The physical layer in the CAN XL world

This article explains the CAN SIC XL transceiver approach and concept, the challenges in the networks, and how to combine the CAN XL protocol with the existing CAN FD transceiver, CAN SIC transceiver, and the CAN SIC XL transceiver.

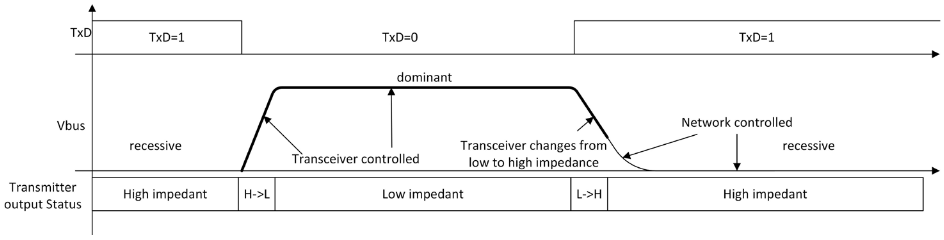

Figure 1: Basic transceiver transmitter concept (Source: Infineon)

CAN XL as an improvement of the well-established CAN FD protocol increases payload and increases the average bit-rate in a CAN network up to 10 Mbit/s. The CAN protocol was first time published more than 35 years ago and 25 years later, the first discussion about an improvement called CAN FD was started. After the successful release of the CAN FD protocol, the corresponding physical layer standard specifications and the availability of CAN FD transceivers and micro-controllers supporting CAN FD, it was time to initiate the next level of CAN called CAN XL. The main motivation was to increase the payload. Starting from 8 byte in CAN and up to 64 byte in CAN FD, CAN XL is now doing a big step up to 2 000 byte in the payload.

To reduce the transmitting time for such a big payload, higher bit-rates are needed to achieve acceptable transmitting times. Transmitting a CAN frame with 2 000 byte data with a bit-rate of 500 kbit/s needs 33 ms. A CAN FD frame transmitted with 500 kbit/s in the arbitration phase and 2 000 kbit/s in the data phase and a payload of 2 000 byte data needs more than 8 ms. For automotive applications, this transmitting time for CAN frames is too long and so the target was to achieve a transmitting time below 2 milliseconds. To achieve this transmitting time with 2 000 byte payload, a bit-rate of 10 Mbit/s and higher in the data phase is necessary. 500 kbit/s in the arbitration phase are set to allow the same distances between ECUs (electronic control units) in networks like CAN FD.

The physical layer concept in CAN

The CAN network is a serial bus system and allows more than two nodes connected on a network. In a serial bus system topology with a higher number of nodes, collisions are possible. To manage these collisions, CAN uses the CSMA/CR (Carrier Sense Multiple Access/ Collision Resolution) concept. In the arbitration phase, one or more nodes can transmit a CAN frame on the network at the same time and the node with the highest priority wins the arbitration. To support this CSMA/CR concept, transceivers controlling both levels (TxD=0 and TxD=1) on the network, cannot be used. In case of a collision, the level on the network will be not defined if one transceiver transmits level 0 and the other transceiver transmits level 1 at the same time. During this collision, the transceiver might be damaged. For that reason, a CAN transceiver controls only one level (TxD=0). This is called dominant level. During the recessive level (TxD=1), the transceiver output stages are high ohmic and the termination resistors are responsible for the recessive state on the network. In figure 1 this behavior is demonstrated. This concept allows a transmitting node to overwrite the recessive state on the network with a dominant level without the risk to damage a transceiver, transmitting a recessive level at the same time. With such a concept, collisions on the network can be supported. The disadvantage is that the transceiver's output stages are changing from high impedance to low impedance and vice versa. This impedance change creates reflection on the network.

Reflection in a CAN topology

In the transmission line theory it is important that the wire impedance and the termination impedance at the end of the wire have the same value. If wire impedance and termination impedance matches, no reflection occurs. If the impedances between the wire and the termination are different, reflection is caused by the different impedances. The formula for reflection is as follows:

$$r = \frac{Zt - Zw}{Zt + Zw}$$

- Z_t is the termination impedance and
- Z_w is the wire impedance.

