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Interoperability test specification for high-speed CAN transceiver or equivalent devices

IOPT.CAN

02d09

by

C&S group GmbH

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(Test Specification)

Disclaimer

Content

Terms and definitions

For the purposes of this document, the following terms and definitions apply:

availability

Full functional communication between nodes.

bus

Topology of a communication network where all nodes are reached by passive links which allow transmission in both directions.

bus failure

Failures caused by a malfunction of the physical bus such as interruption, short circuits etc.

BUS OFF

Stopped network activities.

CH_BAT

Short circuit CAN_H to VBAT.

CH_GND

Short circuit CAN_H to ground.

CH_OW

CAN_H interrupted.

CL_BAT

Short circuit CAN_L to VBAT.

CL_CH

Short circuit CAN_L to CAN_H.

CL_GND

Short circuit CAN_L to ground.

CL_OW

CAN_L interrupted.

Cx_Vx

Short circuit CAN_x to Vx.

DATA

Data field of a CAN frame.

error generator U

Part of LT for generating voltage stimuli.

HS-PMA

High-speed physical media attachment.

low-power mode

Operating mode with reduced power consumption.

normal mode

Operating mode of a transceiver which is actively participating (transmitting and/or receiving) in network communication.

SIC

Signal improvement capability.

standard net

Most realistic test environment for the embedded component system tests from a car manufacturers point of view. The parameters of system configuration and communication of the Standard Net are constant and well defined.

test procedure

Defines the way and order of the execution of the test steps of a test case.

VBAT

Voltage on the battery-pin of the IUT; see Table 2

VCC

Voltage on the supply-pin of the IUT; see Table 2

VIO

Voltage on the input for voltage adaption to the microcontroller supply of the IUT; see Table 2

Vx

Variable voltage, part of error generator U. Ranges and steps for variation are specified in the respective test case.

Symbols and abbreviated terms

For the purposes of this document, the following abbreviations apply:

BRP	bit rate prescaler
CAN	controller area network
CAN-FD	controller area network with flexible data-rate
CAN_H	CAN high bus line
CAN_L	CAN low bus line
CMC	common mode choke
DLC	data length code
FBFF	FD base frame format
FEFF	FD extended frame format
GND	power supply ground
ID	identifier
IUT	implementation under test
LT	lower tester
op. mode	operation mode
REC	receive error counter
SBC	system basis chip
SJW	resynchronisation jump width
SSP	secondary sample point
SV	supervisor
TF	test flow
TDC	transmitter delay compensation
TCP	test coordination procedure
TEC	transmit error counter
transceiver	high-speed CAN transceiver in meaning of HS-PMA [2] or equivalent device (consisting transmitter and receiver)
TRX	transceiver
UT	upper tester

1 Scope

Scope of this document is the definition of test cases and test requirements to realize a test plan for the verification of transceivers in meaning of HS-PMA [2] or equivalent devices e.g. SBC regarding their interoperability even if provided by different manufacturers. Aim of the tests is to increase the probability of collaboration of transceivers within a CAN system and to increase the confidence level in this regard. On the contrary to conformance tests the interoperability tests, which are defined within this test specification, are based on predefined reference environment. Single device measurements are not in focus of the interoperability tests. A data sheet check (static test cases) completes the interoperability test. The tests will be performed within the reference environment using predefined settings to ensure a high level of repeatability and comparability of the test results.

This specification defines interoperability test cases for:

- **high-speed CAN transceiver or equivalent devices**, containing a HS-PMA unit
- **high-speed CAN transceiver or equivalent devices with selective wake-up functionality**, containing a HS-PMA unit with selective wake-up functionality
- **high-speed CAN transceiver or equivalent devices with selective wake-up functionality tolerant to frames in FBFF and FEFF**, containing a HS-PMA unit with selective wake-up functionality tolerant to frames in FBFF and FEFF
- **high-speed CAN transceiver or equivalent devices with additional signal improvement capability [8]**, containing a HS PMA unit

This specification defines a methodology for testing the interoperability of transceiver implementations or equivalent devices within reference environment. Depending on the intended application area for the IUT, different reference environments and settings are defined within this specification. The reference environments are classified in relation to the target bit rate:

- 500 kbit/s reference environment
  - supporting bit rates of 500 kbit/s for the arbitration phase and 500 kbit/s for the data phase
  - valid for IUT designed for bit rates up to 500 kbit/s
- 2 Mbit/s reference environment
  - supporting bit rates of 500 kbit/s for the arbitration phase and 2 Mbit/s for the data phase
  - valid for IUT designed for bit rates up to 2 Mbit/s and 5 Mbit/s (subset of test cases)
- 5 Mbit/s reference environment
  - supporting bit rates of 500 kbit/s for the arbitration phase and 5 Mbit/s for the data phase
  - valid for IUT designed for bit rates up to 5 Mbit/s
- 5 Mbit/s reference environment with ringing topology
  - supporting bit rates of 500 kbit/s for the arbitration phase and 5 Mbit/s for the data phase
  - valid for IUT designed to support signal improvement capability

The interoperability tests defined within this test specification are focused on transceivers, for that reason only limited number of CMC is in use and no electrostatic discharge components are applied. The defined reference environments contain wire harness and passive components (CMC, resistances and capacitors) only.

The behavior of a transceiver can be represented by a state machine. The transitions from one state to another represent reactions to certain events e.g. mode change requests, bus failures, ground shifts (or their combinations). The behavior described by this way is a dynamical sequential behavior. The interoperability tests defined within this test specification verify the sequential behavior of the IUT in reference to the specified sequential behavior.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments and technical corrigenda) applies.

[1] ISO 11898-1:2015, Road vehicles — Controller area network (CAN) — Part 1: Data link layer and physical signalling

[2] ISO 11898-2:2016, Road vehicles — Controller area network (CAN) — Part 2: High-speed medium access unit *(to be updated after release by the ISO)*

[3] ISO 9646-1, Information technology — Open Systems Interconnection — Conformance testing methodology and framework — Part 1: General concepts

[4] ISO 16845-2:2018, Road vehicles — Controller area network (CAN) — Part 2: High-speed medium access unit - Conformance test plan

[5] SAE J2284-3: NOV2016, High-Speed CAN (HSC) for Vehicle Applications at 500 KBPS

[6] SAE J2284-4: JUN2016, High-Speed CAN (HSC) for Vehicle Applications at 500 Kbps with CAN FD Data at 2 Mbps

[7] SAE J2284-5: SEP2016, High-Speed CAN (HSC) for Vehicle Applications at 500 Kbps with CAN FD Data at 5 Mbps

[8] CiA® 601-4: Version 1.0.14, 02 April 2019, CAN FD Node and system design – Part 4: Signal improvement

3 Test method

When testing transceiver the behavior of the IUT is observed and controlled at external points of the IUT, the details of the respective transceiver implementations are not visible. Just phenomena relevant for interoperability of transceivers are considered. Abstract test methods are described by identifying the points closest to the IUT at which control and observation are to be exercised. Since the principle of the chosen tester architecture satisfies the points below according to ISO 9646-1 the test method is the so-called local test method:

- there are two points of control and observation:
  - one beneath the LT and
  - the other at the upper service boundary of the IUT
- UT and LT are both located within the test system[1]
- the SV with its TCPs is located within the test system (the SV controls both LT and UT)

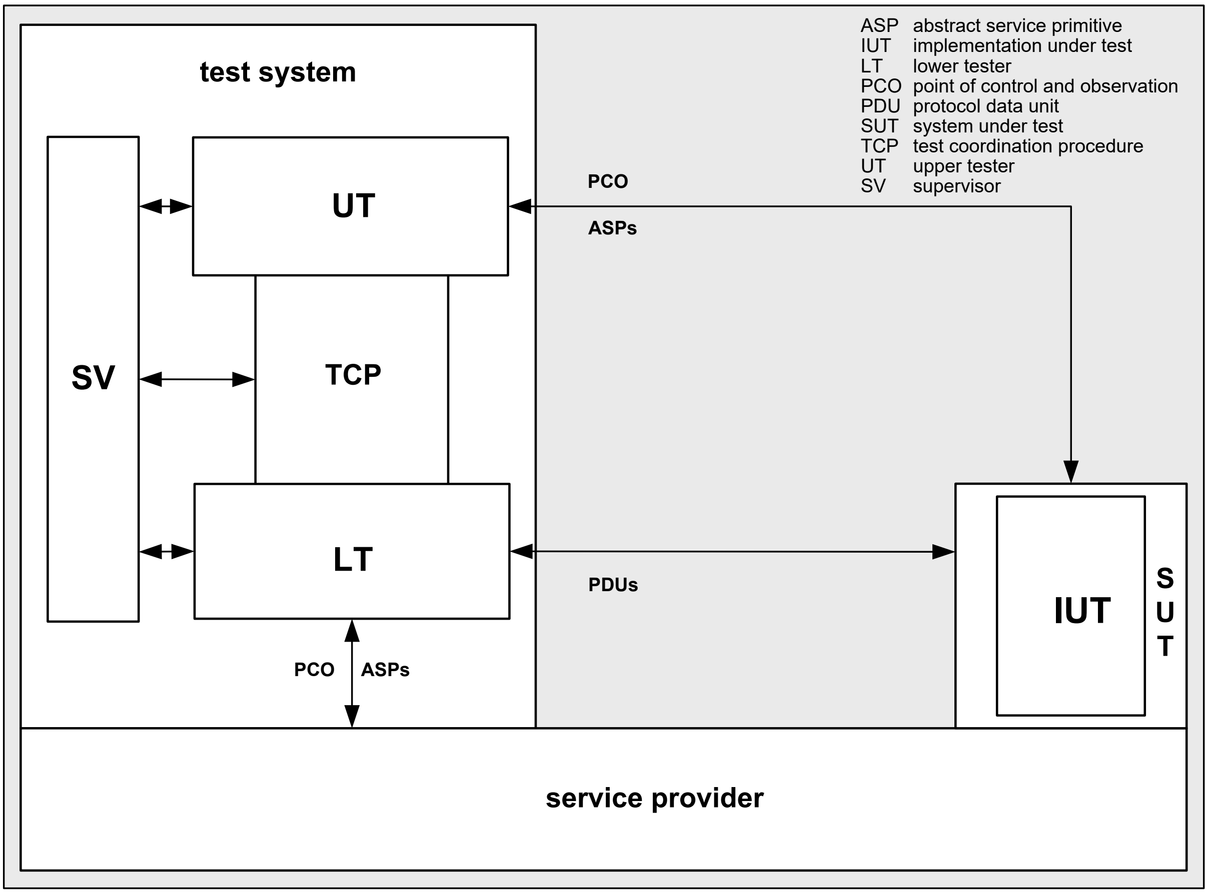


Figure 3-1: Local test method as defined in ISO 9646-1

[1] The real test system which includes the realization of the LT (ISO 9646-1:1994)

4 Test plans

4.1 Static test plan

In order to realize the test plan for verification of transceivers or equivalent devices static test cases as defined within test type 1 of the conformance test plan ISO 16845-2 [4] and additionally as defined within chapter 6.3 "Transmitter characteristics" and chapter 6.4 "Transmitter and receiver timing behaviour" of the CiA 601-4 [8] in case of high-speed CAN transceiver or equivalent devices with additional signal improvement capability have to be proven[2]. These tests verify the availability and the boundaries in the data sheet of the IUT.

