CANopen

Physical & Cabling Guide

(Invariant Specification)

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Document modifications				
Ver.	Date mm/dd/yr	Status	Author	Modifications
01.00	21/11/03	Technically Stable	JH Potiron	Update with results of 18-19th November 2003 meeting.
01.00	04/08/04	Applicable	J. Weiland	Set to Applicable according to TSC decision ID007
01.14	01/26/06	Technically Stable	R. Laetzel	Complete reorganization of the document Integration of power distribution specification Replacement of • must by shall. • Baud rate by bit-rate Clarification of some items: • Figure 13 updated • Table 7 completed. • Table 8 updated. • Table 11 to SE cable adapted. • Table 22 updated. • Chapter 3.9.1.4 extended with time quantum introduction • Chapter 3.9.1.5 spread sheet CAN_bit_timing.xls updated • Chapter 3.9.3.2 spread sheet Max_Length_SE_CANopen.xls updated Update with the results of 24-25th January 2006 meeting
2.00	04/20/06	Applicable	J. Weiland	Applicable according to TSC decision

All changes and in this document are marked as shown here.

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Abbreviations

CiA	CAN in Automation international users and manufacturers group e.V.
COB	Communication Object. A unit of transportation in a CAN Network. Data must be sent across a network inside a COB
COB-ID	COB Identifier. Identifies a COB uniquely in a network. The identifier determines the priority of that COB.
Cord	Cable equipped with connectors at each end.
CRC	Cyclic Redundancy Check
Drop	Derivation Cord used for connection between Tap and device.
LSS	Layer Setting Services
LT	Line Termination
Multi-TAP	TAP provide more than one connection for CANopen devices
NMT	Network Management. One of the service elements of the application in the CAN Reference Model. It performs initialization, configuration and error handling in a CAN network
OD	Object Dictionary.
NP	Network powered CANopen device. A device that gets the power supply from the CANopen network.
PDO	Process Data Object. Object for Process Data Exchange between several CANopen devices
PELV	PELV (protected extra low voltage)[1]
REP	Repeater
SDO	Service Data Object. Peer to Peer communication with access to the Object Dictionary of a CANopen device.
SE	Schneider Electric
SE CANopen Device	Device or Node that implement CANopen in compliance with the SE CANopen Implementation Guide (including this document)
SE Device	SE CANopen Device in this document.
SELV	SELV (safety extra low voltage)[2]
Supply- Multi-TAP	TAP providing power for devices connected to the drop connections
Supply-TAP	TAP providing power for devices connected to one side of the trunk connection
SYNC	Synchronization Object.
TAP	Terminal Access Point(s)

[1] With PE connection
[2] Without PE connection

References[3]

International Standards

N°	Reference	Title
[1]	ISO11898-1	Controller Area Network (CAN) - Part 1: Data link layer and physical signalling; April 2003
[2]	ISO11898-2	Controller Area Network (CAN) - Part 2: High-speed medium access unit; December 2003
[3]	DS102	CiA Draft Standard : CAN Physical Layer for Industrial Application; Version 2.0 – 20 April 1994
[4]	CiA/DR303-1	CANopen Cabling and connector Pin Assignment; Version 1.3 - December 2004
[5]	CiA/DR 303-3	Indicator Specification; V1.2, January 2005
[6]	CiA/DS 301	CANopen Application Layer and Communication Profile; V4.1
[7]	EN 50325-4	Industrial communications subsystem based on ISO 11898 (CAN) for controller-device interfaces Part 4 : CANopen
[8]	CiA/DSP 305	Layer Setting Services and Protocol; V1.1.1, November 2002
[9]	CiA/AN 801	CANopen automatic bit-rate detection; V1.0; January 2005
[10]	IEC61131-2:2003	Programmable controllers – Part 2: Equipment requirements and tests

SE Reference documents

N°	Reference	Title
[11]	33002784 P03	CANopen Conformance Classes
[12]	33002783 P03	CANopen Implementation Guide
[13]		Communication Network Interface Color Marking
[14]		Infrastructure Naming Rules Specification

Informative documents
(available on Schneider Interoperability web site)

N°	Reference	Title
[21]	35007497 P10	Technical Investigations on CANopen Cabling system – JH Potiron – V05-June2003
[22]	51113077-03	SE / ED: TOLI- Chapter 5-4-2 : Bus lengths – JP Conil – June 2003 – Release A3
[23]	TSX DG KBL_E	Electromagnetic compatibility of Industrial Networks and Fieldbuses
[24]	Philips-AN97046	Determination of Bit timing parameters for the CAN controller SJA1000.
[25]	Bosch-K8/EIS	The configuration of the CAN bit timing.
[26]	Motorola-AN1798	CAN bit timing requirements.

[3] The most current version of the references must be used.

1 Introduction

1.1 Scope of this Document

This invariant specification has two objectives

- specify the SE CANopen cabling system and the implementation of CANopen Physical Layer in SE Devices.
- specify the power distribution in a Schneider Electric CANopen network using one cable for power and data distribution.

1.1.1 Cabling system and implementation

Document provides also reference information that will help developers to design and to implement their products.
This specification is part of the SE CANopen core network reference documentation.
The CANopen Implementation Guide [12] will explain the communication and application parts.
The description of the SE CANopen cabling system covers following topics :

- Infrastructure products : cables, line termination, taps, drops and connectors.
- Device physical layer requirement : connectors, bit-rates, number of nodes.
- Layer settings services for bit-rate, address
- Local device diagnostic.

1.1.2 Power distribution

This specification is necessary for a common implementation of power distribution over the network as many different aspects have to be respected. The network reliability must not be affected under any circumstances due to the use of power distribution over the same network.

This specification explains the following aspects of a power distribution on a CANopen network:

- Topology
- Physical aspects including the power consumption and grounding rules

1.2 Conventions

In this document, the following words are used to define the significance of each particular requirement in accordance with IEC definition.

"SHALL"
The word **SHALL** is used to indicate mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (**SHALL** equals **IS REQUIRED TO**). The use of he word **MUST** is deprecated and shall not be used when stating mandatory requirements; **MUST** is used only to describe unavoidable situations. The use of the word **WILL** is deprecated and shall not be used when stating mandatory requirements; **WILL** is only used in statements of fact.
The word **SHALL** is written in **bold**.

"SHOULD"
The word **SHOULD** is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain course of action is deprecated but not prohibited (**SHOULD** equals **IS RECOMMENDED THAT**). The word **SHOULD** is written in **bold**

"MAY"
The word **MAY** is used to indicate a course of action permissible within the limits of the standard (**MAY** equals **IS PERMITTED TO**).
The word **CAN** is used for statements of possibility and capability, whether material, physical, or causal (**CAN** equals **IS ABLE TO**).

1.3 Compliance

A device implementation is **not in compliance** if it fails to satisfy one or more of the **SHALL** requirements from its Conformance Class or from the general implementation rules.
An implementation that satisfies all the **SHALL** requirements and all the **SHOULD** recommendations is said to be "**unconditionally compliant**".
One that satisfies all the **SHALL** requirements but not all the **SHOULD** recommendations is said to be "**conditionally compliant**".

1.4 Conditions for power distribution

Power distribution over the network is an optional feature for Schneider Electric CANopen products. Products that do not need power distribution over the network **shall** not interrupt the power distribution in a powered network segment.

2 Standards Overview

2.1 ISO Standards

<table>
<tr><td>Data Link Layer</td><td rowspan="7">ISO 11898:1993</td><td rowspan="5">ISO 11898-1:2002
Part 1 :
Data link Layer
And
Physical Signaling</td></tr>
<tr><td>LLC (Logical Link Control)
Acceptance Filtering
Overload Notification
Recovery Management</td></tr>
<tr><td>MAC (Medium Access)
Data encapsulation / decapsulation
Frame Coding (stuffing / destuffing)
Medium Access Management
Error Detection
Error signaling
Acknowledgement
Serialization / Deserialization</td></tr>
<tr><td>Physical Layer</td></tr>
<tr><td>PLS (Physical Signaling)
Bit Encoding/Decoding
Bit Timing
Synchronization</td></tr>
<tr><td>PMA (Physical Medium Attachment)
Driver/Receiver characteristics</td><td rowspan="2">ISO 11898-2:2002
Part 2 :
High speed
Medium access unit</td></tr>
<tr><td>MDI (Medium Dependent Interface)
Connectors</td></tr>
</table>

table 1: CANopen ISO Standards

2.2 CAN in Automation (CiA) Standards or recommendations

- CiA DR 303-1 V1.1.1 — CANopen : Cabling and Connector Pin Assignment
  22 pages Draft recommendation.
  Specify naming convention, AC, DC and length parameters on medium and Connectors (14 different).
- CiA DR 303-3 V1.0 — CANopen : Indicator Specification.
  LEDs specification.
- CiA DS301 V4.02 — CANopen : Application Layer and Communication profiles.
  Include also bit timing information.
- CiA DSP305 V1.1.1 — CANopen : Layer Setting Services and Protocol (LSS)
  Draft Standard Proposal

2.3 Global View of CANopen Standards

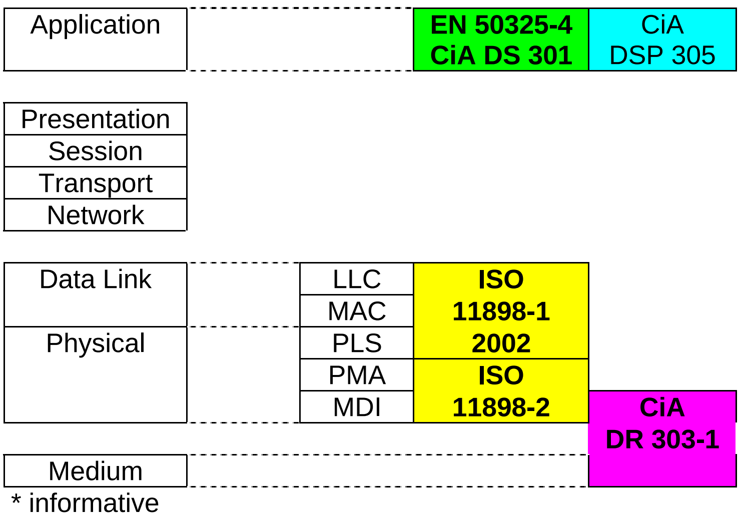


figure 1: CANopen Standards

2.4 SE CANopen Conformance Classes

Conformance Classes are defined in the SE CANopen Conformance Classes document [11]. This document specifies the layer settings, the value range for bit-rate and Node ID and if the Layer Setting Services (LSS) are supported or not.

3 Topology and medium access

3.1 Topology of a CANopen network

The figure 2 shows a CANopen bus with two segments linked by a repeater (REP).
Each segment must have line termination (LT) at each end.
Devices are connected in different ways:

- by a derivation, using drops connected to single or multi port Taps
- by chaining, either on a single connector (nodes 2, 8), either with two connectors (node 7).

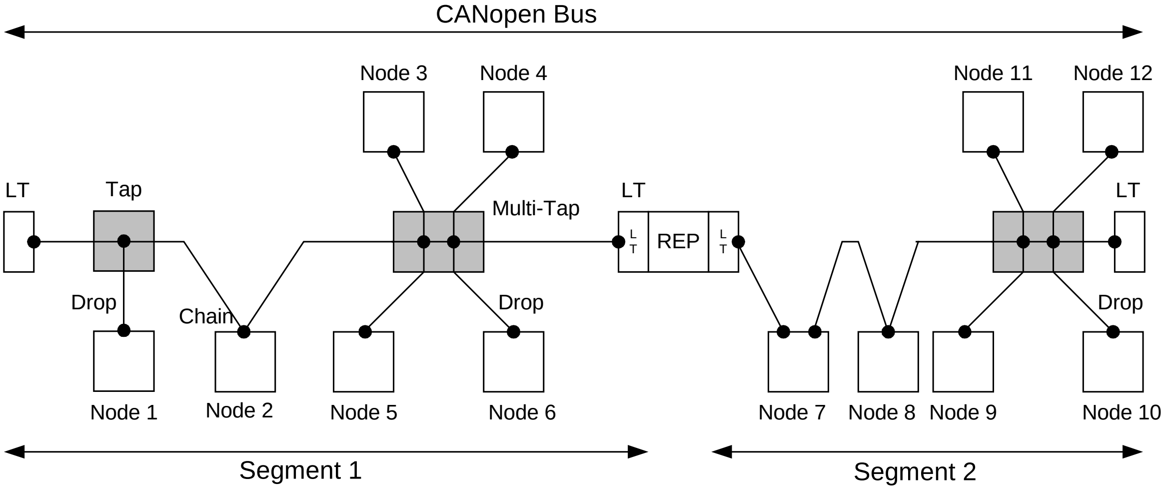


figure 2: CANopen Bus Topology

Note: Chaining devices having two connectors is not recommended, at least for IP20CANopen devices, as device replacement should cut the bus (see node 7).

Length limitations must be applied on such topology and are discussed in further paragraphs.
Limitation concern :

- The length of the CANopen bus, which means the maximum distance between the two ends of the bus.
- The length of a segment,
- The lengths of derivations.

3.2 Topology of a powered CANopen network

The topology of a powered CANopen network is similar to the standard topology possible with an CANopen network. Due to the power consumption restrictions, some additional rules **shall** be respected. The topology of the network is the starting point, describing the physical aspects of the network.

The figure 3 shows the basic CANopen network topology with several nodes, the line terminations, and the possible use of repeaters and TAP.

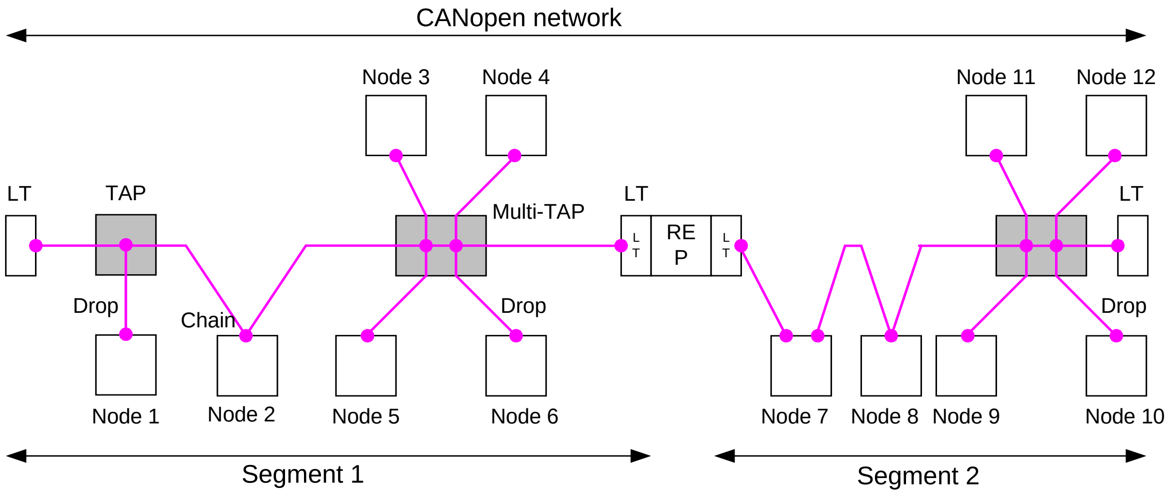


figure 3: CANopen bus non-powered topology

In a powered network the power distribution **shall** not be continued through repeaters or bridges and **shall** be therefore allowed only within a segment. In a segment, powered sub-segments could be opened to distribute the power. Each such powered segment MUST start with a powered TAP.

