CAN Compatibility Test for Subsea Equipment

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In the oil and gas upstream processes, notably for deep water subsea wells, where equipment are commonly deployed beyond 2000m (6500ft) of water depth, the uninterrupted monitoring of process variables such as pressure, temperature and production flow is crucial. CAN technology, compared to the 4-20mA so commonly used in this process today, simplifies the sensor arrangement by using a single bus for several sensors without risking reliability, provides more accurate measurements readings and reduces the cost of special cabling. In the other hand, CAN demands complex electronics to reliably acquire signals while making them accessible to the topside system. Current industry design life for subsea equipment varies from 20 to 30 years, with the requirement of little or no maintenance. This paper presents the particularities of CAN used by subsea players. It will also show a typical arrangement of CAN in a subsea equipment, comparing this solution to the analogic 4-20mA technology and proposes a CAN Compatibility Test which consists of a reproducible method to validate the sensors arrangement and guarantee its correct operation by the measure and analysis of bus signals with the objective of foreseeing limitations and problems early in the project phase reducing risks for the system's long term operation.

Introduction

In order to deliver reliable solutions in oil and gas production, subsea industry, through a joint program of technology companies in this market, has defined a standard interface called SIIS (Subsea Instrumentation Interface Standardization). One result of this JIP (Joint Initiative Program) is the definition of technology CAN protocol as one of the standards for subsea instrumentation.
Once the equipment is installed on the seabed, the need for maintenance on components and premature failure may require the mobilization of resources such as ROV (Remotely Operated Vehicle), auxiliary vessels and eventually a production stop. Therefore, the use of a consolidated technology on the market which provides safety and highly availability is essential in this kind of application.
Among the different factors that contribute to the technical use of the CAN protocol in subsea sensoring is the fault tolerance during a data transmission. This was considered the main advantage over other technologies as 4-20mA. Reliability for subsea oil and gas production is highly relevant mainly to avoid the high costs of resource mobilization for maintenance, as previously mentioned, and a possible production stop.

Definitions for subsea applications

A. *SIIS definitions*

SIIS has 3 levels, the CAN Interface board must comply with SIIS Level II.

- **Level I** defines the interface as simple devices for example 4-20mA sensors.
- **Level II** defines the interface between the SCM (Subsea Control Module) and the third party intelligent instrumentation as using Fault tolerant (low-speed) CAN bus as the physical layer, using CANOpen as the higher layer protocol.
- **Level III** defines Ethernet interfaces to intelligent devices.

The SIIS level II recommended practice states:

- The physical interface shall be through 4 pin or 12 pin connector arrangements and the pin out is defined within the recommended practice.
- Screened cable is not specified but may be used.

- CANH and CANL shall use twisted pair wires as their transmission media.
- Cable type shall be low capacitance cable – e.g. 50pF/m or lower.
- No specific wire colors or gauge are specified, however a wire gauge suitable to cope with the current levels should be used.
- The termination on CAN_H and CAN_L as 1k5Ω for a sensor device and for 620Ω for a master device. This is to achieve as near as possible on a maximum system a line termination of 100Ω.
- The default baud rate shall be 50kbps.
- All instruments shall be electrically isolated from case.
- A maximum of 9 separate nodes (third party instrumentation, not including the board itself) may be connected to a single CAN bus, which would present a termination of 108Ω.
- The instruments are to be powered from 24V DC (minimum and maximum voltages at the instrument are 18V DC and 27V DC respectively).

B. Configurations for a redundancy system

There are three types of configuration that may be used in a redundancy application:

- **Single device** – Devices with a single SIIS 2 interface and a dedicated connection from the device or devices to a SEM (Subsea Electronic Module).
- **Dual device** – Devices with dual SIIS 2 interfaces and a dedicated connection to SEM A and SEM B from the device or devices.
- **Shared device** – Devices with a single SIIS 2 interface and the device or devices are connected via a channel shared between SEM A and SEM B.

CAN vs. 4-20mA Technology

Adopting CAN Protocol as a standard communication interface is the next step moving from an isolated 4-20 mA sensor reading to a sophisticated intelligent sensor network.

Some benefits of this approach are listed:

- Distributed control, instead of control done by a single master computer. This means that the intelligence is brought down and shared into the smart devices.
- Optimization of structure and reduced wiring costs. You only need 2 twisted wire pairs that will be used for the network and to power devices. This dramatically reduces wiring costs from 4-20 mA systems, which requires a minimum of one pair of wires per device.
- To standardize the sensors data and parameters for each device, facilitating the interface between Control Modules and different instrumentation suppliers.
- Increased network robustness: Fault Tolerant feature allow the network to still operate with a short/open circuit in the communication lines. The flying master topology also allows the network mastering to be changed in case of a master device failure.