Table 1: Reflection factor for 120-Ω wire impedance

Termination impedance	Reflection factor
30 Ω	-0,6
40 Ω	-0,5
60 Ω	-0,33
120 Ω	0
100 kΩ (Transceiver input imp.)	+0,99

In table 1 some numbers for the reflection factors are shown. For termination impedances smaller than the wire impedance, the wave will be reflected at the end of the wire and changes the polarity. If the end of a wire is terminated with a transceiver only (100 kΩ), the wave will be fully reflected with an unchanged polarity. On star points, the impedance changes, too. On a star point with 3 stripes (1 line for the incoming wave and two lines for the outgoing wave) the reflection factor is -0,33. The two outgoing lines are in parallel with two times 120 Ω impedance and the overall impedance for the wave is 60 Ω. These reflections are caused with every transition on a wire, independent if the network levels are changing from dominant to recessive or vice versa. However, there is one difference. In case of a recessive to dominant transition, the reflection will be damped by the low ohmic transceiver output stages. In case of the dominant to recessive transition, the network is high ohmic and the reflections fade. The length of the fading phase depends on the wire length and the number of stripes. A long fading phase limits the maximum bit-rate in the data phase because the sampling point has to be set after the fading is finished in order to get a reliable sampling. To realize higher bit-rates, the number of ringing must be reduced and thus the transition from dominant to recessive has to be controlled by the transceiver. This is the concept of the new CAN SIC (signal improvement capability) transceiver.

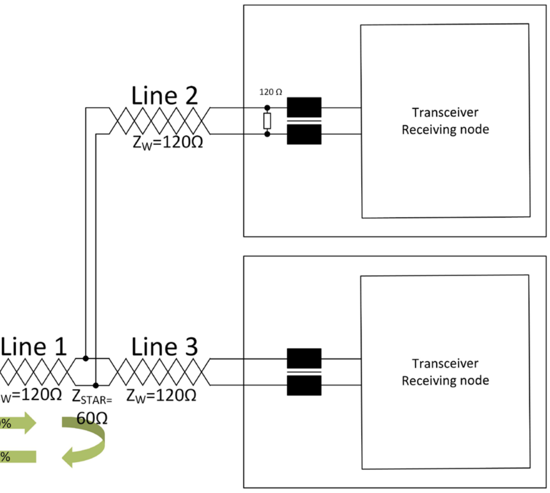

Figure 2: Reflection on a star point (Source: Infineon)

Two different solutions are available to support the SIC concept based on the specification CiA 601-4,

- transmitter (Tx) based concepts and
- receiver (Rx) based concepts.

Transmitter-based concept

In the Tx-based solution, the transmitter controls actively the dominant to recessive transition and afterword's up to 500 nanoseconds (ns) of the following recessive phase. In case of shorter recessive bits, the transmitter changes from active recessive to dominant directly. If the recessive bit is longer, the transmitter changes from active recessive to passive recessive (high ohmic) state like in standard CAN FD transceiver. With CAN SIC transceiver, up to 5 Mbit/s in star topologies and 8 Mbit/s in linear topologies are possible.

Receiver-based concept

In the Rx-based solution, all nodes suppress the recessive signal after the dominant to recessive transition, triggered by the internal receiver. The suppression time depends on the product and is optimized for one bit rate. For example for 2 Mbit/s, the transceiver suppression time is up to 450 ns long.

Performance of SIC transceiver

To achieve higher bit-rates, concept independent, the symmetry parameter of CAN SIC transceiver are improved. The new parameters are shown in table 2. The maximum values are the same as in ISO 11898-2:2016, but all minimum values are reduced and allow higher bit-rates. Figure 3 shows the effect for 5 Mbit/s. The tailored parameters reduce the range of asymmetry dramatically and extend the range for network effects and the sample point position.

Table 2: CAN FD and CAN SIC parameter

Parameter	**CAN FD TrX ISO11898-2**		**CAN SIC TrX CiA 601-4**	
	Min	Max	Min	Max
Transmitted recessive bit width	① -45ns	⑨ +10ns	① -10ns	⑨ +10ns
Receiver timing symmetry	② -45ns	⑧ +15ns	② -20ns	⑨ +15ns
Received Recessive bit width	-80ns	+20ns	-30ns	+20ns

The main impact is coming from the reduction of the minimum limits for transmitted recessive bit width, changing from -45 ns to -10 ns and the reduction of the receiver symmetry minimum value, changing from -45 ns to -20 ns.