Two kinds of powered TAP will be sufficient to fulfil the requirements for a powered network, the “Supply Multi-TAP” and the “Supply TAP”. Both TAP **shall** have a non powered part for the CANopen bus and a possibility to supply the 24V for the power distribution. A mix of powered and non-powered TAP inside one segment **shall** be possible if rules described in this document are followed.

The figure 4 shows the same topology as in figure 3 with a Supply Multi-TAP instead of non-powered TAP.

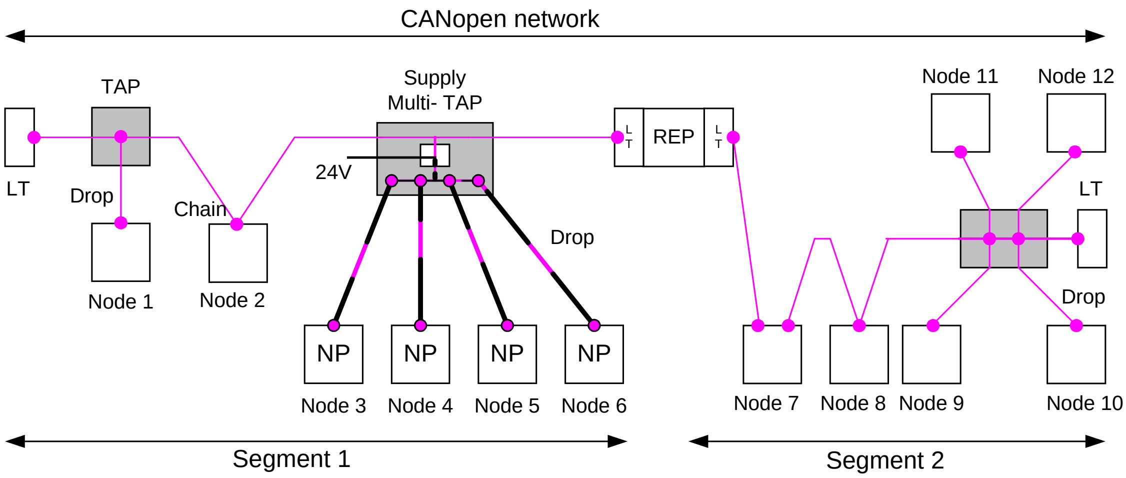


figure 4: CANopen network powered topology (1)

This topology can be realized with a Supply Multi-TAP as shown in figure 5.

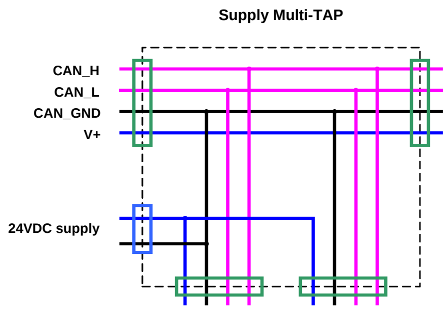


figure 5: Schema of Supply Multi-TAP

Several other topologies are possible with the powered TAP:

- A network could be fully powered, in this case the Supply TAP will be the starting point of the powered portion of the segment. The use of powered repeaters, bridges or other active components **shall** not be possible in such an installation. The CANopen devices can be devices that require power or not.

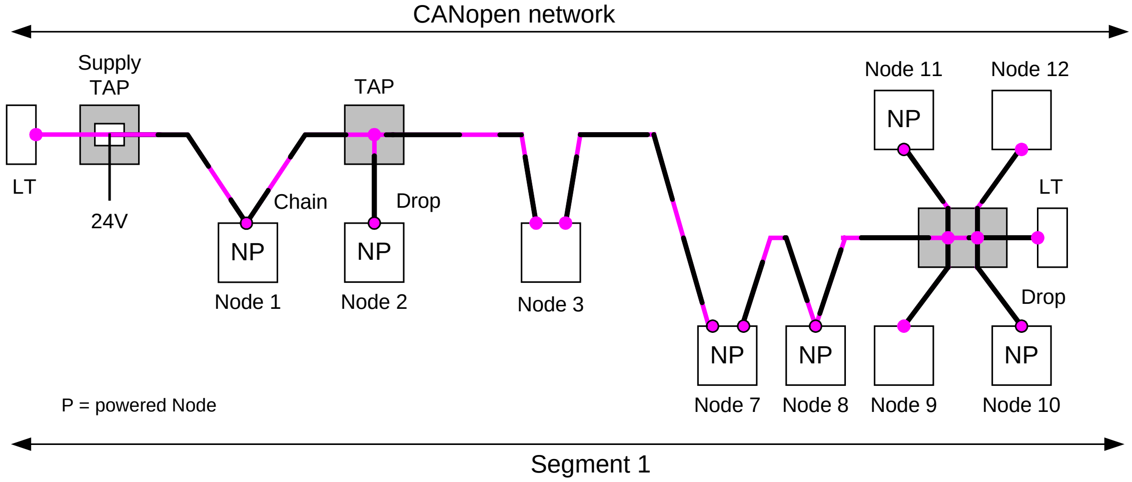


figure 6: CANopen network powered topology (2)

This topology can be realized with a Supply TAP, a TAP and a Multi TAP as shown in figure 7, figure 8 and figure 9.

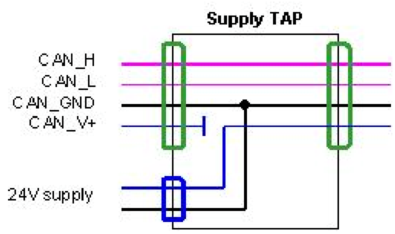


figure 7: Schema of Supply TAP

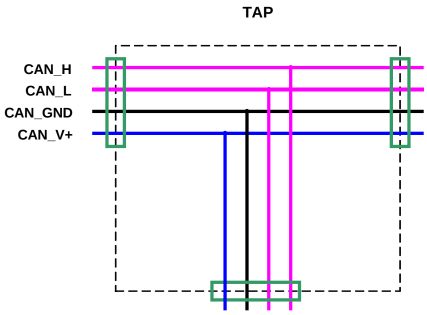


figure 8: Schema of TAP

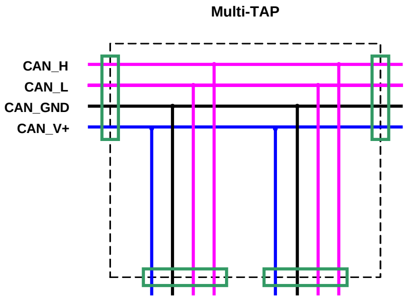


figure 9: Schema of Multi TAP

Note: The non-powered TAP, connectors and nodes **shall** provide the necessary features to distribute power. See note in chapter 3.11.

- A network can have in one segment a powered sub-segment.

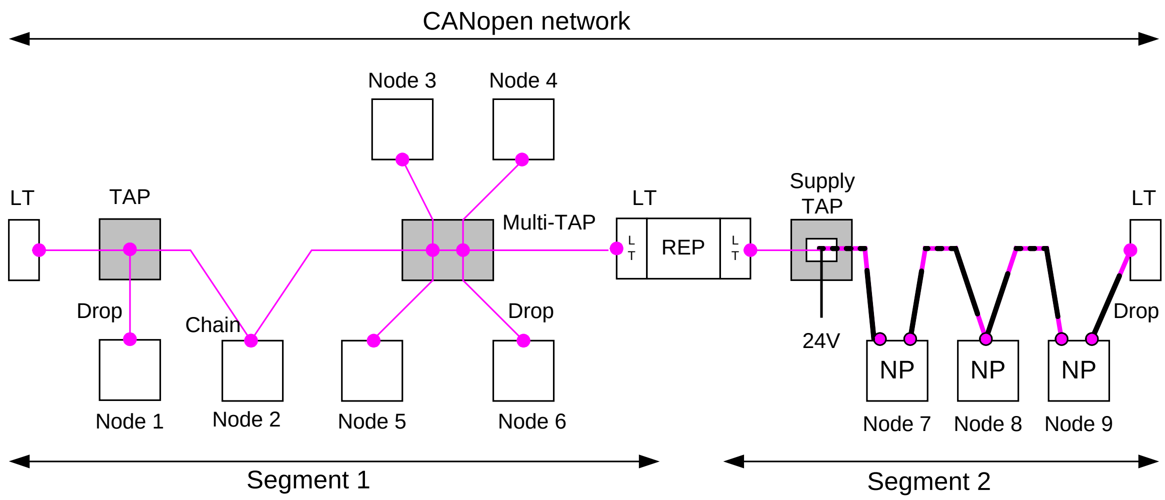


figure 10: CANopen network powered topology (3)

This topology can be realized with a Supply TAP, a Tap and a Multi TAP as shown in figure 7, figure 8 and figure 9.

- A network can have powered sub-segments where the power consumption is higher than a powered segment is able to support. In this case the sub-segment **shall** contain several Supply TAPs.

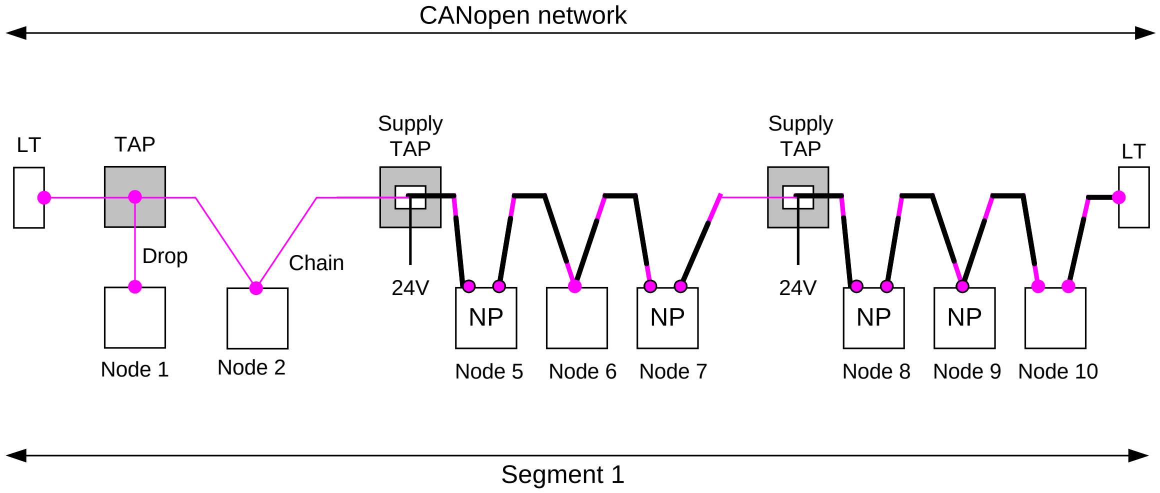


figure 11: CANopen networkpowered topology (5)

This topology can be realized with a Supply TAP and a TAP as shown in figure 7 and figure 8.

3.3 Number of Devices on the same segment

Up to 64 SE CANopen devices can be connected on the same segment. The number of devices on the same segment, in a powered network, depends on the power consumption of the devices in the segment. The total number **shall** not exceed 64 devices.

Any SE CANopen device **shall** comply with this requirement, which means that its CANopen transmitter **shall** drive a minimum of 63 receivers.

Repeaters allow to have more than 64 devices on a CANopen bus and **shall** be taken into account in the number of devices connected on same segment.

For example: with devices having a fanout of 63 and one repeater it is possible to have two segments of 63 nodes with one repeater interface, which gives a CANopen bus of 126 nodes.

3.4 Infrastructure components

3.4.1 Naming and marking

The naming and marking of the infrastructure components are defined in [14] Infrastructure Naming Rules Specification. This Consistency Rule **shall** be applied for all CANopen infrastructure products.

3.4.2 Connectors

See chapter 3.11.2 CANopen device connectors.

3.4.3 Cable

Schneider Electric provides one cable type for trunk and drop. It is furthermore used as well for power distribution over the network.
The CANopen cable **shall** provide two pairs. Each pair **shall** have a separate shield to reduce the disturbances from the power wires to the CANopen signal wires. The pairs **shall** have a different gauge. The pair for CAN_H and CAN_L **shall** be AWG24 (0,205mm²) the pair for CAN_GND and CAN_V+ **shall** be AWG22 (0,324mm²). See table 2 for detailed information.

Number of Pairs min	2	Required - **shall**
Pair A Conductor gauge	AWG 22	
Pair A Linear Resistance	55 Ω/km	
Pair B Conductor gauge	AWG 24	Required - **shall**
Pair B Linear Resistance	90 Ω/km	Required - **shall**
Pair B Characteristic Impedance	120 Ω	Required - **shall**
Pair B Capacitance	40 pF/m	
Pair B Propagation min	66% x C	Required - **shall**
Pair B Attenuation 500 kHz typ	1,64 dB/100m	
Pair B Attenuation 1 MHz typ	2,30 dB/100m	
Shield	Aluminum foil + tinned copper braid + drain	Required - **shall**
Shield Resistance	*≤ 7,6 Ω/km*	
Capacitance Conductor / Shield	*75 pF / m*	
Sheath Color	Magenta RAL 4001	Required - **shall**
Operating Temperature	-10°C +80°C	
Overall Diameter	8 ± 2mm	
Color pair A	Red + Black	Required - **shall**
Color pair B	White + Blue	Required - **shall**
Connection pair B white	CAN_HIGH	Required - **shall**
Connection pair B blue	CAN_LOW	Required - **shall**
Connection pair A black	CAN_GND	Required - **shall**
Connection pair A red	CAN_V+	Required - **shall**

table 2: CANopen cable definition

3.4.4 Drop cords

3.4.4.1 SubD-9 Drop Cords

SubD-9 Drop cords **shall** have female connectors at each end and are used for:

- Chaining TAPs which have male connectors.
- Connect devices on a TAP with a derivation.

They **shall** provide the following wiring:

	Sub-D9 female (socket)		Sub-D9 female (socket)
Pair 1	Pin 7 Pin 2	←----- CAN_H ----→ ←----- CAN_L ----→	Pin 7 Pin 2
Pair 2	Pin 3 Pin 9	←---CAN_GND ---→ ←---- CAN_V+ ----→	Pin 3 Pin 9
	Housing	Shield	Housing

table 3: SubD-9 Drop wiring

The cables used for the drop cords **shall** be as defined in chapter 3.4.3.

3.4.4.2 M12 Drop Cords

M12 Drop cords have connectors at each end and are used for:

- Chaining devices which are fitted with one male and one female connectors.
- Chaining TAP which are fitted with one male and one female connectors.
- Connect devices on a TAP with a derivation.
- Connect two cords together in order to reach greater length.

