

June 2024

CAN Newsletter

Hardware + Software + Tools + Engineering

Functionally-safe J1939 communication

Commercial road and off-highway vehicles and off-road construction machines use often J1939-based application layers. To meet the increasing demand on functional safety, SAE has developed for CAN CC (classic) and CAN FD dedicated protocols: J1939-76 respectively J1939-77.

Cover story



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Please note: The PCAN-MicroMod FD ECU is expected to be available in Q3 2024.



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Cover story

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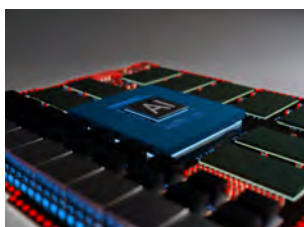
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Feedback by readers

This is the second CAN Newsletter magazine issue, which integrates the CAN Newsletter Online. The editors would like to receive readers' feedback regarding these issues:

- ◆ Which contents are you missing in general?
- ◆ Which topics do you like to see in next issues?
- ◆ How important is the "standards and specifications" column for you?
- ◆ How important are product category summary and trend articles for you?
- ◆ How important are new CiA member summary reports for you?
- ◆ How important are new CANopen vendor-ID summary reports for you?

The editors would also like to ask you to submit article proposals on new CAN-related success stories. In addition, we are hungry on technology-oriented articles.

Any response helps to improve the contents of the CAN Newsletter magazine. The editors depend on the discussion with readers. Please send your feedback to pr@can-cia.org.

Functionally-safe J1939 communication

Commercial road and off-highway vehicles as well as off-road construction machines use often J1939-based application layers. To meet the increasing demand on functional safety, SAE has developed for CAN CC (classic) and CAN FD dedicated protocols: J1939-76 and J1939-77, respectively.

This article discusses the two SAE J1939 standards for functionally safe communications on CAN CC (SAE J1939-76) and CAN FD (SAE J1939-77). For SAE J1939-76, it describes the Safety Header Message (SHM) and Safety Data Message (SDM) pairing approach used to communicate safety-related data from a producing safety application to a consuming safety application. In addition, it details the features of the original version as published in 2020 and lists the deficiencies of this version. Finally, it details features of the revised version currently under development that make up for these deficiencies. For SAE J1939-77, the article describes the use of space allocated for functional safety assurance information in the Multi-PG and FD Transport protocols to communicate safety-related data from a producing safety application to a consuming safety application. In addition, it describes the three profiles currently under development that are tailored to meet different system needs while still meeting functional safety requirements.

IEC 61784-3: Safety-relevant communication principles

The IEC 61784-3 standard defines various communication errors that can occur:

- ◆ **Corruption** refers to the unexpected and undesired transformation of a message such that the message received does not exactly match the message transmitted. This error can occur, for example, when a device driver inadvertently swaps the byte order of a part of the message, or when noise emissions disrupt the bit patterns in communicated signals.
- ◆ **Unintended repetition** refers to the unexpected and undesired repetition of a message. This error can occur, for example, when a device driver fails to update its transmission queue after transmitting a message and so transmits the same message again.
- ◆ **Incorrect sequence** refers to the out-of-order communication of messages in a sequence, e.g., the second message in a sequence gets received before the first message in the sequence. This error can occur, for example, when messages in the sequence get assigned different priorities before the messages are placed in a priority queue for transmission.
- ◆ **Loss** refers to the failure to receive a message that was transmitted. This error can occur, for example, when a message is submitted for transmission to a queue that is already full, with the result being that the

message is dropped and never actually transmitted. Another example, conversely, is when a message is received but cannot be added to a reception queue, with the result being that the message is dropped.

- ◆ **Unacceptable delay** refers to the failure to receive a message within a permitted time window, thereby causing a delay in the system's response. This error can occur, for example, if several messages are communicated at or near the same time, causing congestion on the communication medium.
- ◆ **Insertion** refers to the reception of a message from an unexpected or unknown source. This error can occur, for example, when two or more sources are transmitting the same messages.
- ◆ **Masquerade** refers to the inadvertent handling of a message from a non-safety-related source as if it were from a safety-related source. This error can occur, for example, when a safety-related source, in addition to transmitting its own messages, is forwarding messages from a non-safety-related source. In this example, a recipient inadvertently treats those messages as if they were really from the safety-related source.
- ◆ **Addressing** refers to the delivery of a message to the wrong recipient, which nevertheless treats the reception as correct. This error can occur, for example, when a message is inadvertently addressed to a multicast/broadcast address instead of to a unicast address.

Additionally, the IEC 61784-3 standard defines safety measures that can be used to detect such errors to achieve the desired level of functional safety:

- ◆ **Sequence numbers** embedded in the message identify the position of the message relative to other messages in the same stream. They change from one message to the next in a manner such that both source and recipient can determine what the sequence number for the next message should be.
- ◆ **Time expectations** are when a recipient monitors the time between two consecutively communicated messages to determine whether the period exceeds a threshold; if it does, then the recipient assumes an error.
- ◆ **Connection authentication** is when a message has a unique source and/or destination identifier for the safety-related participants.
- ◆ **Data integrity assurance** adds redundant data (e.g., cyclic redundancy checks, also known as CRCs) to a message to detect corruption in the message. ▷

- ◆ **Redundancy with cross-checking** communicates the safety data in separate instances, either in separate messages or within the same message. A safety-related recipient can then compare the data in both instances and flag an error if differences exist.

Different data integrity assurance systems are designs, in which communicated safety-related data use different integrity mechanisms than those used by the communicated non-safety-related data. This ensures that non-safety-related messages do not affect a safety-related recipient.

Table 1 describes the coverage of various communication errors by safety measures employed in J1939-76 and J1939-77.

Table 1: Coverage of communication errors by employed safety measures (Source: Caterpillar, J1939-76, J1939-77)

Communication errors	Safety measures					
	Sequence number	Time expectation	Connection authentication	Data integrity assurance	Redundancy with cross-checking*	Different Data integrity assurance systems
Corruption				•	•	
Unintended repetition	•				•	
Incorrect sequence	•				•	
Loss	•				•	
Unacceptable delay		•				
Insertion	•		•		•	
Masquerade			•			•
Addressing			•			

* Both SHM1 and SHM2 versions in J1939-76 employ redundancy with cross-checking for some, but not all, communicated data. Profiles in J1939-77 do not employ redundancy with cross-checking.

J1939-76: Two Safety Data Group (SDG) versions

There are two versions of functional safety support specified in J1939-76. This support applies to Parameter Groups (PGs) whose parameter data payloads range from 1 byte to 8 byte in length. Both versions use a Safety Data Group (SDG), which consists of a Safety Header Message (SHM1 or SHM2) and a Safety Data Message (SDM), to communicate safety-related data from a producer to a consumer. The SDM, which is simply any PG to which an SHM is associated, contains the safety-related parameter data to be used as part of a safety function. In contrast, the SHM contains the following additional functional safety assurance data:

- ◆ one 32-bit CRC,
- ◆ one sequence number,
- ◆ the parameter group number (PGN),
- ◆ the destination address (DA) for point-to-point PGs,
- ◆ and the source address (SA) of the associated SDM.

Because of the need for two different messages, J1939-76 specifies timing and order-of-transmission constraints to ensure that the right SHM instance appears with the right SDM instance.

The original publication of J1939-76 in 2020 specified what is now called the SHM1 version of functional safety support. Later analysis showed that the SHM1 version had some deficiencies with regards to the CRC coverage and the size of the Sequence Number field, so SAE (Society of Automotive Engineers) began with development of the SHM2 version to correct those deficiencies. ▷



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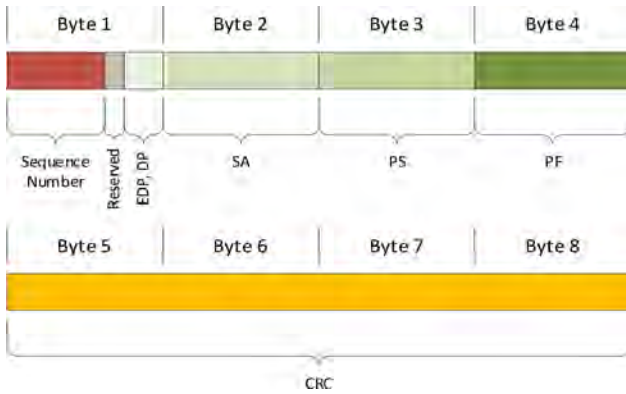


Figure 1: Format of the SHM1 payload specified in J1939-76 (Source: Caterpillar)

Figure 1 illustrates the format of the SHM1 payload. The EDP (Extended Data Page), DP (Data Page), PF (PDU Format), PS (PDU Specific), and SA fields are all bitwise inverted; the values of these fields before inversion match the values in the SDM. The arrangement of the CRC field is least-significant-byte-first. This approach has the following benefits:

- ◆ This version employs a CRC polynomial (labeled as CRC-32K/10 in [2]) with a relatively large Hamming distance for the expected payload size.
- ◆ A system can deploy this version over either J1919-21 communications (based on CAN CC) or J1939-22 communications (based on CAN FD).
- ◆ This version has been available for several years.

But there are also some drawbacks in this version:

- ◆ The CRC calculation only covers the PG's parameter data payload in the SDM; it does not cover the PGN, DA for point-to-point PGs, SA, or Sequence Number fields provided in the SHM.
- ◆ The 5-bit Sequence Number is relatively small.
- ◆ This version doubles the bandwidth needed to communicate safety data.
- ◆ Some relatively complicated timing constraints due to the need for two messages per SDG.
- ◆ This version is not well suited for communications across routers due to a dependence on link-local addresses as part of its connection authentication.

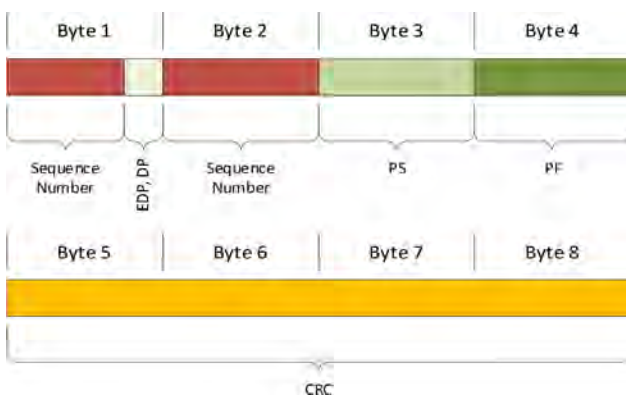


Figure 2: Format of the SHM2 payload specified in J1939-76 (Source: Caterpillar)

Figure 2 illustrates the format of the SHM2 payload. Unlike in SHM1, the EDP, DP, PF, and PS fields are not bitwise inverted; the values of these fields match the values

in the SDM. The SA field is not in the payload, but it appears in the CAN ID and matches the value in the SDM. The six least significant bits of the Sequence Number field are in the first byte of the payload, while the eight most significant bits of the field are in the second byte. The arrangement of the CRC field is least-significant-byte-first.

The benefits of this solution are:

- ◆ Like in the SHM1 version, the CRC calculation in this version covers the PG's parameter data payload in the SDM; however, it also covers the PGN, DA for point-to-point PGs, SA, and Sequence Number fields in the SHM.
- ◆ The 14-bit Sequence Number in this version is larger than that defined in the SHM1 version.
- ◆ Like the SHM1 version, a system can deploy this version over either J1939-21 communications or J1939-22 communications.

The drawbacks are:

- ◆ This version employs a different CRC polynomial (labeled as CRC-32K/9 in [2]) whose Hamming distance is slightly smaller than that used in the SHM1 version. A different polynomial was necessary to cover the larger amount of data.
- ◆ Like the SHM1 version, this version doubles the bandwidth needed.
- ◆ Like the SHM1 version, this version has some relatively complicated timing requirements.
- ◆ Like the SHM1 version, this version is not well suited for communications across routers.
- ◆ This version is still under development.

J1939-77: Three profiles

There are three profiles specified in J1939-77 for functional safety support. These profiles take advantage of the Multi-PG and FD Transport protocols specified in J1939-22 for use over CAN FD. These protocols can allocate a separate space in their messaging for cybersecurity and/or functional safety assurance information for a PG's parameter data. As a group, these profiles support PGs whose parameter data payloads range from 0 byte to 65526 byte in length.

Each of the profiles provides the following functional safety assurance information:

- ◆ Either a 32-bit or a 64-bit CRC.
- ◆ A 32-bit Sequence Number.
- ◆ The length of the data over which the CRC is calculated.

In addition, two of the profiles provide a system-specific connection authentication (DataID) that does not depend on link-local addressing. The definition of this authentication allows producers to communicate safety-related messages to consumers through routers. All three profiles have the disadvantage that they are limited to J1939-22 communications and that they are still under development.

The Profile #1 focuses on minimizing the amount of functional safety assurance information required. To accomplish this, the profile requires a fixed size for the PG's parameter data payload; it also requires the incorporating link-local address information in the data's identification, which limits its usefulness for communication through routers. The resulting functional safety assurance data fits within 8 bytes. ▶

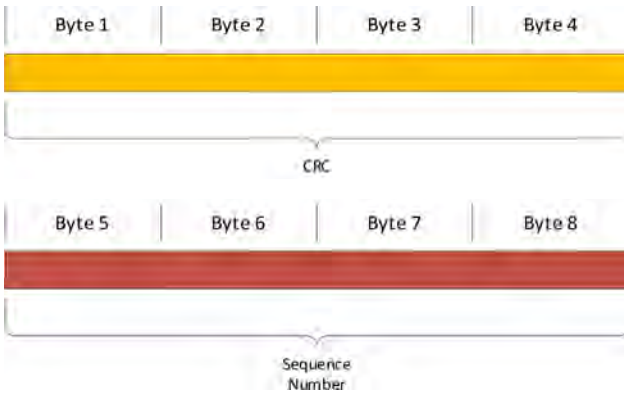


Figure 3: Format of Profile #1 assurance data specified in J1939-77 (Source: Caterpillar)

Figure 3 illustrates the format of the assurance data for Profile #1. The internal arrangement of both fields is least-significant-byte-first. The PGN, DA for point-to-point PGs, and SA fields all appear elsewhere in the Multi-PG messaging and so do not appear here.

The benefits are:

- ◆ This profile has the smallest set of functional safety assurance data of any profile.
- ◆ This profile consumes less space inside the trailer of a single C-PG (Contained Parameter Group, a part of the Multi-PG protocol messaging) than the equivalent pair of C-PGs containing an SDG.
- ◆ The Sequence Number in this profile is much larger than that used in either the SHM1 or SHM2 versions.
- ◆ This profile uses the same CRC polynomial as that used in the SHM2 version.
- ◆ The CRC calculation in this profile covers the PG's parameter data payload as well as the PGN, DA for point-to-point PGs, SA, and Sequence Number fields.

There are some trade-offs:

- ◆ This profile requires that the PG's parameter data payload is exactly 8 byte.
- ◆ Like the SHM1 and SHM2 versions, this profile is not well suited for communications across routers.



Figure 4: Format of Profile #2 assurance data specified in J1939-77 (Source: Caterpillar)

The Profile #2 focuses on the following:

- ◆ Handling a PG's parameter data payload that is of variable length and that can be larger than 8 byte.
- ◆ Supporting communication across routers by not relying on link-local addresses for connection authentication.

The resulting functional safety assurance data fits within 12 bytes.

Figure 4 illustrates the format of the assurance data for Profile #2. The internal arrangement of all fields is least-significant-byte-first. The Length field contains a count of the bytes over which the CRC is calculated. This solution offers the following advantages:

- ◆ This profile can handle a PG's parameter data payload whose length can range from 0 byte to 19 byte.
- ◆ This profile is suitable for communications across routers due to its specification of a 24-bit data identifier, DataID, that provides connection authentication and that must be unique within a system.
- ◆ This profile uses the same CRC polynomial and Sequence Number as that used in Profile #1.
- ◆ The CRC calculation in this profile covers the PG's parameter data payload as well as the Sequence Number, DataID, and Length fields.

The drawbacks are:

- ◆ This profile cannot handle a PG whose parameter data payload is large enough to completely fill a CAN FD data frame.
- ◆ The scope of DataID definitions is specific to a system; there are no globally defined DataIDs.

The Profile #3 focuses on the following:

- ◆ Handling a PG's parameter data payload that is of variable length and that can be much larger than that supported by any other profile.
- ◆ Handling data that can only be communicated via the FD Transport protocol.
- ◆ Supporting communication across routers by not relying on link-local addresses for connection authentication.

The resulting functional safety assurance information fits within 17 bytes.

Figure 5 illustrates the format of the assurance data for Profile #3. The internal arrangement of all fields is least-significant-byte-first. The Length field contains a count of the bytes over which the CRC was calculated. The advantages are:

- ◆ This profile can handle a PG's parameter data payload whose length can range from 0 byte to 65526 byte.
- ◆ This profile makes use of a CRC polynomial (labeled as CRC-64-ECMA in [2]) that results in a 64-bit CRC.
- ◆ The Sequence Number in this profile is the same as that used in Profile #1 and Profile #2.
- ◆ This profile uses the same DataID as that defined in Profile #2.
- ◆ The CRC calculation in this profile covers the PG's parameter data payload as well as the Sequence Number, DataID, and Length fields.

Of course, there are also some drawbacks:

- ◆ This profile has the largest set of functional safety assurance data of any profile.

- ◆ The CRC polynomial used by this profile is computationally more complex than that of any other profile.
- ◆ Like Profile #2, the scope of DataID definitions is specific to a system.

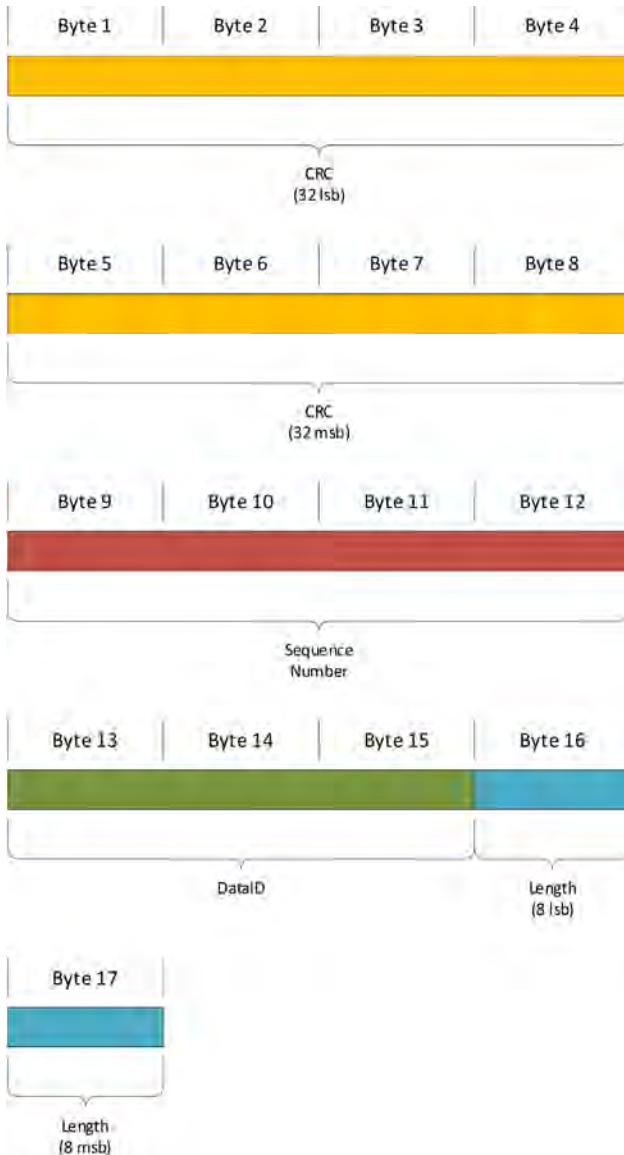


Figure 5: Format of Profile #3 assurance data specified in J1939-77 (Source: Caterpillar)

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- [1] IEC 61784-3:2021: Industrial communication networks – Profiles – Part 3: Functional safety fieldbuses – General rules and profile definitions
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- [3] SAE J1939-21: Data Link Layer, May 2022
- [4] SAE J1939-22: CAN FD Data Link Layer, September 2022
- [5] SAE J1939-76: SAE J1939 Functional Safety Communications Protocol, February 2024 unpublished draft
- [6] SAE J1939-77: SAE J1939 CAN FD Functional Safety Assurance Data, February 2024 unpublished draft

Conclusion

The communication errors and safety measures described in IEC 61784-3:2021 serve as the basis for the functional safety support as specified in SAE J1939-76 and SAE J1939-77. These SAE J1939 specifications provide different versions and profiles for this support over both CAN CC and CAN FD, allowing safety-related applications to select the appropriate version or profile that meets both their systems' needs and their functional safety requirements. ◀

(This article is based on the 18th international CAN Conference (iCC) presentation by Travis Breitzkreutz. The complete paper is published in the 18th iCC proceedings 2024; CiA, Nuremberg.)

