CAN XL: The third CAN protocol generation

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Abstract

In 1986, the first CAN protocol generation was introduced. The second followed in 2012 and is known as CAN FD. The third generation provides payloads up to 2048 byte and embedded layer management functionality. It is going to be released in 2021.

With the introduction of zonal in-vehicle network architectures, backbone and sub-backbone networks need to provide larger frames on the data link layer. There is also a need to integrate sub-networks into Ethernet-based backbone networks. For real-time control networks and mission-critical tasks high-reliable network technologies are still needed. CAN FD is not able to satisfy all these requirements: establishing the transparent integration into an Ethernet environment is not supported sufficiently.

CAN XL is a new CAN protocol optimized for zonal in-vehicle architectures. It can run different application on the same “cable”. It provides a payload of up to 2048 byte and an overall Hamming distance of six. The CAN XL node can use all kinds of CAN high-speed transceivers including the new CAN XL SIC (signal improvement capability) transceiver as specified in CiA 610-3. This transceiver requires a PWM coding of the bit-stream transmitted between CAN XL protocol controller and CAN XL SIC transceiver. The CAN XL data link layer and the physical signalling are specified in CiA 610-1. One of the new features is the separation of frame priority and addressing, which is in Classical CAN and CAN FD combined (CAN identifier). In CAN XL, there are two fields (11-bit priority ID and 32-bit address field).

One of the new functions is the embedding of OSI (open system interconnect) layer management information into the CAN XL frame. This includes the SDU (service data unit) Type field, the VCAN (virtual CAN) field, and the so-called SEC (simple/extended content) bit.
This paper describes the CAN XL functions, its benefits and its limitations. It covers the data link layer protocol, the CAN XL SIC physical medium access sub-layer, and the usage of the layer management functions.

**Some background information**

Since a couple of years, the automotive industry substitutes Classical CAN by means of CAN FD, which is internationally standardized in ISO 11898-1:2015. In parallel, the CAN community develops the next generation of the CAN data link layer (DLL) protocol: CAN XL. Since December 2018, the CiA Special Interest Group (SIG) CAN XL is specifying the CAN XL protocol features. In the meantime, the SIG CAN XL has additionally established three task forces (TF): the TF CAN XL physical layer, the TF CAN XL higher layer, and the TF CAN XL security. Relevant topics are discussed in the respective TFs.

The CAN XL approach supports data fields with a length of up to 2048 byte. It separates frame priority and frame acceptance information, which is combined in Classical CAN and CAN FD. The CAN XL protocol also embeds some more XL frame configuration information. Additionally, there are some new local DLL configuration such as enabling and disabling of the error signalling or of the PWM (pulse-width modulation) functionality.

**LLC and MAC sub-layers**

Similar to Ethernet, the CAN standard (ISO 11898 series) specifies two data link sub-layers:

- The Logical link control (LLC): It acts as a sub-layer between the OSI network layer and the media access control (MAC) sub-layer, and

- the Media access control (MAC): It is responsible for moving frames from the LLC sub-layer to the PMA (physical media attachment) sub-layer and protects the transmission by means of stuff-bits, CRC fields, etc.

The LLC frame structure shall contain all content needed for all specified data frame formats (e.g. XL frame format), including the selection of one of these frame formats. The data used for the selection of frame formats can be regarded as embedded configuration as described in ISO 7498-4 (OSI layer management). In the interaction between LLC and MAC, the content of that parts of the LLC frame that are not used for the selected CAN frame format is ignored. Figure 1 shows the LLC frame format specified in CiA 610-1. The LLC frame supports all three CAN protocol generations: Classical CAN, CAN FD, and CAN XL. The fields of the LLC frame that are used by CAN XL are highlighted.
In Classical CAN and CAN FD, the CAN-ID field (11 bit or 29 bit) is used for both arbitration and addressing purposes. In CAN XL these functions are separated. The CAN XL protocol separates the priority functions (11-bit ID) and the addressing (32-bit acceptance field):

- 11-bit priority ID sub-field: This field provides the uniquely assigned priority of the CAN XL data frame.
- 32-bit acceptance field: This field can contain unique node address or unique content indication information.

MAC frame in XL format

The MAC sub-layer comprises the functions and rules related to encapsulation/de-encapsulation of the transmitted/received data, error detection as well as signalling, and management of the medium access.