Consequently, drop cords **shall** have one male connector at one end and one female connector at the other end. They **shall** provide the following wiring:

	M12 M (pins)		M12 F (socket)
Pair 1	Pin 4 Pin 5	←----- CAN_H ----→ ←----- CAN_L ----→	Pin 4 Pin 5
Pair 2	Pin 3 Pin 2	←---CAN_GND ---→ ←---- CAN_V+ ----→	Pin 3 Pin 2
	Housing Pin 1	Shield	Housing Pin 1

table 4: M12 Drop wiring

The cables used for the drop cords **shall** be as defined in chapter 3.4.3.

3.4.5 TAP

A CANopen TAP provides the following features:

- Connection of devices using drop cords
- Interconnection of all signals available on the interfaces
- Interconnection of cable and connector shields
- Ground connection in accordance with shielding rules described in chapter 5
- Connection to the trunk cable

SubD-9 TAP **shall** provide *male* connectors only which are used for connection of devices on derivation or for chaining the TAP. It **should** provide terminal blocks for connection of trunk cable.

M12 TAP **shall** provide female connectors for connection of drop cables for devices on derivations, and one male connector and one female connector for chaining the TAP.

3.5 Electrical Interface

The CANopen bus use a differentially driven two-wire line with common return:

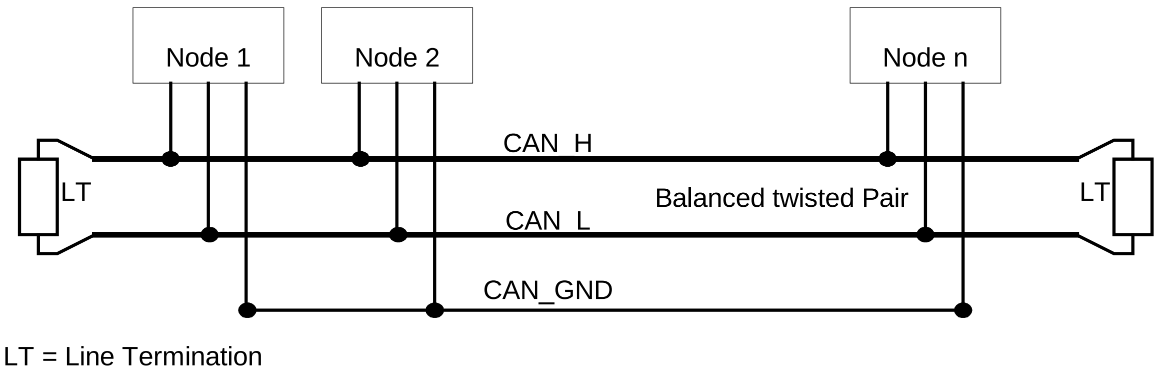


figure 12: Electrical interface

Each SE CANopen device **shall** allow interconnection of following signals:

CAN_H	CAN_H bus line
CAN_L	CAN_L bus line
CAN_GND	CAN ground
CAN_V+	CAN external power supply

Electrical signals **shall** be compliant with ISO11898-2, unless otherwise specified.

3.6 Line termination

To minimize the reflections from the end of the cable, a line termination **shall** be placed close to the 2 ends of the bus.

Each Line termination **shall** be connected between the two conductors of the balanced line: CAN_H and CAN_L.

Line termination **shall** be a 120 Ω resistor, 5%, 1/4W tolerance or better.

The cabling system **shall** provide line termination where necessary. As written in the ISO11898-2 "locating of the termination within a node should be avoided because the bus lines lose the termination if this CAN node is disconnected from the bus line". However, for implementation reasons line termination may be provided by the device (case of chained nodes with drop cords).

3.7 Electrical Isolation

SE CANopen devices **shall** implement electrical isolation.

Note: Isolation level is 500VACrms or 700VDC between communication line and ground.

3.8 Network length and stub length in the user documentation

Technical documentation of SE CANopen devices **shall** provide or refer to information on the maximum allowed length of the network for each speed the device supports. Technical documentation **shall** also provide or refer to information concerning limitation of stubs. The chapters 3.8.1, 3.8.2 and 3.8.3 **may** be used in the user documentation. If not, a reference to an independent document (e.g. CANopen Hardware Setup manual or ist equivalent) **shall** be made.

3.8.1 Network length and bit rate

The length is restricted by the bit-rate due to the bit arbitration process.

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
Max length :	20 m	40 m	100 m	250 m	500 m	1000 m	2500 m	5000 m

table 5: Network length limitation depending of bit-rate in user documentation

In documents about CANopen, you will find often 40m as a maximum length at 1Mbit/s. This length is calculated without electrical isolation as used in the Schneider Electric CANopen devices. With the electrical isolation, the minimum network length calculated is 4m at 1Mbit/s. However, the experience shows that 20m are the practical length that could be shorten by stubs or other influences.

3.8.2 Length limitations concerning stubs

Length limitations concerning stubs have to be taken into account and are fixed by the following parameters.

Bit-rate [kbit/s]	1000	800	500	250	125	50	20	10
L max [m] (1)	0,3	3	5	5	5	60	150	300
ΣL max [m] local star (2)	0,6	6	10	10	10	120	300	600
Interval min [m] 0,6xΣL local (3)	-	3,6	6	6	6	72	180	360
ΣL max [m] on all bus (4)	1,5	15	30	60	120	300	750	1500

(1) L_{max}: Maximum length for one stub.
(2) ΣL_{max} local star: Maximum cumulative length of stubs in the same point when using a multi-port TAP creating a local star.
(3) Interval min.: minimum distance between two TAP.
Value for a maximum length of derivation in the same point. Could be computed case by case for each derivation: Interval min. between two derivation is 60 % of the cumulative length of derivations at the same point.
(4) ΣL_{max} on all bus: Maximum cumulative length of stubs on the all bus.

table 6: Stub length limitations in user documentation

3.8.3 Use of repeaters

A repeater should be used when more then 64 devices are used.
As repeaters add a propagation delay in the bus, this delay reduces the maximum network length of the bus. A propagation delay of 5ns is equal to a length reduction of 1m. A repeater with e.g. 150ns delay reduces the bus length therefore by 30m.

3.9 Length Limitations

3.9.1 Network Length

The maximum achievable bus 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 lines.
- the relative difference of the 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 SE CANopen cabling system provides connection of CANopen devices within limits listed below, applying the more restrictive case:

- The bit-rate selected for the CANopen bus limits the length of the complete network (including repeaters) because management of collision which arbitrates priority must be done within one bit time.

Theoretical computation of these limits is described in detail in chapters 3.9.1.1, 3.9.1.2, 3.9.1.3, 3.9.1.4 and 3.9.1.5, listing which parameters of components in the device must be taken into account.

Applying this computation to an opto-coupled CAN interface, with an average dispersion on parameters, the following table has been established in order to fix common limits:

Bit-rate	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
Defined max length	4 m	25 m	100 m	250 m	500 m	1000 m	2500 m	5000 m
Max length: Average case	4 m	29 m	104 m	254 m	554 m	n.a.	n.a.	n.a.
Max length: Typical case	20 m	45 m	120 m	270 m	570 m	n.a.	n.a.	n.a.
Max length: Worst case	N.A.	21 m	96 m	246 m	546 m	n.a.	n.a.	n.a.

table 7: Network length limitation depending of bit-rate

Any SE CANopen Device **shall** comply with this limits of the defined max. length for the bit-rates it supports. This compliance creates constraint in the choice of components used in design of devices, regarding to specific parameters.

CAN controller: Output propagation delay
Input propagation delay
or
Sum of input and output delays

Oscillator: Tolerance

Opto-couplers: Propagation delay

CAN Transceiver: Output propagation delay
Input propagation delay
or
Loop delay

Note: A list of integrated circuits used within SE is available in Appendix A Integrated Circuits. Use of some of these components is recommended.

3.9.1.1 Minimum bit time

The first obvious requirement for SE Devices is that they use components compliant with their max available bit-rate. This concerns CAN controller, opto-couplers and CAN transceiver.
CANopen devices with a Conformance Class (see [11]) M20, S20 and M30, S30 **shall** implement components which support the 1Mbit/s bit-rate, whereas M10, S10 CANopen devices **shall** use components supporting 500kbit/s bit-rate.

Characteristic is t_{bit} = minimum bit time = 2 µs for x10
1 µs for x20 and x30

3.9.1.2 Collision Management

A CAN device **shall** manage a collision between recessive and dominant states within one bit time. Compliance with this requirement involves following parameters:

- Bit-rate
- Propagation delay on the bus (length of cable, propagation delay of repeaters)
- Propagation delay in nodes which include:
  - Delay of controller
  - Delay of opto coupler
  - Delay of transceiver
- Tolerance of oscillators

Collision phenomena can be described with following drawing:

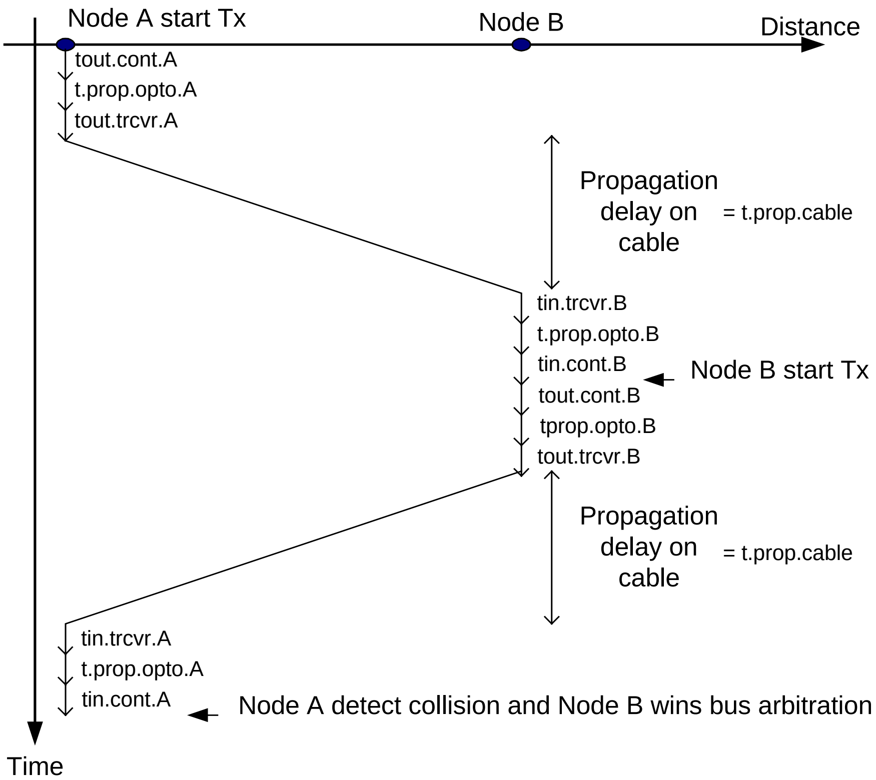


figure 13: Collision

Description :

1- Node A start transmission of a bit in controller (time = 0)
2- Bit signal goes out the controller : delay = tout.cont.A
3- Bit signal goes through opto-coupler delay = tout.opto.A
4- Bit signal goes through transceiver delay = tout.trcvr.A
5- Signal is propagated on the cable delay = tprop.cable
6- Signal goes into node B until controller
Delay = tin.trcvr.B
+ tin.opto.B
+ tin.cont.B
7- Just before Node B start transmission of a bit
8- Bit signal goes out the controller : delay = tout.cont.B
9- Bit signal goes through opto-coupler delay = tout.opto.B
10- Bit signal goes through transceiver delay = tout.trcvr.B
11- Signal is propagated on the cable delay = tprop.cable
12- Signal goes into node A until controller
Delay = tin.trcvr.A
+ tin.opto.A
+ tin.cont.A
13- At this time the Node A can detect if there is collision with B or not.

All that **shall** happen within one bit time, taking into account re-synchronization of asynchronous signals and tolerance of clock devices.

As there is propagation delay on cable, the length of the bus is limited in relation with the bit-rate. This limitation cannot be overridden by repeaters and worst, as repeaters consume propagation delay they can be considered as virtual cable length.

Propagation delay of components used in devices are also important parameters.
So, when SE CANopen cabling system specifies a maximum bus length for a given bit-rate, this creates constraints on choice of device components.

Table below gives Component Parameters that have to be taken into account and some examples extracted from data sheets:

	Definition	Data sheet symbol	Typ Value	Max Value	Reference
Controller					
t.out.cont	Prop delay output				
t.in.cont	Prop delay input				
t.loop.cont (1)	Sum of input and output	tsd-typ tsd-max	26 ns	 40 ns	Philips SJA1000 p59 + note2
Optocoupler					
t.prop.opt	Propagation delay	tplh-max tplh-typ	 23 ns	40 ns	Agilent HCPL-0710
		Tphl-max tphl-typ	 20 ns	40 ns	Agilent HCPL-0710
Transceiver					
t.out.trcvr		tpLH tpHL	40 ns 85 ns	70 ns 125 ns	SN65HVD251
t.in.trcvr		tpLH tpHL	35 ns 35 ns	50ns 50 ns	SN65HVD251
t.loop.trcvr (2)	TXD to RXD active	tonRXD	120 ns	120 ns	PCA82C251
t.loop.trcvr (2)	TXD to RXD inactive	toffRXD	150 ns	150 ns	PCA82C251

table 8: Component parameters

Note: (1) Controller may specify loop delay summing input and output delay:
t.loop.cont = t.out.cont + t.in.cont

(2) Transceiver may specifies loop delay:
t.loop.trcvr = t.out.trcvr + t.in.trcvr

For each CAN device an internal delay time is defined, t_{node} as the sum of all inputs and output delays:

tnode = toutput +tinput

= t.out.cont + t.prop.opt + t.out.trcvr + t.in.trcvr + t.prop.opt + t.in.cont.

3.9.1.3 Oscillator Tolerances

The tolerance of device clock **shall** not be worst than 0,1%.

The worst case for maximum shift between devices is based on an error case at a global recessive stuff-bit error. This means 12 dominant bits are followed by the error delimiter (8 recessive bits). To be compliant to CAN protocol the CANopen devices **shall** be synchronous at least 13 bit times (after the last rec.-dom. Edge) to increase the error counter properly. Thus the maximum shift **shall** be given by 2x13xTbitX0,1%, which value **shall** be 26ns at 1Mbit/s.

This difference will be taken into account by the Synchronization Jump Width described in chapter 3.9.1.4.

3.9.1.4 Bit time definition

The ISO11898-1 Standard describes the management of bit time in its chapter 12.

Bit time is divided into separate non overlapping segments :
- Synchronization segment = Sync_Seg
- Propagation time segment = Prop_Seg
- Phase Buffer segment 1 = Phase_Seg1
- Phase Buffer segment 2 = Phase_Seg2

with a sample point at the end of Phase_Seg1.

←---Nominal bit time ---→

Sync-seg	Prop-Seg	Phase-seg1	Phase-seg2

↑
Sample point

Sync-Seg is used by the receiver to control his local synchronization with the transmitter. It is the period of time when the CANopen device expects an edge.