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NMEA 2000 conformance testing and product certification



The NMEA 2000 product certification guarantees a certain level of quality and interoperability for NMEA 2000 networks by ensuring that a device supports a mandatory set of protocol services and hardware requirements. Developers can carry out the certification themselves or be supported by engineers experienced in the NMEA 2000 certification.

(Source: Adobe Stock)

NMEA 2000 is a higher-layer protocol based on CAN CC (classic) for marine applications. It is the de-facto backbone for marine applications around the world, integrating navigation, propulsion, lighting, power, switching, and entertainment devices. It always uses a bit rate of 250 kbit/s and has a maximum of 50 physical devices on one network. Based on ISO 11783 (SAE J1939), it specifies a set of standardized messages called Parameter Group Number (PGN), each of them has a unique number. There are PGNs available for a wide variety of applications inside a vessel such as navigation, propulsion, lighting, etc. One additional feature that NMEA 2000 requires on top of the ISO 11783 basis is the Fast Packet Protocol. This is an additional transport protocol, which can transfer up to 223 bytes in up to 31 CAN CC frames. Larger vessels typically have one to three NMEA 2000 networks. The typical NMEA 2000 network has a backbone connected via T-pieces and drop cables down to the devices. At each end there is a 120-Ohm termination resistor which is an off-the-shelf component. Figure 1 shows a typical installation for a NMEA 2000 network. In a micro NMEA 2000 network, all cables use the 5-pin M12 type connector.

NMEA 2000 devices have a set of rules that must be followed to operate correctly. These include but are not limited to:

- ◆ Provide configuration services to change features such as update rate, priority, and instance.
- ◆ Operate with a supply voltage between 9 V_{DC} and 16 V_{DC}.
- ◆ DC and AC isolation of I/Os from the NMEA 2000 connector.

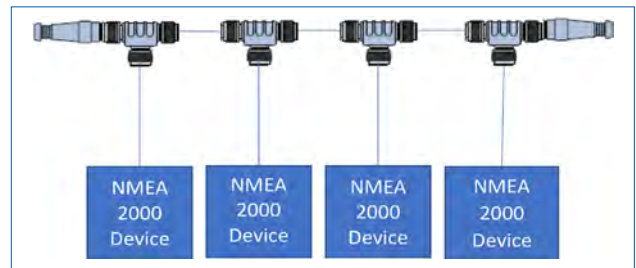


Figure 1: A typical installation for a NMEA 2000 network (Source: Warwick Control Technologies)

These rules are defined in the NMEA2000 specification package, which is available from the National Marine Electronics Association (NMEA) on its website (nmea.org). To be able to state that a product is a NMEA 2000 device, the NMEA requires that manufacturers put their products through the NMEA 2000 certification process. This is broken down into two main parts. The first is concerned with checking the requirements of the embedded software in the device to ensure that its communications conform to NMEA 2000, e.g. timing, requests, responses, and mandatory services. The second part is a self-certification checklist for hardware requirements mostly e.g. connectors, cables, PCB design, AC and DC isolation, and CAN signaling. These are described further in this article. ▶

NMEA 2000 devices and implementations

There is a lot of devices available on the market that claim to be NMEA 2000 compatible devices in some way. However, in reality most of these devices do not actually meet all of the requirements of NMEA 2000. There is also a large number of open-source and private projects available online, which aim to integrate into NMEA 2000. Again, these projects do not support all of the requirements of NMEA 2000. When a device is a NMEA 2000 certified device, it means that it provides certain software services via the protocol and also the hardware meets certain requirements (e.g. DC and AC isolation).

Benefits of NMEA 2000 product certification

Product certification guarantees a certain level of quality and interoperability for NMEA 2000 networks by ensuring that a device supports a mandatory set of NMEA 2000 protocol services and hardware requirements. For device manufacturers, this means that they can state that their product is NMEA 2000 certified and use the NMEA 2000 logo in their marketing.

The NMEA 2000 product certification process partly consists of automated software tests and partly of a self-certification process to check on the hardware and other requirements. Both are specified in Appendix C of the NMEA 2000 specification package available from the NMEA.

Automated tests are specified in Appendix C3 and use the bench setup shown in Figure 2. It uses a CAN CC interface by Kvaser as the other device on the network, which connects to the Device Under Test (DUT) via a terminated bench-based CAN CC network. The NMEA 2000 certification tool is used on a Windows PC and provides instructions for initial conditions of each test. After setup, all of the NMEA 2000 message exchange is started by a press of a button.

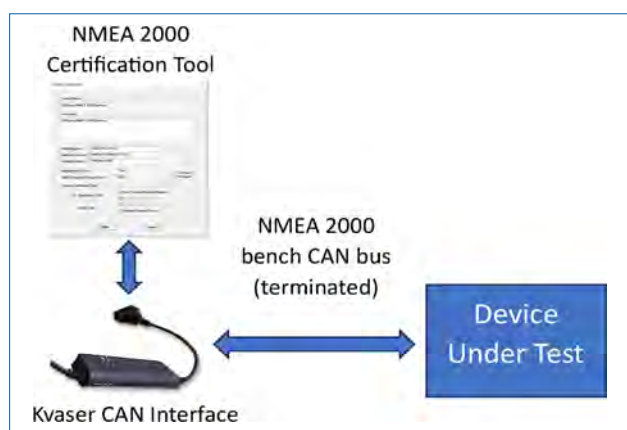


Figure 2: Setup for NMEA 2000 automated software testing (Source: Warwick Control Technologies)

Appendix C2 of the NMEA 2000 specification package is a self-certification process and takes the user through a set of hardware tests and checklist items to ensure that the product meets the requirements. These include such aspects as:

- ◆ Include measurements of DC or AC isolation between the NMEA 2000 connector and any other I/O that may be present on the device.

- ◆ Declaration of storage and operational temperatures.
- ◆ Details of CAN signal timing.

Companies wishing to develop NMEA 2000 devices can carry out the certification of the product to NMEA 2000 themselves by purchasing the NMEA 2000 certification tool from the NMEA. An alternative route is to benefit from the experience and guidance from the team at Warwick Control Technologies with their NMEA 2000 conformance and product certification services.

Whichever route is chosen, a Manufacturer Code (unique to company) and Product Code (unique to product) must be obtained from the NMEA.

Certification service

The main reason why companies use the conformance and product certification services from Warwick, is to benefit from the company's expertise and experience. In general, there are two levels of service available:

- ◆ **Pre-conformance test:** This is recommended for customers who need to check the main software conformance to the NMEA 2000 communication requirements and the CAN signalling of a prototype device. This can also be extended to look at NMEA 2000 hardware requirements if a customer is not confident in its hardware design.
- ◆ **Full product certification:** This is recommended for customers who think that their device is ready to go for full product certification with the NMEA. This includes a check of both software and hardware of the device.

The benefit of engaging Warwick earlier in the project and using the pre-conformance test service is that the developer will get early advice on issues that could delay development, increase project costs, and delay the product release date. The general benefits of the engagement include:

- ◆ Engaged engineers are experienced with the NMEA 2000.
- ◆ Know how to analyse the test failures.
- ◆ Tests provided in addition to those required by the NMEA, therefore helping to provide a high level of product for customers.

Common issues

A common misunderstanding is that NMEA 2000 is simply the SAE J1939 with parameters for marine applications instead of those for trucks. From the experience of Warwick Control Technologies, some companies simply do this and somehow obtain the details of the PGNs that they need from the Internet. When these are put through the software tests that are executed by the official NMEA 2000 certification tool, this often results in many failures.

There are also many commonly seen issues that lead to a failure and the need for re-testing. These are not always obvious initially and include such aspects as:

- ◆ **Sample point:** The requirement is that it should be set between 85 % and 90 %. However, often values of 75 % or less are used. This is often due to the default setting in the example source code that companies new to CAN have obtained for implementation of their low-level CAN drivers.



- ◆ **Automatic retransmission:** In early implementations of CAN, the automatic retransmission of a CAN frame upon corruption was mandatory. This became an option when Time Triggered CAN was introduced. To pass the software tests for NMEA 2000, automatic retransmissions should be enabled. This option is often disabled by default in the CAN drivers.
- ◆ **AC/DC isolation of NMEA 2000 connector:** The pins in the NMEA 2000 connector need to be isolated from other I/Os. If a device is repurposed from another application, often the isolation does not meet the NMEA 2000 requirements.
- ◆ **Use of proprietary PGNs:** The approach should be where possible to use an already available PGN from the standard, even if not all fields are needed. The unneeded fields can be set to “unavailable”. Proprietary PGNs should only be needed when there is not a standardized PGN available for the device’s purpose. The NMEA does strongly encourage companies in this situation to get involved in the standardisation of new PGNs.
- ◆ **Termination:** Often a device is being repurposed from another CAN application to NMEA 2000 and may have a termination inside the device. The original application is sometimes one that uses a PCB populated termination resistor in the device. For NMEA 2000 applications, a device may not have a termination resistor. The termination resistor can only be a harness-fitted component at each end of the backbone network providing two terminations in total.

Final word

Whilst conformance testing and NMEA 2000 product certification ensure that a device meets the protocol requirements, they do not ensure interoperability with other devices. It is part of the testing regime required for a NMEA 2000 product.

The simpler devices usually are quite straightforward. However, vessels tend to have a multi-function display (MFD) for access to the information from NMEA 2000 devices and to control aspects of the vessel. This is one of the more complex devices on the vessel. Entertainment head units and remote controllers are other examples of complex devices needing to integrate with the vessel MFD devices and can often be challenging. Interoperability of new devices with the more complex devices is not guaranteed by the NMEA 2000 product certification process and therefore additional testing is recommended. ◀



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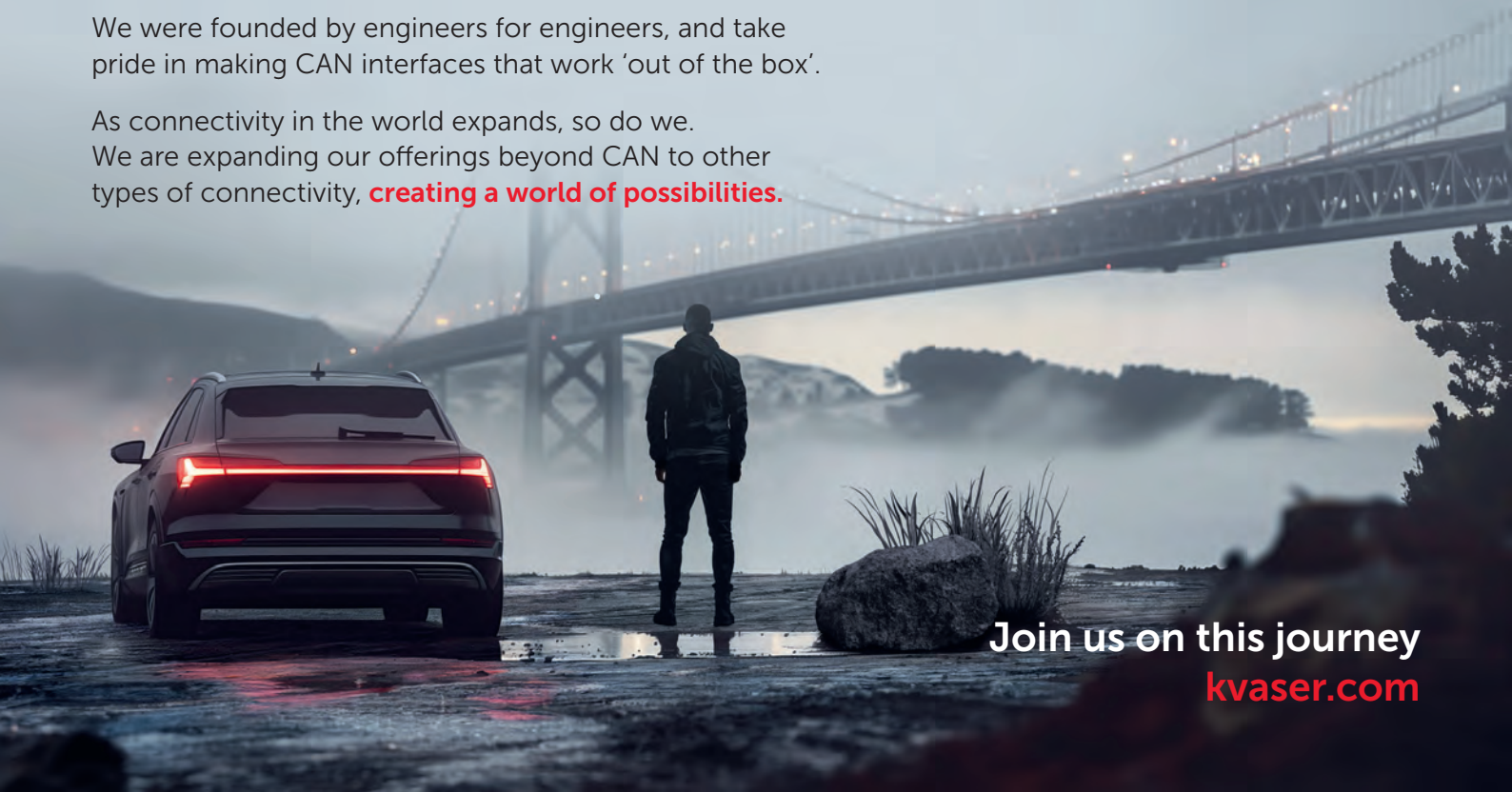
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CAN deeply embedded in intralogistics equipment



(Source: Adobe Stock)

The Logimat trade show 2024 saw nearly 70000 visitors. The international fair for intralogistics solutions and process management took place in Stuttgart (Germany) in March. Several CiA members and their customers exhibited CAN-based products and equipment. Often, CAN networks were deeply embedded and visible only on the second or even the third glance.

The history of logistics dates back to the first ancient civilizations. Already the Egyptian empire developed transport and storage techniques to maintain a steady supply of food and basic commodities. Historically, intralogistics equipment was powered by humans and animals. In the meantime, electric-powered equipment is state-of-the-art. The automatization of intralogistics solutions is a relatively new trend. Autonomously driving vehicles and robots are increasingly in use.

The intralogistics market is growing

According to Next Move Strategy Consulting, a market-research company, the worldwide intralogistics market 2023 counted 43,13 billion US-\$. It will grow to 115,92 billion US-\$ in 2030. This is caused by the increasing international trade. The intralogistics industry facilitates the movement, handling, and storage of materials, goods, and information within a facility or warehouse. This includes also the packing and shipping of goods. Intralogistics involves the use of automated handling systems, conveyors, robots, sensors, and software.

The Logimat trade show covers most of the intralogistics solutions. More than 1600 exhibitors presented their products and services. The Logimat organizer has established similar trade shows in China (Shenzhen), India (Mumbai), and Thailand (Bangkok).

Logistics-IQ has published a market research study about AGVs (automated-guided vehicles) and AMRs (autonomous mobile robots). According to the study, the installed base will exceed 2,7 million units in 2028. Around 670000 units will be sold in 2028.

The evolution of AGVs/AMRs over the last 15 years has created a broad range of types and sub-markets on the factory floor, in the warehouse and, at home, not mentioning the special-purpose solutions for hospitals, hotels, and other unusual applications. One of the key chasms in the world of AGVs/AMRs is the safety requirement differences between "service" AGVs/AMRs and "industrial" AGVs/AMRs. While the intent is that no AGV/AMR harms a human, service robots operate in the realm of the human beings. Working environments for service robots might include operation in a grocery store, a retail store, a mall, a hospital, on the sidewalk, or in the home.

Forklifts and AGVs

The hype in intralogistics are the automated guided vehicles (AGV). They are used on the factory floor, in distribution centers, etc. In some cases, they have substituted classic forklifts. Many of these forklifts use embedded CAN networks to control the drive and lift functions. Forklifts are also becoming driverless. Movanis exhibited on the Logimat a Still-based forklift using CAN-connected cameras by ifm ▶

electronic. The boundary between forklift and AGV blurs. Some companies name their products AGV lifters.

Most of the AGV suppliers do not talk about the used control system and the applied communication network. Behind closed doors, they tell often that CAN-based networks are in the AGV. Especially, wheel-hub drives provide CAN interfaces. Franz Morat Group offers such products integrating CANopen drives by Dunkermotoren. Gefeg-Neckar is another wheel-hub drive supplier. Its CAN-connectable sub-systems are applied in minibar AGVs used in hotels.

EBM-Papst showed at the Logimat the Argodrive driving/steering sub-system, which comes with an embedded CANopen network. It has been launched in 2021. In combination with drive controllers from various manufacturers, the sub-system forms a functioning drive system that enables free-range mobility for driverless transport vehicles. The Argodrive sub-system comprises also a steering angle sensor and two electrical drives featuring an STO (safe torque off) functionality. The two motors contribute towards steering, acceleration, movement and braking. Just two Argodrives on opposite corners of an AGV guarantee full omnidirectionality, two additional freely moving support wheels ensure stability. Depending on requirements, any number of drive systems can also be installed.

B-drives partnering with EBM-Papst offers the E-Wheel sub-system, which features a double-axis controller coming with an optional CANopen interface. The drives provide STO functionality. The company has also integrated a redundant encoder system. It is combined with the host controller from Sick, which communicates with the two drives via CANopen.

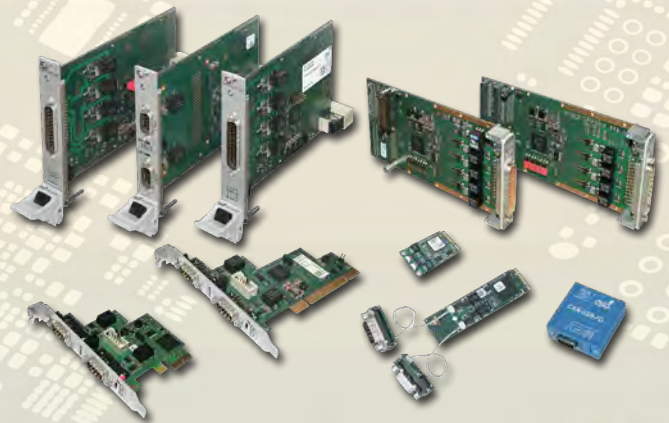
Motors like those in the Argodrive also function as sensors that detect a large number of conditions. Due to condition monitoring, the necessary replacement of the wheel module can be announced before a malfunction occurs. The sub-system can be used even for heavy loads and on inclines. The company offers the sub-system in light, normal, and heavy versions for weight classes up to 100 kg, 300 kg, respectively 500 kg. ▶



Figure 1: Four Argodrive driving/steering systems, for example, in the heavy version allow a total vehicle weight of up to two tons (Source: EBM-Papst)



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Lafert, part of the Suitomo group, offers the Smartris AGV/AMR wheel sub-systems based on CiA 402 compliant drives by Suitomo. The sub-system comprises a drive unit, a servo motor, a wheel, and a gear. STO functionality is provided, too. Two sub-systems integrated in an AGV shuttle enable an electronic differential drive system. Beginning of this year, the product comes in a new more compact version, measuring 120 mm in length and weighing 0,3 kg. It is 80 % smaller than the predecessor.

