Interoperability challenges for CAN FD/PN transceivers: Lessons learned from CAN high speed interoperability tests

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In 2012, Bosch has released the first version of the CAN FD protocol specification to fulfill the increasing demands for bandwidth and cost efficient communication protocols. The first CAN FD transceivers, supporting communication in the CAN FD fast phase at higher data rates, are already available on the market.
New automotive functionalities are required without putting the expected interoperable behavior in risk. After having addressed CAN FD conformance testing in the new international standards, ISO 16845 1 and ISO 16845 2; requirements from OEMs and silicon vendors were collected and aligned, and test cases have been drafted and specified to enable interoperability of CAN FD transceivers in a multi-vendor environment. The first release of the Interoperability test specification for high speed CAN transceiver or equivalent devices [1] was published in 2016.
This paper discloses lessons learned from CAN high speed interoperability tests and gives insight into interoperability aspects dealing with higher data rates communications and, additionally, coexistent scenarios considering CAN FD transceivers and CAN transceivers with selective wake up capability representing used cases intended to be adopted by some carmakers.
This presentation will convey a detailed overview of the new interoperability test specification in conjunction with the respective test system implementation.

Automotive standards are created to improve quality, facilitate innovation and increase speed-to-market, but the major motivation is the costs reduction achieved through multiple supplier solutions and cost sharing among car makers, Tier-1s and suppliers. One of the main problems that often arises is that these standardized specifications are ambiguous or not spelled out clear enough and designers disagree on what is meant by their requirements.

But the network design needs to guarantee interoperability of all network components in order to ensure correct system behavior. To achieve this, some basic assumptions are required, e.g. that the standardized components behave as expected (as standardized). If this is not assured, one can never know what the actual source of error in a complex in vehicle network system is.

If there is a system of more than one node, even if it is a small vehicle network, the purpose of that system is not only to exchange information but to provide certain system functionality. It is important to have reliable components that are approved, that actually do what they are supposed to do.

Conformance tests can certainly not totally guarantee interoperability, but it can safeguard and drastically increase the chance of interoperability in a system with appropriate test coverage. If a standard defines interoperable components (i.e. does not prevent interoperability by specification bugs), the conformance test assures that all implementations to that standard passing the conformance test are most possibly interoperable, even in corner conditions – as such situations can also be tested in the conformance test.

Devices designed to the common standard depend on clarity of the standard, but there may be discrepancies in their implementations that conformance testing may not uncover. This requires the systems, formally be tested in a target scenario – as they will be finally implemented – to ensure they actually will intercommunicate as advertised, i.e. they are interoperable. Interoperability testing is different from conformance testing as conformance to a standard does not necessarily engender interoperability with another product which is also tested for conformance.

What are the differences between conformance and interoperability testing?

The basic idea of conformance testing is testing to determine whether a product or system meets some specified standard that has been developed for efficiency or interoperability. The basic requirement for an application of a conformance test is that a specified standard exists. This could be each kind of standard, even minor company-specific standards. Even if the conformance test can also be applied if only a single implementation according to a standard exists, a typical conformance test is only considered in case that there are more than one implementations, usually also from different implementers. Only this fact creates a situation where different implementations could be combined into a single system or network. Only that combination bears the risk of troubles in case of deviations between the different implementations.

Fundamentals of interoperability testing:

- To apply conformance testing, a specified standard must exist.
- Different implementations of a standard are existing or planned.
- The conformance test does not ensure the quality of the specified standard it-self; it verifies the adherence of implementations of the standard to the standard.

Interoperability is a property referring to the ability of diverse products or systems to work together (to be able to interact, to communicate).

Fundamentals of interoperability testing:

- Interoperability is a property that is based on intended functional.
  - Relevant, if multiple entities shall interoperate.
  - Standards shall describe interoperable products and systems, i.e. the intended functional behavior.
- Consequently, interoperability is the result of adherence of implementations regarding the standard.

Interoperability – problem description

It can be assumed that a solution of a single supplier, even if it would not adhere to the specified standard, is basically interoperable with other implementations of the same kind. If all share the same non-standardized behavior, they have a good chance to „interact“ apparently correctly. But if another implementation is introduced, a non-standardized behavior of an implementation might prevent the expected (specified) behavior in certain situations that are difficult to find in system-level tests and by try-outs. Therefore, the conformance test and the interoperability test need to be considered in case of multi-supplier solutions.