Prop-seg compensate physical delay times within the networks, including internal delay of CAN nodes and propagation time on the bus. Prop-Seg ≥ tnodeA + tnodeB + tbusline must be met.

Phase-Seg1 and Phase-Seg2 are used to compensate for edge phase errors. They may be lengthened or shortened of the time of phase error however the maximum possible correction is the so called "Resynchronisation Jump Width" (SJW).

As Prop-seg and Phase-Seg1 does not need to be programmed separately, most of CAN controller use the following bit time definition :

←---Nominal bit time ---→

Sync-seg	Time-Seg1	Time-Seg2

↑
Sample point

Programming of these phases is done in number of Time-quantum that divide the Bit-Time :

←---Nominal bit time ---→

Time-quantum	Time-quantum	Time-quantum	Time-quantum	Time-quantum	Time-quantum	Time-quantum	Time-quantum

3.9.1.5 Bit timing management

The bit timing management is performed in the CAN controller and **shall** be compliant with the characteristics of the CAN device (transceiver and opto-couplers) and the length of the bus.
The following spreadsheet allows:
to enter programmable parameters which define bit time of the CAN controller.
to enter parameters of the CAN nodes (delays from controller, opto-coupler, transceiver and clock tolerance)
to enter or to compute length of the bus
to check that all this parameters are compliant with CAN rules.

CAN_bit_timing.xls

Note: In case of failure when opening spreadsheet, close Word and Excel and then re-open this document.

- CAN controller configuration:
  - Definition of CAN System clock:

    The clock used in bit timing management **shall** be the system clock (fscl) which **shall** be derived from the basic oscillator of the chip (fclk), applying division by a programmable prescaler value (BRP). Some controllers divide the system clock (fscl) by two automatically (e.g. SJA 1000), this **shall** be considered when calculating the bit timing. It is recommended to use a system wide identical number of time quanta for a bit time and the same size of a time quantum. The period of the system clock is called the <u>Time quantum</u> (tq) and **shall** be used as unit for programming different parts of bit time. The two parameters to enter are :
    - fclk frequency of basic clock of the component.
    - BRP Prescaler value.

    The frequency of CAN system clock is : fscl = fclk/2*BRP, its period is the time quantum tq.
  - Bit time definition :

    Sync-Seg is fixed to one time quantum by the Standard.
    Time-Seg1 is programmed by TSEG1 in number of tq.
    Time-Seg2 is programmed by TSEG2 in number of tq.
    The re-synchronization jump width is programmed by SJW in number of tq.

- CAN node parameters :
  - Basic Clock tolerance df
  - Bit-rate of the CAN bus ftx
  - Controller loop delay tds
  - Opto-coupler delay tPHL or tPLH
  - Transceiver delay tinp + toutp or t.loop.trcvr

- CAN bus characteristics :
  - Length of the bus l
  - Propagation velocity of the cable v

- The spread sheet checks that entered configuration met the applicable rules :
  - Length of SJW covers time difference due to clock tolerance.
  - The sum of Sync-Seg, Time-Seg1 and Time-Seg2 is equal to the bit time.
  - Time-Seg1 ≥ Time-Seg2
  - Time-Seg1 – tsjw ≥ propagation time
    Here it's checked that all propagation round trip delay is included within Time-Seg1 even if it's shortened by tsjw.
  - Time-Seg2 ≥ 2*tscl : Time-Seg2 must include at least one tscl for tsjw and one tscl for information processing.
  - Time-Seg2 ≥ tsjw.

3.9.2 Stub length limitations

Length limitations concerning derivations/stubs are discussed in document [21] and summarized in chapters 3.9.2.1 and 3.9.2.2, they fix following parameters:

- maximum length of one derivation (L_{max})
- maximum cumulative length of derivations in the same point when using a multi-port tap creating a local star. (ΣL_{max} local star).
- minimum distance between two derivations, (Interval min)
- maximum cumulative length of derivations on the all bus (ΣL_{max} on all bus)

The limitations for Schneider Electric are given in the following table and have a higher limitation at higher bit-rates for safety reasons.

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
L max	0,3 m	3 m	5 m	5 m	5 m	60 m	150 m	300 m
ΣL max local star	0,6 m	6 m	10 m	10 m	10 m	120 m	300 m	600 m
Interval min 0,6xΣL local		3,6 m *	6 m *	6 m *	6 m *	72 m *	180 m *	360 m *
ΣL max on all bus	1,5 m	15 m	30 m	60 m	120 m	300 m	750 m	1500 m

(*) Value for a maximum length of derivation in the same point. Could be computed case by case for each derivation : Interval min between two derivations is 60% of the cumulative length of derivations at the same point.

table 9: Stub length limitations

These limitations concern the topology of a CANopen bus and do not create constraints on implementation of devices.

3.9.2.1 Length Limitation for one derivation

(Extract and translation from JP Conil Document referenced [22])

3.9.2.1.1 Physical phenomena

At each end of the main bus (the trunk) there **shall** be a termination load as defined in chapter 3.6, so the signal is propagated at 5ns/m without change, seeing the same impedance on the cable and at the end.

When there is a derivation there is no termination load. The propagated signal is reflected and come back on the trunk and added to the main signal with a shift equal to Tp = 5ns/m x 2L where L is the length of the derivation (propagation time to go forth and back on the derivation).

3.9.2.1.2 Rules of length limitation

- Limit linked to transition delay of the signal

This rule says that the reflected signal **shall** be included in the main signal. It means that the shift of reflected signal is less than the Transition delay (Td) of the signal.
If transition delay is 50ns, the condition is
Tp < 50ns => 5ns/m x 2L < 50ns => L < 5m.

- Limit linked to bit time

This rule says that the shift of reflected signal **shall** not exceed 5% of the bit time (Tb).
This rule leads to the following results:

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
Tbit	1µs	1,25µs	2µs	4µs	8µs	20µs	50µs	100µs
5% Tbit	50ns	62,5ns	100ns	200 ns	400 ns	1000 ns	2500 ns	5000 ns
L max	5 m	6,25 m	10 m	20 m	40 m	100 m	250 m	500 m

- Rule defined in CiA DR-303-1

This rule is Tp < 1/50 x tpropseg where tpropseg = timesegment1 – SJW time
This rule leads to the following results:

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
L max	2 m	3 m	6 m	12 m	24 m	60 m	150 m	300 m

Note1: ISO11898-2 limits the derivation at 1 Mbit/s to 0,3m.

Note 2: DeviceNet and Beckhoff documentation gives following limits:

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
Devicenet			6 m	6 m	6 m			
Beckhoff	1 m		5 m	10 m	20 m	50 m		

3.9.2.2 Limitation of the "density" of derivations

Chapter 3.9.2.1 fixed the limit of length of one derivation, this chapter will discuss and fix following limits:

- minimum distance between two derivations,
- maximum cumulative length of derivations in the same point (use of Multi-TAP – local star),
- maximum cumulative length of derivations on the all bus.

- Minimum distance between two derivations,

Connecting a derivation on the trunk is equivalent to connecting a capacitance load which changes the characteristic impedance of the line. The rule request that the new impedance stay upper than 60% of the initial impedance.
Application of this rule done in [24] gives following result:

D > 60% x L, where L is the sum of all derivation lengths in one point and D the distance with the next derivation.

- Maximum length of derivations in the same point (use of Multi-Tap – local star)

No documentation has been found on this subject, but same rule as serial Modbus will be used:

The sum of all derivations of a local star must not exceed twice the length of a single derivation. (ie: 10m for derivation of 5m).

- Maximum cumulative length of derivations on the network

The CiA DR-303-1 limits the cumulative length of derivations on the network at 5 times the length of a single derivation. This gives following table:

Bit-rate :	1 Mbit/s	800 kbit/s	500 kbit/s	250 kbit/s	125 kbit/s	50 kbit/s	20 kbit/s	10 kbit/s
L max	2 m	3 m	6 m	12 m	24 m	60 m	150 m	300 m
ΣL max	10 m	15 m	30 m	60 m	120 m	300 m	750 m	1500 m

3.9.3 Maximum length of bus due to loads on a segment

3.9.3.1 CiA DR-303-1 specifications

Concerning this topic, parameters that have to be taken into account are:

- Wire gauge for its resistance by length
- Terminal Resistance (min value)
- Number of nodes on the bus
- The differential output voltage of the transmitting node
- The differential input voltage of the receiving node
- The differential input resistance of the nodes

The technical reference on this subject is the Philips Semiconductor Application Note AN96116, which gives meaning for calculating the max length of a CAN bus. Parameter choices and results of calculation are included in CiA DR-303-1 as in the following table:

Wire Cross-section (mm^2)	Wire Gauge	32 nodes max	64 nodes max	100 nodes max
0,25	AWG 24	200 m	170 m	150 m
0,50	AWG 20	360 m	310 m	270 m
0,75	AWG 18	550 m	470 m	410 m

table 10: Max bus length vs. number of nodes and wire gauge

Above values have been calculated with following parameters:

- Safety Margin		= 0,2
- Terminal Load	RT	= 118 Ω
- Differential Input resistance	R.diff.min	= 20 kΩ
- Differential output voltage	Vdiff.out.min	= 1,5 V
- Differential input voltage	Vdiff.in.min	= 1,0 V

Calculation of this results can be done in following spreadsheet:

Max_Length_DR303-1.xls

This spread sheet give results found in CiA documents.

Note: the value of 118Ω used as minimum Terminal Load seems erroneous, as min value should be 108Ω with a 120Ω ±10%.

3.9.3.2 Application to SE CANopen segment

Applicable parameters for a SE CANopen Segment should be :

- Safety Margin		= 0,2	
- Terminal Load (min value)	$R_{T.min}$	= 114 Ω	as specified in chapter 3.6
- Differential Input resistance	R.diff.min	= 20 kΩ	although it is 10kΩ in 11898-2
- Differential output voltage	Vdiff.out.min	= 1,5 V	
- Differential input voltage	Vdiff.in.min	= 1,0 V	

This leads to the following results:

	Resistance	16 nodes	32 nodes	64 nodes
Thick cable (AWG 18)	33 ohm/km	575 m	530 m	460 m
AWG 22 cable	55 ohm/km	345 m	320 m	275 m
Thin cable (AWG 24)	**90 ohm/km**	**210 m**	**195 m**	**170 m**
AWG 26 cable	157 ohm/km	120 m	110 m	95 m

table 11: SE CANopen max. bus length vs number of nodes and wire gauge

Independently of the bit-rate, the number of CANopen devices and the choice of cable limit the maximum length of a segment without repeater:

Computation of these limitations, due to DC characteristics, are described in details in chapter 3.9.3 and in compliance with calculations done in following spreadsheet:

Max_Length_SE_CANopen.xls

The consequence for SE CANopen devices is that they **shall** be compliant with these specifications (R.diff.min, Vdiff.out.min, Vdiff.in.min), which concerns directly the transceiver.

Use of repeaters: As repeaters add a propagation delay in the bus, they must be included in the maximum length of the bus. 5ns propagation delay is equal to 1m cable on the network e.g. a repeater with propagation delay of 75ns is equivalent to 15m of cable and so, shortens the available length of bus by 15m.

3.9.4 Length limitation in a powered network

Distribution of power on the pair CAN_V+, CAN_GND introduce a common mode voltage between devices which could disturb data communication.
In order to avoid such disturbances the voltage drop (common mode voltage) on CAN_GND **shall** not exceed 3,5V. The consequence of this restriction is a limitation of the length of network part where power is distributed.
It could be necessary to connect a second power supply for having an other part of powered network in case that the maximum current consumption for one Supply (Multi-) TAP is reached.

The voltage drop depends of the current flowing in the cable, the linear resistance of the cable and the contact resistances of the connectors.

The different values of these parameters **shall** be the following :

Max voltage drop on CAN_GND	DV_{max}	=	3,5 V
Max distributed current	I_{max}	=	1,5 A
Linear resistance of power pair	R_l	=	55,0 Ω/km
Contact resistance of connectors	R_k	=	10 mΩ

Connection with a TAP = 2 connectors

Validation of a configuration can be done at a glance on the curve or table in figure 15.

As this method uses restrictive hypothesis on the configuration, a more precise method is described in 3.9.4.3, with a complete calculation of the configuration.

3.9.4.1 Voltage drop

The voltage drop in a cable is the maximum voltage loss between two devices where the one is at the beginning of the powered segment and the other at the end. The resulting formula for the voltage at the module **shall** be:

$$V_{Module\_min} = V_{PS\_min} - V_{loss\_max} = 19{,}2V - 3{,}5V = 15{,}7V$$

where: $V_{loss\ max}$ = 3,5V
$V_{PS\ min}$ = 19,2V

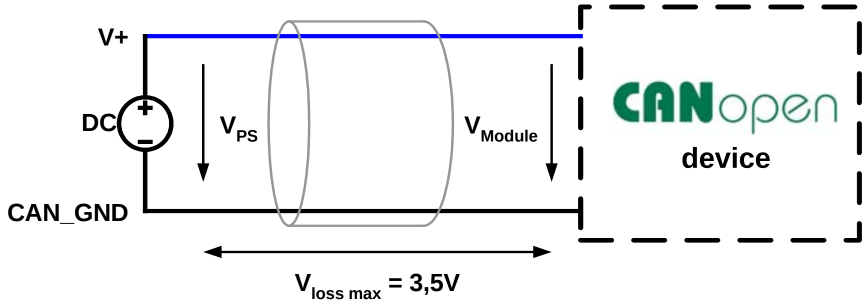


figure 14: voltage drop

3.9.4.1.1 Network Voltage drop detailed calculation

Specification	Tolerance	Actual Voltage
Power Supply Tolerance	3%	0,72 V
Total Temperature Drift *	5%	1,2 V
Line Regulation	3%	0,72 V
Load Regulation	3%	0,72 V
Diode Drop	3,125%	0,75 V
Voltage Drop	14,58%	3,5 V
Supply Ripple	0,833%	0,2 V
Input Ripple	4,112%	1 V
Total Voltage Budget	**36,65%**	**8,81 V**

*Based on a temperature coefficient of 0.1% and an ambient temperature 50 deg C.

3.9.4.1.2 Network voltage tolerance stack up

The following table outlines the stack up of tolerances leading to the +/-4% required by DeviceNet. This **shall** be applied for CANopen as well. By using the information provided, performance tradeoffs **should** be made on the power supply and Schottky diode specifications and still meet the requirements.
Maximum tolerance for the system **shall** be 24 volts +/-4.0%.
Recommended Tolerance Stack Up for Schneider Electric:

Specification	Parameter
Initial Setting	1.0%
Line Regulation	0.3%
Load Regulation	0.3%
Temperature Coefficient*	0.6%
Schottky Diode Drop (0.65 V nominal)	0.75% (of 24 volts)
Time Drift	1.05%
Total Stack Up	4.0%

*The temperature coefficient tolerance of 0.6% is based on an actual rating of .03% per deg C and a 20 deg C differential between supplies that are used on the bus. If a supply in one location is in an ambient of 40 deg C, it is assumed that other supplies are within 10 deg C or in the range of 30 to 50 deg C (or another 20 deg C range). If this stipulation is not met, and all the other tolerances are just being met, then power capability will need to be derated.