The towing AMRs by Tractonomy are based on CANopen drives by Nanotec. They are designed to tow carts and waste bins, for example. They are equipped with 360° lidar sensors. The vehicles stop, when the towed cart is disconnected. Therefore, the drives feature an STO function.

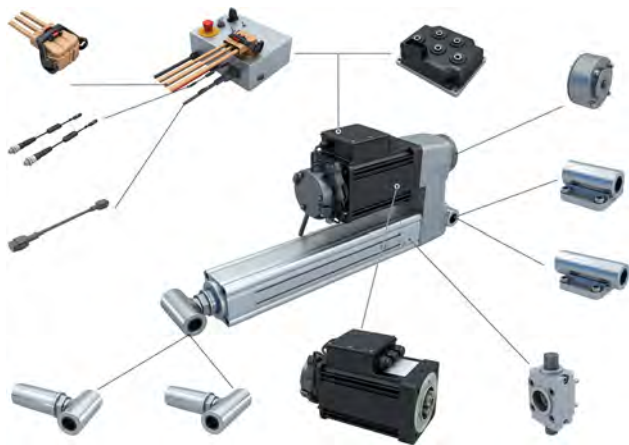


Figure 2: The E-Movekit is a complete CAN-connectable sub-system with all components that are needed to drive and control linear motion in AGVs/AMRs (Source: Ewellix)

For forklifts and AMRs with lifting functions, linear electric-powered drives are used, in some cases. Ewellix owned by the Schaeffler group has launched the E-Movekit, to replace traditional hydraulic devices. The linear drive comes with a CAN interface for integration into the in-vehicle network. Magazino, a Jungheinrich company, offers AMRs for material supply in assembly lines and warehouses. The products make use of the open-source Robot Operating System (ROS), a set of software libraries and tools that help building robot applications. There are libraries for CANopen drives (CiA 402) available.

Some AGV/AMR manufacturers implement only embedded CAN-based control networks. Safelog has accompanied the CAN-based backbone network with an ASi-5 bus system for I/O devices. Oceaneering does it the other way around: Their Unimover AGV is based on Profinet for functional-safety purposes and uses an additional CAN-based network for other non-safety tasks such as connecting I/O modules.

Eceon presented at the Logimat a truck-loading and -unloading robot, looking like a pallet mover. You can name it alternatively AGV with a lifting function. It uses a CANopen CC network as the backbone. The supplier claims a productivity increase, an error-rate reduction, and lower costs compared with traditional pallet movers.

The electric-powered AGVs and AMRs are often equipped with batteries, which have a CAN CC (classic) or CANopen CC interface. In some cases, the CAN-based interface is also used to communicate with the charging station. Multipowr located in Belgium launched at the Logimat the Buzzard80 charging station, which charges wirelessly the battery. The communication between battery (for example from Varta) and charger is based on CANopen FD. The protocol stack provider is Emotas.

Save the date

Broken down by sector, 52 percent of Logimat 2024 visitors came from industry and 16 percent from wholesale and retail. The majority of industry professionals (57 percent) were senior managers, who visited the tradshow to get a picture of the intralogistics solutions currently available and compare offerings. The full 38 percent of visitors came with specific investment projects in mind. And 24 percent of the visiting industry professionals awarded a contract during the show or plan to do so in the near future. These figures have been collected and evaluated by Wissler & Partner, an independent market research institute located in Basel, Switzerland. The next international Logimat trade show will take place in Stuttgart (Germany) from March 11 to 13, 2025.

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Scalable processors for future software-defined vehicles

NXP has announced the S32N family of vehicle super-integration processors to support the transition to future vehicles. The first family member S32N55 includes a CAN hub with four CAN XL and 24 CAN FD ports.

The S32N family enables automakers to evolve their vehicle electrical/electronic (E/E) architectures and centralize cross-vehicle functions previously implemented as individual hardware boxes (ECUs: electronic control units) into a central compute ECU. The latter can be a central vehicle controller focused on real-time applications or a central vehicle computer that also provides applications processing.

The introduced processors can integrate dozens of cross-vehicle functions with mixed-criticality. The used hardware isolation and virtualization technologies ensure freedom from interference between functions. Supported by complementary system components, software tools, and pre-integrated software, the processors are designed to accelerate software-defined vehicle (SDV) development and reduce vehicle cost and complexity. The processors offer many combinations of safe, real-time, and applications processing cores. This meets central computing needs ranging from real-time operating systems running deterministic vehicle control to high-level operating systems running vehicle management and OEM (original equipment manufacturer) applications and services.

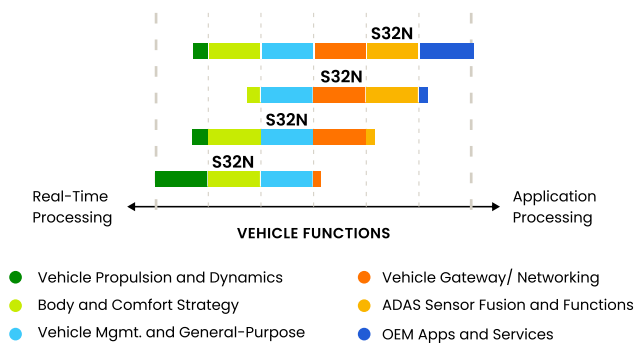


Figure 1: S32N processor is scalable across core vehicle functions (Source: NXP)

All S32N products integrate a CAN hub, an advanced hardware security engine, and a multi-port TSN Ethernet switch. Some processors also support Ethernet packet acceleration, AI/ML acceleration, and inter-compute PCI Express services.

Core vehicle functionality

Using S32N processors enables automakers to centrally consolidate core vehicle functionality in a central compute ECU. The latter can be custom-built to suit the diverse

requirements of vehicles (see Figure 1). In current vehicles, around 40% of the weight is electronics and wiring. Reducing the number and weight of car components enables the automotive industry to offer lighter and more energy-efficient vehicles.

NXP's S32 Coreride central compute solution is based on S32N processors. The solution combines S32N compute, vehicle networking, and system power management (such as the FS04 safe power management IC) to accelerate central compute development. The solution was designed to adhere to the automotive industry standards for vehicle functional safety (ISO 26262), security (ISO/SAE 21434), and reliability. When combined with software from company's partner ecosystem, including NXP's pre-integrated isolation execution environments, NXP will offer the holistic SDV (software defined vehicle) solution that can scale across the vehicle, and vehicle fleets.

First family member: S32N55

NXP released the first S32N55 family member as the heart of the S32 Coreride central compute solution. Former, vehicle propulsion, vehicle dynamics, chassis control, body, and other core vehicle functions have been implemented as discrete electronic control units (ECUs), each with their own micro-controller and wiring. Vehicle functions can now be consolidated into an S32N55 processor with multiple isolation execution environments, which allows to reduce ECU hardware costs. Decreased material and reduced weight also contribute to sustainability and extended driving range. For carmakers, it results in lower manufacturing complexity and time.



Figure 2: S32N55 family targets centralized, safe, real-time vehicle control in software-defined vehicles (Source: NXP)

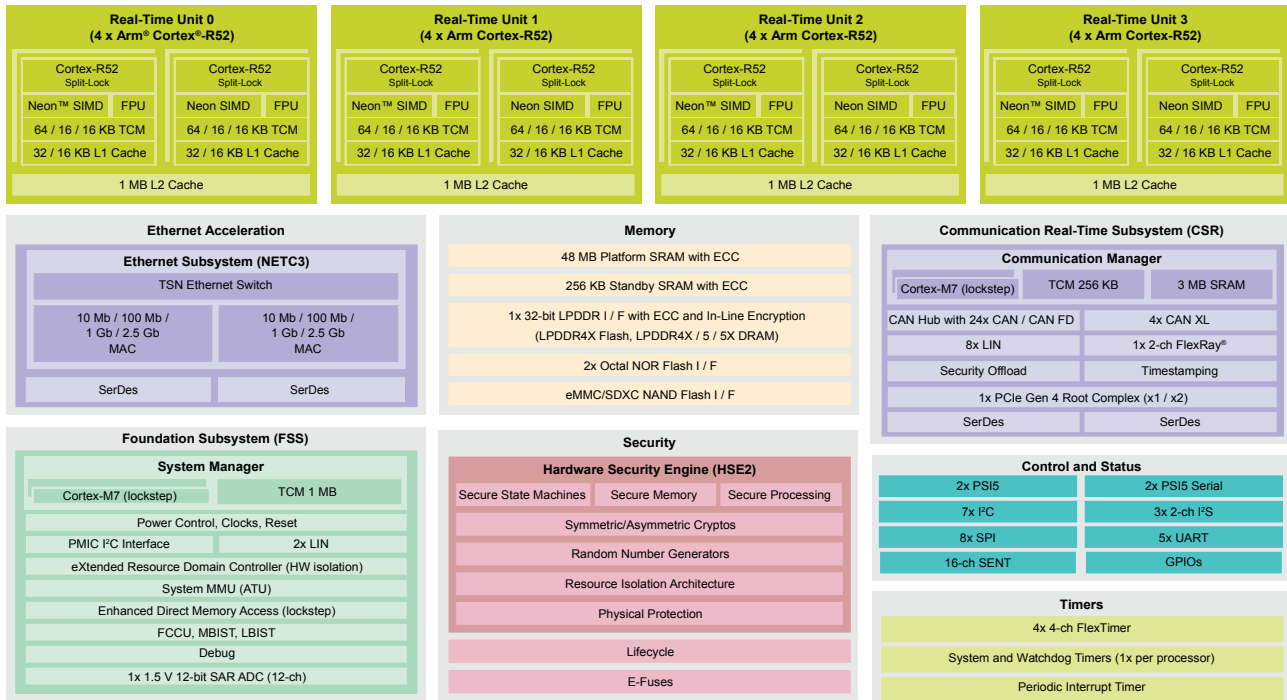


Figure 3: Block diagram of the S32N55 processor (Source: NXP)

With the “core-to-pin” hardware isolation and virtualization technologies, processor’s resources can be dynamically partitioned. Vehicle functions can be managed independently, including fault handling and reset. They can receive independent software updates with the over-the-air (OTA) upgradeability.

The automotive-grade S32N55 processor integrates 16 split-lock Arm Cortex-R52 processor cores running at 1,2 GHz for real-time compute. The cores can operate in split or lockstep mode to support different functional safety levels up to ISO 26262 ASIL D (automotive safety integrity level). Two auxiliary pairs of lockstep Cortex-M7 cores support system and communication management. Tightly-coupled integrated memory and 48 MiB of system SRAM enable fast execution with low-latency accesses. A firewalled Hardware Security Engine provides a root of trust for secure boot, security services, and key management.

An integrated CAN hub for internal routing of 24 CAN FD networks and four CAN XL interfaces, time-sensitive networking (TSN) 2,5-Gbit/s Ethernet switch, and a PCI Express Gen 4 interface help reduce wiring and system cost. Memory can be expanded with LPDDR4X/5/5X DRAM, LPDDR4X flash, and NAND/NOR flash interfaces. Functional safety and security requirements are supported with memory error correction and in-line cryptography. The S32N55 is complemented with NXP’s system power management and vehicle networking devices as the S32 Coreride platform’s central vehicle controller solution to accelerate customer designs. The FS04 safe system power management IC combined with PF53 scalable core supply for platform design, provides high-efficiency power conversion, supports low-power modes, and handles power sequencing, informs the manufacturer.

The S32N55 is sampling to lead customers. Enablement by NXP and a partner ecosystem, including the S32 Coreride software partner ecosystem, include comprehensive board, enablement software, tools, and systems support to accelerate customer designs.

Debug engine for S32N55

PLS Programmierbare Logik & Systeme (Germany) has released the UDE 2024 version of the Universal Debug Engine at the Embedded World 2024. This version supports the multi-core debugging and tracing for the S32N55 vehicle super-integration processor. The processor targets central vehicle controllers that can consolidate dozens of electronic control units (ECUs) in software-defined vehicles (SDVs).



Figure 4: UDE offers an intuitive user interface for debugging and runtime analysis of applications when developing software for the S32N55 (Source: PLS)

UDE offers an intuitive user interface for debugging and runtime analysis of applications when developing software for the S32N55. The processor’s Cortex-R52 main cores and the Cortex-M7 auxiliary cores are all visible and can be controlled from one common, customizable debugger user interface supporting multi-screen operation. This eliminates the need to open separate debugger instances for each core. It is possible to define multiple views and switch between them to focus on a particular debugging task. Pre-defined configurations for the S32N55 also allow developers to quickly get started with their actual debug or test tasks.

Depending on the software partitioning of the applications running on the processor and the particular debug scenarios, the UDE's synchronization behavior can be flexibly changed. The integrated run control management allows to define a run control group for partial synchronization, for example, in which only a subset of the cores is synchronized. To control all cores individually, synchronization can also be deactivated. For applications where tasks are distributed across multiple cores and shared code is used, UDE's

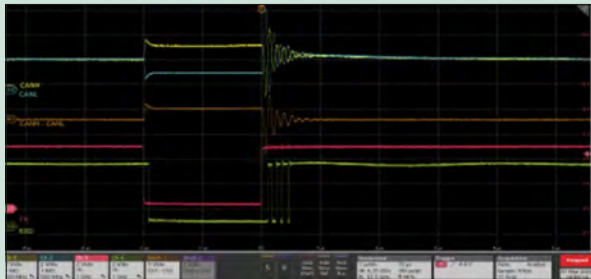
multi-core breakpoint feature eases debugging. The multi-core breakpoint is effective regardless of which core is currently executing the specific code.

The UDE also provides developers with a detailed insight into the runtime behavior of the system and enables comprehensive analysis based on the recorded trace data. These include profiling, call graph analysis, and code coverage to verify the quality of software tests.

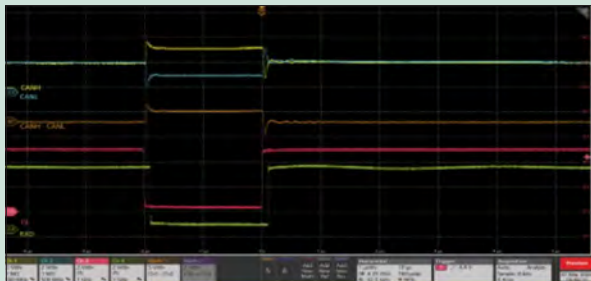
of

CAN SIC transceiver

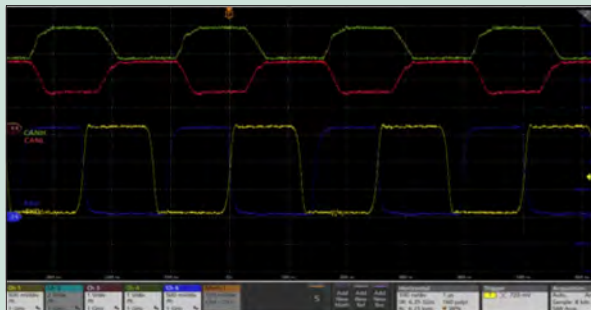
CiA member Novosense has introduced the NCA1462-Q1 transceiver, which provides signal improvement capability (SIC) as standardized in ISO 11898-2:2024 (formerly specified in CiA 601-4). According to the Chinese company, the chip features a high EMC performance. This improves the network robustness and optimizes system costs.



CAN FD star network multi-node communication waveform without SIC transceiver



NCA1462-Q1 star network multi-node communication waveform with SIC transceiver



NCA1462-Q1 communication waveform at a bit rate of 8 Mbit/s

Figure 1: Waveforms of the NCA1462-Q1 (Source: Novosense)

In automotive applications with complex working conditions, harsh electromagnetic interference (EMI) in the environment can be coupled to the transceiver

through the cable, which can lead to abnormal transmission and even damage the transceiver. The NCA1462-Q1 transceiver has anti-interference capability. Even in extremely harsh electromagnetic environments, it can still maintain CAN FD communication, laying a solid foundation for a robust communication. On the other hand, EMI within the application system can also radiate externally, thus affecting the transmission of communication signals. The launched transceiver is optimized for EMI based on an innovative patented architecture and tested in accordance with IEC 62228-3, as shown in the figures.

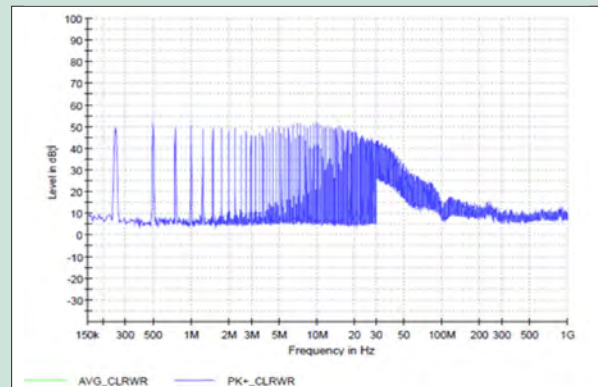


Figure 2: EMI test chart of NCA1462-Q1 without common mode choke (Source: Novosense)

In addition, the CAN SIC transceiver achieves a ± 8 -kV ESD performance by optimizing the circuit structure and layout area. Additionally, it provides a reliable circuit protection against transient ESD threats during automotive driving, while achieving better device cost performance. With this EMC/ESD performance, the transceiver can help engineers to eliminate common mode choke or TVS tubes from peripheral circuits in some designs. Furthermore, the VIO design as low as 1,8 V can further save the use of LDO or level shifter in the system, helping engineers to reduce overall costs.

The NCA1462-Q1 is available in SOP8 and DFN8 packages and is compatible with other CAN HS (high-speed) and CAN FD transceivers. The transceiver meets AEC-Q100, Grade 1 requirements, supports a wide operating temperature range of -40 °C to $+125$ °C, and provides over-temperature protection. It supports TXD explicit timeout protection and features remote wake-up in standby mode. Samples of the device are available.

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CAN in airport logistics



CAN networks are often deeply embedded and invisible. However, on the Passenger Terminal Expo 2024, the tip of the CAN iceberg became to the fore. One typical example are CANopen-connectable drives in doors and access gates.

(Source: Ametek)

CiA member Dunkermotoren, a brand of Ametek, exhibited on the Passenger Terminal Expo 2024 trade show its drive solutions for the door automation. They are used for sliding and swing doors. They provide CANopen interfaces compliant with the CiA 402 profile, internationally standardized in IEC 61800-7 series. Tobias Johnston, key account manager building automation at Dunkermotoren, explained: “Equipped with brushless DC motors and integrated or external motor control units, those access gates provide additional safety for passengers. Customized and parametrizable motion profiles contribute to smooth and safe airport operation.” Due to its expansive modular system including motors, gearboxes, encoders, brakes, and control electronics, drive system combinations can be configured for any application. At airports or metro stations, for example, entry systems such as access gates ensure that only authorized persons get access to the airport terminal, or that the door to a platform is only released after the metro has stopped.