If multiple suppliers create products or components based on the same specified standard, there is unfortunately a certain chance to create implementation containing deviations. Of course, each supplier has got own ideas on how to realize a product. Of course, all of them consider the specified standard. But, due to the fact that everybody has got a specific knowledge and a specific idea on the product, different suppliers may read the specified standard differently (Figure 1). Everybody might know that a message, a note or a text can be read by different people, resulting in different interpretations. This is even possible in very simple messages like „Buy some bread when you come home.“ Unfortunately, human language is very imprecise by nature: How much is „some bread“ – 200 g, 500 g, 1000 g?, what kind of bread – white, grey, soft, with wheat, grains?, what time will you come home – do you have to be there at a certain time?

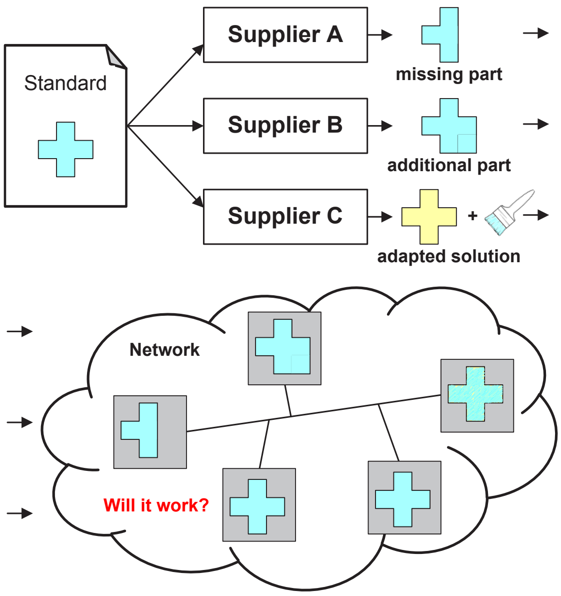

Figure 1: Multi-Supplier-Solution

Interoperability – ways to achieve it

The goal of all network and application designers is certainly interoperability and a correct application and system behavior. To achieve interoperable nodes in a system and thereby a running and stable system, different approaches are theoretically applicable.

The first, and maybe most established way, is to build up specific systems out of components to a specified standard and test the overall system for a proper operation. In this case, it is just assumed that the sub-components are working as expected (as specified). Such tests are performed on the system level and typically care for the behavior of the application that is realized by a distributed system. The benefit is that such tests can be set up quite easy, by a simple mock-up. The disadvantages are that each system and each system option needs to be set up, needs to be tested. In addition, corner cases cannot be injected easily into a fixed system, as there are many fixed and pre-defined parameters. The whole system and all included components are tested in that specific scenario, without variation and only with one fixed configuration. To consider all design options and all potential extensions of a system in the future is rather neither easy nor feasible in terms of the testing effort. In addition, system-level tests typically do not focus on the correct behavior of system components, but on the overall system. The wider the focus is, the more difficult it is to find out the actual source of error if something goes wrong.

Another option would be to check the ability to interact with all combinations of devices. But, the mathematical representation of all combinational options increases rapidly with more available implementations to a specified standard. As a consequence, you can never check all combinations.

The third option is to run dedicated tests that verify at first the conformance of each implementation according to its underlying specified standard and afterwards the general interoperability explicitly according to the specified interoperability tests. All implementations are tested for basic operations, but also for corner case behaviors in terms of configuration, functionality timing and fault tolerance. In that way, it can be proven that each implementation adheres to the specified standard and that all nodes in a system can rely on the respective capabilities, ranges and limits given by the standard. In that way, also scenarios that are very difficult or not to test in a system can be tested as the conformance test intends to go to the absolute limits of the specified standard instead of selecting a single configuration and scenario somewhere in the "middle" of all specified limits. Furthermore, the efforts to test single implementations are linearly increasing, far slower than all other types of test.

Options to check interoperability:

- Check all systems explicitly in all potential operating conditions.
  - Detailed tests need to be repeated for each new system and system option.
  - The efforts are represented by a product of systems, multiplied by options.
- Check interoperability explicitly for all device combinations.
  - Detailed tests need to be applied for all potential system combinations and for all available devices.