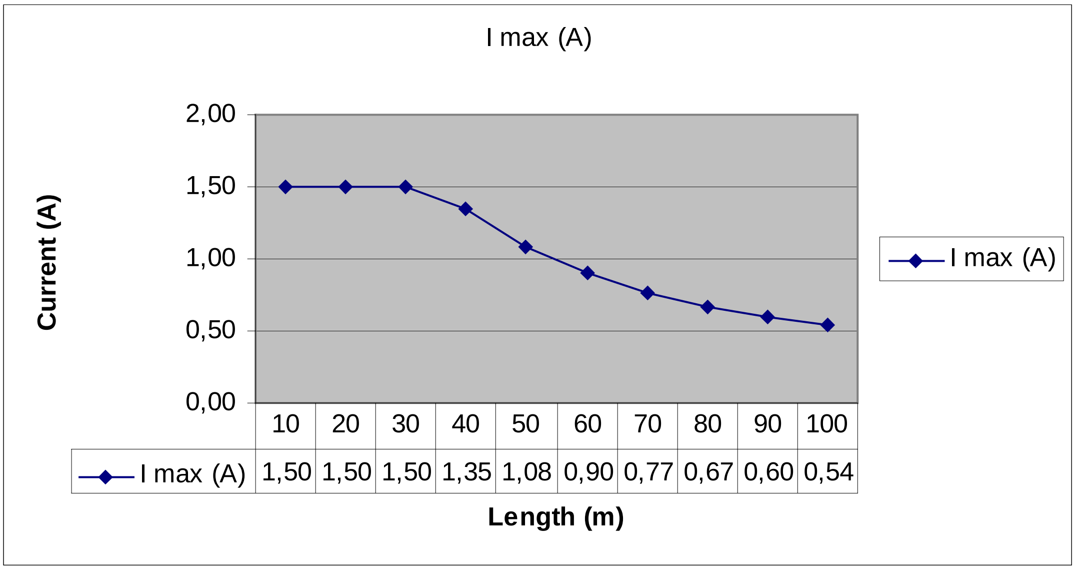
3.9.4.2 Estimation on length limitation at a glance

The curve and table give the max current it's possible to distribute on a given distance.
Hypothesis of the calculation are :

- all devices are at the opposite end of the Power supply.
- There is one connector each m of cable (e.g. one TAP each 3m)

The computation gives following result :

Max. voltage drop: 3,5V
Max. current: 1,5A
Linear resistance: 0,055Ω/m
Contact resistance: 0,01Ω



Length (m)	10	20	30	40	50	60	70	80	90	100
I max (A)	1,50	1,50	1,50	1,35	1,08	0,90	0,77	0,67	0,60	0,54

figure 15: Length limitation at a glance

3.9.4.3 Calculation of length limitation

For a given configuration, it **shall** be checked that the total voltage drop on the power pair does not exceed 3,5 V.

For this computation, it is necessary to know, for each device :

- The maximum current consumed by the device $I_{n\,max}$
- The distance between the device and the Supply TAP L_n
- The number of TAP between the TAP and the Supply TAP NT_n

The checking formula to be applied **shall** be:

$$\sum_{n=1}^{127}\{(R_l * L_n + NT_n * 2 * R_k) * I_n\} \leq 3{,}5V$$

where:

- R_l is the linear resistance of the pair used for power distribution
- R_k is the contact resistance of the connectors

Examples:
The attachment "Complete_Length_Computation.xls" provides examples of computation for different configurations.

Complete_Length_Computation_V2.xls

To open the document Adobe Arcobat Reader version V6.0 or higher is required.

Configuration 1 has 15 devices consuming each 100mA. They are regularly placed along the bus (one each 4,7m), and in this case complete computation shows that 1,5A are distributed until 70m.

Configuration 2 has length of 100m. If devices are regularly placed (one each 9m), 1,1A can be distributed to 11 devices on this bus length.

Configuration 3 has also length of 100m but devices are all placed at the opposite end of the power supply. In this case computation shows that 7 devices can receive 100mA each. The spread sheet shows that similar configuration with 8 devices should override the 3,5V limit.

3.10 Power Supply distribution

CiA standard reserve pins of CAN connector for power supply but only for transceiver and opto-couplers of physical layer (CiA DR303-1). Modification of the standard should be necessary for having compliant devices powered by the network.

3.10.1 Power consumption

The length limitation depends on the power consumption and the resulting voltage drop over the cable. Therefore the maximum current in a powered segment of the CANopen network has to be fixed.
The power consumption (max current) for a powered segment **shall** not exceed 1500mA. This value allows the use of available connectors and has a 33% reserve for peak currents.
The maximum current draw for one device **shall** be therefore equal to the maximum current of one powered segment or sub-segment, i.e.1500mA.

3.10.2 Power distribution and power supply

The CiA standard reserves pins of CAN connectors for power supply but only for transceiver and opto-couplers. However, devices like sensors already use this supply for the whole device. The CiA will tolerate the power distribution on the network when guaranteed that the CANopen communication is not affected.

Power distribution on a Schneider Electric CANopen network may be provided for segments, sub-segments or the whole network (only one segment).

The power distribution and the installation **shall** respect some rules given. This rules will ensure a network where co-existence between non-network powered and network powered devices is possible.

3.10.2.1 Classification of the power

The IEC61131-2 declares three kinds of power supply: the "mains power supply", the "IO power supply" and the "auxiliary power supply".
The IEC defines mains power supply for PLCs and RIO (remote I/O). The IEC does not declare a power supply type for the DIO (Distributed IO) over fieldbusses.

The power supply for CANopen devices **shall** be classified as “I/O power supply” according to IEC61131-2:2003. The EMC zone **shall** be B. With this declaration the application is able to identify the power loss and able to react on the diagnostic information.
For CANopen devices with controller functionality a "mains power supply" declaration **should** be used according to IEC61131-2:2003, the device **should** not be powered via the network only. Doing so a controlled shut down in case of power loss **shall** be possible. The EMC zone **shall** be B.

3.10.2.1.1 EMC test values according to IEC 61131-2:2003

The EMC values given in the following tables **shall** be for Zone B. Please see the standard for additional information. This is an extract only, the standard **shall** be the valid reference.
The values in the following table **shall** be for the test of radiated immunity and enclosure ports conducted immunity, Zones A-B.

Environmental phenomenon	**Basic standard**	**Units**	**Test severity**
Electrostatic discharge	IEC 61000-4-2	kV	± 4 contact ± 8 air
Radiofrequency Electromagnetic field Amplitude modulated	IEC 61000-4-3	GHz MHz MHz V/m % AM, 1kHz, sinus	1,4 - 2,0 800-960 80-1000 10 80
Power frequency magnetic fields	IEC 61000-4-8	Hz A/m	60 30
		Hz A/m	50 30

table 12: Radiated immunity and enclosure ports conducted immunity, Zones A-B

The values in the following table **shall** be for the test for conducted immunity, Zone B.

		Environmental phenomenon		
		Fast transient burst	**High energy surge**	**Radiofrequency interference**
Normative items		IEC 61000-4-4	IEC 61000-4-5	IEC 61000-4-6
Interface / Port	**Specific Interface / port**			
Data communication (AI and Ar for I/O racks and Be, Bi and E for peripherals)	communication Shielded cable	- 1 kV	- 1 kV CM[4]	- 10 V
	Unshielded cable	1 kV	n. a.[5]	10 V
Digital and analogue inputs/outputs (C and D)	AC-I/O (unshielded)	2 kV	2 kV CM 1 kV DM[6]	10 V
	Analogue or DC-I/O (unshielded)	1 kV	0.5 kV CM 0.5 kV DM	10 V
	All shielded lines (to shield)	1 kV	1 kV CM	10 V
Mains power	AC-power	2 kV	2 kV CM 1 kV DM	10 V
	DC-power	2 kV	1 kV CM 0.5 kV DM	10 V
Protective earthing	PE	n.a.	n.a.	n.a.
Functional earthing	FE	1 kV	n.a.	10 V
I/O-power and auxiliary power output	I/O-power and AC-auxiliary supply	1 kV	2 kV CM 1 kV DM	10 V
	I/O-power and DC-auxiliary supply	1 kV	0.5 kV CM 0.5 kV DM	10 V

table 13: Conducted immunity, Zone B

[4] CM = common mode
[5] n.a. = not applicable, no test
[6] DM = differential mode

3.10.2.2 Power supply and CANopen nodes

The power supply is one of the most important components for a network powered segment. The following rules **shall** be respected:

- Only electrically isolated power supplies **shall** be allowed (see figure 20) that are compliant to IEC61131-2. They **shall** fulfill the SELV or PELV requirements.
- Each Supply TAP **shall** be supplied with its own power supply. The power supply **shall** not have any other connections (see figure 20).
- Addition of power supplies or the supply of several Supply TAP with one power supply **shall** not be allowed.
- Each device **shall** provide a protection against polarity reversal and broken GND wire (see the following drawings).
- The power supply of the network **shall** not have any electrical connection to the field power. This can be avoided with four different implementations:

  a. The device **shall** represent a closed system (e.g.: Ositrack)

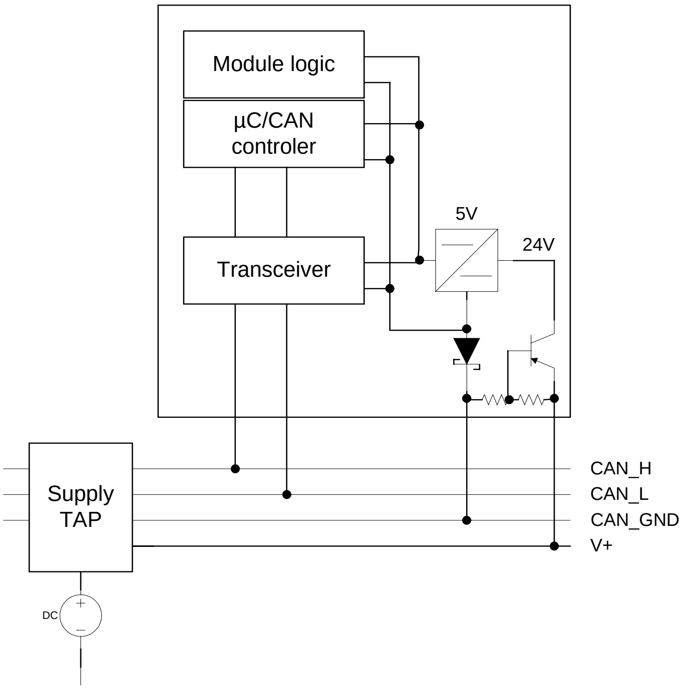


figure 16: CANopen device (closed system)

b. The device **shall** provide a electrical isolation for the I/O

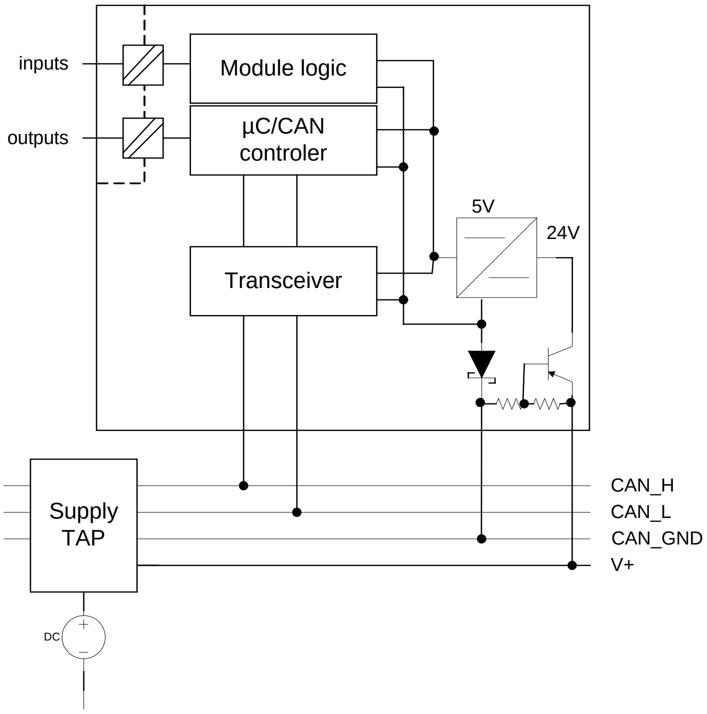


figure 17: CANopen device without additional logic supply

c. The device **shall** provide an electrical isolation for V+ (e.g.: for sensor supply)

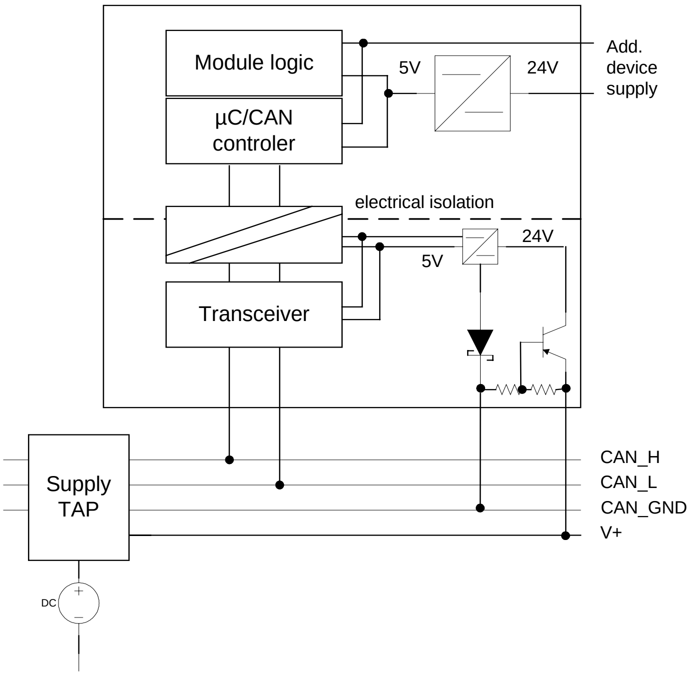


figure 18: CANopen device (isolated)

The electrical isolation **shall** be mandatory to avoid ground loops in the system. An optical power indication for the power supplied over the network **should** simplify the diagnosis.

d. The device **shall** provide an electrical isolation internally (e.g.: TeSys U)

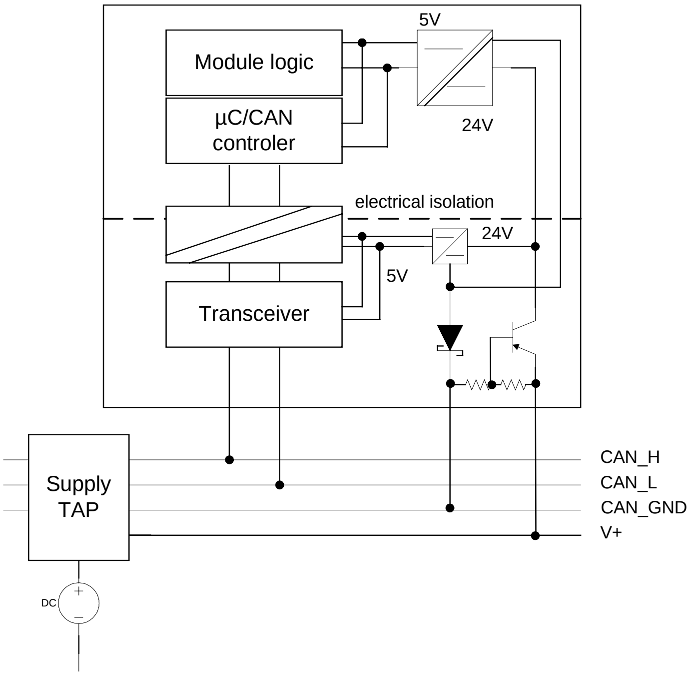


figure 19: CANopen device (isolated) (2)

Note: If optical isolators are used the propagation delay of the component is an important parameter influencing the maximum network length. Therefore the propagation delay of a optical isolator **shall** not exceed 40ns as described in chapter 3.9.1.2.