Different types of access gates, such as a one-way corridor or automated passport control, provide different installation spaces for the drive solution. The option to select from both, planetary as well as angular gearboxes such as worm or bevel gearboxes, allow Dunkermotoren to configure the suitable drive solution for each entrance system no matter the space constraints.

When using appropriate control electronics from the drive supplier, the motor can be set torque-free via appropriate safety functions. Reversible gearboxes allow a manual opening for escape and rescue routes.

One of the customers is the Gunnebo Group headquartered in Gothenburg, Sweden. The group provides access gates and turnstile products. They embed several drives by Dunkermotoren communicating via CANopen with the host controller. The human machine interfaces are not yet CANopen-connected, but some sensors are.

There are also CANopen drives by CiA member EBM-Papst used in access gates, rotating doors, etc. The company offers motors and drive controllers. As the competitors, the modular drive systems are designed for customer-specific solutions with generic building blocks.

The EN 17352 standard

By publishing the EN 17352:2022 standard, suppliers of power-operated access control devices such as turnstiles, swing lanes, and retractable lanes have been confronted with additional requirements and test methods. This European standard covers safety in use of pedestrian entrance control equipment used for normal access as well as in escape routes and emergency exits.

Thus, manufacturers of such products are required to take further safety characteristics into account when designing their product. Dunkermotoren helps to contribute to the compliance of these requirements. Reversible gearboxes, for example, allow a manual opening for escape in case of emergencies, ensuring the vital safety of passengers. Additionally, the motor controllers can safely switch off the drive torque so that no one is harmed on their escape route. They are certified to EN ISO 13849-1 for Performance Level d (PL d) / Category 3.

The EN 17352 standard applies also for revolving doors. In 2021, Boon Edam has already introduced the Tourlock series of security doors. The Tourlock 180 (4-winged) and Tourlock 120 (3-winged) doors now offer compliance with the EN 17352 standard. These doors have been updated to provide security protection through anti-tailgating and piggybacking functions. They use embedded CAN networks to communicate with sensors and actuators.

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CAN in baggage handling



(Source: Sick)

CiA member Sick presented in Frankfurt on the Passenger Terminal Expo 2024 its sensors able to sense baggage. The company offers different sensing technologies: laser, camera, and RFID. These products can be combined to detect and to identify the baggage. The communication between them is possible by means of CAN networks. Multiple of such stations installed along the conveyors allow an end-to-end tracking.

The company has set the goal of implementing gapless baggage tracking hand-in-hand with customers in line with IATA (International Air Transport Association) Resolution 753. Roland Karch, Global Industry Manager airports at Sick, said: “We are market-leading in this application with a market share of more than 70 percent.”

CiA member Nord Drivesystems offers CANopen-connectable drives to move the baggage conveyors. The Logidrive product family comes with Duodrive, Nordac-on, or IE5+ synchronous motors. The integration

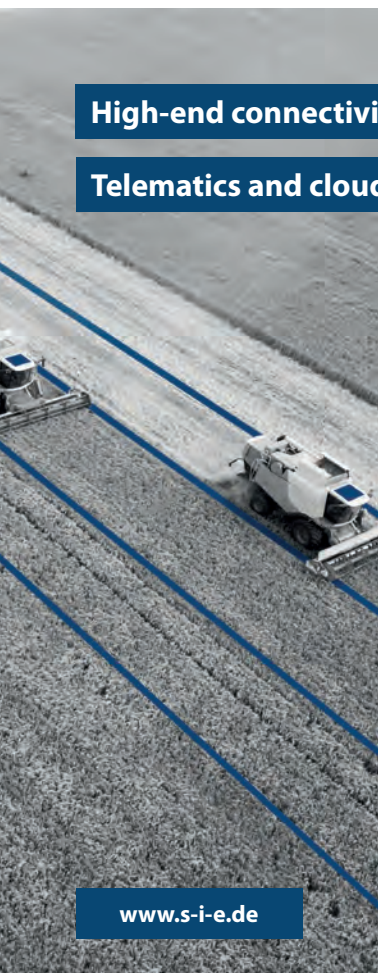
of the drive into the gear unit housing reduces installation space, the number of wear-prone parts, and thus also the maintenance effort.

There are also self-contained transport vehicles moving and loading baggage carriers to aircrafts such as the Intrac pallet mover by Dimos, Germany. Such special airport vehicles often use embedded CAN networks to drive the vehicle and to control the lifting equipment. Some of them drive already autonomously.

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Migrating from Flexray to CAN XL



The VW Group has started to consolidate its EE architectures towards E³.2.0 for all types of cars, e.g. volume, premium, sports, etc. A solution is required to have one communication technology for all vehicles, together with some other handy features. This article describes the challenges and gained possibilities of migrating from Flexray to CAN XL networks using the powertrain example, also considering CAN FD and why it is only an intermediate solution.

(Source: Adobe Stock)

Flexray [1] was designed to provide a high-performance networking technology to cope with time-critical communication demands in drive and powertrain control loops between ECUs (electronic control units) distributed throughout the car. Due to its complexity, limitations, and involved costs, it only found its use in premium cars. IC (integrated circuit) supplier support as well as OEM (original equipment manufacturer) market acceptance was not overwhelming.

Flexray started to enable time-triggered fast network communication for use cases like x-by-wire. These use cases required redundancy by concept, a synchronized system by design to enable precise causal computation and control loops in drive and the powertrain sub-systems as well as the first steps for assisted driving. In order to be safe and reliable, the system requires a fledged specification, where almost no room for interpretation should be given.

On the other hand, OEMs wanted design flexibility regarding communication schedule, redundancy, topology (e.g. active star couplers), etc. This led to vast amount of configuration parameters and cross dependencies, making it severe complex and expensive to handle. Furthermore, the physical layer was a challenge and had to be limited due to some design constraints, such as the majority voting and configurable receiver thresholds leaving almost no room for flexible networks under generalized configuration set-ups.

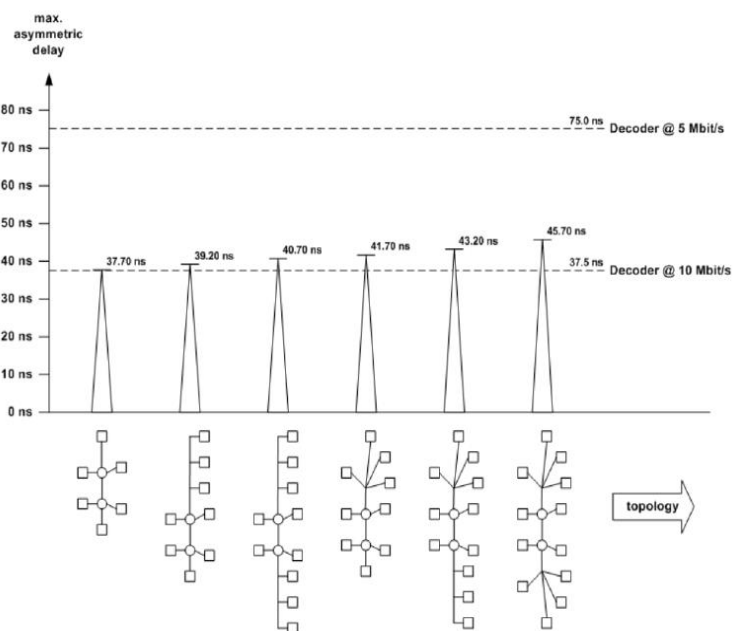


Figure 1: Asymmetric delay limitations at several topologies (Source: ISO 17458-4)

Finally, the daisy chaining of networks brought limitations in flexibility in production when it came to flashing and calibrating of ECUs, if not all ECUs were assembled to the vehicle at the same time and simple parameters such as bus terminations could not be met.

The CAN FD option

One option to solve the above-mentioned cost problems and the demand of system design flexibility is the CAN FD [2] approach for faster bit rates and larger payloads than CAN CC (classic) to still provide assisted driving and faster causal computation and control loops in a reasonable way for volume cars. But CAN FD does not feature a 256-byte payload as Flexray provides. Additionally, the limitation to 500 kbit/s in the arbitration phase when using CAN SIC transceivers and the maximum possible data phase bit rate of 5 Mbit/s are not sufficient for future application demands.

Prior to the introduction of CAN FD networks in VW Group cars (volume and premium) in 2019, many investigations have been conducted to check the system behavior for networks running in different configurations between 500 kbit/s and the desired and reasonable bit rate of 5 Mbit/s. It turned out, that networks in (multiple)star configuration for the most flexible use with 5 Mbit/s were extremely sensible and prone to ringing in areas, where a system designer does not want them to be.

It also turned out, that reducing network flexibility down to daisy chains adds other types of issues (e.g. plateaus in the area of receiver thresholds), see Figure 2 showing the TXD and V_{DIFF} signal of a high-ohmic ECU inside the daisy chain at a desired network topology size about to turn over the 0,5-V threshold.

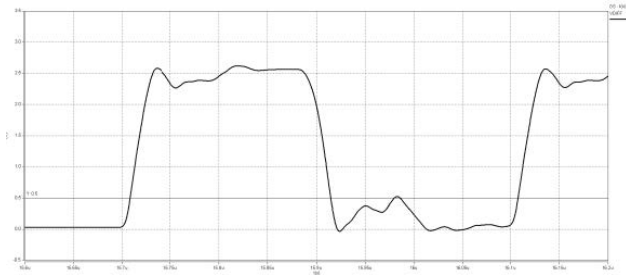


Figure 2: Example of CAN-FD daisy-chain-based signal plateau (Source: CARIAD SE)

The total line length and number of nodes had to be stripped down to a very short end, which led to a refusal of CAN FD networks (without SIC transceivers) using 5 Mbit/s in our systems. Thus, judging by the signal quality in those systems, being no alternative fallback or future-proof solution.

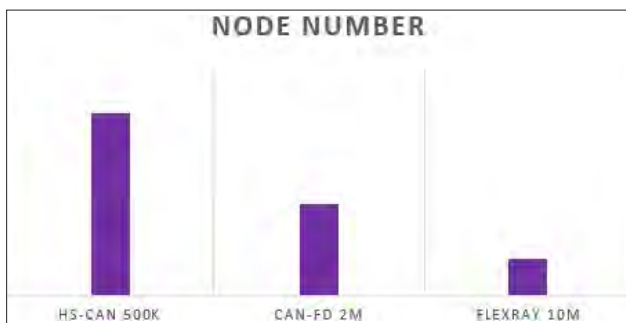


Figure 3: Node number comparison between CAN CC, CAN FD, and Flexray with maximum bit rates, based on single-wire harness topology layout limits (Source: CARIAD SE)

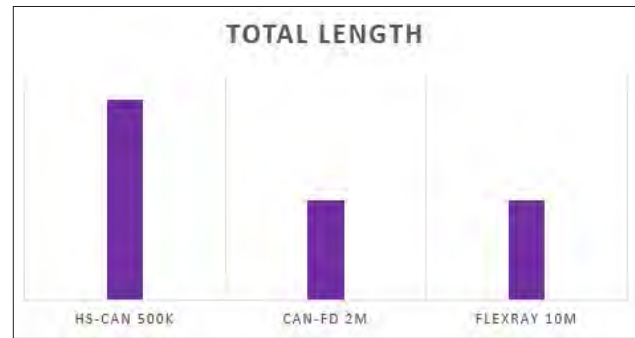


Figure 4: Total length comparison between CAN CC, CAN FD, and Flexray with maximum bit rates, based on single-wire harness topology layout limits (Source: CARIAD SE)

Flexibility in network topology size in terms of number of nodes and total line lengths was less compared to CAN CC, but still better than Flexray, as production line limitations could be omitted by star-based network topology layouts as well as customer-based demands to assemble ECUs in such network topologies.

Additional to the physical layer aspects, by the nature of the CSMA/CA bus-access method in CAN FD, to reach as less latencies and respective timing jitter, bus-loads had to be kept unusually low to achieve the required real-time behavior. Such bus-loads were required to be the half of bus-loads from other “regular” networks together with short payloads and limited number of frames. This effectively limited the net bit rate, compared to what is possible with Flexray by guaranteed bus access within a given communication cycle time.

The CAN XL alternative

Considering the above-mentioned requirements and the CAN FD limitations, it seems that CAN XL is a possible alternative for Flexray. The maximum bit rate of up to 20 Mbit/s when using CAN SIC XL transceivers in FAST mode and the 2048-byte payload of the CAN XL data frames overcome the limitations of CAN FD networks, also those using CAN SIC transceivers.

A practical example shows, how a network system migration towards CAN XL can be done. This takes an already transferred communication system example from Flexray to CAN FD with CAN SIC transceivers. Sharpening the focus, two example CAN FD networks (with SIC transceivers) are taken into account, which could represent the split of a real-time and additional data communication for a system design within a possible drive or power-train sub-system.

The goal is a real-time communication having these two network topologies consolidated back on one bus, which required to be split up from a Flexray system design.

This consolidated bus takes both communication set-ups into account and is furthermore designed to work from a physical layer perspective under all environmental conditions and specification limits.

For this, two different analyses are done. The first covers the consolidation of the communication on protocol layer by calculations and the second covers the feasibility of the physical layer by simulations.

Protocol layer analysis

One of these sibling networks sends real-time data for fast control-loop precision. The other bus takes all the "organizational" and "safety/security" related overhead. Within this context several meanings and system measures are used:

- ◆ **Real-time:** A communication loop shall be less than 5 ms, where data is available between a given sender/receiver combination in a repetitive manner;
- ◆ **Message cycle:** Repetitive transmission loop of a message;
- ◆ **Cycle jitter:** Timing variation of the message cycle based on best and worst case prioritized bus access;
- ◆ **Latency:** Time for the transmission of a message from message buffer at a sending node over the network topology to the message buffer of a receiving node;
- ◆ **Minimum latency:** Latency value for the transmission of a message with immediate and undisturbed bus access;
- ◆ **Worst-case latency:** Latency value for the transmission of a message with worst case bus disturbance;
- ◆ **Bus-load:** Average time of active message transmission/communication time over a given time period.

All of the above-described system measures are affected by the configuration of the active communication time on the bus and its detailed configuration, which shall be kept as low as reasonable and equally distributed. Equal distribution at first is affected by the differing size of message payloads and number of messages in conjunction. Furthermore, equal distribution requires a proper scheduling of message cycle loops in a communication set-up for a bus system inside the participating microcontrollers in the ECUs, meaning not all message cycles start at a defined cycle start point in time. How to achieve this, will not be discussed in this article.

The bus-load is affected by the number of messages sent on the bus, as well as by the length of data to be transmitted in each message and the used cycle time for each message. When using CAN CC or CAN FD, the arbitration length via the use of 11-bit or 29-bit IDs is also affecting the bus-load. Using the CAN XL protocol, only priority IDs with a fixed length of 11 bit are used [2]. Less messages for less arbitration overhead, lower message cycles and less message payload data basically lead to lower bus-loads.

The latency is affected by the number of messages sent on the bus and especially the length of data in each message, together with its priority identifier and message cycle. Less messages for less arbitration overhead and losses as well as smaller message payloads basically lead to lower latencies, respectively lower minimum and worst-case latencies. Worst-case latencies together with message cycle times directly affect the cycle jitter.

Message payloads using CAN FD are additionally affected by the limited and not byte-wise configuration of the DLC. Payloads above 8 byte almost always added fill bytes to conform the DLC configuration in case of signal data being not a multiple of 4 (up to 24 byte) or 8 (up to

32 byte) or 16 (up to 64 byte). This limitation is not existing in CAN XL and byte-wise configuration is possible. The derivation of the formulas behind the calculation of the latencies, bus-load, and cycle jitter are based on a VW Group internal paper [3].

Physical layer analysis

For the physical layer analysis, a reference model for mixed signal (analog, digital) simulation has been developed, which can be configured in different manners to walk on the physical layer specification limits, given in [2]. This includes for example output driver slopes and amplitudes, as well as transmitter and receiver asymmetries. Further PMD (physical medium-dependent) sublayer and transmission line components were taken from existing simulation ecosystems for CAN SIC and Flexray networks.

System termination values have to be derived based on the number of expected ECUs and total line length in one network topology to stay within physical layer specification limits. This is not being discussed in this article.

Within the physical layer context, several meanings and system measures are used:

- ◆ **Signal integrity:** Describing the necessary level of signal quality at the CAN pins analyzed by appropriate qualification criteria;
- ◆ **Eye diagram:** Single bit-wise qualification criterium on the convoluted differential signal between the CAN pins.

The signal integrity is evaluated by the measurement of the eye diagram at each sender/receiver combination in the network topology at each receiver, except the sender itself. The eye diagram is configured by means of the possible asymmetries, passive parasitic effects (based on the expected network topology size in terms of number of ECUs and total line length) and tolerances in the system, safety margins for EMC (electro-magnetic compatibility) robustness and bit-timing configuration.

The maximum eye opening is at the sampling point, which is configured to be in the middle of the bit plus one time-quanta. The calculation of the eye-opening values mentioned above is not part of this article.

Many analyses via simulation testbenches, lab, and EMC chamber measurements have shown, that the switching between SLOW and FAST mode in CAN XL networks turns out to be less as critical as the pure signal integrity at the FAST mode. However, the switching from SLOW to FAST mode has still an impact on the asymmetry on the first FAST mode bit pulse on the bus, a reasonable PCS (physical signaling sublayer) stimulus implementation is necessary for simulation-based analysis.

Communication set-up analysis

Flexray as a time synchronous bus system has regularly a reasonable message cycle of 10 ms or less with theoretically no cycle jitter, meaning the worst-case latency basically being equal to the minimum latency.

By the arbitration scheme used in CAN-based asynchronous bus systems with prioritized bus access, cycle jitter is very likely to happen and worst-case latency ▷

itself as well as cycle jitter must be limited, even when keeping fast message cycles equal to or less than the real-time window.

The premise for a possible consolidation shall be to keep the quality of the real-time communication besides the additional communication demand in one single CAN XL network from the former sibling networks in terms of the initial bus facts. Furthermore, there is room for future extensions of the target CAN XL bus, if further functionalities or ECUs are added to the network.

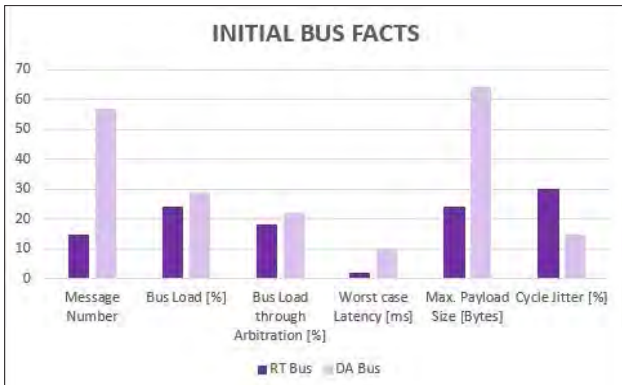


Figure 5: Initial bus facts of the real-time bus (RT) and data bus (DA) before merging to CAN XL (Source: CARIAD SE)

Figure 5 shows the initial facts from the two busses, using the CAN FD protocol with a 500-kbit/s arbitration rate and a 5-Mbit/s bit rate and parameter-based communication set-up. The calculations shown below ignore any non-cyclic messages in the communication set-up, as these are defined to play no role for the computational loop operation and repetitive exchange of vehicle state data during customer use. Examples are developer, diagnosis, flashing, or similar messages.

The message amount sent to the data bus is around four times the value of the real-time bus. The bus-loads are in the range of approximately 24 % to 29 % with approximately 18 % to 22 % overhead by arbitration.