A general disadvantage of the CAN FD and CAN SIC physical layer concept is the asymmetric distance between transmitter levels and receiver thresholds. The distance from the recessive level to the highest possible receiver threshold is 900 mV (millivolt) and the distance from the typical dominant level to the lowest receiver threshold is 1,5 V. This difference causes conceptual asymmetry for ▷

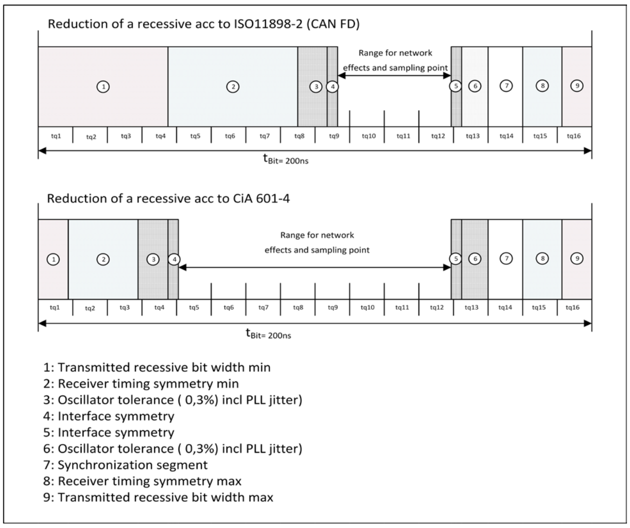

Figure 3: Bit asymmetry for CAN FD and CAN SIC (Source: Infineon)

the timings. To achieve bit rates above 5 Mbit/s, another transmitter concept in the data phase is necessary.

The main targets for the CAN SIC XL transmitter concepts are:

- Support of CSMA/CR and minimum 500 kbit/s in the arbitration phase
- Same pinning like for CAN FD transceiver
- Support minimum 10 Mbit/s in the data phase or more
- Reduce the timing asymmetry in data phase

To cover all these requirements for the arbitration phase, the CAN SIC concept is used. In the data phase, an alternating network voltage concept is choosen based on the Flexray idea. The advantage of the Flexray concept is that the levels are symmetric to ground and the receiver thresholds. The impedances of both levels are close to the wire impedance (less reflection) and the timing asymmetries are very small. The new CAN SIC XL transceiver has now two modes instead of one mode like implemented in CAN and CAN FD transceiver. The new modes are:

- The slow mode (arbitration phase)
- The slow mode is used in the arbitration phase and based on the CAN SIC transceiver concept. All parameters are accordance with CiA 601-4.
- The fast mode (data phase)
- In the fast mode, the transceiver controls both levels. The network levels (V_{diff}) are alternating between +1 V (level 0) and -1 V (level 1)

The new fast mode

In fast mode, the transmitter concept changes completely, compared to the established HS CAN and CAN FD transceiver. The output signal will be transmitted as symmetric alternating differential signal. The new levels are named

- Level0 if TxD0
- Level1 if TxD1

The receiver threshold is 0 V with a tolerance of ±100 mV. The output levels are now symmetric to the receiver threshold and reduces the timing asymmetries of transmitter and receiver.

The output impedance of the transmitter output stage will be 105 Ω for both levels and fits to most used unshielded twisted pair wires. For CAN SIC transceiver the output impedances are different for dominant state and active recessive state, and not specified in a standard specification. Transmitter output stage impedances matching with the wire impedances and reduces the reflection in a network too. All these parameter are specified in the CiA 610-3 specification. This specification will be released end of 2020.

The SIC transceiver mode changes

The transceiver modes are controlled by the CAN XL controller. Without a mode change, the transceiver can be used as a CAN SIC transceiver only. That allows using the CAN SIC XL transceiver in combination with a CAN FD and/or CAN XL protocol. In the CAN XL protocol two fields are reserved for the transceiver mode switch:

- The ADS field (arbitration to data switch)
- The DAS field (data to arbitration switch)

The ADS field is a part of the control field and located after the arbitration field and before the data field. The ADS field consists of four bits:

- ADH (A=arbitration bit-rate), TxD=1
- DH1 (D=data bit-rate), TxD=1
- DH2 (D=data bit-rate), TxD=1
- DL1 (D=data bit-rate), TxD=0

ADH is transmitted in arbitration bit-rate and during this bit, the transceiver will be switched from slow mode into fast mode. The ADH bit is a recessive bit but at first the network level stays dominant, and after the mode change command from the CAN XL controller, the CAN SIC XL transceiver changes from dominant to recessive level with SIC performance and after a defined time the network level changes from recessive level to level 1. In parallel the CAN SIC XL transceiver switches the receiver thresholds from slow mode threshold levels to fast mode threshold. DH1, DH2, and DL1 are transmitted with the data bit-rate and will be used in the CAN controller for synchronization.