The benefit of multiplexing several sensors in one channel is shown in a typical CAN sensor arrangement in Figure 1. It shows the subsea control system where up to 9 CAN sensors may be attached to each SCM channel. In comparison Figure 2 shows a typical 4-20mA topology where each channel may support only one sensor.

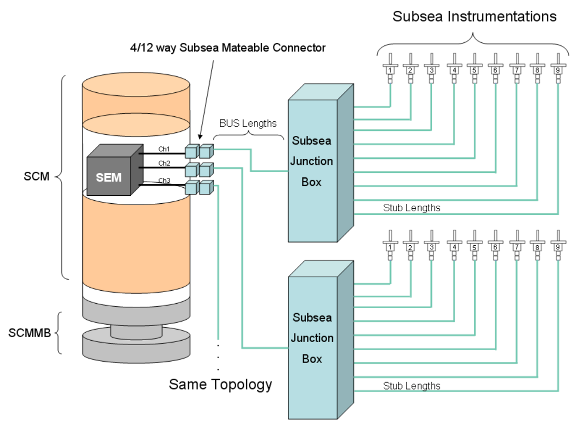

Figure 1: Typical Subsea CAN Topology

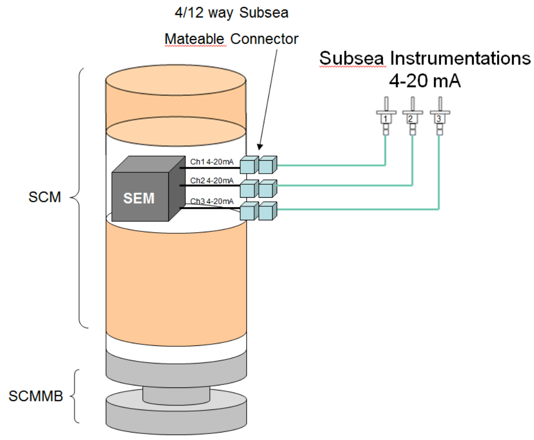

Figure 2: Typical Subsea 4-20mA Topology

The limitation on the total maximum cable length is determined by a number of factors such as the number of nodes, the characteristics of the sensor transceivers, the cable performance. The most significant timing constraint occurs in a fault condition during a transition from a dominate (bit 0) to recessive (bit 1) state where only the terminating resistance of the network facilitates the cable discharge. Using typical and worst case parameters for transceivers, *Table 1* defines the maximum total cable length permitted on a SIIS 2 network [1].

Table 1 - Maximum cable length per sensor on the bus

Sensors		1	2	3	4	5	6	7	8	9
Length	Low	35	60	85	110	130	155	180	200	225
(m)	Med	70	120	170	220	265	310	355	405	450
by risk	High	95	170	235	300	365	430	490	560	615

CAN Compatibility Test

This CAN compatibility test proposes a method to validate the correct functionality of subsea sensors individually, proving its compliance with SIIS-L2, and in group where the final arrangement will be evaluated and its functionality after installed will be proved. The method is based on SIIS Generic Test Procedure [2], with some other tests added for the array validation. This section will describe the materials and tools necessary for the test, it shows some test setup arrangements and proposes the tests to be realized and the results expected. This will enable the subsea equipment manufacturer to lower the risks and troubleshooting the installed sensors.

Materials and Tools

This compatibility test will require a set of material and tools to analyze several aspects of CAN bus in both physical and logical layers. The main items for this purpose include an oscilloscope, CAN protocol analyzers, ampere-meter, volt-meter, cabling and the sensors. The test equipment chosen must fulfill some requirements in terms of bandwidth, protocol, decoding capabilities and message filtering features which will be described here.
Oscilloscopes will be used to analyze the physical layer of each node, its electrical characteristics, evaluate the bit timing and amplitude. The oscilloscope must have enough bandwidth to make deeper bit profile analysis which helps in troubleshooting investigations of problematic nodes on a complex system. The preferable bandwidth is 500 MHz minimum [3]. Modern oscilloscopes are able to decode CAN bus, showing not only the pure signal but the meaning of each bit in the message providing means for analysis of both physical layer and data link layer. This feature makes the analysis and troubleshooting faster, otherwise the bus signals will have to be manually decoded, a difficult and error prone task. The oscilloscope will be used to analyze mainly a short period due to its internal memory limitation which restricts the protocol messages storage to a few seconds. The oscilloscope probes for this test must include one differential probe for CAN bus analysis and one current probe for inrush and power analysis.