The worst-case latency at the real-time bus calculates to 2 ms and at the data bus to 10 ms. The minimum used message cycle at the real-time bus is 5 ms and the maximum used message cycle is 200 ms, whereas the numbers for the data bus are 10 ms and 1000 ms. The maximum used payload at the real-time bus is 24 byte or less and at the data bus 64 byte or less.

The cycle jitter at the real-time bus reaches 30 % especially at messages with low message cycle time and low priority identifier due to many fast messages with very low message cycle times. In contrast, the cycle jitter at the data bus is approximately the half of the value due to no messages with very low message cycle time, blocking the transmission of other messages with lower priority.

The first step to one CAN XL bus is the raw merge of the communication set-ups from both initial CAN FD networks. With this raw merge, the arbitration rate will be kept at 500 kbit/s and bit rates from 10 Mbit/s to 20 Mbit/s are analyzed. In Figure 6, the initial comparison of the raw merger from the sum of both CAN FD networks (light grey bars) to CAN XL with 10 Mbit/s (light violet bars) and 20 Mbit/s (dark violet bars) is given.

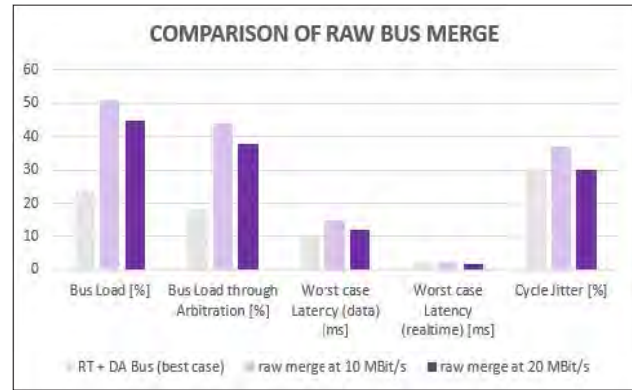


Figure 6: Comparison after initial merging to CAN XL (Source: CARIAD SE)

This first comparison shows, that as expected, the bus-load increases heavily due to the combined number of messages from both initial CAN FD networks. This further implies, that the bus-load overhead by arbitration increases accordingly and the worst-case latencies for the data bus related messages increase by some milliseconds. The worst-case latency for the real-time data remains around 2 ms or slightly better and the cycle jitter keeps the same dimension.

To possibly gain more potential with CAN XL communication, another paradigm in the communication set-up design should be analyzed in contrast to nowadays parameter-based communication with probably unchanged message routings throughout a vehicle and equal cycles for application and message transfer. Two different optimization approaches exemplarily show, how this can be achieved. Both initial busses operate with six ECUs, which plays a role at the discussed optimization steps.

Optimization

The first approach focuses on reducing the bus-load by a consolidation of signal data sent by one ECU into only a few messages. This means, that at first data with nearby message priority and cycle time is merged into as less messages as possible.

As a premise for the consolidation of signal data, only application-based data are merged. Other parameter data, e.g. for network management, remain untouched.

To reach a bus-load as low as possible, a good balance should be found with regard to which messages are consolidated into each other to:

- ◆ Not send too much data too fast and
- ◆ Not send too much low-priority data with too high priority

This prevents too long messages with too high priority on the bus and in general an equally distributed message size.

Figure 7 (for 10 Mbit/s) and Figure 8 (for 20 Mbit/s) show the comparison between the sum of both CAN FD networks (light grey bars) to CAN XL as raw merger (light violet bars) and as bus-load optimized set-up (dark violet bars).

The results after the bus-load-based optimization show, that the achieved bus-load is heavily reduced, compared to the raw merging of the CAN-FD networks and is even below the bus-load of one single CAN FD network. ▷

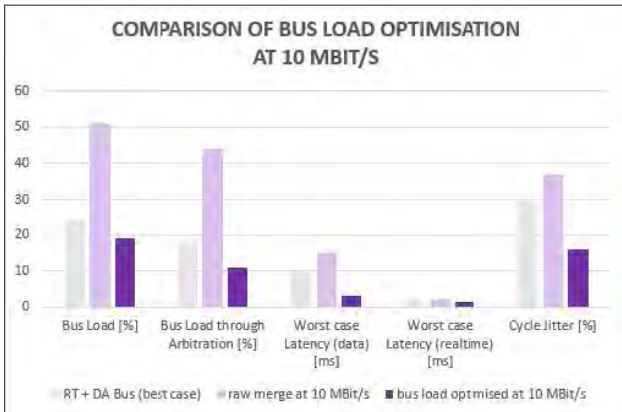


Figure 7: Comparison at 10 Mbit/s after bus-load-based optimization of merged CAN XL (Source: CARIAD SE)

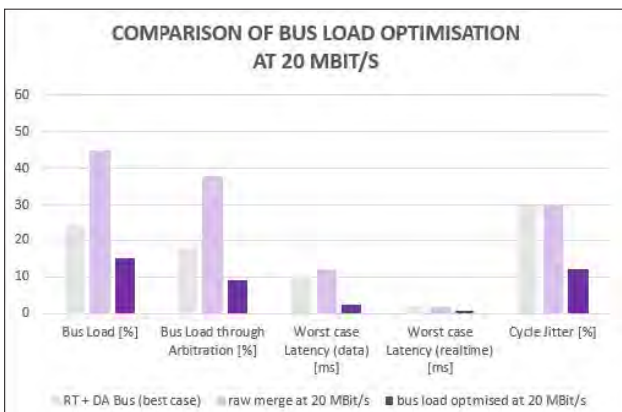


Figure 8: Comparison at 20 Mbit/s after bus-load-based optimization of merged CAN XL (Source: CARIAD SE)

Consecutively the overall worst-case latency of the data from the initial data bus improved to approximately 2,4 ms to 3 ms (depending on the CAN XL bit rate) and for the data of the initial real-time bus to 1,4 ms to 0,9 ms (depending on the CAN XL bit rate), which means that all transmitted data has real-time latency and very stable cycle jitter of even less than the half of the raw merged bus.

With the consolidation through the first approach, the maximum payload reaches approximately 180 byte, which is almost three times the maximum of CAN FD. The number of messages was reduced to nearly a quarter of the whole initial communication set-up.

The second approach focuses on reducing the worst-case latencies even more. This is achieved by drastically reducing the number of sending application messages to one. This implies, that all application data of each ECU is sent with the fastest message cycle and highest bus priority from the original data set of the initial busses. The results of the second approach slightly differ compared to the first approach. The overall worst-case latencies could be further reduced by approximately 0,5 ms. The worst-case latencies for the real-time data remained the same. Due to the above-mentioned fact, sending all data with highest priorities and fastest message cycles, the maximum payload increased to around 360 byte.

The bus-loads and cycle jitters remained the same at 20 Mbit/s, whereas slightly increased by 2 % to 3 %. This shows, that the “one message for all” approach improves best by increasing the bit rate.

Physical layer signal quality

Additionally, the network topology must work under the desired bit rates and further premises from the physical layer perspective, such as the wire-harness topology design needs to be as flexible as with CAN CC networks avoiding daisy-chain or linear topologies.

The network topologies for drive and powertrain sub-systems are by their nature mainly located in the area around the moving axles of a vehicle, far from the passenger cabin. Scalable electric powertrains exemplarily have accelerating and decelerating parts at the front and the rear axle, such as one or more electric motors and possibly further active differentials or torque distributors and braking system assembled. Finally, they are somehow connected to a central computing instance.

Initial example topologies are built up as 5-Mbit/s daisy-chain networks with six ECUs and a 20-m total line length each and additional six inline connectors due to exemplary modular part assembly.

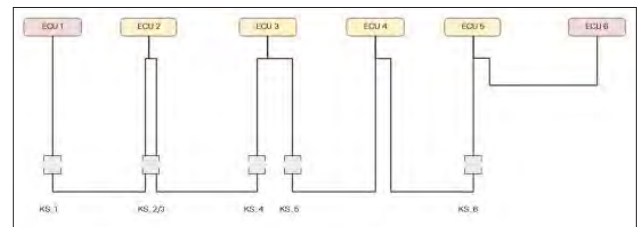


Figure 9: Example daisy-chain network in modular set-up for CAN networks using SIC transceivers running at 5 Mbit/s (Source: CARIAD SE)

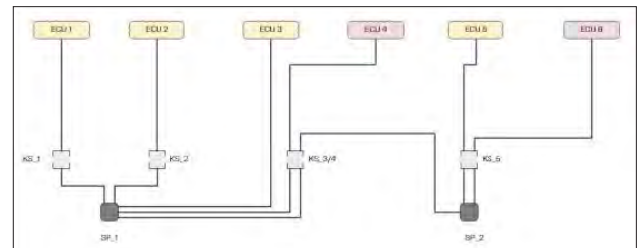


Figure 10: Example star network in modular set-up for CAN networks using SIC XL transceivers at 10 Mbit/s or 20 Mbit/s (Source: CARIAD SE)

The yellow marked ECUs are high-ohmic and the red marked ECUs are low-ohmic. As this network topology system is a scalable powertrain example, low-ohmic termination points must still be set at the daisy-chain end-points, increasing wire-harness complexity, handling subsets of the complete system. Star-based topologies can be configured in a more flexible way keeping the low-ohmic terminations stable at the minimum subset of network topology.

The remaining star-based network topology design for CAN XL is comparable to the CAN SIC network topologies in terms of total line length and in-liners, due to the exposed areas and modular assemblies of the ECUs.

In parallel to the communication set-up analysis, the derived CAN XL network topology is executed in simulation set-ups from 10 Mbit/s to 20 Mbit/s and evaluated by the signal-integrity measures discussed above. The creation ▶

of the eye-diagram signals is done directly by a simulation-model implementation to provide a correct synchronization of the given signals with an emulated PCS for worst-case stimulus according to [2] as only a little overhead in the executable testbench without having a complex post processing.

Figure 11, Figure 12, and Figure 13 show the worst-case signal integrity found in the network topology with worst-case transmitter asymmetry and weakest transmitter output driving values and an eye opening considering 200 mV additional EMC safety margin on top of the worst-case receiver thresholds given by [2]. The differential voltage signal is shown as the bold line, the synchronized eye-diagram raw signals are shown as dotted lines.

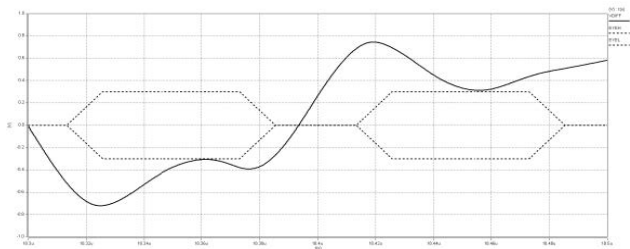


Figure 11: Worst case signal integrity at CAN XL network topology at 10 Mbit/s (Source: CARIAD SE)

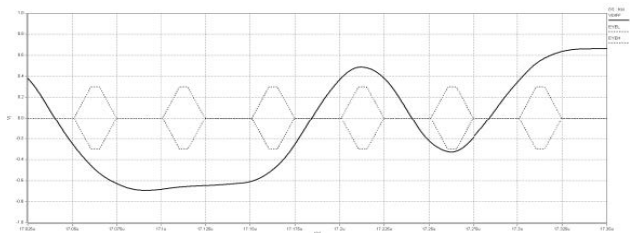


Figure 12: Worst case 1 signal integrity at CAN XL network topology at 20 Mbit/s (Source: CARIAD SE)

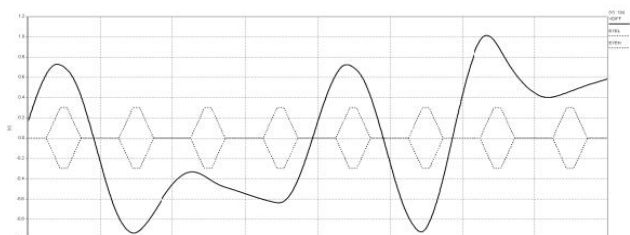


Figure 13: Worst case 2 signal integrity at CAN XL network topology at 20 Mbit/s (Source: CARIAD SE)

According to the results it can be said, that at lower bit rates the signal reflections implied by the network topology layout can shrink bit amplitudes in the same bit after initiating a slope, basically stressing the sample point. Whereas at the faster bit rates the signal reflections are jumping over to the following bits. This further implies, that depending on the number of sent bits of the same logical bit level have a huge impact on the signal shapes, see Figures 19 and 20. Simulations with bit rates between 10 Mbit/s and 20 Mbit/s show the overlapping of these effects from the corner case bit rates, but still keeping outside of the eye.

Together with in-vehicle EMC measurements of similar network topologies in terms of number of nodes and total line lengths, it can be said that the given example is capable of running at any bit rate up to 20 Mbit/s.

References

- [1] ISO 17458 series: Road vehicles – FlexRay communications system. ISO, Geneva, Switzerland.
- [2] ISO 11898 series: Road vehicles – Controller area network. ISO, Geneva, Switzerland.
- [3] Dr. Anna Engelmann: Method for analytical latency evaluation of time critical messages sent of CAN, CAN-FD, CAN XL. CARIAD SE, Wolfsburg, Germany.

The physical-layer simulations show, that any of the bit rates up to 20 Mbit/s are visible, even under worst-case conditions and flexible star-based network topology designs.

Conclusion

Summing up all of the previous analyses, using CAN XL makes Flexray obsolete, reduces the number of necessary network interfaces in central computing or zonal ECUs, reduces the number of network interfaces in real-time sensing/acting ECUs, reduces the number of wiring harnesses, omits private direct connections between real-time sensing/acting ECUs, and omits oversized automotive Ethernet-based and switched multiple point-to-point connections in real-time vehicle movement and control loops. This leads to an overall reduction of development and system complexity, material use, vehicle weight, and therefore to less costs. All of the above-mentioned benefits lead to a lot of headroom in network design in terms of number of nodes, total line length and bit rates for being a future-proof technology.

The heavy improvement of flashing time through faster bit rates and larger payloads just comes as a bonus factor by the technology itself, as well as built in Ethernet frame mapping, routing, tunneling. Adding functionalities can happen with a stable and powerful physical layer, without adding more and more networks to the network architecture. This helps even more when thinking about development concepts such as software-defined vehicles (SDV).

Based on the analysis described above, the communication set-up analysis in particular, focused on the pure consolidation of parameters with the drawback of probably sending some data more than necessary. A PDU-based communication set-up as a further optimization step must be analyzed. Only transmit data, when needed and not all at once furthermore reduces the calculated bus-load and latencies giving even more headroom for a stable and future-proof network design. ◀

(This article is based on the 18th international CAN Conference (iCC) keynote presentation by Marko Moch. The complete paper is published in the 18th iCC proceedings 2024; CiA, Nuremberg.)



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Standards and specifications



This section provides news from standardization bodies and nonprofit associations regarding CAN-related documents. Included are also recommended practices, application notes, implementation guidelines, and technical reports.

ISO 11898-2:2024 and ISO 11898-1:2024 published



The CiA 140 technical report provides ISO 11898-2:2024 corrigendum proposals (Source: CiA)

ISO has released new editions of the ISO 11898-1 (CAN, Part 1: Data link layer and physical coding sublayer) and ISO 11898-2 (CAN, Part 2: Physical medium attachment (PMA) sublayer) standards. These new editions contain all three CAN protocol variants: CAN CC (classic), CAN FD (flexible data-rate), and CAN XL (extended data-field length) respectively all PMA options. The PMA options cover all kinds of CAN HS (high-speed) transceivers including CAN FD, CAN SIC (signal improvement capability), and CAN SIC XL transceivers. Of course, also the low-power and selective wake-up functionality is standardized in ISO 11898-2. The CiA documents, which have been submitted

for these two standards, are withdrawn, in order to avoid double-specifications and not to infringe the ISO copyrights. The withdrawn documents are CiA 601-4 (SIC transceiver), CiA 610-1 (CAN XL protocol), and CiA 610-3 (CAN SIC XL transceiver). Additionally, the CiA 604-1 (CAN FD Light) specification has been withdrawn. It is now in the annex of ISO 11898-1:2024.

Unfortunately, not all final submitted comments on ISO 11898-2:2024 have been considered by the ISO Central Secretariat (ISO CS). This is why CiA has released a corrigendum (CiA 140). This technical report proposes improvements and corrections, in order to avoid misunderstandings and misinterpretations. In the current ISO

11898-2:2024 standard, several figures and tables are not consistent. The CiA 140 documents can be requested from the CiA office. This service is free of charge. The technical report is individualized by means of a watermark. The for ISO 11898-2 responsible working group will revise the standard as soon as possible. In the meantime, the CiA 140 technical report overcomes the weaknesses of the standard.

There are also some minor final editorial comments on the ISO 11898-1:2024 standard, which have not been accepted by the ISO CS. They will be considered in the next edition.

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Brief news

- ◆ **SAE J1939DA:** In April, the quarterly updated digital annex of J1939 has been published. It contains suspect parameter (SP) and parameter group (PG) specifications.
- ◆ **DIN 14700:** The German standard proposal for CAN-connected fire-fighting truck body application units has passed positively the final ballot. It is based on CANopen with some dedicated additional functions. This approach is also known as FireCAN.
- ◆ **DIN 4630:** The German standard for a CAN-based commercial vehicle body application network has been submitted to ISO for international standardization. The new work item proposal within ISO TC22 (road vehicles) is in ballot to be accepted under the number ISO 25200. This standard needs to be functionally extended regarding a secondary display and an (electric) PTO (power take-off) manager. Additionally, there are some pending requests for new body application units, e.g. hook-loaders.
- ◆ **ISO 15765-2:2024:** ISO has released a new edition of the Road vehicles – Diagnostic communication over Controller Area Network (DoCAN) – Part 2: Transport protocol and network layer services standard. The main changes are the restructuring of the document to achieve compatibility with the OSI model, the introduction of the T_Data abstract service primitive interface to achieve compatibility with ISO 14229-2, and clarifications as well as editorial corrections.
- ◆ **ISO TC347:** In April, ISO has established a new technical committee (TC) with the name data-driven agrifood systems. The scope also includes greenhouse automation. An ad-hoc task force to be established will evaluate the use of CAN-based embedded networks. The initiative comes from South Korea and is supported by CiA.
- ◆ **Isobus plugfest:** The nonprofit AEF association has organized an Isobus plugfest in Houston (TX), U.S.A., end of February. Some 75 participants from 20 companies tested 33 products on compatibility to the ISO 11783 series.
- ◆ **CAN XL plugfest:** On May 16, CiA has organized a CAN XL plugfest testing CAN XL protocol implementations and CAN SIC XL transceivers on interoperability. The CAN XL implementations by Digital Core Design (Poland) and Peak-System (Germany) were tested for the first time. About 60 experts participated in the plugfest.

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AI evaluation boards with CAN connectivity

For four years, Nvidia offers several system-on-modules (SOM) with one or two CAN FD interfaces. The CAN FD protocol controllers support the time-triggered CAN (TTCAN) protocol extension. These SOMs are Jetson AGX Orin, Jetson Orin NX, Jetson Orin Nano, Jetson Xavier NX series, and Jetson AGX Xavier series.

The CAN protocol controller is part of Nvidia's system-on-chips. It supports CAN CC (classic) and CAN FD data frame formats with 11-bit and 29-bit CAN-Identifiers. In CAN FD mode the maximum data-phase bit rate is specified as 15 Mbit/s. Using the SN65HVD230 CAN transceiver piggy-back module by Waveshare enables transmission rates up to 5 Mbit/s depending on the used topology. These modules recommended by Nvidia are based on 3,3-V CAN FD transceiver chips by Texas Instruments. The nominal and the data-phase bit rates are configurable. The Jetson AGX Orin and the Jetson AGX Xavier board families come with two CAN ports accessible at the 40-pin header connector.