3.10.2.2.1 Selection of power supply

The power supply is one of the most important devices in a network with power distribution. Beside the requirements in 3.10.2.2 the following requirements **shall** be respected by the selected power supply:

Standard:	IEC61131-2:2003, PELV or SELV
Initial tolerance:	24V +/- 3% or better (no load voltage)
Line regulation:	+/-3% max
Load regulation:	+/-3% max
Output ripple	200mV p-p max
Load capacitance capability	7000uF max
Isolation	output isolated from AC and Chassis ground
Minimum output voltage	19,2V @ full load
Current limit	2A

It is recommended to use Schneider Electric power supplies from the Phaseo product family such as e.g.: ABL-7RE2402 or ABL-7CEM24....

3.10.2.2.2 CANopen device characteristics

The input voltage range for a CANopen device **shall** be: +15V … +30V.
Max. inrush current **shall** be: 4 times the typical current with a maximum of 2A.

3.10.2.3 Supply TAP

A TAP with power distribution capability **shall** at least provide a filter circuit and an over-voltage protection (see figure 20). It **should** provide a LED for power indication.
The cable between the power supply and the Supply TAP **shall** not exceed 3m.

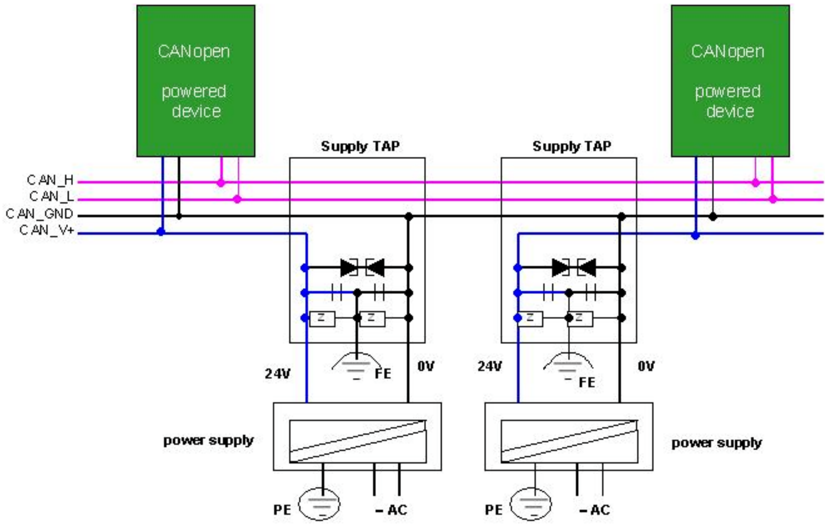


figure 20: Power distribution (principle)

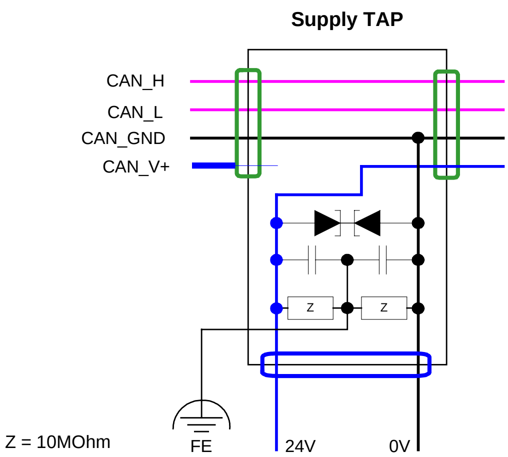


figure 21: Supply TAP

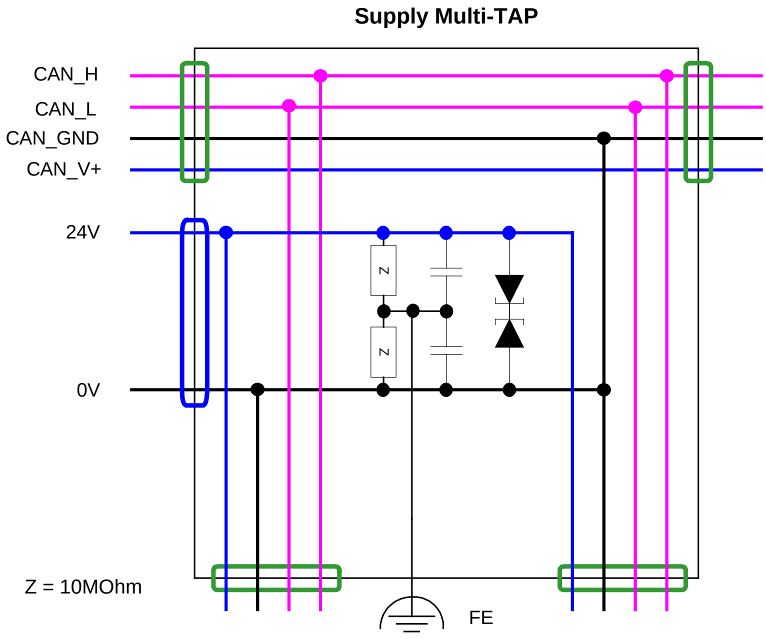


figure 22: Supply Multi TAP

3.11 Mechanical Interfaces

A CANopen device provides a CANopen interface. The connection to the interface **should** made through connectors. For the co-existence of network powered and non-network powered devices on the network, the mechanical interface **shall** pass through the power even if they don't need the power for themselves.

Each CANopen device independent from the need of power supply over the network **shall** provide the capability to pass through the power. An interruption of power distribution by a device **shall** not be allowed. So the pins CAN_H, CAN_L, CAN_GND and V+ **shall** be connected when a device or a connector provides a CANopen IN and a CANopen OUT interface.

Each network powered CANopen device **shall** provide at least a protection against polarity reversal and broken ground wire (see figure 16 until figure 19).

Note: The conductor path **shall** allow the distribution of the power supply current limitation i.e. 2A.

3.11.1 Colors

SE document "Communication Network Interface Colour Marking" [13] defines rules of marking used for differentiation of connections to SE networks.

Dedicated marking **shall** be used for devices implementing several communication interfaces.
Color marking **should** be used.
Dedicated marking **should** be used for devices implementing one communication interface, for device connector, cable connectors and for cable.

When a marking color is used for CANopen, it **shall** be the color specified in following table:

interface type	**color marking for device connector**	**cable connector color**	**cable color**
CANopen	Magenta or Violet	Magenta or Violet	Magenta or Violet

table 14: CANopen color

Note: Magenta or Violet are two naming of same color recommended by DESINA under reference RAL4001:

3.11.2 CANopen device connectors

A SE CANopen node **shall** provide one of these following connectors for its connection to the cabling system:

Shielded Sub-D9 (male)	dedicated to IP20 SE devices
Micro style M12 (male)	dedicated to IP67 SE devices

Note 1: If a device does not use one of these connectors, it **shall** provide an accessory offering a connection compliant with above rules. This solution is allowed only for devices with contract book signed before 6th June 2003.

Note 2: IP67 CANopen devices using and M12 connector may offer a chaining feature with two connectors. In this case one connector **shall** be male and the other one **shall** be female. The male connector **shall** be sufficient to use the module. As disconnection of device should cut the bus this solution is not recommended.

3.11.2.1 Sub-D9 connector pin-out

When using Sub-D9 connectors on the CANopen device or infrastructure component the following pin-out **shall** be implemented. This pin-out is in accordance with CiA DR-303-1 [4].

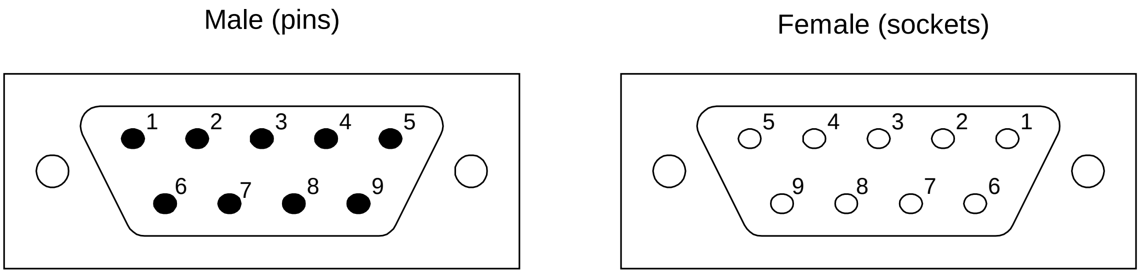


figure 23: Sub-D9 pin-out

Pin N°	Signal	Description	
1	-	Reserved	
2	CAN_L	CAN_L bus Line	Required - **Shall**
3	CAN_GND	CAN Ground	Required - **Shall**
4	-	Reserved	
5	(CAN_SHLD)	Optional CAN Shield	Optional – May
6	GND	Ground	Required - **Shall**
7	CAN_H	CAN_H bus Line	Required - **Shall**
8	-	Reserved	
9	(CAN_V+)	Optional CAN external positive supply	Conditional: **Shall** if device provides two connectors or uses CAN_V+ May if device provides one connector only

table 15: CANopen Sub-D9 pin-out

In accordance with [4] pin 3 and 6 **shall** be interconnected within the device.
Connector mounting **shall** be front female screw lock, with 4.40 UNC thread.
Maximum end of life resistance for the connector **shall** be 10mΩ.
Constraints concerning implementation of connectors are described in paragraph 3.11.4.
Shell of the connector should be connected to CAN_SHLD (see 5.2).

3.11.2.2 Sub-D9 connector sense

When using Sub-D9 connectors on the CANopen device or infrastructure component there are two ways to implement the connector. The sense of the connectors **shall** be implemented as shown in figure 24 and figure 25.

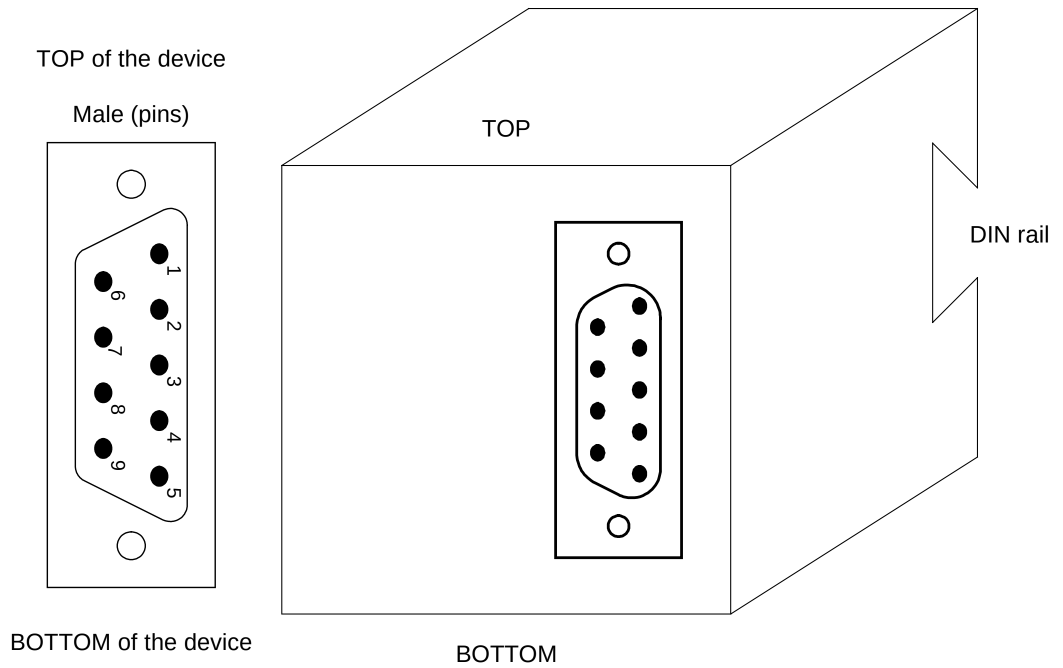


figure 24: Sense of Sub-D9 connectors on front side

When applying this sense the 90° connector **shall** be used.

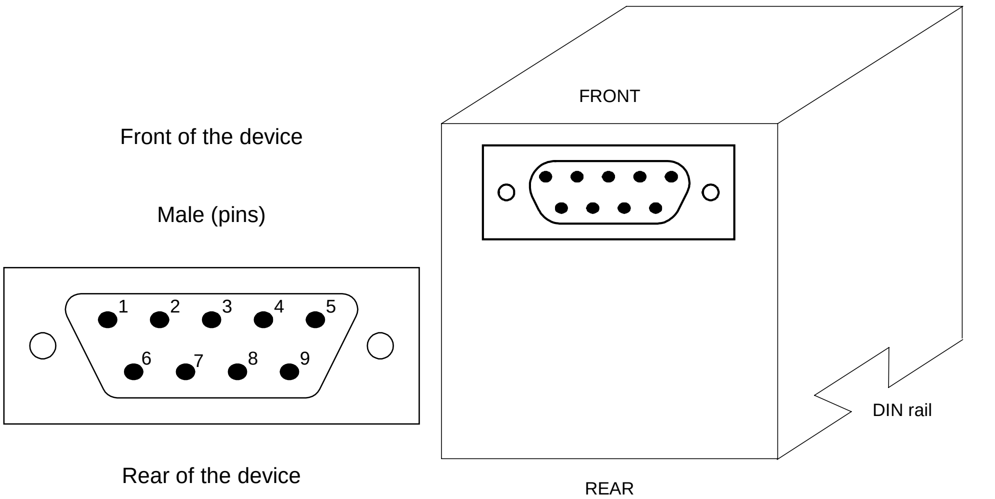


figure 25: Sense of Sub-D9 connectors on bottom side

When applying this sense the 180° connector **shall** be used.