There is just one data frame format specified. It is called XL frame format (XLFF). This data frame has a variable length and can hold 1 byte to 2 048 byte in the data field, while the data length can change in one-byte steps. On transmission, an LLC frame is converted into a MAC frame. On reception, a MAC frame is converted into an LLC frame. MAC frames in XLFF are composed of seven different bit fields as shown in Figure 2. In Figure 2, 3, 4, and 5 the fields marked in green are automatically added by the MAC sub-layer, and the grey fields are provided by the LLC frame.
The CAN XL data frame includes two CRC (cyclic redundancy check) fields: the 13-bit Preamble CRC (PCRC) and the 32-bit frame CRC (FCRC). The CRCs are cascaded, which means FCRC protects the whole frame, including the PCRC. The university of Stuttgart proposed the CRC polynomials for PCRC and FCRC, and they published their argumentation in iCC (international CAN conference) 2020 proceedings. The university of Kassel has double-checked the error detection capabilities of the XL MAC layer. Both CRCs are able to detect any five randomly distributed bit-errors. This corresponds to a Hamming distance of 6.

**ADS field in control field and DAS field in ACK field**

For higher bit-rates (10 Mbit/s and above) the CAN XL SIC transceivers specified in CiA 610-3 are suitable. The CAN XL SIC transceivers have three modes to achieve the “fast bits” in the data phase but also allow arbitration in the same frame. The modes are named SIC mode, Fast TX mode, and Fast RX mode. In the SIC mode, the transceiver drives dominant and recessive bits, as known from Classical CAN. In the Fast TX mode, the transceiver drives level-1 and level-0 signals with differential voltage levels of -1 V and +1 V. In Fast RX mode the transceiver does not drive the network.

The first bit in the ADS (arbitration-to-dataphase switch) field is the ADH bit. It is sent as logical 1. During this bit, the CAN XL SIC transceiver is switched from SIC mode in Fast TX or Fast RX mode. The MICI interface sends PWM symbols of arbitrary value to perform the proper transceiver mode switch. All CAN XL nodes ignore the sampled value of the ADH bit. The first bit of the DAS (dataphase-to-arbitration switch) field is DAH bit. It is sent as logical 1. This is the bit, where the transceiver mode in the CAN XL SIC transceiver is switched back to SIC mode.
CAN XL and transceivers

CAN XL is scalable regarding bit-rates and the medium access unit (MAU) physical sub-layer (normally implemented in transceiver chips or system base chips). CAN XL controllers can be used with CAN high-speed and CAN SIC (signal improvement capability, specified in CiA 601-4 version 2.0.0) transceivers using the AUI (attachment unit interface) as specified in ISO 11898-2:2016. Additionally, CAN XL controllers can be used with CAN XL SIC transceivers to support bit-rates of 10 Mbit/s and beyond. To signal the mode switch from the CAN controller to the transceiver, CAN XL controllers and transceivers implement the TX-based single-path PWM (pulse width modulation) symbols. This preserves the two-pin interface (RxD, TxD) also for CAN XL SIC transceivers.

Fig. 6: Implementation example with CAN XL controller and CAN XL SIC transceiver

Embedded OSI management information

The 8-bit SDT (service data unit type) field is used to indicate the used higher-layer protocols. It is an embedded (OSI) layer management information as described in ISO 7498-4 and is similar to the Ethertype field in the Ethernet frame. CiA 611-1 specifies the SDT values and the corresponding. This includes the tunnelling Ethernet frames.

The 8-bit VCID (virtual CAN network identifier) field allows running up to 256 logical networks on one single CAN XL physical network segment. This allows to use many protocols in parallel, on the same physical CAN network. This field is also an embedded (OSI) layer management information as described in ISO 7498-4.
The standardization of higher-layer protocols is essential to enable interoperability of devices with CAN XL connectivity. The CAN XL TF (task force) higher layer works for example on the following topics: specification of SDU types, Multi-PDU concept (similar to the concept known from Autosar) that allows to aggregate several different PDUs and to send this as a Multi-PDU inside a single CAN XL MAC frame. Previously, the TF higher layer defined, that CAN XL controllers would use 64-bit time stamps, which cannot wrap around during life time. TF higher layer also requested the introduction of the SDT field and the VCID field in the LLC and XL MAC frame.