To start CAN communication, the user needs to load CAN kernel drivers in the right order. To use the network, the developer first brings up CAN nodes on the network and installs a group of CAN utilities for testing. Then he/she can transfer frames (loopback test) and debug the network interface, if necessary. Several other debugging techniques can be useful in appropriate cases:

- ◆ If a loopback test shows that the CAN controller is working correctly and it is still not possible to send or receive frames, try reconnecting the transceiver and confirm that the connections are correctly made.
- ◆ Check whether all of the steps necessary to enable CAN communication were done properly.
- ◆ Connect an oscilloscope and see whether the bus is behaving properly.

- ◆ If the device logs a "No buffer space available" message during transmission, enter the command `$ cangen -L 8 can0 -p 1000` to use the polling mechanism.

The user can obtain higher data bit rates by configuring the TDCR (transmission delay compensation register), but should make sure that the transceiver being used is able to support higher bit rates. Additionally, it is possible to change the CAN parent clock on T194 platforms (only on Jetson Xavier NX series and Jetson AGX Xavier series boards). On development cards with the T194 SOC, the CAN parent clock is PLL_C. The PLL_C clock's core clock frequency is set to 34 MHz. To set a higher clock frequency or to obtain a bit rate of exactly 1 Mbit/s, the user can enable the PLLAON clock and make it the parent clock of the MTTCAN protocol controller. ▶

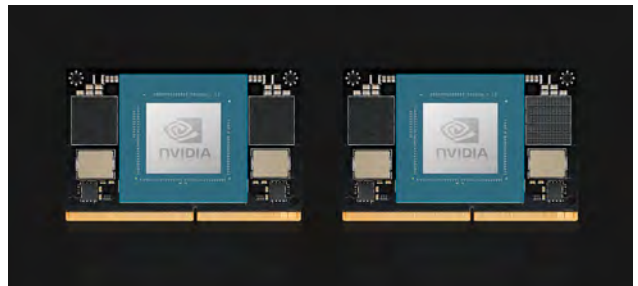


Figure 1: Jetson Orin Nano evaluation board (Source: Nvidia)

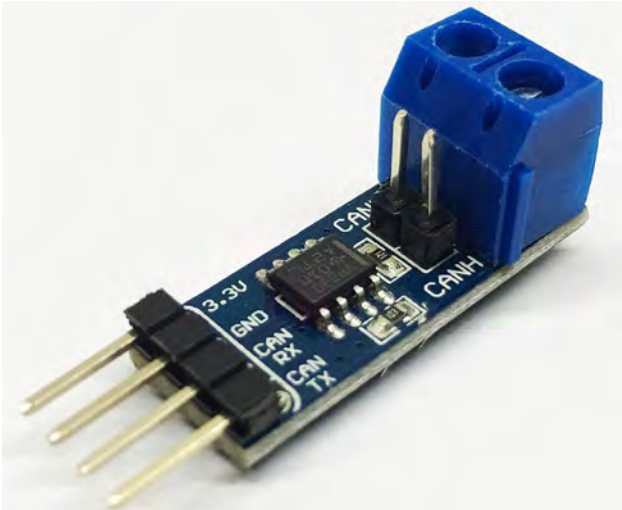


Figure 2: CAN transceiver piggy-back (Source: Waveshare)

Linux and QNX operating systems support Nvidia SOCs. Jetpack is a Linux-compliant software development kit (SDK) from Nvidia. Redhawk Linux is also available for the Jetson platform, accompanied by Nightstar real-time development tools, CUDA/GPU enhancements, and a framework for hardware-in-the-loop and man-in-the-loop simulations. The QNX operating system is also suitable for the Jetson platform. There are success reports of installing and running specific QNX packages on certain Jetson boards.

Developer kit for autonomous machines

Four years ago, the Jetson Xavier NX module, a platform to develop AI applications, has been launched. Using cloud-native technologies, developers can take advantage of the module's AI and compute performance in its credit-card-sized form factor. Manufacturers of smart machines and developers of AI applications can build and deploy software-defined features on embedded and edge devices targeting robotics, smart cities, healthcare, industrial IoT (Internet of Things), and more.

Sertac Karaman, associate professor of aeronautics and astronautics at the Massachusetts Institute of Technology, said: "The Jetson Xavier NX allows us to get higher performance within a tighter size and power budget, enabling innovative development of compact drones for a variety of practical applications. We believe the Jetson platform with cloud-native support is an important new development to help build and deploy future generations of autonomous machines."

The developer kit is smaller than a credit card (70 mm x 45 mm). It is powered by the Cuda-X computing stack and comprises the Jetpack SDK. It combines a reference module and carrier board with a Linux software development environment.

Two years ago, the Jetson AGX Orin developer kit followed. It is intended for advanced robotics, autonomous machines, and next-generation embedded as well as edge computing. The product delivers 275 trillion operations per second (TOPS), giving customers over eight times the processing power of its predecessor, Jetson AGX Xavier, while maintaining the same palm-sized form factor and pin

compatibility. It features an Ampere architecture GPU, Arm Cortex-A78AE CPUs, deep learning and vision accelerators, high-speed interfaces, faster memory bandwidth, and multi-modal sensor support to feed multiple, concurrent AI application pipelines.

"As AI transforms manufacturing, healthcare, retail, transportation, smart cities, and other essential sectors of the economy, demand for processing continues to surge," said Deepu Talla, vice president of Embedded and Edge Computing at Nvidia. "A million developers and more than 6000 companies have already turned to Jetson. The availability of Jetson AGX Orin will supercharge the efforts of the entire industry as it builds the next generation of robotics and edge AI products."

"With the global population expected to reach nearly 10 billion people by 2050, farmers have a steep challenge of feeding the world and they can't do it alone. With less available land and labor, and many variables to work through, deploying and scaling advanced technology like autonomy is key to building a continually smart, evolving and more efficient farm. Our fully autonomous tractor, featuring two Nvidia Jetson GPUs for quick and accurate image classification at the edge, will be on farms this year, supporting farmers in overcoming challenges and providing for our growing world," explained Jahmy Hindman, chief technology officer at John Deere.

"As a recognized medical technology leader, Medtronic continues to innovate and advance solutions to improve surgical patient care. We recognize the key role for AI in digitization of surgery through quantitative analytics and real-time clinical decision support systems. The latest Nvidia Jetson platform brings us a new level of computational performance in the operating room and enables us to advance intraoperative systems to better support surgeons, through data-enabled solutions," said Dan Stoyanov, chief scientific officer at Medtronic Digital Surgery.

One and a half year ago, the Jetson Orin Nano system-on-module that delivers up to eighty times the performance over the prior generation, has been introduced. It is also intended for entry-level edge AI and robotics. Now, the Jetson family spans six Orin-based production modules. This includes the Orin Nano — which delivers up to 40 TOPS of AI performance in the smallest Jetson form factor — up to the AGX Orin, delivering 275 TOPS for advanced autonomous machines. The product supports multimodal sensors and addresses Robotics Operating System (ROS) developers. ROS is a development environment, which supports CAN-based communication including CANopen CC (classic).

The Orin Nano modules are available in two versions. The Orin Nano 8GB delivers up to 40 TOPS with power configurable from 7 W to 15 W, while the 4GB version delivers up to 20 TOPS with power options as low as 5 W to 10 W. The Jetson Orin platform is designed to solve the robotics challenges and brings accelerated computing to over 700,000 ROS developers. Combined with the powerful hardware capabilities of Orin Nano, enhancements in the latest Isaac software for ROS by Nvidia put more performance and productivity in the hands of roboticists. ◀

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CAN XL IP core



Digital Core Design (Poland) in cooperation with DCD-Semi (Poland) has unveiled its DCAN-XL IP Core implemented according to the latest ISO 11898-1:2024 standard.

(Source: Digital Core Design)

The DCAN-XL IP Core has been designed to bridge the gap between CAN FD and 100-Mbit/s Ethernet. It should enable faster high-speed communication and reliable data transmission for automotive and industrial applications. The introduced IP core supports data rates up to 20 Mbit/s and provides a data field length of up to 2048 bytes, making it suitable for demanding real-time applications. By maintaining the advantages and reliability that CAN is renowned for, while offering enhanced speed and flexibility, the DCAN-XL opens up different possibilities for next-generation automotive and industrial systems.

One of the key features of the IP core is its backward compatibility, providing support for CAN CC (classic), CAN FD, and CAN XL protocols. This ensures seamless integration with existing systems while future-proofing designs for evolving industry standards.

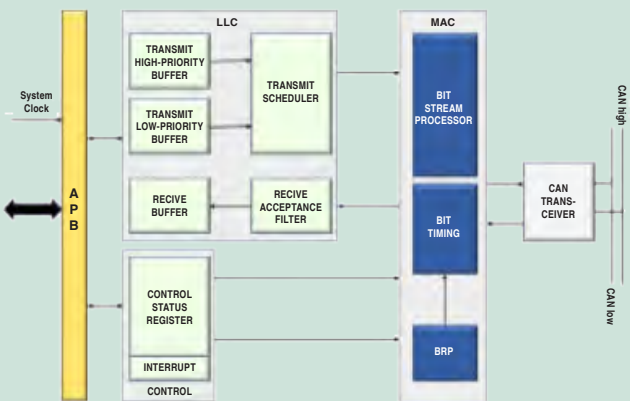
To establish a physical connection to the CAN network, external transceiver hardware is required. DCD recommends to use CAN transceivers for bit rates below 10 Mbit/s and CAN SIC XL transceivers for bit rates over 10 Mbit/s. The DCAN-XL utilizes a single or dual ported message RAM connected via the Generic

IP core featuring CAN FD light

The CAN FD light specification is available in the ISO 11898-1:2024 standard (formerly in the CiA 604-1 specification). Arasan offers a compliant IP core implementing a CAN FD light responder node. The launched CAN FD light IP (intellectual property) core can be integrated in host processor using the AMBA-APB interface. The configurable core supports programmable interrupts, frame acceptance filters, and frame buffering schemes. The bit rate is configurable, too.

The offered IP core complies with the CAN FD light responder specification in ISO 11898-1:2024. Additionally, it supports the time stamping as specified in CiA 603 as well as TTCAN level-1 functionality as specified in ISO 11898-4. According to the supplier, the IP core is optimized for Autosar and J1939 support. The provided listen-only mode enables analysis of CAN FD traffic and automatic bit-rate detection for performance measurement. The loopback mode is intended for debugging and self-testing during integration and system set-up.

Arasan delivers Verilog RTL source code, a simplified test bench with simulation models, to run the initial set of



Block diagram of the CAN FD light core (Source: Arasan)

tests after release. Besides other deliverables, the company provides synthesis scripts, exception lists, and timing reports as well as application notes. Sample firmware with software drivers is available, too. CAN protocol and trademark licenses are not included.

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Master Interface, enabling efficient message handling and streamlined data exchange. Integration with the host CPU (central processing unit) is possible through the 32-bit Generic Interface, compatible with interface wrappers such as AMBA, Altera Avalon Bus, and Xilinx OPB Bus.

"The DCAN-XL represents a significant leap forward in CAN technology, offering unparalleled speed, reliability, and flexibility," said Jacek Hanke, CEO of Digital Core Design. "With its support for higher data rates and larger data frames, the DCAN-XL is poised to revolutionize automotive and industrial applications, enabling the development of advanced systems that were previously beyond reach."

The IP core is available in two versions: Basic and Safety-Enhanced. The Safety-Enhanced version has been developed as an ISO 26262-10 Safety Element out of Context, providing additional safety mechanisms and comprehensive safety documentation to meet the stringent requirements of automotive safety standards. Third-party audits validate the safety-related work products, ensuring compliance with the ASIL-B (automotive safety integrity level) requirements. The thorough FMEDA (failure modes effects and diagnostic analysis) analysis provided by DCD offers step-by-step instructions for seamless integration and system-level safety analysis. Achieving ASIL-B readiness, this design is suitable for integration into automotive safety systems, with the option for higher ASIL level readiness.

The DCAN-XL is designed in accordance to ISO 11898-1:2024 and CiA 610-1 specifications, with support for CAN CC, CAN FD, and CAN XL frames. Its flexible data rates, Autosar support, and SAE J1939 compatibility make it a versatile solution for a wide range of applications.

Digital Core Design (DCD) is a provider of semiconductor IP cores, specializing in solutions for automotive, industrial, and consumer electronics applications. With a focus on innovation and quality, DCD's IP cores are trusted by leading companies worldwide to power their most demanding designs. This year, DCD is celebrating its 25th anniversary, operating in the IP core market since 1999. ◀

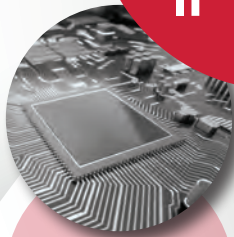


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FLEXIBLE
ASICs or FPGAs; Works with any Transceiver

New CiA members by June 2024

The most asked CiA membership benefits are the access to CiA specifications and the possibility to influence their development process. Currently, CAN in Automation (CiA) has about 743 members. In the first five months of 2024, 35 companies have joined CiA.

A further important reason to be part of the CAN community is to get in touch with other CAN product and service providers. In particular, small and medium-sized companies need to be networked with partners to be successful in the today's world.

Semiconductor suppliers

The market-leading micro-controller vendors supporting CAN connectivity are members of the CiA community for many years. This applies also for CAN transceiver suppliers. In the last years, other chipmakers joined the CiA association. This trend is continuing. There are more than 30 members offering CAN-related integrated circuits.

Unisemipower (China) is designing, manufacturing, and selling power semiconductor chips with sales and technical support offices in Shanghai, Beijing, Shenzhen, and the United States. The products are used in communication systems, information security, automotive electronics, medical, industrial, and other application fields.

Another new CiA member, Silvaco (U.S.A.) offers solutions spanning from simulation of material behavior impacting semiconductor devices, to design and analysis of transistor circuits, and providing IP blocks for systems-on-chips (SoC). The solutions are deployed by display-manufacturing companies, automotive OEMs (original equipment manufacturer), memory, 5G, and IoT (internet of things) providers. For example, the MultiCAN controller IP core supports up to six CAN CC interfaces supporting TTCAN (Time Triggered CAN) functionality as standardized in ISO 11898-4.

Development and engineering services

Some 100 members provide development and engineering services regarding CAN-related hardware and software development. Additionally, many members offer system design and system integration services.

Development of circuit boards, layout changes, as well as the compilation or unbundling of circuit boards are part of the service range offered by HTH Sinus Electronic (Germany). Prototypes and samples, as well as the actual series, are manufactured by the same company. Together with joining CiA, the developer has also registered a CANopen vendor-ID.

Embedded Brains (Germany) offers expertise on system development in the automotive engineering, telecommunications, and industrial automation. The company

is specializing in customized software and hardware development for single and multi-core systems.

JK Energy (United Kingdom) has been founded in 2003 to develop solutions for resource-constrained hardware embedded in products. The specialists work with embedded Linux and have their own-build environment. The company's network management technology has been developed to monitor devices for automated setup and operation. The provider also designs GUIs (graphical user interface) for embedded systems with LCD panels.

Avineas IT Consulting (the Netherlands) offers software (product) development, services for change, and training for the technical implementation of processes with a (software) IT component.

Megmeet Electrical (Germany) is a solution provider in the field of electrical automation, integrating software and hardware development, production, sales, and services. The business areas include industrial automation (e.g. drives, servo systems, and encoders), electric vehicles, railway solutions, power solutions, home appliance control, etc.

A further CiA member Lachmann & Rink (Germany) is engaged in embedded software development for customer's hardware and the connection to the HMI (human machine interface). The company is involved in development of Linux operating systems, firmware, device drivers, sensor solutions, embedded apps, user interfaces, as well as application and business logic software. The application areas span from the machine construction, Industry 4.0 and IoT environment, automotive, and agriculture to building automation.

E.S.T.E. Technology (Italy) offers engineering solutions focusing on automotive, agricultural, heavy-duty, and industrial sectors. Established in 2012, the company deploys a group of entrepreneurs and researchers from the Imamoter Institute, the Italian National Research Council, and the University of Ferrara. The company operates throughout Italy and offers services ranging from hardware and software design, to the advanced on-board diagnostics, functional safety, precision farming systems, etc.

Homatic Engineering (Denmark) is offering customized development and technological consultancy in automation, mechanics, hardware development, software development, and product approval. Application areas include e.g. automation and robotics. Beside others, the company offers PC applications and various drivers for CAN. ▶

CanBusHack (U.S.A.), established in 2010, is a reverse engineering services corporation specializing in automotive embedded controller software and communication understanding.

Sensing technologies providers

More than 130 CiA members develop and manufacture CAN-connectable sensors. This includes single devices as well as sub-systems for more complex sensing applications.

A further new CiA member Matrix Elektronik (Switzerland) is a provider of sensor technologies since 1976. The manufacturer is specializing in sensor solutions used in applications with explosive and high-temperature environments. The CANopen vendor-ID registration shows that the manufacturer is working on CANopen-based products.

Founded in 2005 Joral (U.S.A.) develops and manufactures harsh-duty electronic devices (e.g. encoders, inclinometers) for mobile hydraulics and industrial applications. Its rugged position sensors provide total electronic package encapsulation, LED status indicators, and true non-contact coupling. For instance, the SGAM and DGAM inclinometers utilize the sensor fusion technology combining more than one sensing method. The IP67-rated incline sensors take input by a gyroscope, accelerometer, and magnetometer to provide a 3-axis output as well as feedback for pitch, yaw, and roll. J1939 and CANopen are the supported higher-layer protocols.

Sika (Germany) is producing sensors for measuring flow, temperature, and pressure. Together with the membership, it registered a CANopen vendor-ID, which is cost-free for members. In addition, the Idec Alps Technologies (Japan) has assigned a CANopen vendor-ID. The company designs, develops, manufactures, and sells sensors, security devices, and value-added human-machine interfaces for industrial applications.

Novotechnik Messwertaufnehmer (Germany) provides sensors for linear and rotary measurements. The devices are available with different measuring technologies and communication interfaces e.g., CANopen and J1939. Versions for redundant measurements, single-turn or multi-turn encoders, compact-size devices, or rugged metal housings are offered, too.

Klug Avalon Mechatronics (India) has joined CiA in April. It provides load cells, limit switches, draw wire sensors, wind speed sensors, inclinometers, as well as HMIs mostly dedicated for use in cranes, lifting solutions, and material-handling equipment.

Solutions for the energy sector

In the last years, the number of members providing batteries and chargers has increased. This trend goes on. About 40 members offer CAN-connectable electric power solutions. This includes also energy management systems.

For more than half a century, Benning Elektrotechnik und Elektronik (Germany) produces solutions for the conversion of energy in multi-purpose or energy storage. Company's power systems and battery chargers

are dedicated for the telecommunications, industrial, medical, and IT industries. Since its establishment in 2014, Shenzhen ACE Battery (China) offers solutions and services for energy storage, including battery materials, battery cells, battery modules, battery packs, storage systems, and recycling. To equip its products with CANopen connectivity, the company has registered a CANopen Vendor-ID by CiA. ChargePoint (Great Britain) is offering the electric vehicle (EV) charging solutions for passenger cars, delivery vehicles, buses, trucks, etc. Therefore, the company has built an integrated portfolio of hardware, cloud services, and support. Milwaukee Electric Tool (U.S.A.) is another provider of batteries, chargers, modular storage systems, and power supplies.