3.11.2.3 M12 connector

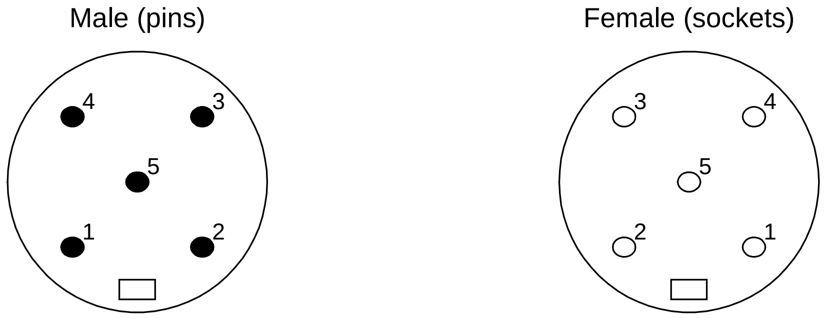


figure 26: M12 connector pin-out

Pin N°	Signal	Description	
1	CAN_SHLD	CAN Shield	Required - **Shall**
2	(CAN_V+)	CAN external positive supply	Conditional: **Shall** if device provides two connectors or uses CAN_V+ May if device provides one connector only
3	CAN_GND	Ground / 0V / V-	Required - **Shall**
4	CAN_H	CAN_H bus Line	Required - **Shall**
5	CAN_L	CAN_L bus Line	Required - **Shall**

table 16: CANopen M12 connector Pin out

3.11.2.4 M12 connector for Supply TAP

To harmonize the connectors and the accessory offer common regulations for the TAP are given. An IP20 Supply TAP **shall** provide screw terminals for the 24VDC.
An IP67 Supply TAP **shall** provide a M12 male connector for the 24VDC. This connector is A-coded with 4 pins.

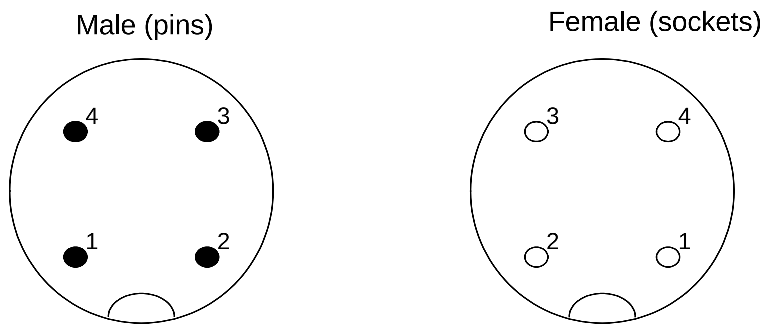


figure 27: M12 connector for IP67 Supply TAP[7]

Pin N°	Color	Signal	Description	
1	Brown	CAN_V+	24V DC	Required - **Shall**
2	White	CAN_V+	24V DC	Required - **Shall**
3	Blue	CAN_GND	0V	Required - **Shall**
4	Black	CAN_GND	0V	Required - **Shall**

table 17: M12 IP67 Supply TAP connector pin-out

[7] e.g.: XZC P1141Lx with a connector on one side and opens ends on the other

3.11.3 Terminal blocks

In TAP or inside a Sub-D9 connector terminal blocks are used to make the connection of the bus cable. These terminal blocks **shall** have the following order from left to right or from top to down:

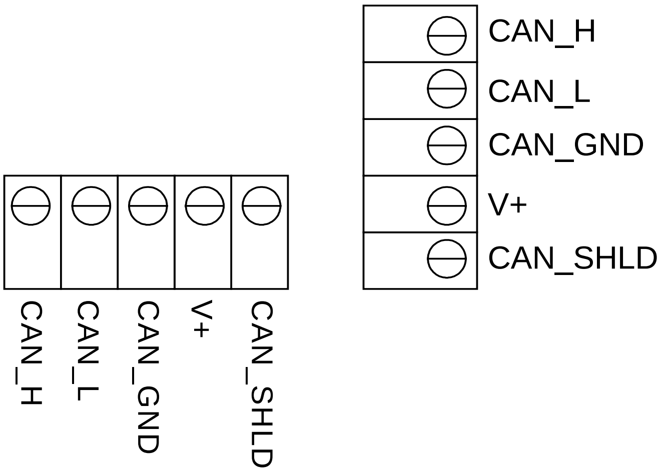


figure 28: Terminal blocks

The following short denomination **shall** be used to allow smaller size of the components and to harmonize the marking. In the user documentation the standard marking and the relation to the short denomination **shall** be given as defined in [4]. Where two terminal blocks are used a "1" or a "2" **shall** be added to the name. “1” **shall** indicate the terminals for the incoming cable, “2” **shall** indicate the terminals for the outgoing cable being switched off when activating the termination resistor.

Short denomination	Signal	Description	
CH	CAN_H	CAN_H bus Line	Required - **Shall**
CL	CAN_L	CAN_L bus Line	Required - **Shall**
CG	CAN_GND	Ground / 0V / V-	Required - **Shall**
V+	(CAN_V+)	Optional CAN external positive supply	Optional - **Should**
CS	CAN_SHLD	Conditional CAN Shield	Conditional – May

table 18: Terminal blocks pin-out

The CAN_SHLD connection **shall** be provided, if no other shield connection is available.

3.11.4 Mechanical Constraints

Any SE CANopen device **shall** be compliant with at least one CANopen connector or cabling accessory as a drop cord for example.

The technical documentation of the device **shall** provide the reference of connectors and cabling accessories with which it is compliant.

In order to help choice of the SE CANopen infrastructure products and mechanical design of the devices, mechanical plan and constraints of the infrastructure products will be available in the SE CANopen data base as soon as possible.

4 SE CANopen Physical Layer

Schneider Electric CANopen devices **shall** be compliant with this specification and the standards ISO 11898-1/2 and DR-303-1.

4.1 Bit-rates

4.1.1 Available bit-rates :

- On a CANopen network the following bit-rates are available :
  10 kbit/s, 20 kbit/s, 50 kbit/s, 125 kbit/s, 250 kbit/s, 500 kbit/s, 800 kbit/s and 1000 kbit/s.
  A 100kbit/s may be available for customer applications with a separate device description file. However, this bit-rate **shall** not be part of the Interoperability Tests or Conformance Class.
- SE CANopen devices **shall** support at least the bit-rates defined in [11].

4.1.2 Bit-rate Selection

SE CANopen Devices **shall** provide <u>at least one</u> mean of selection of the bit-rate chosen in following list:

- Dip Switches or Rotary Switches,
- Software Parameter setting (master or slave with configuration tool only),
- Layer Setting Services (LSS) as defined in the Conformance Classes.

4.2 CANopen device Identification

4.2.1 Address Range

- On a SE CANopen network any address in the range 1 to 127 is allowed.

- SE CANopen devices support a part or all this range of address, depending of their Conformance Class, as described in [11].

- Any address value out of the supported range is considered as an invalid address.

4.2.2 Address Selection

- SE CANopen Devices **shall** provide selection of their Address with <u>at least one</u> of these means:
  - Dip Switches or Rotary Switches,
  - Software Parameter setting (master or slave with configuration tool only),
  - Layer Setting Services (LSS) as defined in the Conformance Classes.

4.3 Node_ID and Bit-rate Configuration

4.3.1 Configuration modes

A SE CANopen device may have several ways for getting it's Node_ID (Address) and baud-rate :

- Use of Default Configuration
- Use of Switches
- Use configuration previously stored
- Use configuration received by Layer Setting Services (LSS)
- Use configuration received by a tool, which could be a device HMI (local or remote), or a commissioning tool (PC, Pocket PC, etc…).

4.3.2 Behavior of Devices relating to configuration

At power up behavior of different SE CANopen devices can be summarize by following diagram :

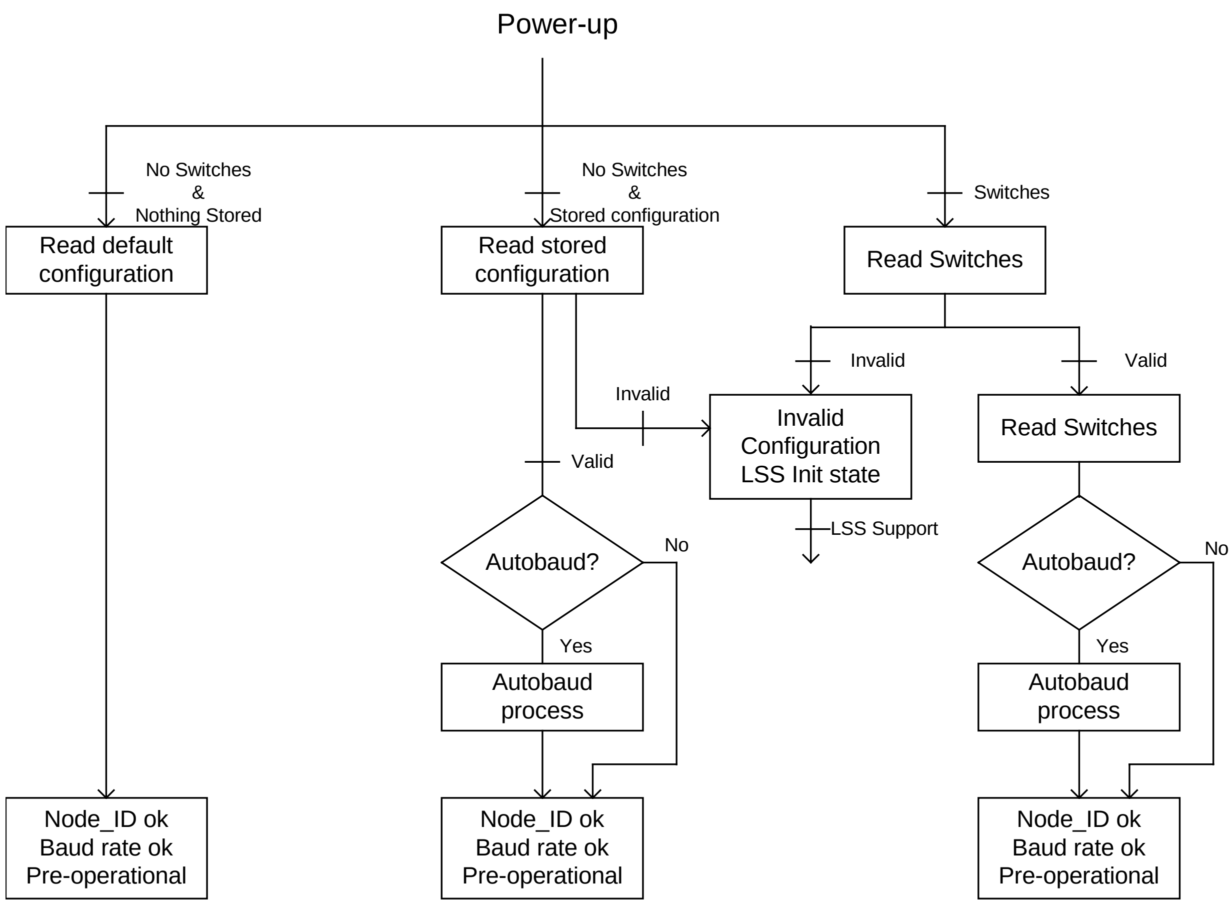


figure 29: Configuration at power-up

After these first steps, configuration can be modified by software tools, LSS services if supported, etc…..

Device with switches **shall** apply following rules:

- at power-up or on hardware reset device gets its address and bit-rate at the same time. Consequently, a non-volatile memory is not required.
- Under power, any change to the switches are ignored until next power up or hardware reset.

Devices without switches **shall** receive their configuration by a locally connected software tool or by network protocols. They **shall** support a non-volatile memory in order to store their configuration.

Invalid configuration :

Configuration is said invalid when Node_ID or Bit-rate are set to a value which is not supported by the device. It could be a value without signification as a Node_Id=195, or a significant value that is not supported by the device (as Node_Id=123 for Basic device without option).

Default values / Factory settings:

Default Bit-rate **shall** be 250 kbit/s.
Default master address **shall** be 127.
Default slave address **shall** be 0.

Factory setting is 250 kBit/s. If the speed selector has a default position, the factory **shall** set the selector to this position. If the speed selector has no “Default” position, it **shall** be set to the “250 kBit” position. The default slave address **shall** be zero in order to avaid potential duplicate addresses.

4.3.3 Coding rules

SE CANopen devices with Conformance Class x10 implementing only mandatory bit-rates **shall** use following bit-rate coding which allows use of two dip switches only:

Bit-rate [kBit/s]	Coded value [decimal]	Coded value [binary]
125	0	00
250	1	01
500	2	10
Autobaud or Software configuration	3	11

table 19: BASIC devices bit-rate coding

SE CANopen devices implementing other bit-rates **shall** use following bit-rate coding :

Bit-rate [kBit/s]	Coded value [decimal]	Coded value [binary]
10	0	0000
20	1	0001
50	2	0010
125	3	0011
250	4	0100
500	5	0101
800	6	0110
1000	7	0111
Autobaud	8	1000
Default	9	1001

table 20: Bit-rates coding

These coding rules **shall** be applied for switches and for configuration screens in software tools.

4.3.4 Configuration using switches

Two switch types are possible
- DIP switches
- Rotary switches (coding wheels)

In order to have same look for SE CANopen devices, dip switches **shall** have one of the two following layouts, horizontal or vertical:

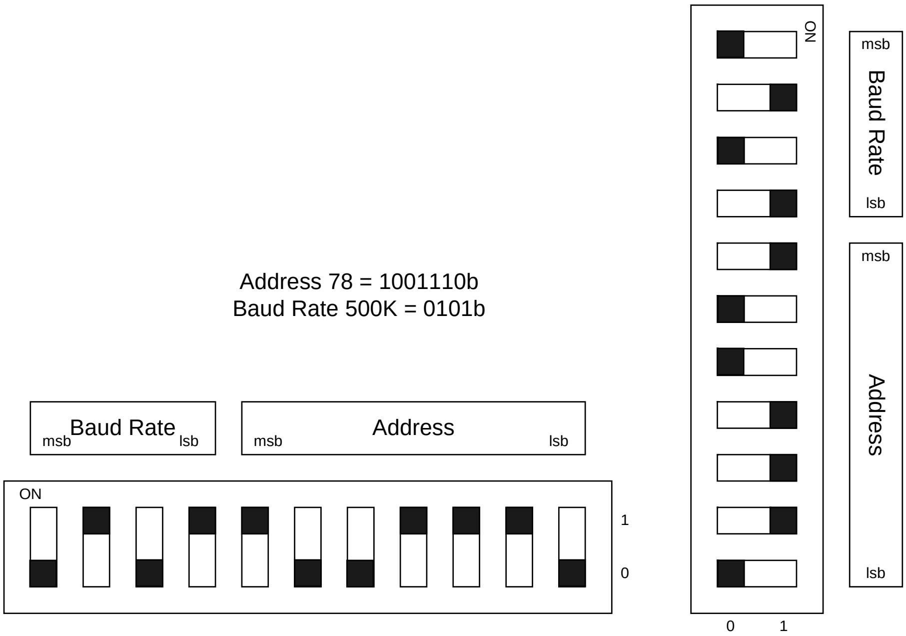


figure 30: Dip switches layout

Depending on the Conformance Class of the device, the number of digits may be reduced and limited to the range of values that are supported. Bit-rate is coded on 2 or 4 digits. Address is coded on 6 or 7 digits.
As in figure 30 the bit-rate switches and address switches **should** be on the same row or in the same column. It may be possible to have them on two separate rows or columns.