For all IUTs except high speed can transceivers or equivalent devices without additional Signal improvement capability every related parameter listed within test type 1 of ISO 16845-2 [4] shall be part of the data sheet and fulfil the specified boundaries in terms of physical worst case condition. For all IUTs with high speed CAN transceivers or equivalent devices with additional signal improvement capability every related parameter listed within test type 1 of ISO 16845-2 except the parameters 26 to 32 and the parameter in Table 10 shall be part of the data sheet and fulfil the specified boundaries in terms of physical worst case conditions. Data sheet parameter names may deviate from the listed names, but in this case a cross-reference list shall be provided for this test. Parameter conditions may deviate from the listed conditions, if the data sheet conditions are according to the listed physical worst case context at least.

4.2 Dynamic test plan

In order to realize the test plan for verification of transceivers dynamic test cases as defined in 5 and 5.4.8. Aim of the dynamic tests is to increase the probability of collaboration of transceivers within a CAN system and to increase the confidence level in this regard. The definition of the environment of the dynamic test plan in 5 and 5.4.8 aligns in a wide rage to the recommendations of SAE J2284-3/-4/-5 [5, 6 and 7][3].

The dynamic test plan is defined supporting three different data bit rates (500 kbit/s, 2 Mbit/s and 5 Mbit/s) while the arbitration phase is always running with 500 kbit/s. The according hardware test platform shall provide the capability running any of the above mentioned data bit rates in combination with 500 kbit/s arbitration bit rate. In order to keep the overall test efforts per physical layer implementation as low as possible, following simplification is defined:

[2] For transceiver with selective wake-up functionality, containing a HS-PMA unit with selective wake-up functionality and for transceiver with selective wake-up functionality tolerant to frames in FBFF and FEFF, containing a HS-PMA unit with selective wake-up functionality tolerant to frames in FBFF and FEFF tests according to the test types 2, 3, 4 and 5 of the ISO 16845-2 [4] as well as the "Device tests for CAN transceiver with selective wake-up function" are strictly recommended.

[3] Exceptions: exact sampling point position and the definition of wire and topology of the 5 Mbit/s

A) For physical layer devices, which solely support data bit rates up to 1 Mbit/s, all applicable test flows have to be executed with the 500 kbit/s data bit rate in the 500 kbit/s reference environment. If those physical layer devices support selective wake-up functionality also, additionally the selective wake-up function need to be tested by execution of test flow 5, test flow 6 and test flow 7 with low-power mode with selective wake-up function enabled.

B) Physical layer devices, which support higher data bit rates (2 Mbit/s or 5 Mbit/s) are not required to perform the 500 kbit/s data bit rate tests, because the fundamental 500 kbit/s functionality is implicitly tested through the arbitration phase running always with 500 kbit/s. The data bit rate of 2 Mbit/s is used for these devices as standard data rate for all applicable test flows in the 2 Mbit/s reference environment. If those physical layer devices support selective wake-up functionality tolerant to frames in FBFF and FEFF also, additionally the selective wake-up function need to be tested by execution of test flow 5, test flow 6 and test flow 7 with low-power mode with selective wake-up function enabled.

C) Physical layer devices, which support 5 Mbit/s shall be tested using test flow 1 with a data bit rate of 5 Mbit/s in the dedicated 5 Mbit/s reference environment while all other tests are run with 2 Mbit/s in the 2 Mbit/s reference environment. Rationale for this simplification is that the fundamental function of the device is already proven with the 2 Mbit/s test flows and the bit rate of data communication has no impact on the fundamental mode control functions and failure recovery. The 2 Mbit/s reference environment is more complex and as such regarded to represent a more severe use case in the scope of interoperability. Due to redundancy flow 1 is only executed with 5 Mbit/s according below table. If those physical layer devices support selective wake-up functionality tolerant to frames in FBFF and FEFF also, additionally the selective wake-up function need to be tested by execution of test flow 5, test flow 6 and test flow 7 with low-power mode with selective wake-up function enabled.

D) Physical layer devices, which support signal improvement capability shall be tested using test flow 1 and flow 8 with a data bit rate of 2 Mbit/s or 5 Mbit/s in the dedicated signal improvement reference environment depending on the maximum supported bit rate while all other tests are run with 2 Mbit/s in the 2 Mbit/s reference environment. Rationale for this simplification is that the fundamental function of the device is already proven with the 2 Mbit/s test flows and the signal improvement capability has no impact on the fundamental mode control functions and failure recovery. The 2 Mbit/s reference environment is more complex and as such regarded to represent a more severe use case in the scope of interoperability. Due to redundancy flow 1 is only executed with the dedicated signal improvement reference environment according below table. If those physical layer devices support selective wake up functionality tolerant to frames in FBFF and FEFF also, additionally the selective wake up function need to be tested by execution of test flow 5, test flow 6 and test flow 7 with low power mode with selective wake up function enabled. Further the single device test shall be tested.

Table 1: Default test applicability due to device implementation[4]

IUT specification[5]			reference environment					
max. supported data bit rates	**bus wake-up capability**	**signal improvement capability**	**500 kBit/s**	**2 Mbit/s**	**5 Mbit/s**	**2 Mbit/s SIC**	**5 Mbit/s SIC**	**single device test**
< 1 Mbit/s	no	no	TF 1 and TF 2	n.a.	n.a.	n.a.	n.a.	n.a.
	yes	no	TF 1 to TF 7	n.a.	n.a.	n.a.	n.a.	n.a.
2 Mbit/s	no	no	n.a.	TF 1 and TF 2	n.a.	n.a.	n.a.	n.a.
	yes	no	n.a.	TF 1 to TF 7	n.a.	n.a.	n.a.	n.a.
	no	yes	n.a.	TF 2	n.a.	TF 1 and TF 8	n.a.	yes
	yes	yes	n.a.	TF 2 to TF 7	n.a.	TF 1 and TF 8	n.a.	yes
5 Mbit/s	no	no	n.a.	TF 2	TF 1	n.a.	n.a.	n.a.
	yes	no	n.a.	TF 2 to TF 7	TF 1	n.a.	n.a.	n.a.
	no	yes	n.a.	TF 2	n.a.	n.a.	TF 1 and TF 8	yes
	yes	yes	n.a.	TF 2 to TF 7	n.a.	n.a.	TF 1 and TF 8	yes

[4] The bit rate mentioned in this table represents the used data bit rate.
[5] According to the IUT documentation.

5 Tests in homogeneous network

Because of focus on interoperability of transceiver components in system application not just one single transceiver is considered as the IUT but the transceivers in their entirety in a net environment. The transceivers are tested in their entirety of a defined number of transceivers in a defined standardized bus environment, the so called standard net, which is related to the IUT. The definition of the standard net environment considers the most realistic and relevant system operation conditions.

The standard net consists of defined number of nodes, each node consisting of the following well defined components:

- capacitors
- CMCs at specified positions
- transceivers as IUT
- certified CAN-FD controller
- communication software lying above which implements a token passing between the nodes including also possibility of multi casting of messages
- Furthermore each node has a stub, the respective length resulting from a defined total wire length.

5.1 General system configuration

As result of the definition of the variants of the test network reference environments (Table 1), the general system configuration is represented by the following definitions (Table 2).

Table 2: General system configuration for tests in homogeneous network

reference environment	**500 kbit/s**	**2 Mbit/s**	**5 Mbit/s**	**2 Mbit/s SIC**	**5 Mbit/s SIC**
field of application	see 4.2 and Table 1				
composition	Homogeneous				
environmental conditions	temperature = ambient, moisture = ambient				
power supply	13.5 V ± 10 % constant • VBAT according to IUT documentation • VCC according to IUT documentation • VIO according to IUT documentation NOTE: Not every IUT requires all 3 supply voltages; see IUT documentation.				
bus communication	logical ring • node x receives token • node x sends token to logical successor node x + 1 after one circulation of token all nodes transmit one message (arbitration)				

reference environment	500 kbit/s	2 Mbit/s	5 Mbit/s	2 Mbit/s SIC	5 Mbit/s SIC
identifier	respective identifier of node (compare Table 4 communication in logical ring without arbitration and communication in logical ring with arbitration)				
data	logical ring: number of the logical successor, arbitration: no data (compare Table 4 communication in logical ring without arbitration and communication in logical ring with arbitration)				

5.2 System operation vector space (SOVS)

The functionality of an IUT must be tested under conditions which represent real application situations. These system operation conditions are given from experience. To establish however a systematic basis for the derivation of test cases the normal/abnormal system operation conditions are grouped into a system operation vector space (SOVS). The SOVS is given by system vectors. Each vector representing a system operation condition.

SOVS:
{test flow} x {GND shift} x {failure OR availability}

By varying these vectors formally all possible test cases are found. From these test cases the relevant test cases have to be selected. The varied components are indicated by numbers like *A(1… n), B(1…n)* to derive the test case numbers.

5.2.1 Test flows

The single test cases are gathered within main test cases according to test flows between all possible combinations of normal mode and low-power mode. The test flows are described within the corresponding main test case.

The relevant SOVS values are:

Test flow	a =	1:	test flow 1
		2:	test flow 2
		3:	test flow 3
		4:	test flow 4
		5:	test flow 5
		6:	test flow 6
		7:	test flow 7
		8:	test flow 8

5.2.2 GND shift

The relevant SOVS values are:

GND shift	b =	1:	0.0 V ± 10 %
		2:	+1.0 V ± 10 %
		3:	-1.0 V ± 10 %

Location of GND shift: each node against the others, daisy chain like

5.2.3 Failures

The relevant SOVS values are:

Failure	c =	1: CH_OW[6]
		2: CL_OW[7]
		3: CH_VBAT[8]
		4: CL_VBAT
		5: CH_GND
		6: CL_GND
		7: CL_CH
		8: disconnection of one terminating node

5.2.4 Availability

The relevant SOVS values are:

Availability[9]	c =	12: node 1 and node 2
		13: node 1 and node 3
		14: node 1 and node 4
		…
		1n: node 1 and node n
		23: node 2 and node 3
		24: node 2 and node 4
		25: node 2 and node 5
		…
		2n: node 2 and node n
		…
		(n-1)n: node (n-1) and node n

5.2.5 Varying the vectors of the SOVS

The test cases for testing transceivers are resulting from the variation of the vectors of the SOVS. Thus the vectors which have to be varied are: {test flows}, {GND shift} and {failure}.

[6] CH_OW in combination with positive GND shift may cause a structural wake-up condition for the IUT at the transition to low-power mode depending on the relative timing between the nodes in the test system. Therefore, the IUT may or may not be able to enter low-power mode in this specific test case. Both IUT behaviors are accepted and the individual IUT response shall be documented in the test report.