   - The efforts are represented by following equation[1] (Figure 2):

$$A = \sum_{k=1}^{k=n} \frac{(N+k-1)!}{(N-1)! \cdot k!}$$

- Check conformance and interoperability of all system components within appropriate test scenarios.
   - Only one conformance test and one interoperability test per device, each device usable in all systems.
   - The test efforts increase linear, i.e. $A=2 \cdot N$

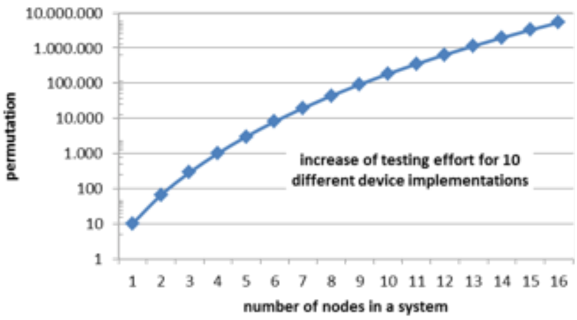

Figure 2: Permutation for 10 available devices and systems of a maximum of 16 nodes.

Interoperability – test specification

The scope of the interoperability test specification [1] 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 declared in the dynamic test plan is to increase the probability of collaboration of high speed CAN transceivers within a CAN system and to increase the confidence level in this regard. Contrary to conformance tests, the interoperability tests, which are defined within the interoperability test specification, are based on a predefined reference environment. Single device measurements are not in focus of the interoperability tests. A data sheet check according to ISO 16845-2 [2] as a static test plan 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.

The specification defines interoperability test cases for high speed CAN transceiver containing:

- HS PMA unit
- HS PMA unit with selective wake up functionality
- HS PMA unit with selective wake up functionality, tolerant to frames in CAN-FD format

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

Depending on the intended application area for the implementation under test, different reference environments and settings are defined within the interoperability test specification. The reference environments are classified in relation to the target bit rate:

- 500 kbit/s reference environment
- 2 Mbit/s reference environment
- 5 Mbit/s reference environment

Generally, the behavior of a transceiver or equivalent device 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 defined interoperability tests, defined by the interoperability test specification, verify the sequential behavior of the implementation under test in reference to the specified sequential behavior.

[1] N = number of different implementations, k = number of nodes in a system (combinations with repetition), n = maximum number of nodes

When testing a transceiver, the behavior of the implementation under test is observed and controlled at external points, the details of the respective high speed CAN transceiver implementations are not visible. Just phenomena, relevant for the interoperability of transceivers, are considered. Abstract test methods are described by identifying the points closest to the implementation under test 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 [3], the test method is the so called local test method (Figure 3).

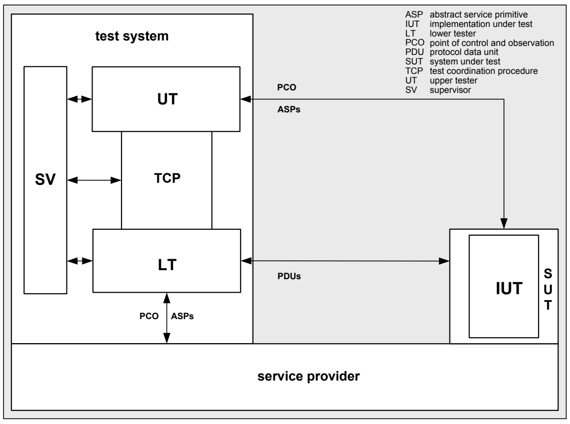

Figure 3: Local test method as defined in ISO 9646 1

Interoperability – test cases

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. Single test cases are gathered within seven main test cases according to so called test flows (Figure 4) between all possible combinations of normal mode and low power mode:

- Operation mode variation after recovery at normal mode, failure application on startup
- Operation mode variation after recovery at normal mode, failure application in normal mode
- Operation mode variation before recovery at normal mode, failure application in normal mode
- Operation mode variation with failure before recovery at normal mode, failure application on startup
- Operation mode variation with failure before recovery at low-power mode, failure application in normal mode
- Operation mode variation with failure before recovery at low-power mode, failure application in low-power mode
- Operation mode variation with failure before recovery at normal mode, failure application in low-power mode