When using rotary switches 1 wheel **shall** be used for the bit-rate and 2 wheels **shall** be used for the address.

On SE CANopen devices, rotary switches **shall** provide 16 positions and **shall** provide indication of decimal value corresponding to these positions.
In order to have same look for SE CANopen devices, rotary switches **shall** have one of the two following layouts, horizontal or vertical:

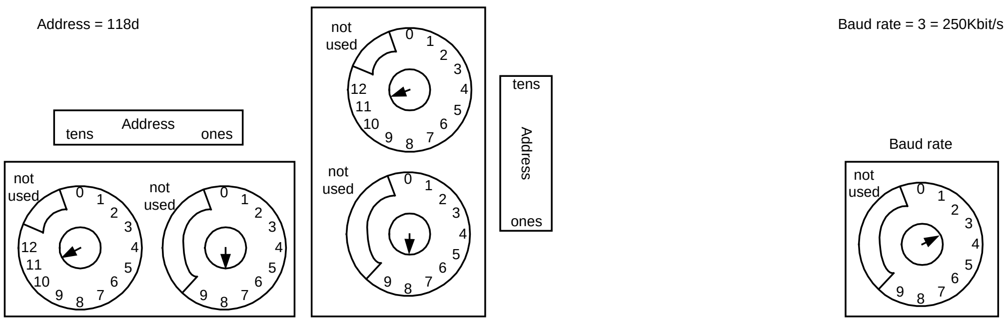


figure 31: Rotary switch layout

4.4 Local Diagnostic

Implementation of Local diagnostic on SE CANopen devices **shall** comply with requirements described in CANopen Conformance Class document [11].

When local diagnostic is implemented it **shall** be one of the following modes:
- Two LEDs, a red one called CAN_ERR and a green one called CAN_RUN.
- One bicolor (green/red) Led called STATUS
- A display providing two indicators clearly identified as CAN ERR and CAN RUN.

The states of the indicators and their flash rates **shall** be compliant with the CiA DR 303-3 Indicator Specification [5].

The behavior of the LED and the signification of their status **shall** be compliant with the CiA DR 303-3 Indicator Specification [5].

In addition to the CiA DR303-3 requirements, the following behaviors are added and **shall** be applied:

N°	Error Led	State	Description	Category
7	Blinking	Invalid Configuration	Address and/or bit-rate settings are invalid.	**Shall**

table 21: Invalid Configuration Indication

5 Grounding Arrangements

5.1 Overview

Within Schneider Electric, two shielding recommendations are available :

- One from HEC described in TSX DG KBL [23].
- One from Selectron described in the CANopen System Manual (393.0071), using TAP CTA 701 and drops CCA701.

Main principles of HEC recommendations are :

- Equipotential bonding with a proper inter-linking of ground connections
- Use of cables shielded with braid
- Shield connection at both ends to functional ground.

Main principles of Selectron recommendations are :

- Only one connection to ground
- HF grounding via capacitor on each tap
- Use of cables shielded with braid
- No Shield connection with device.

A set of cabling accessories (drops and TAP) are already provided for this implementation.

- As targeted applications for SE CANopen are for small areas, as most of SE products are qualified in this configuration, the SE CANopen cabling system **should** use equipotential bonding with a proper inter-linking of ground connections as described in TSX DG KBL manual from HEC [23].

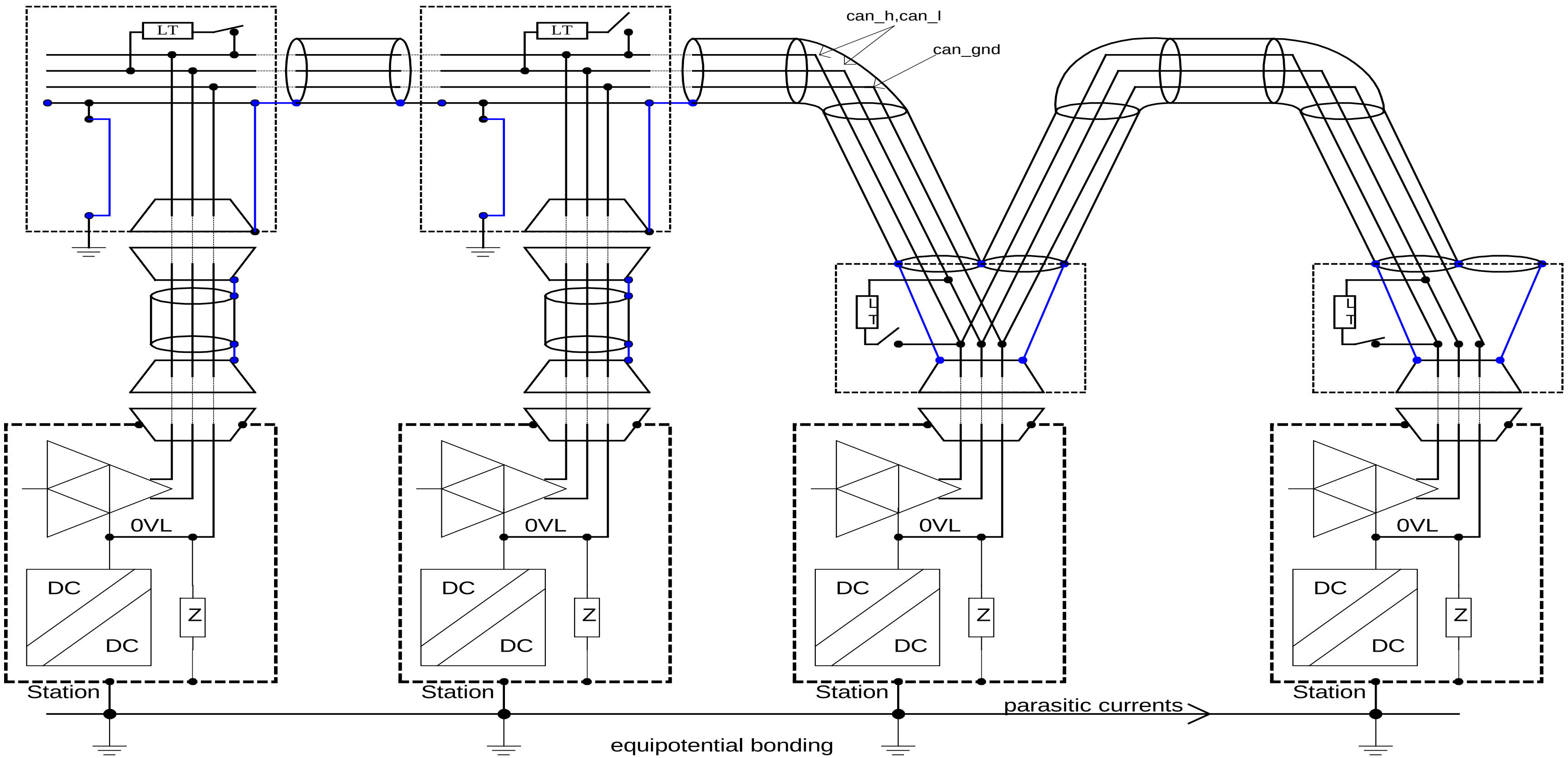
This rule implies following requirements :

- On devices :
    - Use of shielded connectors if the device provides either grounding to the functional earth or ensure continuity of shielding.
    - Connection of shield of connector to the functional ground of the device if available.
    - For a connector, that does not provide a shield connection through the housing, the shield **shall** connected to the dedicated pin of the connector.
- On cabling system :
    - Continuity of cable shield in chaining connectors, drops and TAP.
    - Connection to ground in TAP

- Capacity grounding may be implemented for wide area and/or applications requiring it. Specific cabling accessories may be used in this case. These accessories **shall** comply with specifications described in this document, except for their specific connection for grounding.

Note: Elements of cabling system will provide a good implementation of these rules in order to comply with Electromagnetic tests required by product standards (as IEC61131-2 for PLCs for example).

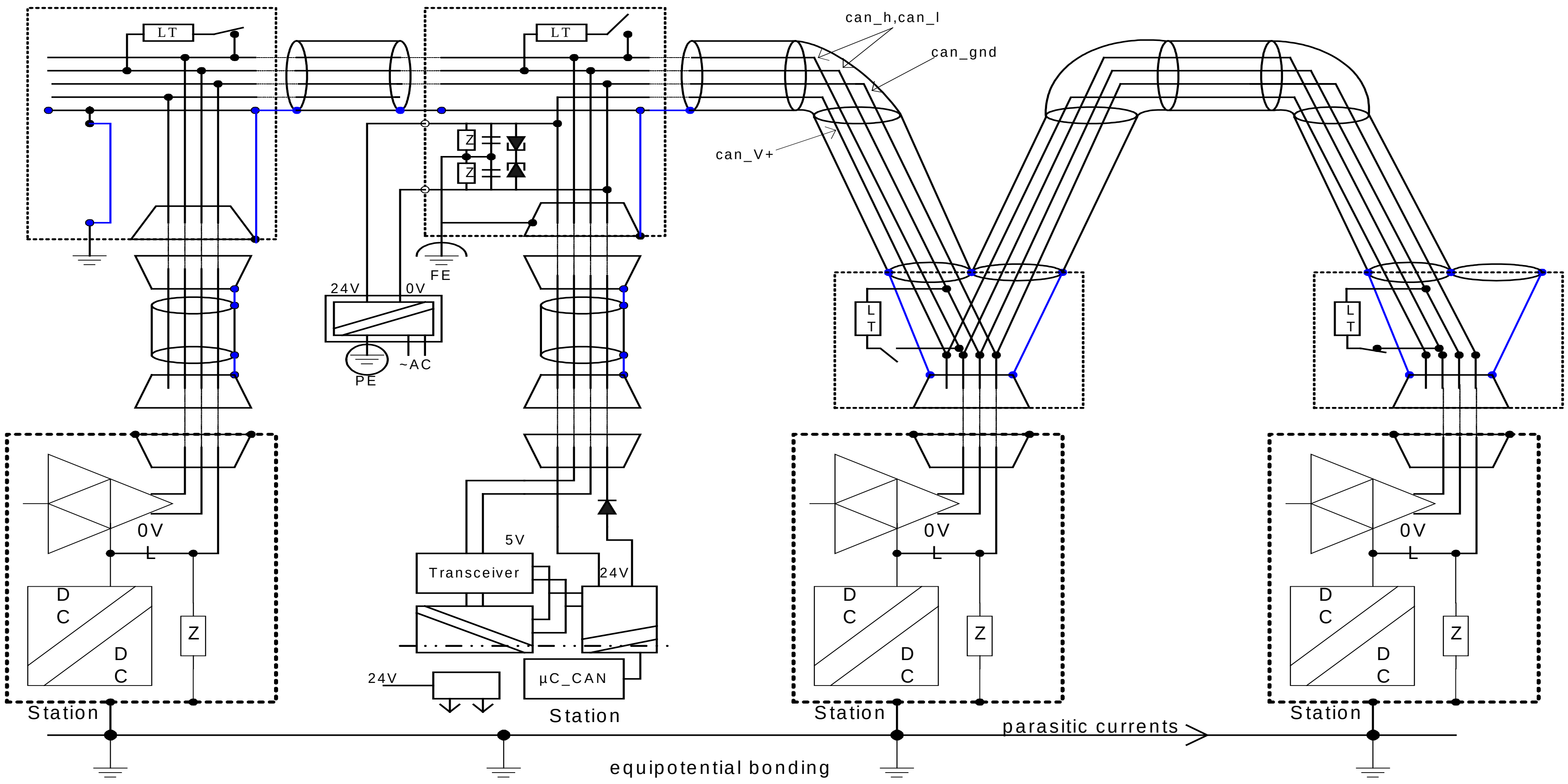
5.2 Shielding principles



The Z impedance is an high resistor (10M Ohm) with in parallel a low capacitor.
figure 32: Shielding implementation

5.3 Shielding principles in a powered network

The grounding arrangements in 5.2 will be also used for a CANopen network with powered segments or sub-segments.



The Z impedance is an high resistor (10M Ohm) with in parallel a low capacitor.

figure 33: Shielding implementation within a powered network

APPENDIX

A Integrated Circuits

Here is a list of Integrated Circuits used within Schneider Electric for CANopen implementation. This list is not exhaustive and other qualified components can be proposed for including them.
An updated list of CAN components will be available on SE CANopen data base.

A.1 CAN Controllers

List of recommended CAN controllers will be in the CANopen Stack document.

A.2 CAN Transceivers

Founder	Reference		Max bit-rate	Fan out Max	
Texas Instrument	SN65HVD251DR		1Mbit/s	120 nodes	Recommended SE Ref = HUA10215
Philips	PCA82C251	"Iso-11898-24V"	1 Mbit/s	110 nodes	Not recommended for new designs
Philips	TJA 1050		1Mbit/s	110 nodes	
AMI	AMIS-30660		1Mbit/s		Under qualification

table 22: CAN Transceivers

Note: The TJA 1050 / AMIS-30660 may require certain considerations at higher bit-rates.

A.3 Opto-couplers

Founder	Reference		
Agilent	HCPL-x710	40ns propagation delay	Recommended
Analog Devices	AduM1100A	Digital isolator, faster than HCPL-710	Under qualification

table 23: Opto-couplers

B SE CANopen Device Physical and Cabling characteristics

Table below could be used to summarize mains characteristics of SE CANopen Device on Physical and cabling aspects. Values are given as example

SE CANopen Device	Physical and Cabling characteristics							
Identification :								
Product Department :	MAC / LEC / PCP / VVD / HEC / AGP / HMI / Motion							
Product family :	Premium							
Product Description :	CANopen Pcmcia Card							
Product Reference :	TSX CPP100							
Conformance :								
CANopen Device type	Master / Slave							
Conformance Class	Basic / Regular / Extended							
Address range	1-63 / 1-127 / 1- xxx							
Bit-rates supported	1 M	800 K	500 K	250 K	125 K	50 K	20 K	10 K
	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
LSS supported	Yes / No							
Network Powered	Yes / No							
Connectivity :								
CANopen Connector	Sub-D9 / M12 / other							
Specific Accessory	Yes / No							
	if yes : Accessory Reference							
Compliant SE Connectors	list of references							
Compliant SE Drop Cables	list of references							
Fan out Max	63 (at least) / 110 / …							
Implementation :								
Galvanic Isolation	Yes / No							
CAN Controller Reference	ex : Philips SJA1000							
Controller loop delay Max (ns)	40 ns							
Controller loop delay Typ (ns)	26 ns							
Optocoupler Reference	ex : Agilent HPCL-0710							
Prop delay Max (ns)	40 ns							
Prop delay Typ (ns)	23 ns							
Transceiver Reference	ex : Philips PCA82C251							
tloop Max (ns)	150 ns							
tloop Typ (ns)	80 ns							
Node delay								
tnode Max (in ns) =	270 ns							
tnode Typ (in ns) =	152 ns							

table 24: Physical and Cabling Characteristics

Note: a delay of 5ns is equivalent to a length of 1m of cable. However this is depending on the velocity of the cable.