Summary of Oscilloscope Preferable Characteristics:

- 500MHz+ bandwidth
- 2+ analogue channels
- 16 digital channels
- Decoding of CAN bus signals
- Differential probes, 500MHz+
- Current probe

Protocol analyzers normally are composed of a CAN interface/gateway, a hardware used to interface a regular computer to the CAN bus, and a software that will be used to log, analyze, and stimulate the bus.

As there is no standard definition for such analyzers, there is a plenty of different functionalities and prices. The main features to be considered [4], specially related to this test are:

CAN Interface/Gateway

- Support PC interfaces PCI, USB or Ethernet
- CAN connector – Male 9-pin D-Sub
- Support all CANOpen bitrates (most used for subsea is 50kbps)
- ISO-11898 compliant transceiver. (fault-tolerant ISO-11898-3 is preferable)
- Able to generate error frames

Software

- Trace Display, displaying each message with the timestamp
- Logging, create large record databases
- Symbolic Display, interpret the bus data showing identifiers instead of pure bytes (CANOpen known symbols)
- Load and interpret EDS files
- Transmission of CAN messages, periodically send messages allowing the data to be changed in time.

For the cabling used to interconnect the sensors, the recommendation is to use low capacitance cable (50pF/m or lower). The electrical characteristics of this cable must be equivalent to the electrical jumper that will be used in the field.
The use of Subsea Control Module (subsea electronics) may be used to execute the integration test in which all sensors, connectors, junction boxes and cabling (with correct lengths) will be used and assembled as the final arrangement. This will be used to evaluate the whole system guaranteeing the correct functionality of the proposed system.

Test Setup Arrangements

The following arrangements will be used for the proposed tests. ***Figure 3*** shows the individual sensor test setup in which the sensor's compatibility to SIIS-Level2 is verified. The sensor is attached to a CANOpen Analyzer/Simulator, with message sending feature to configure the sensor and set it to operating state. The bus electrical analysis is performed with an oscilloscope, which may be used also to evaluate the data link layer.

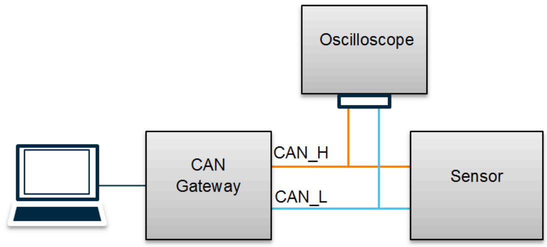

Figure 3: Single Sensor Test

Figure 4 shows the integration of control system's electronics and sensors. This setup includes all main components, including cable lengths, of the final arrangement. A CAN gateway with CAN analyzer software will be used to register the communication, filtering special messages which will help to evaluate the data transfer quality. Electrical signals in each node will be registered by an oscilloscope in different points. This will be used to guarantee that the length of cabling, generally tenths of meters, will still provide a reliable path for the signal.

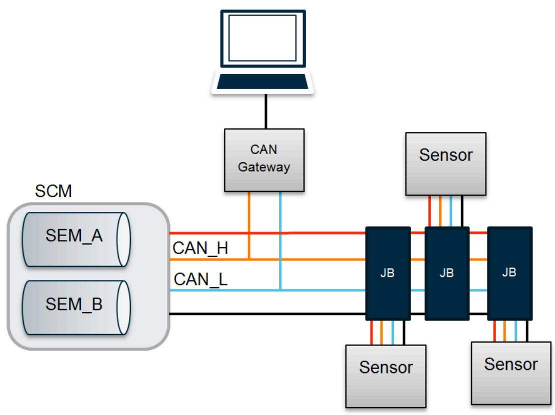

Figure 4: Subsea Control System Integration Setup

Power consumption and Inrush

The power consumption and inrush current analysis will verify the start-up and stable state sensor power consumption profile. This information will be used to configure the control systems interface which generally restricts the maximum current per CAN channel. ***Figure 5*** shows the inrush current setup, with an oscilloscope with a current clamp probe where the transient current will be registered in different operation states.