Established in 2021, Hirschvogel E-Solutions (Germany) is a part of the Hirschvogel Group, founded for work in the electric mobility market. A separate business area for bicycles and micro-mobility is being created with the brand Aximo. The first series product, the Aximo drive axle, is being used in a cargo bike from Cube. Further series for e-bike drive systems are in development. For this company, a CANopen Vendor-ID has been assigned, too.



Figure 1: Aximo Pedelec wheel hub motor with a 60-Nm peak torque (Source: Hirschvogel E-Solutions)

Optical Metrology Services (Great Britain) is a measurement, inspection, and remediation company working within the energy sector. The company's crawlers, tools, and services support and deliver critical requirements. For example, it offers camera and laser inspection services for hard-to-reach areas within energy production. Services include cleaning and surface preparation, weld scanning, defect identification and remediation, pre-coating inspection, and data analysis. Pipes and welds are independently verified. The weld inspection services are mostly deployed within the oil, gas, renewable energy, and nuclear energy sectors.



Figure 2: The Agility.mini crawler is dedicated for pipes from 200 mm to 400 mm internal diameter (Source: Optical Metrology Services)

Another company in this sector is Megger (Sweden) offering electrical testing and measurement services including monitoring solutions. The critical electrical measurements include insulation and ground resistance testing, dielectric testing, transformer diagnostics, dissolved gas analysis, partial discharge analysis, cable fault locating and diagnostics, smart grid testing, and more. The firm serves a range of industries, spanning utilities, manufacturing, maintenance, renewable energy, heavy industry, transportation, etc.

Welding and cutting equipment suppliers

Last year, CiA started the development for CANopen profiles suitable for manual welding and cutting equipment. This is the reason, why several new members are related to this application.

Lorch (Germany) is one of the recently joined CiA members participating in the SIG (special interest group) specifying the CiA 464 profile for manual arc welding and laser cutting. Two further companies also joined CiA to work in this group. These are EWM (Germany) developing complete welding solutions (e.g. multi-process welding machines) together with its customers. To digitize the used welding technologies and move towards the Industry 4.0, the company participates in the CiA SIG welding and cutting. The same goal follows ESAB (Sweden). It provides advanced welding equipment, welding consumables, automation, and digital solutions that enable the everyday and demanding welding work. The company already uses CAN for communication between the welding equipment.



Figure 3: PEK is a controller for several ESAB power sources and is connected to them via CAN (Source: ESAB)

Remote control solutions

Remote control is in some applications a requirement, especially in lifting devices, construction machines, etc. Additionally, there is an increasing demand on telematics services for embedded CAN-based control systems.

Cattron (Germany) offers remote control systems, panels, machine stop systems, and telemetry monitoring solutions with CAN(open) CC and J1939 connectivity. The products are dedicated for agriculture, industrial automation, material handling, mining, mobile equipment, oil and gas, power and fluid solutions, rail operations, and water management.

Founded in 1988, IMET (Italy) is a designer and manufacturer of industrial safety radio remote controls used primarily in the construction, ecology, and concrete-processing sectors. The portfolio includes transmitters, receivers, and CAN-based wired remote control also dedicated for explosive and other demanding environments.

Since 2001, Almec (Italy) provides electronics and mechatronics including customized design, production, and technical consulting. The products comprise radio

remote controls, electronic control units, PLCs, push-button panels, operator panels, angular sensors, and actuators. For example, the TRS.ALMX is a safety angular inclinometer sensor with two independent CAN interfaces. Another device, the AL35R15 is an electro-pneumatic distributor for moving machinery and equipment. It supports the CiA 401 device profile for I/O modules.



Figure 4: AL35R15 is an electro-pneumatic distributor (Source: Almec)

Another kind of remote control is offered by telematics systems. With the GPS-based telematics devices, Globtrak (Poland) enables monitoring of the vehicles (e.g. location and speed) and vehicle fleets. Analysis of the collected data reveals functions that could be managed in a more efficient way. Globtrak offers a so-called “cloud tool” that collects, processes, analyses data, and produces ready-made reports. The company has also registered a CANopen vendor-ID at CiA.

Further new members

Some new members are original equipment manufacturers (OEM). They are looking for CAN-connectable devices and sub-systems featuring interoperability and partly exchangeability. Some of these members are interested in dedicated CiA application profiles, for example the CiA 417 series also known as CANopen Lift.

Won Tech Won (South Korea) is a company working in the medical sector. Since establishment in 1999, it has been researching and developing laser systems, for example, the WON-PDT (photo dynamic therapy) laser for various cancer treatments.

CiA has also assigned a CANopen vendor-ID to Swift Home Lifts (Sweden) providing a lift concept for use in modern homes. The Swift Lite is a small house lift version and the Swift Pro is the company’s residential lift with advanced design features, a dynamic touch display, and several options for personalized settings.

Gunda Automation (Germany) is producing motion control solutions including stepper motor drives, servo drives, positioning systems, multi-axis systems, and linear actuators. For instance, the Colibriservo drive is housed in a compact housing that is directly connected to the motor. The device is available in three performance groups covering torque ranges from 0,22 Nm to 20 Nm. The drive supports the CiA 402 CANopen device profile for drives and motion controllers.

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Correction for “CANopen-certified by March 2024” article

In the March 2024 issue of the CAN Newsletter magazine, we reported about the recent CANopen-tested devices. It should be corrected that the XU Endurance joystick series from the CiA member Sure Grip Controls (Canada) are not CE-certified and not SIL-2 compatible.

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Edge-AI boards and computers with CAN interfaces

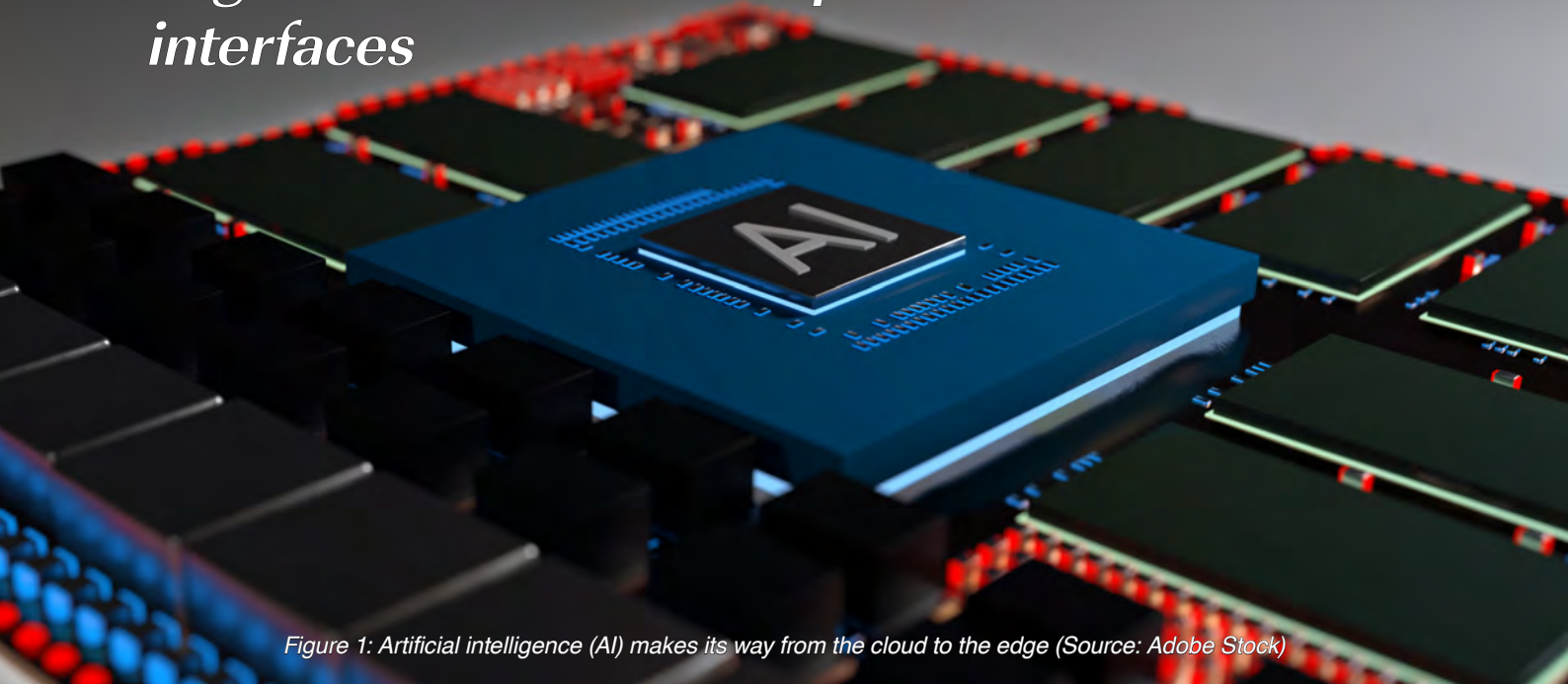


Figure 1: Artificial intelligence (AI) makes its way from the cloud to the edge (Source: Adobe Stock)

On the Embedded World 2024 trade show, several companies exhibited edge-AI (artificial intelligence) products providing CAN connectivity. Such devices allow computations to be done close to where data is actually collected, rather than at a centralized cloud computing facility or an offsite data center.

The Embedded World exhibition in Nuremberg (Germany) is an important exhibition to get an idea of the latest trends in embedded control technologies. Over 1100 exhibitors from almost 50 countries presented their products, solutions, and innovations. "The resounding response from the well over 32000 visitors from more than 80 countries emphasizes the significance of the Embedded World as the key meeting place for the embedded community," said Benedikt Weyerer, Executive Director of the trade show organizer.

Several companies exhibited in Nuremberg so-called edge devices featuring processors deploying AI algorithms and AI models. These products with local AI computing capability are called edge-AI devices enabling real-time data processing and analysis without constant reliance on a cloud infrastructure.

In some AI applications, CAN-networked sensors feed the AI processor with data collected in the local (front-end) control systems. Application examples include in-vehicle data for fleet management. Such vehicles could be road, off-highway, off-road (e.g. agriculture vehicles and forklifts), rail, or automated-guided vehicles for intralogistics. Other examples are AI-powered machine or process control systems. An example is the AI-supported laser welding as introduced in 2023 by Trumpf, a German machine builder. To ensure that the weld seam is always in the right place, the laser's sensor technology positions the weld geometry precisely on the component – otherwise there is a risk of

rejects. Dirt or scratches on the component, poor lighting conditions in the work area, or highly reflective materials such as copper make positioning difficult.

Offering only CAN hardware interfaces on edge-AI boards and computers is not convenient for system designers. In many application domains, the currently applied CAN networks connecting sensors and actuators use standardized HLPs (higher-layer protocols) such as CANopen, DeviceNet, Isobus, or J1939. The support of HLPs would decrease the effort to adapt edge-AI technology, especially for small and medium-sized companies.

On the Embedded World, many Taiwanese suppliers offered edge-AI products with CAN connectivity. According to the International Trade Administration (TITA) and the Taiwan External Trade Development Council (TAITRA), Taiwanese companies manufacture over 90 percent of AI servers worldwide. This trend seems to go on for edge-AI products.

Many of the edge-AI boards are equipped with Nvidia processors (see also article "[AI evaluation boards with CAN connectivity](#)" in this issue). Diamond Systems offers, for example, carrier boards for the Jetson processor by Nvidia designed for industrial and military applications. The Taiwanese company has married AI and the PCIe/104 board format. The carrier boards provide dedicated I/O functionality, which includes one or two CAN CC interfaces. The PCIe/104 is the stackable version of the PCIe format. ▶

The company provides additional PCIe/104 modules with two CAN CC (classic) ports.

Advantech, another Taiwanese company, has launched AI acceleration modules and edge-AI computers powered by processors from Nvidia and Hailo. Many of these products come with two CAN CC interfaces. The company is an Nvidia distributor of industrial PCs that are certified with the AI Enterprise software platform for

the development and deployment of production-grade AI applications. Edge-AI products by Advantech come with ROS (robot operating system) support. ROS is a set of software libraries and tools for robot applications, which supports CANopen and some of its profiles.

The edge-AI computers by Neosys are based on Jetson processors by Nvidia. Some of them come with one CAN CC port. They are mainly intended for camera-based AI solutions. The Taiwanese products are water-proofed and suitable for industrial and vehicle applications. Some housings are IP69K-rated. These products are suitable for unmanned ground vehicles and drones. For example, the SEMIL-2000 series, featuring IP69K protection, can operate in temperatures ranging from -40 °C to +70 °C. It is designed for enabling autonomous applications in military UGVs (unmanned ground vehicles), mining trucks, or agricultural tractors. The FLYC-300 series based on the Jetson Orin NX processor comes with a built-in CAN CC interface to interact with the flight controller.

Acrosser is another Taiwanese manufacturer of edge-AI computers, which comprise AI processors from Nvidia or Intel. Some of them are designed for AGVs (automated guided vehicles), but they do not feature CAN connectivity. But the Nvidia-powered computers provide even one CAN FD interface.

The edge-AI computers by Aaeon (Taiwan) are suitable for intralogistics devices such as AGVs and AMRs (autonomous mobile robots). They use Intel processors and many of them feature one CAN CC interface.

C&T Solution from Taiwan launched in Nuremberg a series of edge-AI computers. Some of the family members feature CAN CC connectivity. The real-time industrial PCs are designed to withstand harsh-environment conditions.

Vecow located in Taiwan partners with Hailo AI chipmaker. The company also offers products with AI processors by Intel and Nvidia. The edge-AI computer for rail vehicles applications comes with two CAN CC channels. Other products like the EAC-2100 powered by a Jetson Xavier processor come with one CAN CC interface.

Forecr situated in Estonia has developed carrier boards for Nvidia processors. The company is an Nvidia partner as Diamond Systems. Their boards feature one or two CAN CC channels and several other connectivity ports including M.2 slots for expansion cards. The company offers also the Milbox-AGX ruggedized AI computer supporting two CAN CC interfaces. It is equipped with Jetson processors.

Bressner, a German company, offers fan-less edge-AI computers with CAN CC interfaces. These products use Nvidia Jetson Orin processors and measure 105 mm x 90 mm x 52 mm. This makes them suitable for applications, in which space is limited.

AI in healthcare

Edge-AI products are expected to be used in medical and healthcare equipment. This seems to become a huge market. However, there are risks and ethical impacts to be considered. The European Parliament has released a study on AI in healthcare. As in other AI applications, there are two phases: First is the training phase, in which

CAN XL on Embedded World

On the CiA booth, NXP, ST Microelectronics, and Vector demonstrated running CAN XL networks with attached oscilloscopes by Pico Technology showing the transmitted CAN XL data frames and the bit wave forms. Cast exhibited the CAN XL IP core by Fraunhofer on its booth and reported a high interest in CAN XL associated with the CANsec security protocol, which is still under development within CiA. Peak-System and DCD-Semi launched prototypes of their CAN XL core implementations on the trade show in Nuremberg, Germany.



The Miriac module provides two CAN XL ports and up to 16 CAN FD interfaces (Source: Microsys)

Microsys launched the Miriac MPX-S32Z2 interface module with two CAN XL and 16 CAN FD ports based on the S32Z2 micro-controller by NXP, currently available in engineering sample. The MCU features eight ARM R52 cores. The module measuring 82 mm x 50 mm does not provide transceiver chips for CAN interfaces, they need to be added on a carrier board.

On the Embedded World trade show, Green Hills Software introduced RTOS (real-time operating system) software support for the Aurix MCU family by Infineon coming with CAN XL interfaces. The μ -velocity operating system is intended for SDV (software-defined vehicle) electronic control units (ECU). The Aurix TC4x micro-controller provides an upward migration path from the previous TC3x family of ASIL-compliant automotive MCUs. The TC4x featuring CAN XL connectivity includes a parallel processing unit (PPU) as well as several accelerators, in areas such as data routing, digital signal processing, radar processing, and cryptographic computing. According to the supplier, the launched RTOS complies with the ISO 26262 ASIL-D safety level.

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Figure 2: Edge-AI computers are available in rugged housings (Source: Neousys)

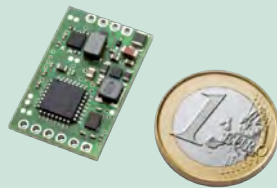
information is recorded, stored, and labeled. This includes information from human doctors and scientific studies. In a second step, the AI machine uses the intelligence gathered and stored to understand the new data. In this phase, the edge-AI product uses inference to identify and categorize the provided information, in order to provide a diagnosis. In such complex scenarios, the AI inference learning can be used to augment human decision making.

In many medical laboratory and healthcare equipment, embedded CAN networks are applied. CAN-connected sensors can feed the edge-AI products with dedicated information and CAN-linked actuators can be controlled by edge-AI computers. Advantech offers dedicated edge-AI devices for this purpose as well as Seco. The SOM-Smarc-Genio700 board offered by Seco (Italy) is powered by the Genio 700 processor from Mediatek (USA) featuring multiple Arm-Cortex cores. This module comes with a stand-alone CAN CC controller connected via SPI to the host processor. In addition, Seco has developed the Clea AI software platform. According to the company, it is partnering with NXP and will support in the future the eIQ processors.

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CAN interface module for sensors

CiA member Microcontrol (Germany) has introduced the μ CAN-sensor module family featuring CAN CC and CAN FD hardware. It can run locally CANopen CC, CANopen FD, J1939-21/71 protocol stacks or customer-specific higher-layer protocol software. These one-euro sized products are available in customized board designs for implementation directly into the sensor casing.



(Source: Microcontrol)

According to the supplier, the board features sampling rates of up to 1 kHz. The one-channel module can handle voltage signals in a range from ± 10 V, current signals from 0(4) mA to 20 mA as well as signals from strain gauges, thermocouples, and Pt100 as well as Pt1000 sensor elements. Two-channel modules are available, too.

hz



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Real-time communication: Part III - Temporal dynamics of CAN-based systems



(Source: Embedded Systems Academy)

Within this article series, Olaf Pfeiffer from Embedded Systems Academy is setting in perspective the timing requirements for different real-time capable communication systems, such as CAN, CANopen, and real-time Ethernet.

In this third article, the author examines the real-time capabilities and limitations of CAN and CANopen in greater detail. The Part I, published in the December 2023 issue of the CAN Newsletter magazine, describes how to select the right real-time timeframe for certain applications. The Part II, published in March 2024, shows the different timeframes required by different applications and reviews what this means for the communication system used. The last article "Part IV – From theory to practice: CANopen source code configuration" shows which optimization options are typically available when working with CANopen source code, here, on example of Micro CANopen Plus from EmSA.

The Controller Area Network (CAN) protocol serves as the foundation for numerous applications across a wide range of industries, each with its own distinct real-time demands. Prominent examples like CANopen and J1939 highlight the diverse adaptations of this protocol to meet specific needs. It's important to note that the real-time requirements for these applications are not uniform across the board. While some applications require reaction times measured in milliseconds, many others operate effectively under more relaxed criteria. Factors such as physical constraints, network topologies, and computational tasks play a crucial role in shaping these requirements. As we explore tighter real-time constraints, the complexity of communication configurations and code handling increases. However, when real-time requirements are more relaxed, it opens up opportunities for simpler, more streamlined system designs without sacrificing functionality or reliability.

Although both safety and security have been addressed with (by CANopen Safety and CANcrypt) there is currently

no standardized solution that provides both. The CiA (CAN in Automation) user's group currently has multiple working groups reviewing various aspects of both safe and secure communication with CAN CC (classic), CAN FD, and CAN XL.