[7] CL_OW in combination with negative GND shift may cause a structural wake-up condition for the IUT at the transition to low-power mode depending on the relative timing between the nodes in the test system. Therefore, the IUT may or may not be able to enter low-power mode in this specific test case. Both IUT behaviors are accepted and the individual IUT response shall be documented in the test report.

[8] CAN bus shall be in permanent dominant state by applying this failure. This may need some additional load CAN_L to GND such as 820 Ω.

[9] 2-combination of a set n $\binom{n}{2}$

The test cases defined in this specification are a selected subset of the test cases resulting from the variation of the vectors above "sufficiently" representing real application situations. The respective variation of the vectors is shown in Table 3.

Table 3: Variation of the vectors of the SOVS

{test flow}		x	{GND shift}		x	{failure}	
						failure applied	
a			b			c	
1	test flow 1		1	0V		1	CH_OW
2	test flow 2		2	+1V		2	CL_OW
3	test flow 3		3	-1V		3	CH_VBAT
4	test flow 4					4	CL_VBAT
5	test flow 5					5	CH_GND
6	test flow 6					6	CL_GND
7	test flow 7					7	CL_CH
						8	disconnection of one terminating node
{test flow}		**x**	**{GND shift}**		**x**	**{availability}**	
a			b			c	
8	test flow 8		1	0V		12	node 1 and node 2
			2	+1V		13	node 1 and node 3
			3	-1V		…	…

The derived test case numbers will be in the form: ***a . b . c.***

5.3 Tester definition

As mentioned above the implementation follows the local test method.

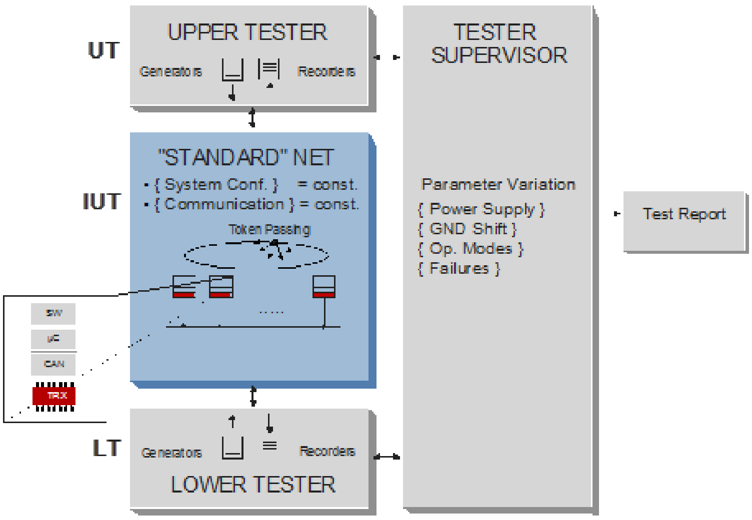


Figure 5-1: Sequential behavior tests with constant standard net environment

The transceivers in their entirety of a net environment are considered as the IUT.

In the following the components of the tester architecture are defined.

5.3.1 Test networks

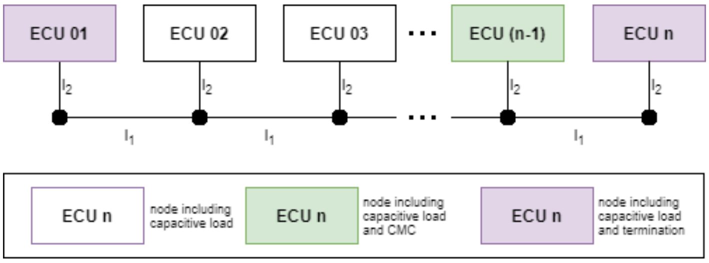


Figure 5-2: Standard net

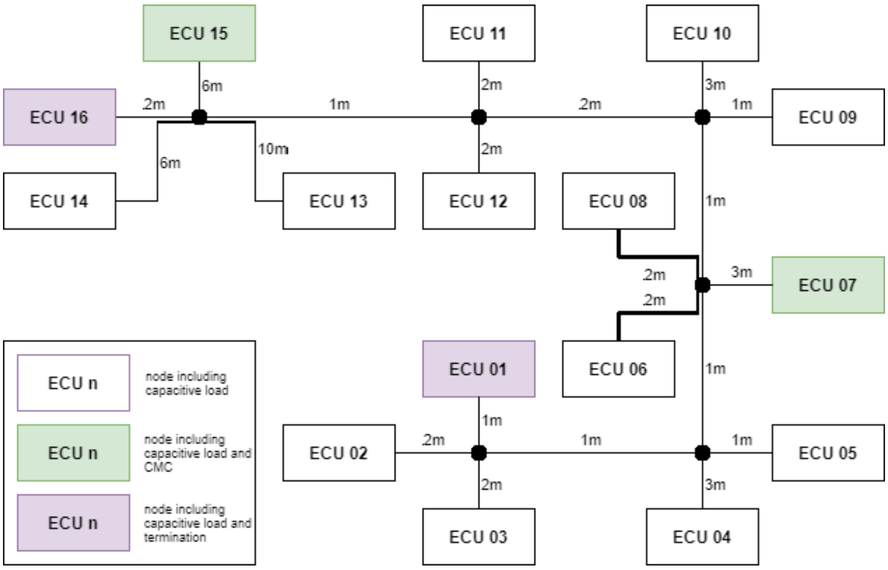


Figure 5-3: 2 Mbit/s SIC net

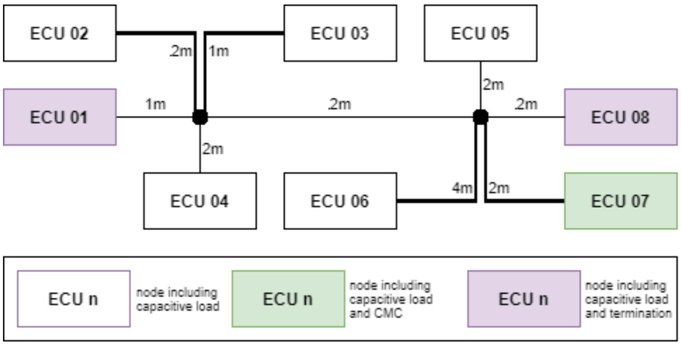
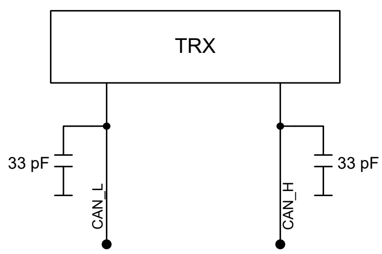


Figure 5-4: 5 Mbit/s SIC net

Table 4: Reference environment and test network configurations for tests in homogeneous network

<table>
<tr><th>reference environment</th><th>500 kbit/s</th><th>2 Mbit/s</th><th>5 Mbit/s</th><th>2 Mbit/s SIC</th><th>5 Mbit/s SIC</th></tr>
<tr><td>test networks</td><td colspan="3">standard net</td><td>2 Mbit/s SIC net</td><td>5 Mbit/s SIC net</td></tr>
<tr><td>number of nodes (#n)</td><td colspan="2">16</td><td>8</td><td>16</td><td>8</td></tr>
<tr><td>definition of µC / board</td><td colspan="4">CAN controller according to ISO 11898-1 [1]</td><td></td></tr>
<tr><td>system clock</td><td colspan="5">40 MHz</td></tr>
<tr><td>BRP</td><td>5</td><td colspan="4">1</td></tr>
<tr><td>bit rate arbitration phase</td><td rowspan="2">500 kbit/s</td><td colspan="4">500 kbit/s</td></tr>
<tr><td>bit rate data phase</td><td>2 Mbit/s</td><td>5 Mbit/s</td><td>2 Mbit/s</td><td>5 Mbit/s</td></tr>
<tr><td>time quanta per bit in arbitration phase</td><td rowspan="2">16</td><td colspan="4">80</td></tr>
<tr><td>time quanta per bit in data phase</td><td>20</td><td>8</td><td>20</td><td>8</td></tr>
<tr><td>sample point in arbitration phase</td><td rowspan="2">13 (81,25% of bit time)</td><td colspan="4">64 (80% of bit time)</td></tr>
<tr><td>sample point in data phase</td><td>14 (70% of bit time)</td><td>5 (62,5% of bit time)</td><td>12 (60% of bit time)</td><td>5 (62,5% of bit time)</td></tr>
<tr><td>SJW in arbitration phase</td><td rowspan="2">3</td><td colspan="4">16</td></tr>
<tr><td>SJW in data phase</td><td>6</td><td>3</td><td>8</td><td>3</td></tr>
<tr><td>TDC mechanism</td><td rowspan="3">n.a.</td><td colspan="4">Active</td></tr>
<tr><td>TDC measurement</td><td colspan="4">Active</td></tr>
<tr><td>SSP offset in data phase</td><td>14 (70% of bit time)</td><td>5 (62,5% of bit time)</td><td>12 (60% of bit time)</td><td>5 (62,5% of bit time)</td></tr>
<tr><td>node coupling</td><td colspan="5">Figure 5-5: Not terminated node</td></tr>
</table>

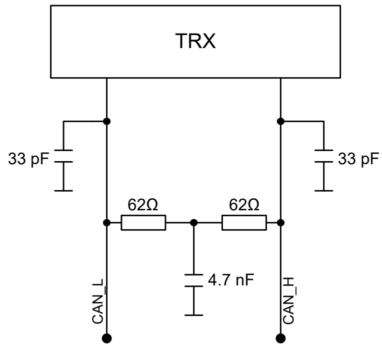
<table>
<tr><th>reference environment</th><th>500 kbit/s</th><th>2 Mbit/s</th><th>5 Mbit/s</th><th>2 Mbit/s SIC</th><th>5 Mbit/s SIC</th></tr>
<tr><td>node coupling inclusively net termination</td><td colspan="5">