**CAN XL related documents**

The CiA special interest group (SIG) CAN XL coordinates the development of CiA documents. The physical layer is developed within a task force (TF) reporting to the SIG. There is also the TF higher-layers specifying the SDU types and the CAN XL frame fragmentation, which can be used to improve the real-time capability of the CAN XL communication in case of transmitting frequently blocks of long frames. The TF also supports the extension of the ISO 15765-2 transport protocol for CAN XL frames. Another TF has been established to specify a CAN XL data link layer security protocol. An additional TF is going to specify a modelling of CAN communication systems, in order to support a consistent description of the lower OSI layers.
Table 1: CAN XL related documents

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>610-1</td>
<td>CAN XL specifications and test plans – Part 1: Data link layer and physical coding sub-layer requirements</td>
<td>Work Draft</td>
</tr>
<tr>
<td>610-2</td>
<td>CAN XL specifications and test plans – Part 2: Data link layer and physical coding sub-layer conformance test plan</td>
<td>Proposal</td>
</tr>
<tr>
<td>610-3</td>
<td>CAN XL specifications and test plans – Part 3: Physical medium attachment sub-layer requirements</td>
<td>Work Draft</td>
</tr>
<tr>
<td>610-4</td>
<td>CAN XL specifications and test plans – Part 4: Physical medium attachment sub-layer conformance test plan</td>
<td>Proposal (static test)</td>
</tr>
<tr>
<td>611-1</td>
<td>CAN XL higher-layer services – Part 1: SDU types</td>
<td>Work Draft</td>
</tr>
<tr>
<td>611-2</td>
<td>CAN XL higher-layer services – Part 2: Multi-PDU</td>
<td>Work Draft</td>
</tr>
<tr>
<td>611-3</td>
<td>CAN XL higher-layer services – Part 3: Generic transport layer requirements</td>
<td>Proposal</td>
</tr>
<tr>
<td>611-4</td>
<td>CAN XL higher-layer services – Part 4: Generic transport layer conformance test plan</td>
<td>No proposal</td>
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<tr>
<td>612-1</td>
<td>CAN XL guidelines and application notes – Part 1: System design recommendations</td>
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<tr>
<td>612-2</td>
<td>CAN XL guidelines and application notes – Part 2: PWM coding implementation guideline</td>
<td>Proposal</td>
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<tr>
<td>613-1</td>
<td>CAN XL add-on services – Part 1: Simple/extended content (SEC) indication</td>
<td>Proposal</td>
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<td>613-2</td>
<td>CAN XL add-on services – Part 2: Security</td>
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<tr>
<td>613-3</td>
<td>CAN XL add-on services – Part 3: LLC frame fragmentation</td>
<td>Proposal</td>
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The set of CAN XL documents comprises also device and network design recommendations. CiA also organizes CAN XL plugfests testing the interoperability of different CAN XL node implementations as well as CAN XL SIC transceivers. Beginning of July 2021, the first CAN XL plugfest took place. Bosch, Fraunhofer IPMS, Infineon, and Vector tested their first CAN XL IP cores. The first test set-up was a bus-line topology with an overall length of 19 m. There were connected five nodes plus some tools – only listening. The bit-rate was increased from 1 Mbit/s to 10 Mbit/s using busloads up to 100 %. The tests were performed...
with and without error signalling. Furthermore, the attendees tested also a mixed transmission of data frames: Classical CAN, CAN FD, and CAN XL. An interesting test was the simultaneous transmission of CAN XL and CAN FD frames using different bit-rates in the dataphase. CAN XL frames were sent with 10 Mbit/s and CAN FD frames with 2 Mbit/s. In all these basic tests, no problems occurred.

NXP demonstrated during the plugfest its double-star topology test network with eight CAN XL nodes running at 10 Mbit/s. Using one star with four NXP nodes and connecting two nodes from Fraunhofer IPMS as well as one node from Infineon, the achieved bit-rate was also 10 Mbit/s. In this test set-up, one stub was about 6 m, the others between 1 m and 2 m. In another test, the NXP single-star was linked to two Fraunhofer IPMS nodes running at 20 Mbit/s. Of course, all these tests were made under laboratory conditions (room temperature).

**Summary and outlook**

CAN XL runs in the data phase bit-rates of up to 10 Mbit/s and a little bit more depending on the network topology. It provides data fields of 1 byte to 2048 byte, and it features some embedded layer management information for higher-layer protocols. Important is its backwards compatibility with CAN FD. You can mix Classical CAN, CAN FD, and CAN XL communication on one cable. CAN FD and CAN XL may use different bit-timings. CAN XL is highly scalable regarding the applications but also regarding the supported bit-rate, as CAN XL can be used with all kinds of CAN high-speed transceivers.