	Signal
(GND)	6	1	reserved
CAN_H	7	2	CAN_L
reserved	8	3	CAN_GND
(CAN_V+)	9	4	reserved
		5	(CAN_SHLD)

9-pole DSUB-connector

CAN_L, CAN_H CAN-signal lines

CAN_GND reference potential of the local CAN-physical layer. (Here the shield has to be connected or, when using double shielded cables, the inner shield has to be connected.)

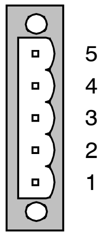
(GND) optional GND and reference potential of CAN_V+ (Is assigned with CAN_GND on esd-boards.)

(CAN_SHLD) CAN-shield
CAN-SHLD has to be connected to the outer shield and the shield case of the DSUB-connector when using double shielded cables. In addition, the shield has to be connected to pin 5 in order to guarantee that the potential is connected through when using connectors without shield connection.

(CAN_V+) optional, to be externally fed supply voltage of the CAN-interface (+7V< V+< +13V).
The voltage feed via the CAN is not required by most of the esd-boards. If the voltage feed is required, however, make sure to route the line outside of the first shield of the signal lines and to use a sufficiently strong line in order to keep the voltage loss low.

2.2 Connecting the 5-Pole Combicon-Style-Connectors

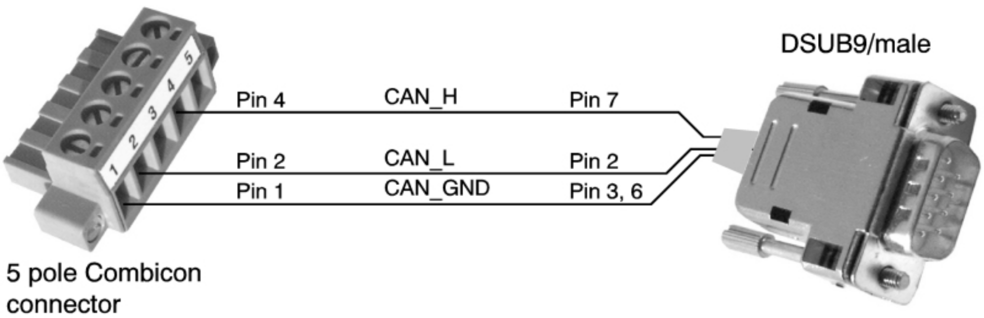
Pin-Assignment: **Signals:**



Pin	Signal
5	(CAN_V+)
4	CAN_H
3	(CAN_SHLD)
2	CAN_L
1	CAN_GND

Signal Terms:
see DSUB connector at previous page

Pin assignment of an adapter cable 5-pole Combicon to 9-pole DSUB (without power connection):



The 9-pin DSUB connector is assigned in accordance with CiA DRP303-1.

3. Available Accessories

Type	Characteristics	Order No.
CAN-Termination	Terminating impedance in 9-pole DSUB-connector (female) with a 4.8 mm fast-on plug to earth the reference potential CAN_GND	C.1301.01
	Terminating impedance in 9-pole DSUB-connector (male) with a 4.8 mm fast-on plug to earth the reference potential CAN_GND	C.1302.01
CAN-T-Connector	2 x female DSUB9, 1 x DSUB9-male	C.1311.03
CAN-cable-SB	CAN-cable with two DSUB-connectors (Grade 3 quality), 1 x female contact, 1 x male contact, dimension 2 x 0.22 mm² xxx... three-digit specification of line length in decimeters Following prevered cable length are available on stock: 0.3 m 0.5 m 1.0 m 2.0 m 2.5 m 3.0 m 4.0 m 5.0 m 10 m Other lenght are available on request.	C.1322.xxx
CAN-CBM-cable	CAN-cable with one DSUB-connector (male contacts, Grade 3 quality) and one open end, e.g. to connect a Combicon-style connector, dimension 2 x 0.22 mm², lenght 0.3 m	C.1323.03
CAN-FB-cable-SB	CAN-flat-ribbon cable with two DSUB-connectors (Grade 3 quality), 1 x female contact, 1 x male contact, length 0.1 m	C.1323.01