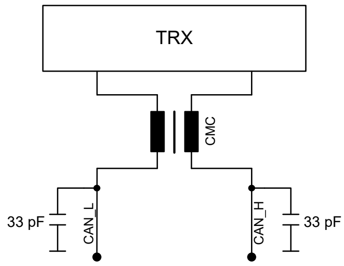
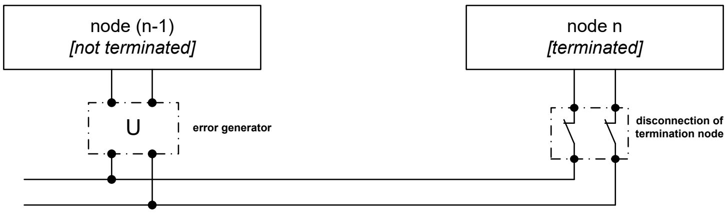
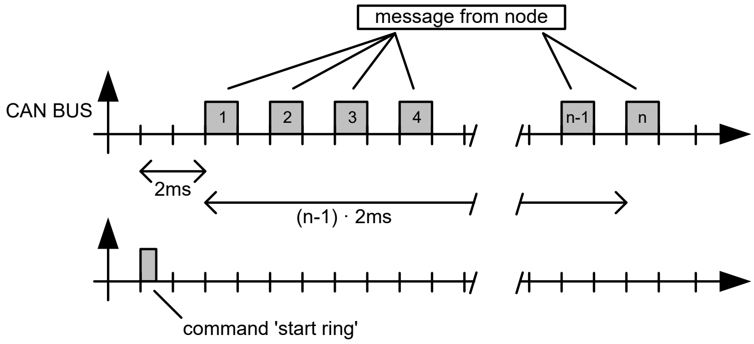
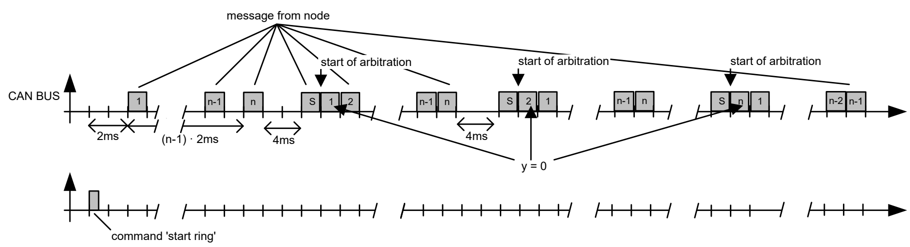
Figure 5-6: Terminated node</td></tr>
<tr><td>node coupling inclusively CMC</td><td colspan="5">

Figure 5-7: Node with CMC</td></tr>
<tr><td>wire of the CAN lines</td><td colspan="5">unshielded twisted pair: FLRYW-A 2 x 0.13 mm²
characteristic impedance: 120 Ω
characteristic dc resistance: 160 mΩ/m
twist lengths: 11 mm</td></tr>
<tr><td>topology</td><td colspan="2">total length:
46 m
stub length (l2):
1 m
distance (l1):
2 m
(Figure 5-2)</td><td>total length:
11 m
stub length (l2): 0,5 m
distance (l1):
1 m
(Figure 5-2)</td><td>Figure 5-3</td><td>Figure 5-3</td></tr>
<tr><td>termination</td><td colspan="5">split termination of 2 x 62 Ω with 4.7 nF to GND</td></tr>
<tr><td></td><td colspan="2">at nodes #1 and #16</td><td>at nodes #1 and #8</td><td>at nodes #1 and #16</td><td>at nodes #1 and #8</td></tr>
<tr><td>external node capacity</td><td colspan="5">CAN_L to GND of 33 pF and CAN_H to GND of 33 pF at all nodes</td></tr>
<tr><td>CMC</td><td colspan="5">TDK ACT1210R-101-2P</td></tr>
<tr><td></td><td colspan="2">at nodes #7 and #15</td><td>at node #7</td><td>at nodes #7 and #15</td><td>at node #7</td></tr>
<tr><td>GND shift</td><td colspan="5">each node against the other nodes, permutable</td></tr>
<tr><td>position of failures</td><td colspan="5">• bus failures are positioned in the stub of node #(n-1)</td></tr>
</table>

reference environment	500 kbit/s	2 Mbit/s	5 Mbit/s	2 Mbit/s SIC	5 Mbit/s SIC
and disconnection of terminating node	• disconnection of termination node is located at node #n  Figure 5-8: Location of failures				
communication in logical ring without arbitration	If a node gets a start command for the logical ring, a timer is started. Depending on the number of the node, the node starts its ring message after node_number * 2 ms  **Figure 5-9: Definition of communication: logical ring** definition of CAN message for the logical ring: • ID: 00xxxxx1110b (standard identifier - 11Bit). The number xxxxx is reserved for each node •				
	• DLC=1	• DLC=15			
	CAN DATA: 21 bytes consisting 55h, 21 bytes consisting 00h, 21 bytes consisting FFh and 1 byte consisting number of the next node				
communication in logical ring with arbitration	If a node gets a start command for the logical ring with arbitration, a ring is started as per description in logical ring without arbitration. 4 ms after the end of the ring an arbitration sequence is started. Node 1 sends a single message for synchronization purposes. Within this message is on the bus all nodes set a transmission request. The identifiers for the arbitration message are the same as the identifiers for the logical ring. On the bus the messages appear in order from node 1 to node #n.  **Figure 5-10: Definition of communication: logical ring with following arbitration** definition of CAN message for arbitration:				

reference environment	500 kbit/s	2 Mbit/s	5 Mbit/s	2 Mbit/s SIC	5 Mbit/s SIC
	• ID: y0xxxxx1110b (standard identifier - 11Bit). The number xxxxx is reserved for each node The number y is set dominant for the node which shall win the arbitration, for all other nodes y is set recessive. • DLC=0 DATA: --				

5.3.2 Upper tester

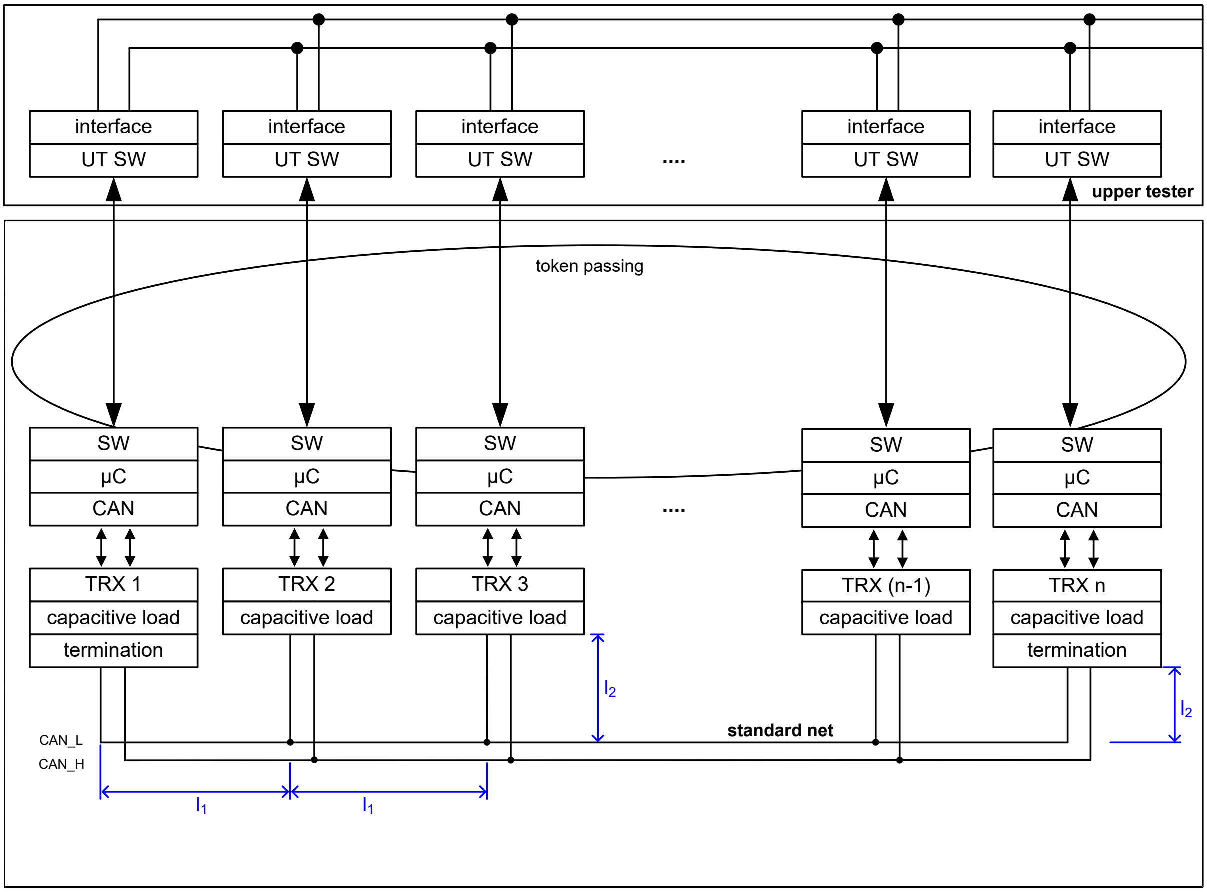


Figure 5-11: Upper tester

Control and observation of the upper service boundary of the IUT is provided by the UT. The generators and recorders of the UT have the following functions:

- handling CAN
- handling IUT specific signals resp. their emulation of for instance EN, ERR, STB, INH, WAKE, CAN error counter TEC / REC, BUS OFF flag, communication
- changing op. modes of transceivers
  Location of node which initiates wake-up via bus: each node against the others, daisy chain like

5.3.3 Lower tester

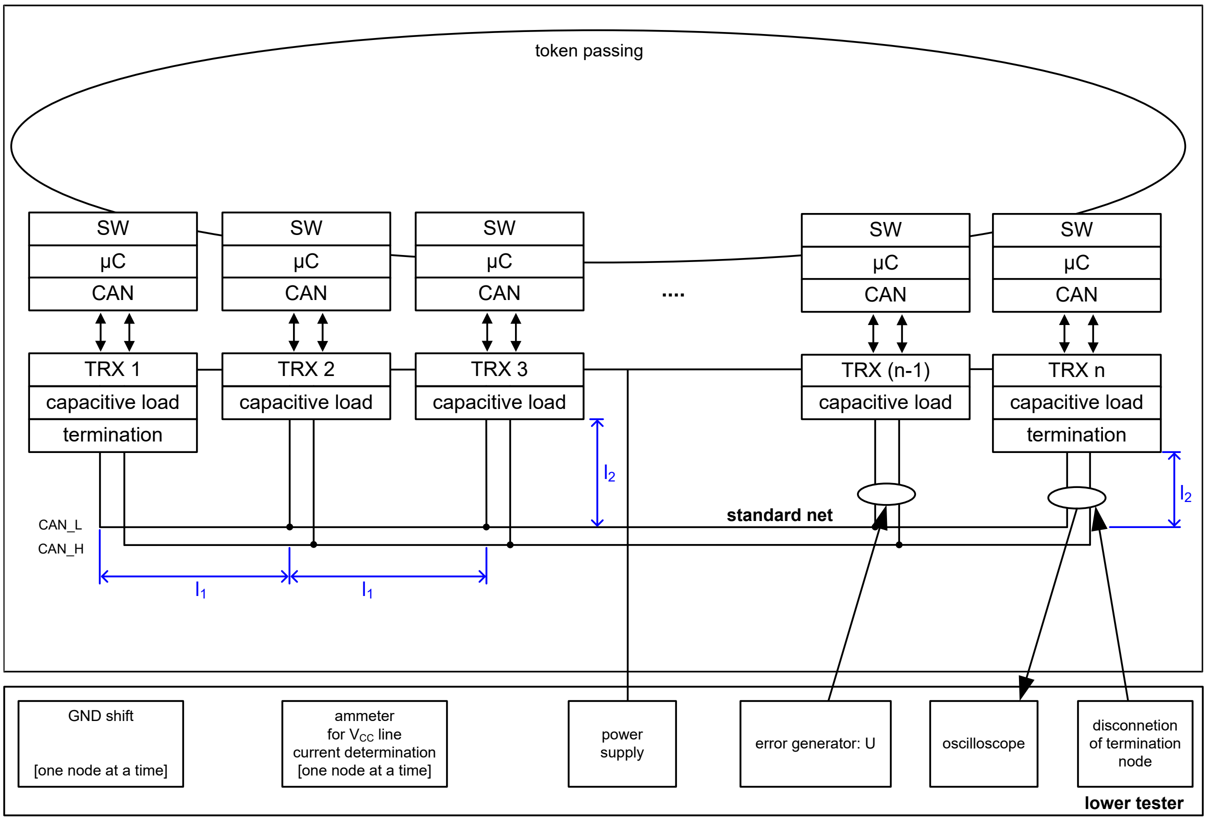


Figure 5-12: Lower tester

Indirect control and observation of the lower service boundary of the IUT via the underlying service provider is provided by the LT. The generators/recorders of the LT have several functions:

- generating and controlling bus failures
- generating GND shift
- current measurement to check the present state of the transceivers

The LT offers the following bus failures:

- Short circuit between CAN_H and VBAT

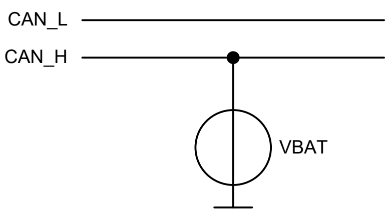


Figure 5-13: Short circuit CH_VBAT

- Short circuit between CAN_L and VBAT

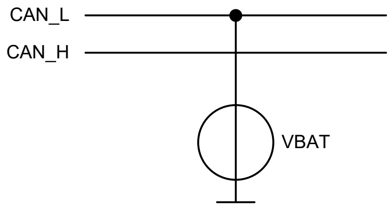


Figure 5-14: Short circuit CL_VBAT

- Short circuit between CAN_H and GND

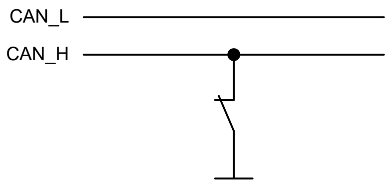


Figure 5-15: Short circuit CH_GND

- Short circuit between CAN_L and GND

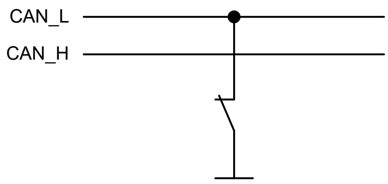


Figure 5-16: Short circuit CL_GND

- Short circuit between CAN_H and CAN_L

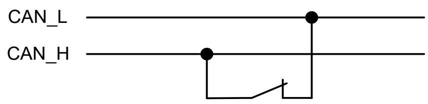


Figure 5-17: Short circuit between CL_CH

- Open CAN_H line

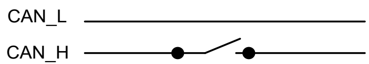


Figure 5-18: Open wire CH_OW

- Open CAN_L line

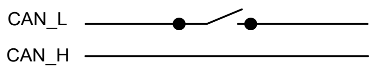


Figure 5-19: Open wire CL_OW

- Disconnection of termination node

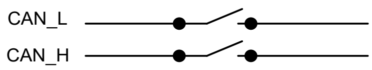


Figure 5-20: Disconnection of termination node

5.3.4 Supervisor

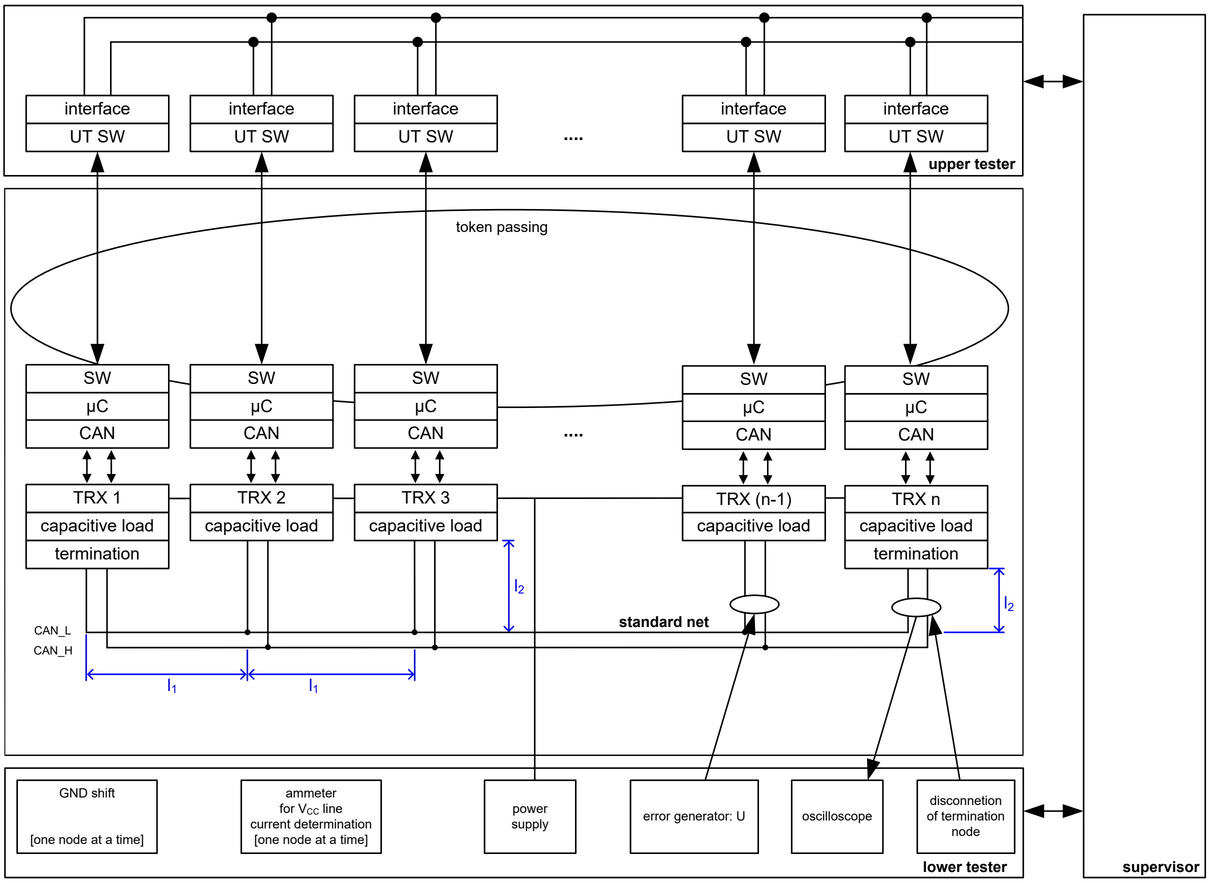


Figure 5-21: Supervisor

To coordinate the test procedures the SV offers several services:

- SV sets IUT to a defined initial state according to specification of test case TestCaseNumber by using dedicated services of UT and LT
- SV starts execution of test case TestCaseNumber according to specification by using dedicated services of UT and LT
- SV records behaviour of IUT while executing test

- SV uploads the information from the recorders and comparison of recorded behaviour with the expected response according to specification of test case TestCaseNumber
- SV generates a test report with relevant information and test verdict

5.4 Test Cases

Within this chapter the test cases related to the homogeneous network tests are described. The test cases are gathered within 8 main test cases according to different flows between all possible combinations of normal mode and low-power mode with and without failures:

- Op. mode variation after recovery at normal mode, failure application on startup
- Op. mode variation after recovery at normal mode, failure application in normal mode
- Op. mode variation before recovery at normal mode, failure application in normal mode
- Op. mode variation with failure before recovery at normal mode, failure application on startup
- Op. mode variation with failure before recovery at low-power mode, failure application in normal mode
- Op. mode variation with failure before recovery at low-power mode, failure application in low-power mode
- Op. mode variation with failure before recovery at normal mode, failure application in low-power mode
- All except two nodes in unpowered state. Both powered nodes have to transmit dedicated frames and to receive all transmitted frames. No failure application.

Within each main test all failures according to 5.2.3 and all GND shift scenarios according to 5.2.2 will be applied. The possible combinations are disclosed in 5.2.5.

Each specification of a test case within this document consists of three parts:

- test configuration (initial state)
  Defines to what state the IUT must have been set before starting the execution of the test steps.
- test steps
  Defines the way of stimulating the IUT.
- response
  Defines the expected behaviour of the IUT when executing the test steps.

5.4.1 Op. mode variation after recovery at normal mode, failure application on startup

5.4.1.1 General test description

Within the sub tests of the main test "op. mode variation after recovery at normal mode, failure application on startup" the test flow 1 (Figure 5-22) will be obeyed.

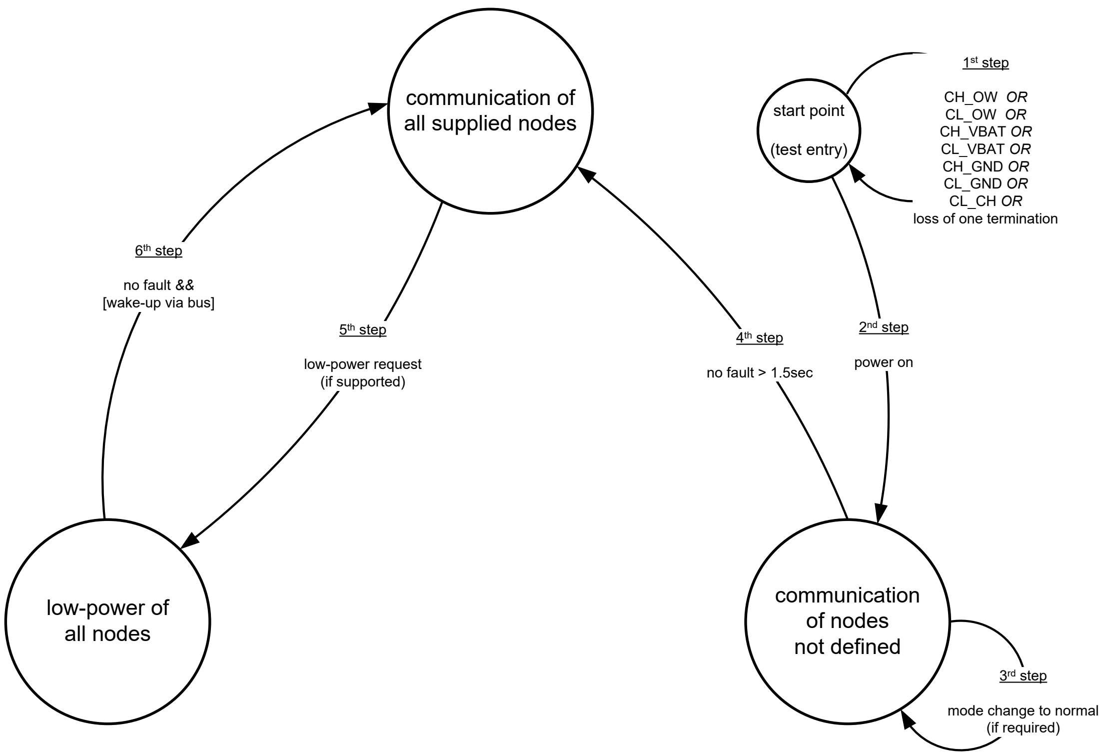


Figure 5-22: Test flow 1 –
Op. mode variation after recovery at normal mode, failure application on startup

5.4.1.2 Response for test flow 1

1. After finishing test flow step 4 all nodes have to transmit dedicated frames and to receive all transmitted frames
2. After finishing test flow step 5 low-power mode has to be detected at all nodes
3. After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames.