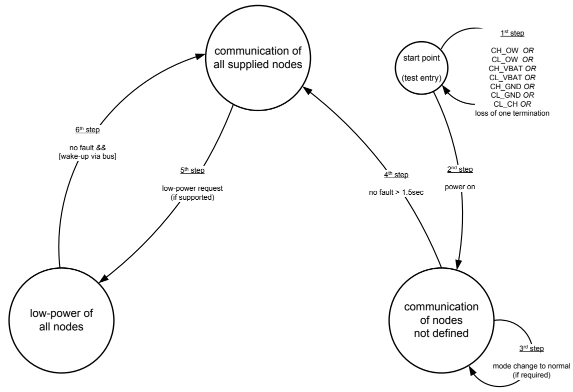

Figure 4: Example test flow

Within each test flow, eight different failures will be applied:

- open wire on CAN high
- open wire on CAN low
- short circuit between CAN high and battery voltage
- short circuit between CAN low and battery voltage
- short circuit between CAN high and ground
- short circuit between CAN low and ground
- disconnection of one terminating node

Another three different ground shift scenarios (neutral, positive and negative) will be in use. The ground shift will be applied at each node against the others, just as with the initialization of wake-up via bus. The tests will be conducted twice: Once within a so called homogeneous network – here a mix of implementation under test and reference devices is installed – and once within so called heterogeneous network – here only the implementation under test is installed. The interoperability test specification defines nearly 60 thousand single test cases. The correct behavior of the implementation under test will be verified between two and four times per test flow. This results in more than 190 thousand checks per test where the high speed CAN transceiver has to behave correctly.

In order to keep the overall test efforts preferably low per high speed CAN transceiver implementation, the following simplification is defined:

For high speed CAN transceivers which solely support data bit rates up to 1 Mbit/s, all applicable test flows will be executed in 500 kbit/s reference environment.

High speed CAN transceivers, 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. The 2 Mbit/s reference environment is used for these devices for all test flows.

High speed CAN transceivers, which support 5 Mbit/s, will be tested using one test flow in the dedicated 5 Mbit/s reference environment while all other tests are run in the 2 Mbit/s reference environment. (Rational for this simplification is that the general 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 main fundamental mode control functions and failure recovery.)

Interoperability – test environment

Because of focusing on the interoperability of high speed CAN transceiver components in system application, not just one single device is considered as the implementation under test but the high speed CAN transceivers in their entirety in a network environment. The transceivers are tested in their entirety of a defined number of devices in a defined standardized bus environment, the so called ‘standard net’, which is related to the implementation under test. The definition of the standard net environment considers the most realistic and relevant system operation conditions.

The standard net consists of defined numbers of nodes, each node consisting of capacitors, common mode chokes at specified positions, implementation under test, certified CAN-FD controller and communication software laying above which implements a token passing between the nodes including also the possibility of multi casting messages. Furthermore, each node has a stub, the respective length resulting from a defined total wire length (Figure 5).

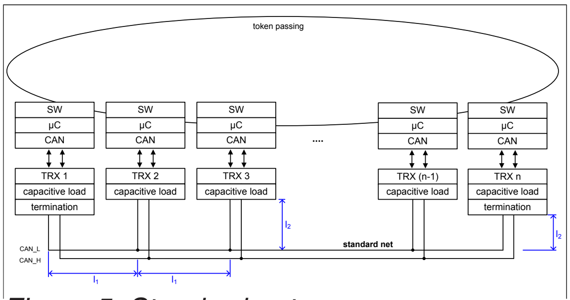

Figure 5: Standard net

Industry acceptance

Network design has to guarantee functionality and interoperability of all network components in order to ensure a correct system behavior even if multiple supplier solutions are used. Utilization of standardized components, which follows a conscientious defined standard, is the key step to achieve the aim. The adherence to the standard itself needs to be proven. A conformance test only is not capable to guarantee total interoperability, but this gap is closed by an additional interoperability test.

However, complete test coverages through conformance and interoperability testing are useless if it ignores the needs of the automotive industry and consequentially does not find any kind of acceptance. To avoid this, C&S has been actively working with partners in the automotive and semiconductor industry in order to develop an interoperability test specification which will relish wide acceptance. Together with CAN experts from these companies, the interoperability test scenarios and the failures settings were discussed and afterwards defined within the specification. Based on the resulting interoperability test specification, C&S has created the interoperability test system.

References

[1] [1] Interoperability test specification for high speed CAN transceiver or equivalent devices, revision 00, 2016 12 12
[2] ISO 11898 2, Road vehicles — Controller area network (CAN) — Part 2: High speed medium access unit, second edition 2016 12 15
[3] ISO 9646 1, Information technology — Open Systems Interconnection — Conformance testing methodology and framework — Part 1: General concepts

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