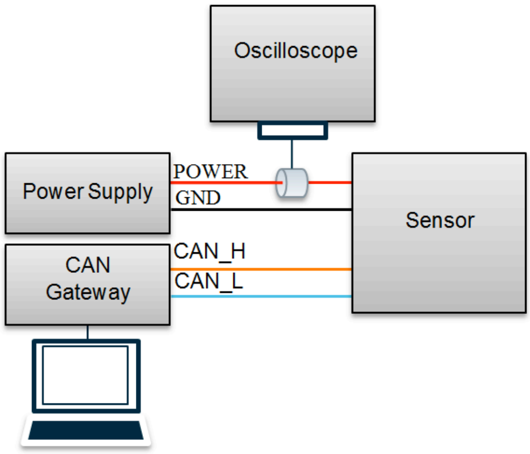

Figure 5: Inrush Current Setup

Figure 6 shows the power consumption setup composed of an ampere-meter and voltmeter.

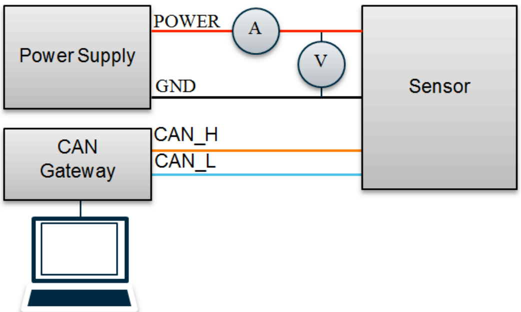

Figure 6: Power Consumption Setup

Configuration

Initial configuration of node-id and baud rate for all sensors is suggested as a first step in order to eliminate the commonly misconfiguration issues faced in complex arrangements, reason of man-hour lost in troubleshooting of basic problems [5].
At this step, it is suggested to register the identification for each sensor which includes the Device Name, HW Version, SW Version, Vendor ID, Product Code, Revision Number, Serial Number, available in sensor documentation.
The proper configuration of node-id and baud rate will be executed for each sensor individually using LSS (Layer Setting Service) switch mode selective and switch mode global [6].

After each configuration process, a device power cycle must be executed. This will prove the correct functionality of sensors by receiving LSS messages in both modes and storing the configuration properly.

Measurements

The following measurements will determine if the sensor is compatible with SIIS-2 by verifying the required features as per CiA443 [7]. This part, named here as CANOpen CiA443 Test, verifies the implementation of all mandatory objects in boot loader (BL) mode and application mode (AP). It commands PDO transfers and verify the correct operation of inhibit time. Firmware update feature and performance tests will also be executed. This phase is normally executed with the sensor individually connected. The next test will focus on the physical layer where the consumption profile for all sensors will be registered, fault-tolerance tests will be executed and the final arrangement will be tested.

CANopen CiA443 Test

The measurements start with the verification of sensor's OD in boot loader mode. Load the sensor's boot loader EDS and read the object 0x1000, this must show that the boot loader is active (0x000001BB). If not in this state, switch the sensor into BL. Ensure no heartbeats are transmitted and check all the mandatory objects as *Table 2* and its access rights. Check if the values of 0x1018 match the identification values registered earlier.
Execute the same procedure as before for the sensor in AP (value of 0x1000 shall be 0xYYYY01BB).

Table 2: Mandatory OD registers for SIIS-Level2 devices

OD	BL	AP	Characteristics
0x1000	X	X	ro
0x1001	X	X	ro
0x1005		X	rw
0x1008		X	const
0x1009		X	const
0x100A		X	const

0x1010		X	const, others rw / ro
0x1011		X	const, others rw
0x1014		X	rw / const
0x1015		X	rw
0x1017		X	rw
0x1018	X	X	1st const, others ro
0x1F50	X		1st const, others rw / wo
0x1F51	X	X	1st const, others rw
0x1F56	X		ro
0x1F57	X		ro
0x1800		X	1st const, 2nd, 3rd const/rw, rw, n/a, rw, rw/const
0x1A00		X	const / rw
0x6000		X	1st const, implemented if bit 15 in 0x1000 is set
0x6001		X	const

The verification of PDO transmission is done with the sensor in AP in event driven and in sync type. Set transmission type of TPDO1 to event-driven, set event timer to 1000ms. Ensure TPDO1 is enabled (0x1800|1 bit 31 is '0') and send NMT-Start command. Sensor should send PDOs with correct values at the predetermined time. Change the transmission type to SYNC, send a NMT-Start command and a sequence of SYNC commands. For each SYNC command sent, verify the transmission of PDO. Configure the sensor to send asynchronous PDOs, set inhibit time to a value greater than event timer. Start transmission and check that the transmission rate is not greater than that configured in inhibit time. Execute the same verification with the sensor configured as SYNC and verify that the transmission rate is not greater than the inhibit time, even if SYNC commands are sent at a higher rate. This test is used to verify the device's CANOpen correct implementation, crucial for bus performance.