All designated points have to be fulfilled

5.4.1.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.2 Op. mode variation after recovery at normal mode, failure application in normal mode

5.4.2.1 General test description

Within the sub tests of the main test "op. mode variation after recovery at normal mode, failure application in normal mode" the test flow 2 (Figure 5-23) will be obeyed.

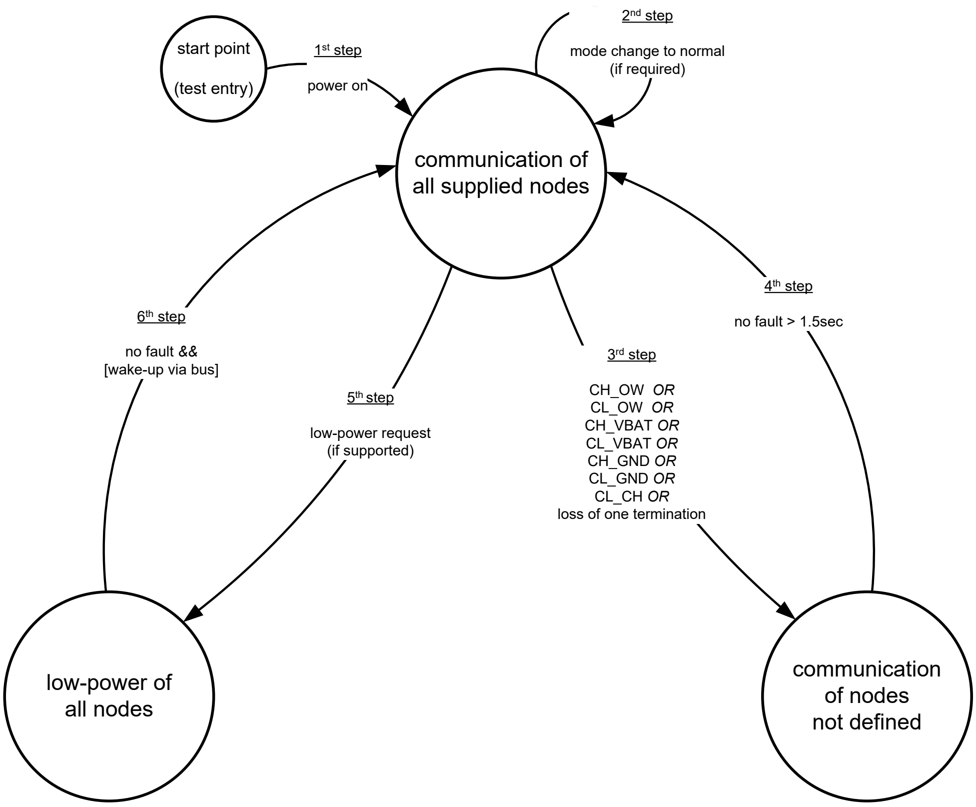


Figure 5-23: Test flow 2 –
Op. mode variation after recovery at normal mode, failure application in normal mode

5.4.2.2 Response for Test Flow 2

1. After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2. After finishing test flow step 4 all nodes have to transmit dedicated frames and to receive all transmitted frames
3. After finishing test flow step 5 low-power mode has to be detected at all nodes
4. After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.2.3 Sub Test Cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.3 Op. mode variation before recovery at normal Mode, failure application in normal mode

5.4.3.1 General test description

Within the sub tests of the main test "op. mode variation before recovery at normal Mode, failure application in normal mode" the test flow 3 (Figure 5-24) will be obeyed.

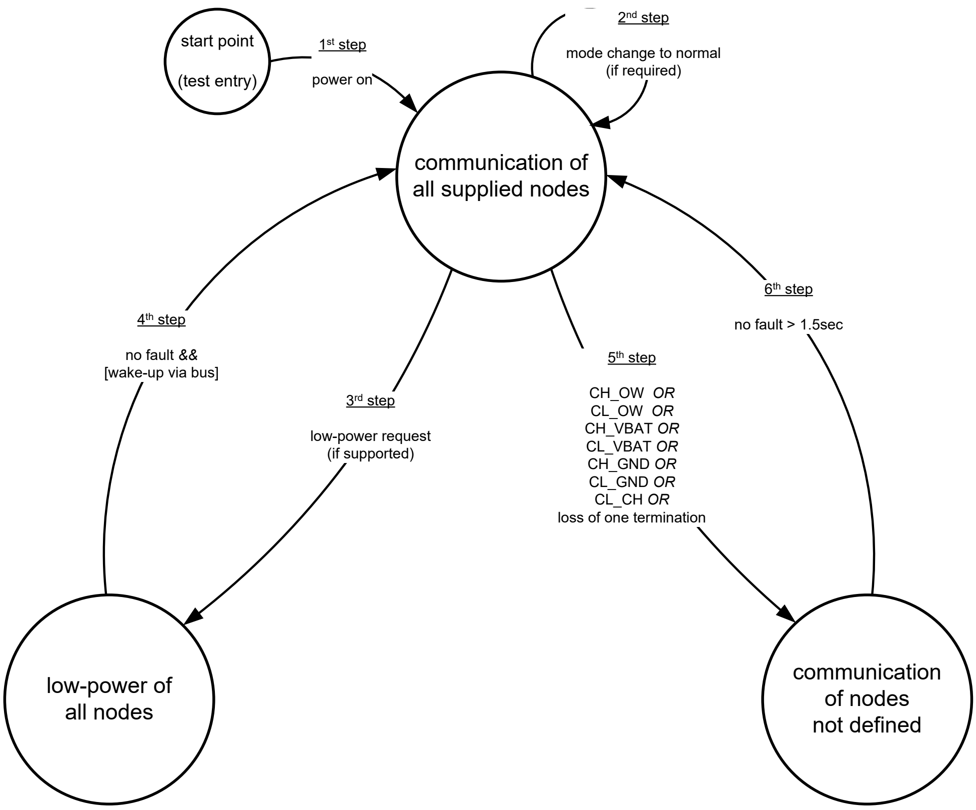


**Figure 5-24: Test flow 3 –
Op. mode variation before recovery at normal Mode, failure application in normal mode**

5.4.3.2 Response for test flow 3

1. After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2. After finishing Test flow step 3 low-power mode has to be detected at all nodes
3. After finishing Test flow step 4 all nodes have to transmit dedicated frames and to receive all transmitted frames
4. After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.3.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.4 Op. mode variation with failure before recovery at normal mode, failure application on startup

5.4.4.1 General test description

Within the sub tests of the main test "op. mode variation with failure before recovery at normal mode, failure application on start-up" the test flow 4 (Figure 5-25) will be obeyed.

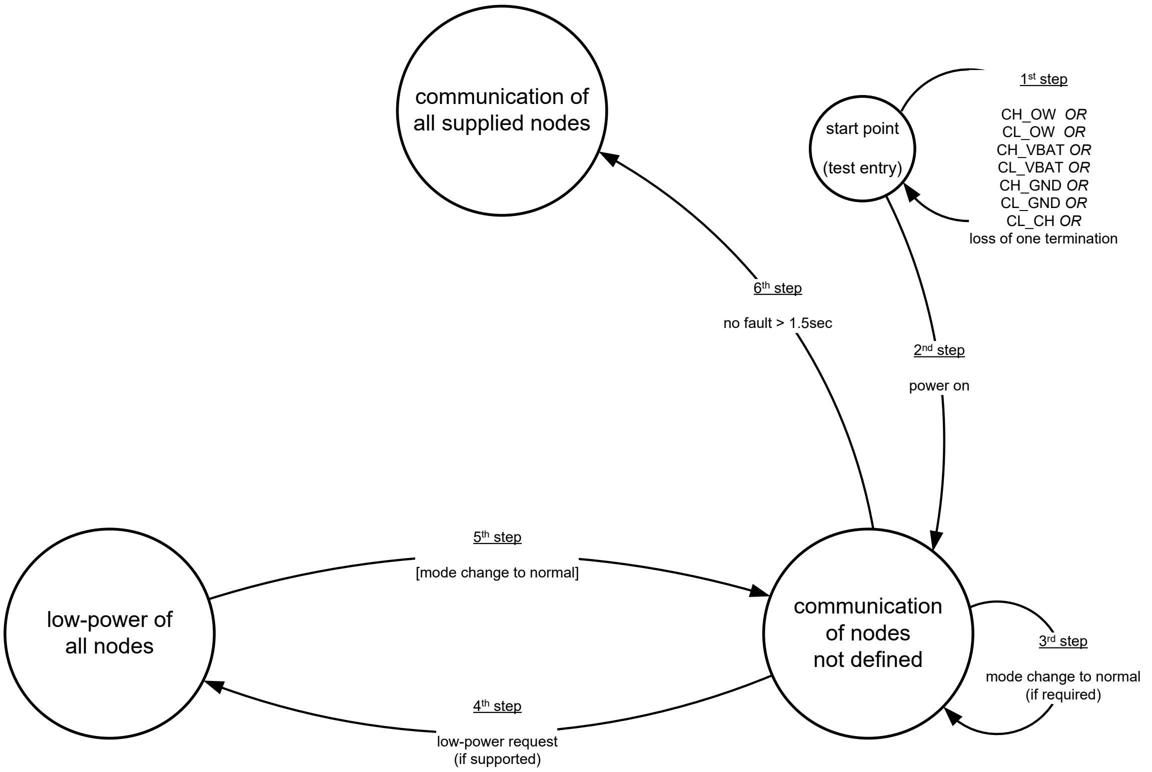


Figure 5-25: Test flow 4 –
Op. mode variation with failure before recovery at normal mode, failure application on startup

5.4.4.2 Response for test flow 4

1 After finishing test flow step 4 low-power mode has to be detected at all nodes
2 After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.4.3 Sub Test Cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.5 Op. mode variation with failure before recovery at low-power mode, failure application in normal mode

5.4.5.1 General test description

Within the sub tests of the main test "op. mode variation with failure before recovery at low-power mode, failure application in normal mode" the test flow 5 (Figure 5-26) will be obeyed.