Real-time capabilities of CAN

CAN's real-time effectiveness is closely tied to its communication speed, and further affected by its priority-based arbitration mechanism. Calculating CAN frame transmission times is not a straightforward task; the time depends on both the number of data bytes and their content. This complexity arises because stuff bits may be added to a frame depending on its data. Therefore, the following determined values should be considered as approximations, providing a general sense of the scope at hand.

It's important to remember that your maximum bit rate also depends on the physical topology of the cabling, and depending on your application, the total transfer required for a single control cycle might include two transmission paths: one for input data to the control unit and another from the control unit to the outputs.

Though the author focuses on CAN CC here, most of the following considerations also apply to the CAN FD (flexible data rate) and CAN XL variants. Both of these protocols feature a dual bit rate mechanism, further enhancing their data throughput capabilities. However, when discussing timing-related dynamics, most of the considerations outlined here predominantly apply to the "nominal bitrate." This foundational bit rate essentially establishes the pace for control information such as arbitration, acknowledgment, and error signaling. For those using CAN FD and

CAN XL, it's crucial to be aware of the additional complexities introduced by the "data phase bitrate," which governs the transmission of the actual data. One of the key concerns in these systems is determining the maximum duration a lengthy message might occupy the network and how much longer this delay might be compared to the longest CAN CC (classic) frame with 8 bytes.

At its maximum speed of 1 Mbit/s, CAN CC allows for the exchange of more than ten frames within a millisecond. Conversely, at a modest rate of 125 Kbit/s, it averages around one frame per millisecond. Beyond mere transmission times, signals or frames can experience delays if higher-priority communication is in the queue. To put it simply, the worst-case transmission time would be the sum of the frame's own transmission time and the delay expected from the longest sequence of higher-priority traffic in the system. This assumes that all communication happens on a single CAN network. If signals need to be forwarded via bridges or gateways, delays become longer and even more challenging to predict.

The system of message prioritization can be a double-edged sword. However, there is a mitigating factor: by strategically limiting the duration of sequential high-priority traffic, even communications with the lowest priority can be dispatched with minimal delay. This approach ensures consistent and timely data exchange throughout the system.

Looking at CAN (and the FD and XL variants) by itself, it is clear that "as is" it is not deterministic. A single device producing high priority frames can block the communication for all others. To make CAN deterministic, we need to ensure a controlled frame triggering – when may which CAN ID be used. To activate CAN's real-time capabilities, the following design goals should be considered. While these guidelines may vary based on application specifics, they serve as a reliable starting point:

- A)** Aim to keep the overall busload at a level where even low-priority frames have sufficient time to access the network. While the exact threshold can vary by application, the author's initial recommendation is to stay below 75 % busload (less if communication is purely change-of-state-based).
- B)** Ensure that no individual node can generate an extended stream of consecutive messages. Some drivers offer a transmission "throttle" to limit the maximum transmission rate.
- C)** For those seeking finer control over transmission timing and sources, consider the SYNC mode of CANopen. This mode enables trigger messages, providing enhanced control over transmission schedules, allowing trigger modes like those used by time triggered systems.

Mastering temporal dynamics

After exploring the various use cases and their respective temporal demands of CAN-based systems, you can imagine that matching CAN configurations to specific time requirements is both an art and a science. Table 1 summarizes some of the main numbers and factors to consider. The first section of the table gives a summary of the CAN timings and throughputs that you can expect at various bit rates – this is all for CAN CC using 11-bit CAN identifiers. The fact is that even at the lower bit rates we are still talking about potentially

thousands of CAN frames per second. There is so much room for communication that one can easily grasp that with some well-defined parameters on how to use all this "space", one can very well design real-time capable systems.

Table 1: Ballpark figures for transmission delays (Source: EmSA)

CAN Timings and Throughput				
CAN Bitrate	1000kbps	500kbps	250kbps	125kbps
Shortest 11bit CAN Frame	50us	100us	200us	400us
Longest 11bit CAN Frame	130us	260us	520us	1040us
Max shortest frames per second	20000	10000	5000	2500
Max longest frames per second	7700	3850	1925	960
Max data throughput 70% load	400kbps	200kbps	100kbps	50kbps
Possible transmission delays (ms)				
CAN Bitrate	1000kbps	500kbps	250kbps	125kbps
Network in use	0.13	0.26	0.52	1.04
Arbitration delay for 5 frames	0.5	1	2	4
Transmission throttle delay	0.5	1	2	4
Sum	1.13	2.26	4.52	9.04
MCU/CPU Processing delays				
Higher Layer Stack Processing	fractions of milliseconds			
App processing RTOS	fractions of milliseconds			
OS (non RT) minimal proc. Delay	single milliseconds			
OS (non RT) minor delay	some 50 to 100ms			
OS (non RT) mayor delay	can be above 1s			

The next section of the table shows potential transmission delays and depends on many factors. Therefore, it is only a rough estimate for a specific use case, you need to adapt it to your own use case. The first row shows the delay even the highest priority will have, if the bus is currently in use (arbitration already started, transmitter is too late to join). Transmission has to wait, until the current frame is completed. The second row shows an arbitration delay – if there are other devices also trying to transmit a frame, how long do we have to wait? Here is shown the delay for five other frames currently pending for transmission and having a higher priority followed by a line of further delays, if a throttle mechanism is used protecting from back-to-back transmissions. Further on in this article will be reviewed what can be done if the sum of delays shown is unacceptable in your application.

The last section of the table shows the potential processing delays caused by executing various code on the device handling the CAN communication. Here is assumed that a modern 32-bit MCU (micro-controller unit) with an integrated CAN CC interface is used, running at 80 MHz or faster. In such environments, the code execution directly related to handling the CAN frames is typically marginal. Potential delays come from "what else is happening" on that MCU.

Translating this knowledge into real-world system performance requires actionable strategies and considerations. With the previously established benchmarks from Part I – seconds, 100 ms, 10 ms, and single milliseconds – as the guideposts, let's review practical recommendations for optimizing your CAN-based systems.

Mastering CAN applications with response times beyond seconds

In the domain of applications operating with delays stretching into seconds or even minutes, designing ▶

CAN-based systems to meet these response times is not particularly challenging. Interestingly, even a device burdened by sub-optimal drivers or firmware might still be suitable, as even sub-optimal drivers will even still perform within 10 to 100 of milliseconds.



Figure 1: For applications operating with delays stretching into seconds, even a device burdened by sub-optimal drivers or firmware might still be suitable (Source: EmSA)

However, when working with devices that rely on non-real-time operating systems, the challenge lies not so much in countering communication delays, but rather in upholding consistent performance and avoiding the worst-case possible delay. Regular testing and thorough monitoring are essential to ensure that these devices never falter in allocating the necessary resources for seamless CAN communication. It is also crucial to proactively curb any potential system disruptions. Simple yet effective measures, such as ensuring the absence of updates or other resource-draining operations during active communication periods, can strengthen the system's responsiveness and reliability.

Mastering CAN applications with response times of 100 ms

This domain is where the potential of CAN, in synergy with higher-layer protocols like CANopen, truly comes into play. The CANopen PDO (process data object) communication mechanisms inherent in CANopen provide users with flexible control, simplifying the configuration of message content and triggering. These PDOs facilitate real-time data exchange between nodes, optimizing communication efficiency.

At this response time, CAN-ID assignment and overall busload remain critical, but not overwhelmingly so, as they are unlikely to cause delays approaching anywhere near 100 ms. The system architecture should be designed such that even frames with the lowest priority have timely bus access, ensuring their transmission within the stipulated timeframes. As we navigate this middle ground, it becomes increasingly important to review potential high-priority frame bursts. Back-to-back high-priority transmissions



Figure 2: While many non-real-time operating systems can still achieve a 100-ms response, it is advisable to lean towards a real-time operating system (Source: EmSA)

can dominate the bus, posing risks of delays for lower-priority messages. Effective strategies for avoidance or control, such as limits on what each node can transmit per timeframe or synchronized triggering, can be employed to mitigate these bursts, ensuring more predictable and harmonious network communication, even as the system scales.

While many non-real-time operating systems (OS) can still achieve a 100-ms response, it is advisable to lean towards an RTOS (real-time operating system) in such scenarios (if an OS is required at all, many simple I/O devices typically do not have an OS at all). Using an RTOS aligns naturally with the demands of a 100-ms response window. If a non-RTOS is chosen, rigorous and extended testing becomes imperative to ensure the OS consistently meets the desired response times under all conceivable operational circumstances.

Within this 100-ms response time framework, the software and firmware requirements remain relatively forgiving. Specific optimizations are often unnecessary; even drivers or stack implementations deemed sub-optimal in high-performance environments (for example not taking advantage of CAN controller hardware features for advanced filtering and buffering) can adequately serve the purpose.

Mastering CAN applications with response times of 10 ms

As we move into the 10-ms response time zone, precision and control over every system component becomes essential. This is where detailed scrutiny of network data flow is essential.

Time-triggered networks, optimized for hard real-time applications, are often the preferred choice in such demanding scenarios. The CANopen SYNC mode is an effective approach to mimic communication behavior as used in time-triggered communication systems. By utilizing SYNC triggering messages, it enables specific nodes to transmit their associated PDO messages at precise moments, bringing predictability and consistency to system communication. ▶

While an RTOS might seem ideal for such tight timing requirements, it comes with its set of challenges. An RTOS offers a range of configuration options, and managing these tasks requires careful coordination. Within the tight 10-ms window, the process involves a sensor sending its current data, a control device with an RTOS receiving and processing this data, and then acting upon it.

However, simply implementing an RTOS does not guarantee the desired outcomes. Task prioritization and configuration must align perfectly with the system's stringent timing requirements. Additionally, a detailed review of driver functionality, firmware, and stack structures is crucial. Potential issues, such as priority inversion where a low-priority message in the queue might delay a higher-priority one, need to be addressed. Highly optimized drivers can address priority inversion, but this may cause changes in transmission sequences. A change in transmission sequences can be problematic for certain higher-layer protocols and needs to be reviewed carefully.

Mastering CAN applications with response times of 1 ms

Venturing into the 1-ms response time territory for CAN-based applications is akin to treading on the edge of the protocol's capabilities. These applications truly push the boundaries, requiring an unparalleled level of optimization and attention to every detail.

At this threshold, conventional approaches and tools often prove inadequate. Even some RTOSs, which typically excel in managing real-time tasks, may struggle to consistently adhere to this tight window. This necessitates reliance on micro-controller-specific implementations, where most tasks are handled directly within interrupt service routines, bypassing the typical layers of an RTOS.



Figure 3: Venturing into the 1-ms response time territory for CAN-based applications is akin to treading on the edge of the protocol's capabilities (Source: EmSA)

The extreme precision required at this level means that many system configurations may need to be hardcoded, potentially bypassing higher-layer protocol stacks like CANopen that would otherwise delay processing. This also helps avoid potential delays introduced by configuration handling, ensuring maximum predictability. Every component, message, and byte transmitted on the network must be judiciously managed. Given the stringent requirements, if a 1-ms response time is a necessity for your application, it is wise to review if other communication solutions beyond CAN might be better suited to your needs. This domain requires significant commitment in terms of development time, testing, and optimization. If this endeavor is taken on, one should be fully prepared for a time-consuming project journey.

Conclusion

The exploration of the temporal dynamics of CAN-based systems has underscored the adaptability and capabilities of the CAN protocol across various response time requirements. For applications with response times extending beyond seconds, there is less emphasis on precise timing, and decisions regarding CAN-ID usage, higher-layer protocols employed, or the operating system selected generally have a less pronounced impact on performance.



Figure 4: In conclusion, understanding the balance between application requirements, the inherent strengths of CAN, and the related temporal constraints is vital (Source: EmSA)

However, as we reach into tighter time constraints of 100 ms and 10 ms, system design considerations become of greatest importance. These include total busload, message priorities, and the strategic employment of functionalities like CAN-open's SYNC mode. When navigating the demanding 1-ms response time domain, every element of the system requires meticulous attention and may even prompt a re-evaluation of the network system selected.

In conclusion, understanding the balance between application requirements, the inherent strengths of CAN, and the related temporal constraints is vital. It's this knowledge that empowers CAN system designers to make informed decisions across diverse temporal scenarios.



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In-vehicle device temperature acquisition

Hongke (China) is a company providing automotive technology solutions and acting as a distributor of Peak-System and other CiA members, for example, in China, Japan, and Korea.

With the advancement of the automotive industry, the importance of monitoring and acquiring temperature data from in-vehicle devices has increased. Hongke provides a solution for monitoring and acquiring in-vehicle device temperatures, utilizing a thermocouple module to achieve accurate and real-time temperature measurement and transmission, thereby ensuring the safe and reliable operation of the vehicle system.

The MU-Thermocouple1 CAN FD module from Peak-System is a temperature measurement sensor based on the thermoelectric effect. It converts the measured temperature into electrical signals. It is widely used in automotive, industrial, aerospace, and scientific application fields. The module offers eight measurement channels and supports both CAN CC (classic) as well as CAN FD transmission. The device provides different temperature range options with T, K, and J thermocouple type models, depending on the specific requirements.

Thermocouple modules in automotive applications

To ensure the normal operation and safety of the vehicle system in the automotive manufacturing process, it is necessary to monitor and collect real-time temperature data of various devices within the vehicle. The thermocouple modules are applied in three main sections:

- 1. Avoid damage from high engine temperatures:** Thermocouple modules can detect the temperature of the engine, such as coolant temperature and oil temperature, to avoid abnormal conditions such as overheating. This prevents engine damage and improves the internal performance parameters of the ECU (electronic control unit).
- 2. Optimizing exhaust system performance:** Replacing traditional temperature sensors with thermocouple modules not only prevents failures at high temperatures but also optimizes the performance of exhaust gas treatment devices (e.g., catalysts) and reduces exhaust emissions, thus ensuring the stable operation of the exhaust system.
- 3. Ensure safe operation of the braking system:** Thermocouple modules can be used to monitor the temperature of brake discs and pads, ensuring the safety performance of the brake system at high speeds or under high load conditions.

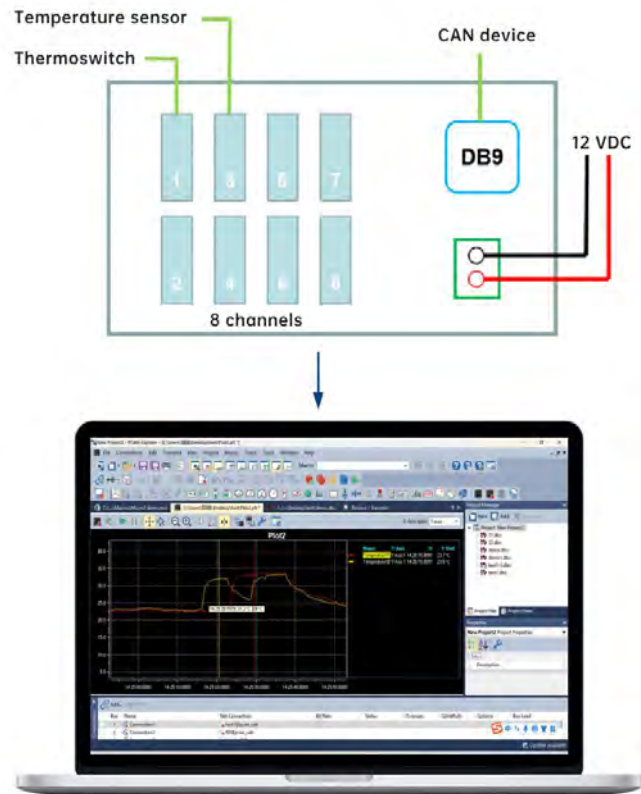


Figure 1: Vehicle battery system temperature monitoring (Source: Hongke)

Temperature monitoring of vehicle battery systems

For electric and hybrid vehicle manufacturers, monitoring and updating the temperature of the battery pack in real time is crucial to ensure the safety and performance of the vehicle's battery system. To achieve this, the thermocouple module enables stable and rapid temperature monitoring.

By integrating the thermocouple module with CAN CC and CAN FD connectivity, the measured temperature value can be packed into a CAN-based message, enabling real-time updates of the temperature change curve. This integration not only ensures the safety and stability of the vehicle battery system but also provides manufacturers with critical data for optimizing battery performance and extending its lifespan.

Thus, the electric and hybrid vehicle manufacturers can monitor and maintain their battery systems, ensuring peak performance and safety for their customers. ▶

MU-Thermocouple1 CAN FD

Depending on the product version, eight connectors for thermocouples of the types J, K, or T are available for temperature measurement. Temperatures can be captured in Celsius, Fahrenheit, or Kelvin and processed with an individual scale and offset. The CAN communication is done via a D-Sub connector. The measuring unit supports CAN FD with data bit rates up to 10 Mbit/s and is at the same time downward compatible to CAN CC (classic). With the product, temperature measurement can be integrated directly into automotive test benches or industrial plants using CAN FD communication.

A router for the conversion from CAN CC to CAN FD is no longer necessary. The configuration of data processing, CAN communication, and LED indication is done with the company's free Windows software. Several devices can be operated and configured independently on a single CAN network.



of (Source: Peak-System)

Sensor monitoring in extreme conditions

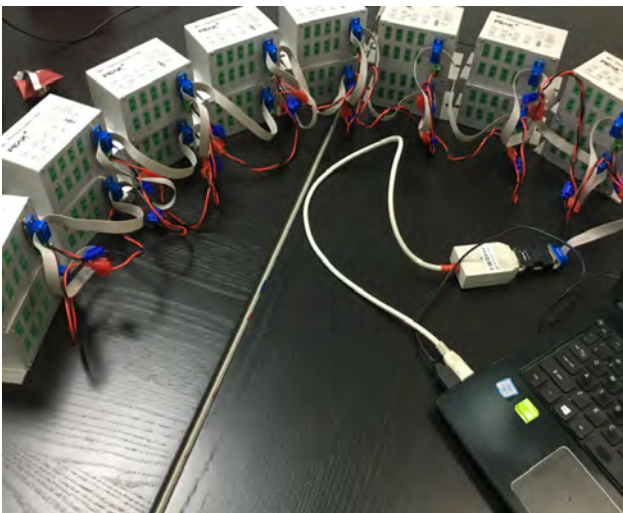


Figure 2: Simultaneous temperature measurement of eight sensors (Source: Hongke)

Monitoring the temperature of vehicle sensors in hot, high-pressure, and extremely cold environments is crucial for ensuring their reliability and performance. Engineers face significant challenges in such conditions, as temperatures can vary widely and affect the sensor performance.

The MU-Thermocouple1 CAN FD addresses these challenges with an operating temperature range of $-40\text{ }^{\circ}\text{C}$ to $+85\text{ }^{\circ}\text{C}$, an aluminum casing, a measurement accuracy of 0,2 %, and support of multiple parallel acquisition channels. Thus, the module is capable of measuring the temperature changes of multiple sensors simultaneously. This allows engineers to make on-site adjustments and controls, ensuring the stability and high quality of the production process. By monitoring the temperature of critical systems and devices in real-time, engineers can anticipate and mitigate potential issues, thus improving the overall safety and reliability of the vehicle system.

Conclusion

The thermocouple modules enable real-time temperature data acquisition and monitoring of key in-vehicle systems and devices. It enhances the safety and stability of the vehicle system and also offers flexible configuration options to adapt to different environmental and application requirements. By leveraging the capabilities of the MU-Thermocouple1 CAN FD, engineers can monitor vehicle sensor temperatures in extreme environments, ensuring reliable performance and safety of the vehicles. ◀

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CAN in Automation

The nonprofit CiA organization promotes CAN. CiA and its members shape the future of CAN-based networking, by developing and maintaining specifications and recommendations for CAN CC (classic), CAN FD, and CAN XL.

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