Firmware update functionality must be verified. SIIS-2 compliant devices must implement program control and program download. In order to verify this feature set the sensor to BL, erase the application, downloading the new binary, check the flash status, start AP and read the object 0x1000 to verify that application is running. Execute the same process with a corrupted binary data (invalid CRC), verify that the application can't be started. This will prove that a new firmware, with features upgrade for example, may be applied in the field without further intervention (a device replacement).

Performance tests must be executed in order to evaluate the correct functionality of sensors in normal operation with high bus load conditions. Firstly, with one sensor connected to the bus in normal operation condition, configure the CANOpen software to write '1000' to heartbeat configuration every 2-5ms, monitor the system for 10 minutes, registering any abnormal operating condition (watchdog resets, sensor readings freezing, system stuck, etc.), check if CAN detected any error.

With all sensors connected (as per ***Figure 4***), power the system and let it operating in normal condition. At this time, one may use the subsea electronics to drive the sensor arrangement or simply the CANOpen SW with the CAN gateway. When using the gateway, its transceiver must comply with ISO11898-3.

Physical

The next tests will evaluate the hardware of sensors in terms of supply and fault tolerance. Register the inrush current profile with the setup shown in ***Figure 5*** using the oscilloscope to trigger on current spike. Register the same profile when the sensor is commanded from BL to AP. Using the power consumption setup, as per ***Figure 6***, command the sensor to AP and register the power consumption. Measure and register the current drawn by the sensors supplied with the minimum voltage (20V) and the maximum voltage (27V). This information will be used to validate the device's datasheet information and configure the SCM power supply accordingly.

Fault-tolerance tests will evaluate if sensors are compliant with ISO11898-3 0 and the system arrangement will continue to work in all failure conditions. Using the setup shown in ***Figure 3***, set the sensor to communicate as in normal operation. Exercise each condition from ***Table 3*** monitoring the system and registering any malfunctioning, use the oscilloscope to verify that the step was executed. An additional hardware may be used in this procedure which will enable a fast disconnection and short-circuit. In the table, consider "D" as disconnect procedure and "S" as a short-circuit between two cables. Execute the same test for the complete setup shown in ***Figure 4***. The system may be considered fault-tolerant compliant if no abnormal operation is observed for any fault condition.

Table 3: Fault-Tolerance Tests

	Cables				
Step	POWER	CAN_H	CAN_L	GND	**Check**
1		D			
2			D		
3		S		S	
4			S	S	
5	S	S			
6	S		S		
7		S	S		

The final test ensures the system will behave as expected after installed. Still using the setup in ***Figure 4***, configure all the system to operate in normal condition. Using the oscilloscope, measure and record the signals of CAN_H and CAN_L near each node. Enable the CAN analyzer software to log all data transferred. The registers gathered with the oscilloscope must show enough signal margins at each node at bit level and the logs must be filtered in order to identify the quantity of error frames on the bus (preferable zero).

Conclusion

A typical sensor arrangement may have several types of sensors, e.g. flow meters, pressure and temperature sensors, displacement sensors, provided by different manufacturers. This test procedure may prevent common problems with unknown devices guaranteeing the correct interaction between subsystems.
The increasing use of CAN sensors in subsea equipment will demand methods to guarantee the functionality of the chosen arrangement early in project phase. Due to the nature of this market, any intervention on equipment after deployed involves high costs and must be diminished. This paper proposes a method for testing the CAN sensor arrangement based on the SIIS-Level2 requirements and procedures.
It also adds some other tests to prove the correct functionality of both physical and data layers. At the end of the test, one player may have enough information to evaluate the system functionality diminishing its risks.

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References

[1] M. Schwab, "Case of Study of Applying the CANOpen Communication Protocol on Sensoring in Subsea Equipment for Oil and Gas Production", 2012.
[2] SIIS Generic Test Procedure – SIIS Level 2 (Digital Serial Devices), 2011.
[3] A. Siegert, "Debugging CAN Buses Using Mixed Signal Oscilloscopes", 2012.
[4] O. Pfeiffer, "Embedded Networking with CAN and CANOpen", pp.240-244, 2008. Copperhill Media.
[5] Tobias Frey, Thomas Waggershauser: New methods for the analysis of the physical layer of CAN networks and possibilities for robustness improvement, 2012.
[6] CiA DSP 305, CANOpen Layer Setting Services and protocols, 2013
[7] CiA DSP 443, CANOpen Profile for SIIS level-2 devices, 2012
ISO 11898-3, Low-speed, fault-tolerant medium-dependent interface, ISO, 2006.