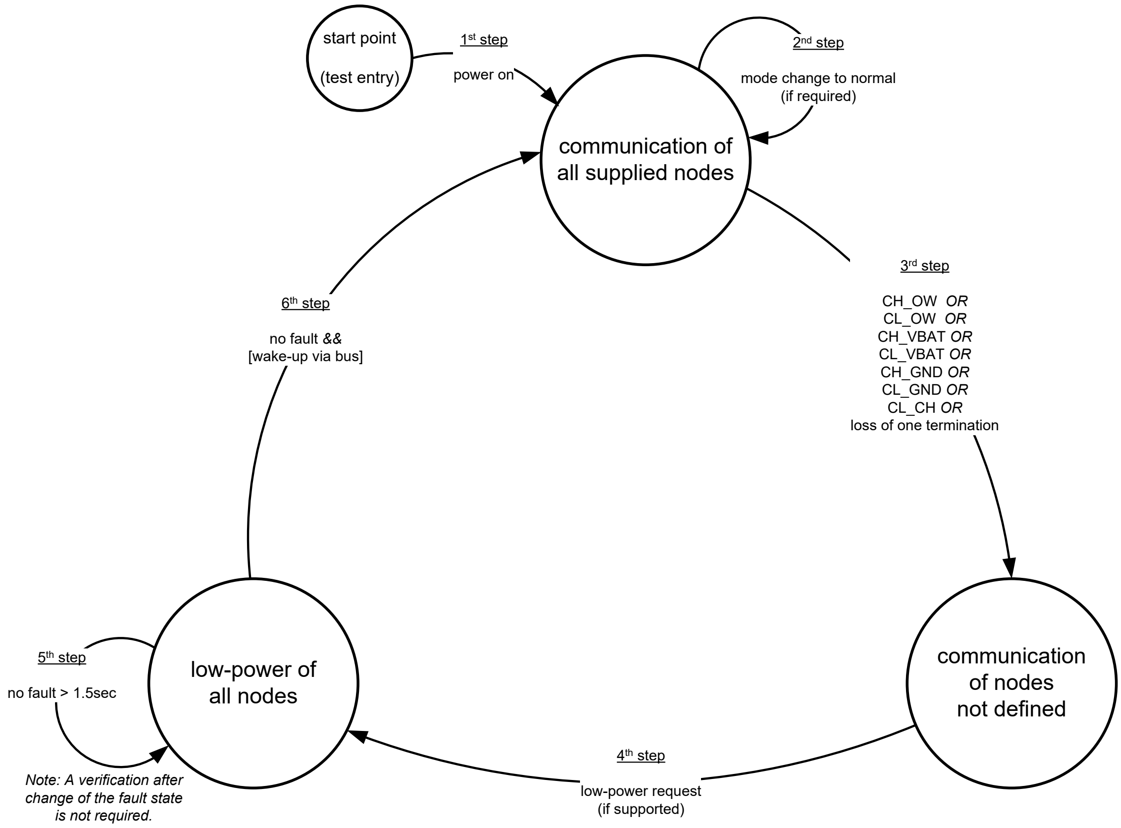


**Figure 5-26: Test flow 5 –
Op. mode variation with failure before recovery at low-power mode, failure application in normal mode**

5.4.5.2 Response for test flow 5

1. After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2. After finishing test flow step 4 low-power mode has to be detected at all nodes
3. After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.5.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.6 Op. mode variation with failure before recovery at low-power mode, failure application in low-power mode

5.4.6.1 General test description

Within the sub tests of the main test "op. mode variation with failure before recovery at low-power mode, failure application in low-power mode" the test flow 6 (Figure 5-27) will be obeyed.

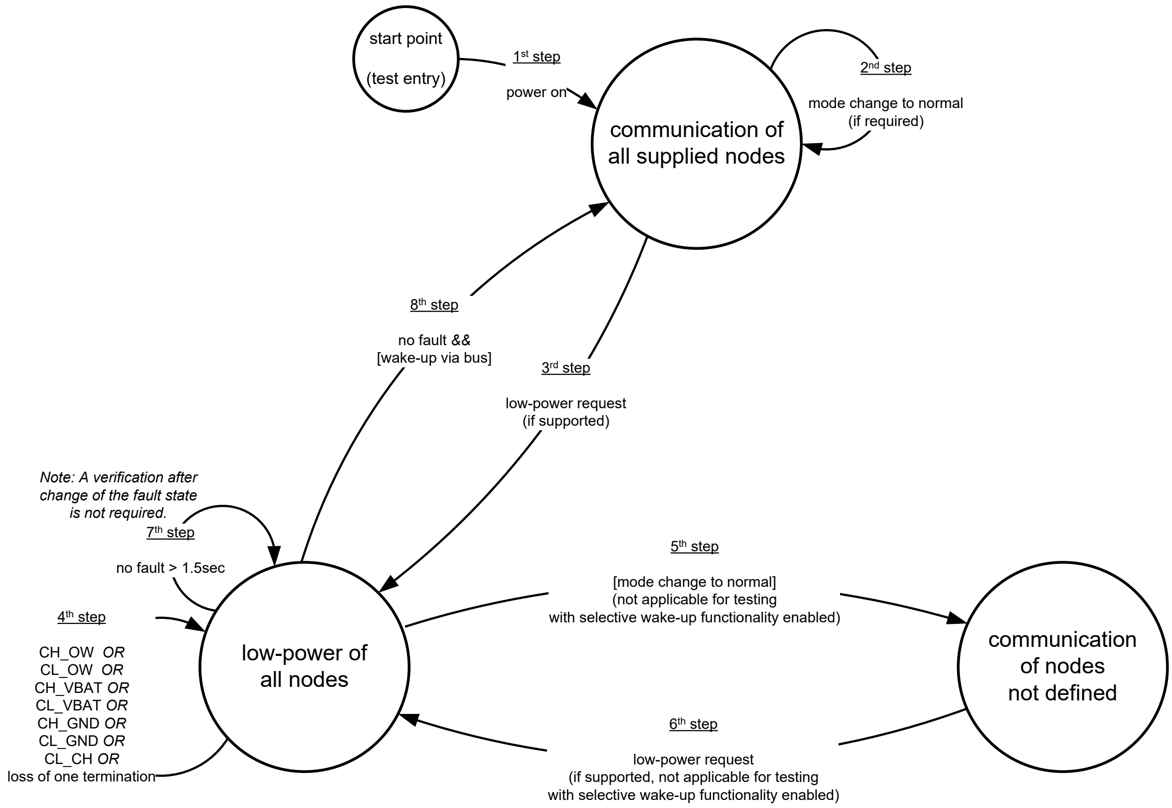


**Figure 5-27: Test flow 6 –
Op. mode variation with failure before recovery at low-power mode, failure application in low-power mode**

5.4.6.2 Response for test flow 6

1 After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2 After finishing test flow step 3 low-power mode has to be detected at all nodes
3 After finishing test flow step 6 low-power mode has to be detected at all nodes
4 After finishing test flow step 8 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.6.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.7 Op. mode variation with failure before recovery at normal mode, failure application in low-power mode

5.4.7.1 General test description

Within the sub tests of the main test "op. mode variation with failure before recovery at normal mode, failure application in low-power mode" the test flow 7 (Figure 5-28) will be obeyed.

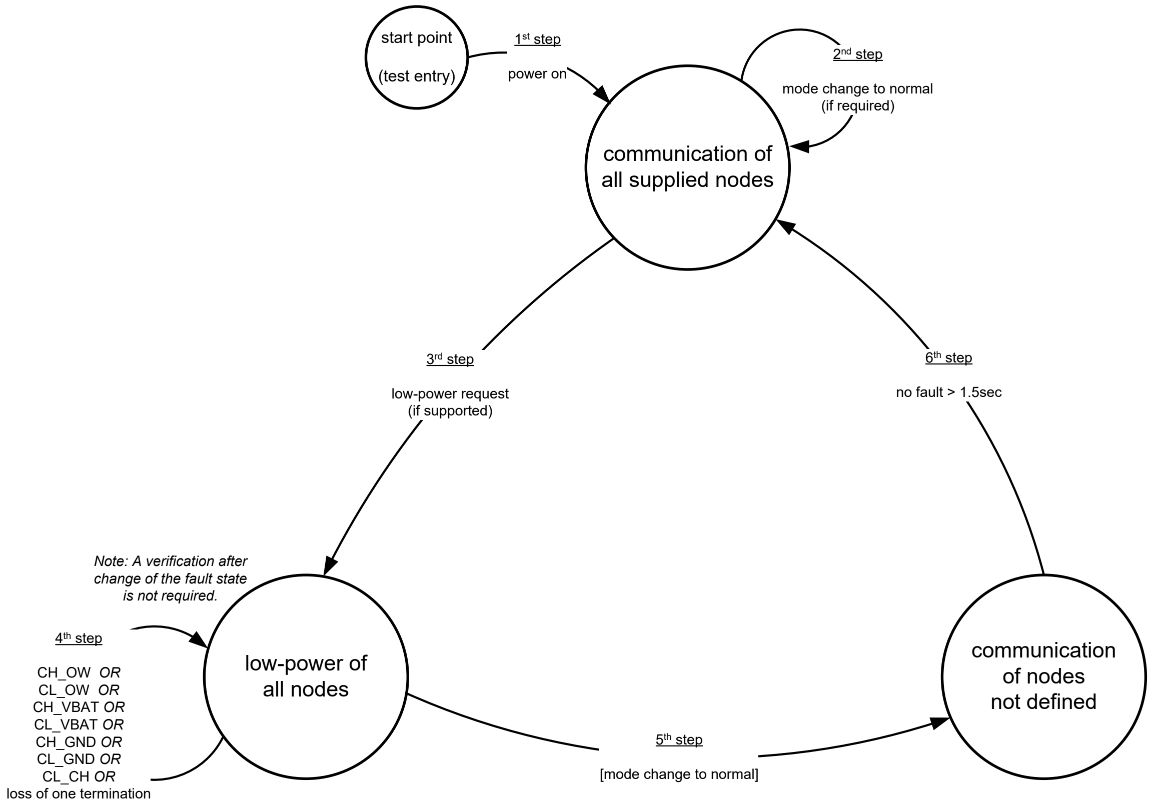


**Figure 5-28: Test flow 7 –
Op. mode variation with failure before recovery at normal mode, failure application in low-power mode**

5.4.7.2 Response for test flow 7

1 After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2 After finishing test flow step 3 low-power mode has to be detected at all nodes
3 After finishing test flow step 6 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.7.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

5.4.8 Communication of two powered nodes without failure application.

5.4.8.1 General test description

Within the sub tests of the main test "communication between two nodes at normal and remaining nodes in unpowered mode without failure application" the test flow 8 (Figure 5-29) will be obeyed.

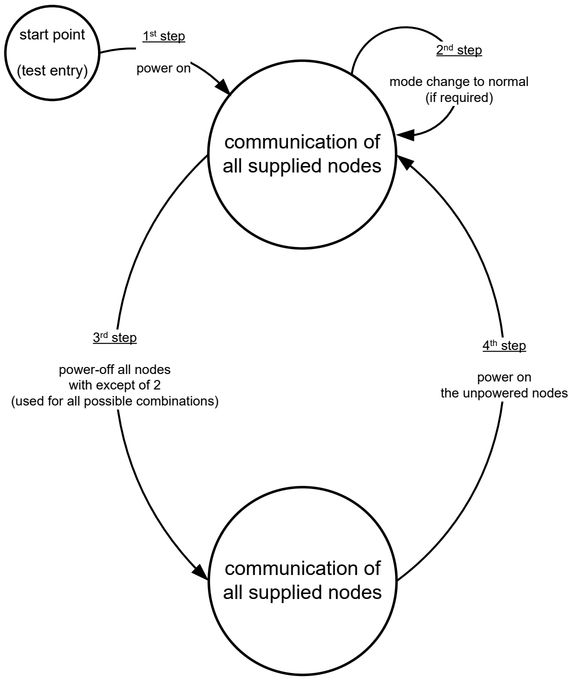


Figure 5-29: Test flow 8 –
Communication between two nodes at normal and remaining nodes in unpowered mode without failure application

5.4.8.2 Response for test flow 8

1 After finishing test flow step 2 all nodes have to transmit dedicated frames and to receive all transmitted frames
2 After finishing test flow step 3 two powered nodes have to transmit dedicated frames and to receive all transmitted frames
3 After finishing test flow step 4 all nodes have to transmit dedicated frames and to receive all transmitted frames

All designated points have to be fulfilled

5.4.8.3 Sub test cases

The sub test cases are composed corresponding to 5.2.5. The test case number is represented by the SOVS.

6 Tests in heterogeneous network – mixed

Introduction to this corresponds with introduction to 5, except transceivers which are IUT as well as reference devices see 6.1.

6.1 General system configuration

All definitions and specifications in table 2 apply with the modifications in table 5.

Table 5: Delta reference environment for tests in heterogeneous network

reference environment	**500 kbit/s and 2 Mbit/s**	**5 Mbit/s**	**2 Mbit/s SIC**	**5 Mbit/s SIC**
composition	heterogeneous			
position reference devices	The positions of the reference devices are defined as follows:			
	see Table 6	see Table 7	see Table 6	see Table 7
	NOTE: {A, B,…,E} are identifiers for used reference devices, see below			
reference devices for testing <u>without</u> selective wake-up functionality available or enabled	**2xA:** TJA1044GT **3xB:** TJA1043T **2xC:** TLE9252 **2xD:** TLE9255WSK **3xE:** TLE9251	**1xA:** TJA1044GT **2xB:** TJA1043T **1xC:** TLE9252 **2xD:** TLE9251	**2xA:** **3xB:** **2xC:** **2xD:** **3xE:**	**1xA:** **2xB:** **1xC:** **2xD:**
reference devices for testing <u>with</u> selective wake-up functionality available	**2xA:** TJA1145T/FD **3xB:** TLE9255WSK **2xC:** UJA1168ATK/FD **2xD:** MLX80070LDC **3xE:** ATA6570	NOTE: currently no devices available		

Table 6: Positions of the reference devices in 500 kbit/s and 2 Mbit/s reference environments

Node:	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**
TRX:	B	A	**IUT**	C	E	D	**IUT**	B	E	A	**IUT**	B	C	D	**IUT**	E

Table 7: Positions of the reference devices in 5 Mbit/s reference environments

Node:	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
TRX:	A	B	**IUT**	C	B	D	**IUT**	D

6.2 System operation vector space (SOVS)

Corresponds fully with 5.2 inclusive all sub chapters.

6.3 Tester definition

Corresponds fully with 5.3 inclusive all sub chapters.

6.4 Test cases

The test cases which are executed in the heterogeneous network are the same test cases which are executed in the homogeneous network 5.4.

7 Single device tests

In order to check the specific functionality such as signal improvement capability (SIC) of transceivers in meaning of HS PMA [2] or equivalent devices e.g. SBC the single device tests are defined.

7.1 General system configuration

As result of the definition of four variants of the standard net reference environment (Table 1), the general system configuration for single device tests is represented by the following definitions (Table 8). Only applicable for signal improvement reference environment.

Table 8: Reference environment for single device tests[11]

reference environment	signal improvement
field of application	see 4.2 and Table 1
used data bit rate	
topology	ringing network
number of nodes (#n)	1
environmental conditions	temperature = ambient, moisture = ambient
power supply	As defined within the IUT data sheet
data	According to HS-PMA implementation timing diagram (source: ISO 11898-2:2016 [2])

7.2 Tester definition

As mentioned above the implementation follows the local test method.

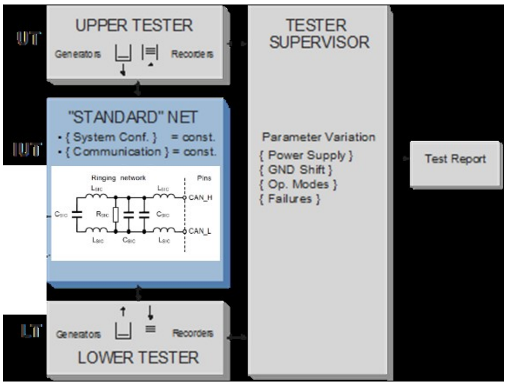
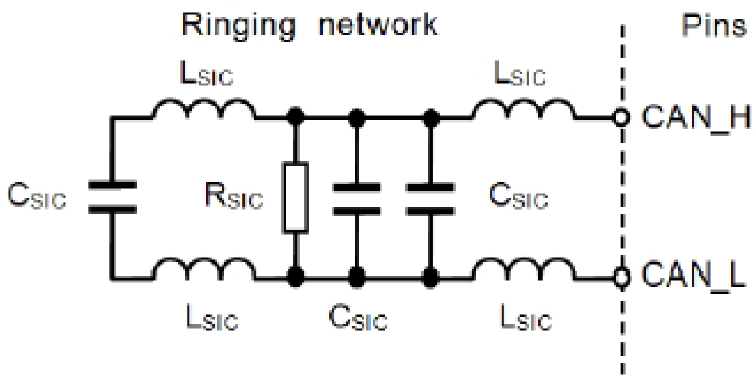


Figure 7-1: Sequential behavior tests with constant standard net environment

[11] All not listed parameter are not applicable.

The transceivers in their entirety of a net environment are considered as the IUT.
In the following the components of the tester architecture are defined.

7.2.1 Test networks



Key
C_{SIC} capacitor C = 220 pF ± 1 %
L_{SIC} Inductor L = 3 µH ± 5 % (RDC ≤ 4 Ω)
R_{SIC} resistor R = 60 Ω ± 1 %

Figure 7-2: Ringing network

Table 9: Standard net configuration for single device tests[12]

reference environment	signal improvement
number of nodes (#n)	see 7.1, Table 8
node coupling	see Figure 7-2
topology	see Figure 7-2

7.2.2 Upper tester

Control and observation of the upper service boundary of the IUT is provided by the UT. The generators and recorders of the UT have the following functions:

- handling IUT specific signals resp. their emulation of for instance EN, ERR, STB, INH, WAKE, CAN error counter TEC / REC, BUS OFF flag, op. modes of transceivers, communication

[12] All not listed parameter are not applicable.

7.2.3 Lower tester

Observation of the lower service boundary of the IUT via the underlying service provider is provided by the LT. The recorders of the LT have several functions:

- observation of the bus signal

7.2.4 Supervisor

To coordinate the test procedures the SV offers several services:

- SV sets IUT to a defined initial state according to specification of test case TestCaseNumber by using dedicated services of UT and LT
- SV starts execution of test case TestCaseNumber according to specification by using dedicated services of UT and LT
- SV records behavior of IUT while executing test
- SV uploads the information from the recorders and comparison of recorded behavior with the expected response according to specification of test case TestCaseNumber
- SV generates a test report with relevant information and test verdict

7.3 Test Cases

Within this chapter test cases related to the single device tests are described.

7.3.1 SIC test on ringing network

7.3.1.1 General test description

Check of the general SIC functionality of the IUT under ringing conditions.

1 Disconnect the IUT to the ringing network.
2 Supply IUT and set to normal operation mode.
3 Apply data on TxD.
4 Observe TxD, RxD and bus signals of the IUT.

7.3.1.2 Response

Record TxD, RxD and bus signals.

8 Static tests

The motivation of static test cases is to check the availability and the boundaries in the data sheet of the IUT.

Table 10: Static test case summary

No.	Parameter	Reference to CiA 601-4 table 2	Limits			Conditions[b]	Conformance test is passed if value		Test case valid for HS-PMA type: [a]			
			Min	Max	Unit		≤	≥	a	b	c	d
1	Signal improvement time TX-based	Parameter 1	n.a.	530	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF			y	y	y	y
2	Signal improvement time Ry-based	Parameter 2	n.a.	450	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF			y	y	y	y
3	Transmitted bit width variation	Parameter 3	-10	10	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max	min	y	y	y	y
4	Received bit width variation	Parameter 4	-30	20	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max	min	y	y	y	y
5	Receiver symmetry	Parameter 5	-20	15	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max	min	y	y	y	y
6	Propagation delay from TxD to bus dominant	Parameter 6	n.a.	80	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max		y	y	y	y
7	Propagation delay from TxD to bus recessive	Parameter 7	n.a.	80	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max		y	y	y	y
8	Propagation delay from bus to RxD dominant	Parameter 8	n.a.	110	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max		y	y	y	y

Table 10: *(continued)*

No.	Parameter	Reference to CiA 601-4 table 2	Limits			Conditions[b]	Conformance test is passed if value		Test case valid for HS-PMA type: [a]			
			Min	Max	Unit		≤	≥	a	b	c	d
9	Propagation delay from bus to RxD recessive	Parameter 9	n.a.	110	ns	R_L = 60 Ω; C_1 = 0 pF; C_2 = 100 pF, C_{RxD} = 15 pF	max		y	y	y	y

a HS-PMA types: a - without low-power mode and partial network, b - with low-power mode, normal biasing and without partial network, c - with low-power mode, automatic biasing and

b Parameters within the conditions are aligned with ISO 16845-2:2018 Figure 4 [4] for test.

9 Lists

9.1 List of figures

9.2 List of tables

9.3 Revision history

Revision		Date	Changes applied
from	to		
00	01	2017-02-06	Normative references [2] and [4] updated according to new official revisions.
			Table 5 column “reference environment”: “without … functionality enabled” changed to “without … functionality available or enabled” and “with … functionality enabled” changed to “with … functionality available”. Further testing definitions for selective wake up function is specified within the “dynamic test plan” section.
			Improvement of the introductory text in section 6.1 for a better understanding.
			Cancellation of the line CMC in Tables 6 and 7 because of redundant information to table 2 (double specification).
			Improvement of the text in section 6.2 for a better understanding.
			Improvement of the text in section 6.3 for a better understanding.
			Cancellation of misleading document reference in the list in section 5.
01	02	2018-03-23	5.2.3 Failures additional test requirement for failure 3 CH_VBAT added, due to current ISO 11898-2:2016 input resistance range definition.
		2019-03-01	Recommendation for additional load CAN_L to GND defined to 820 Ω.
		2020-05-18	Update of section 5.2.3 Failures by including footnotes explaining relationship between OW_C/L failures and GND-Shift.
		2020-05-18	Extended in order to cover devices with additional signal improvement capability.