The DAS field is a part of the acknowledge field and located between the CRC field and the EOF field. The DAS field consists of four bits

- DAH (A=arbitration bit-rate); TxD=1
- AH1 (A=arbitration bit-rate); TxD=1
- AH2 (A=arbitration bit-rate); TxD=1
- AL1 (A=arbitration bit-rate); TxD=1

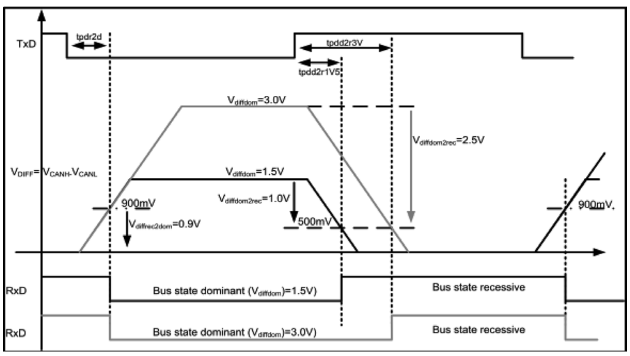

Figure 4: Bit asymmetry caused by dominant level variation (Source: Infineon)

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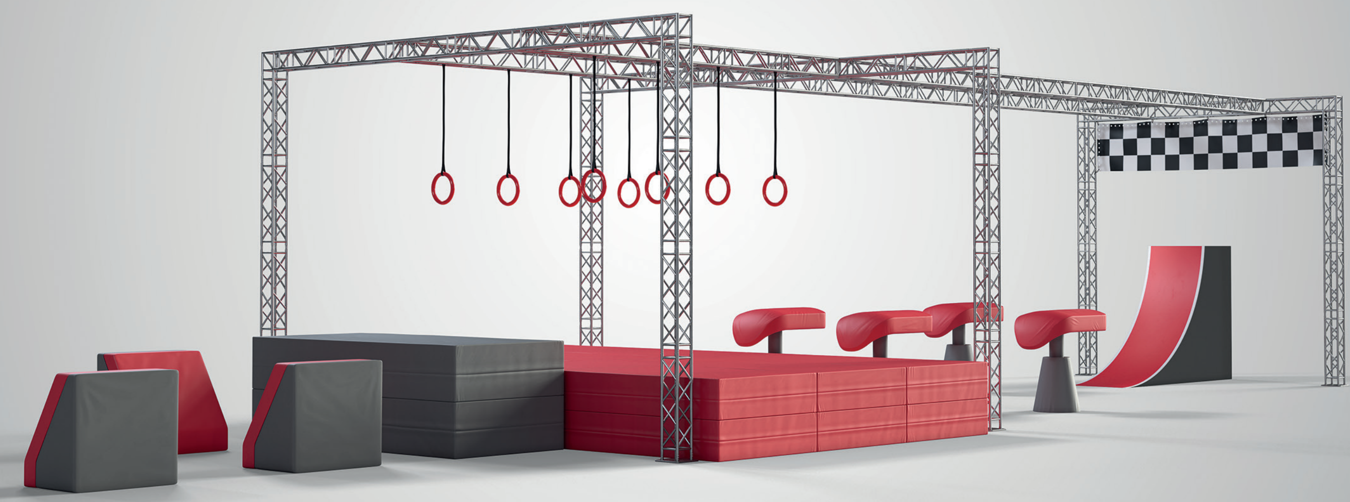

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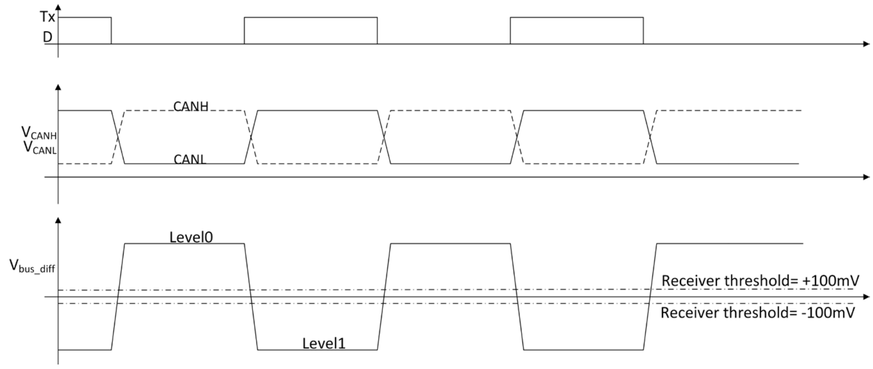

Figure 5: Bus signals in the fast mode (data-phase) (Source: Infineon)

All bits in the DAS field are transmitted in arbitration bit-rate. During the DAH bit, the transceiver will be switched from fast to slow mode. At the beginning of the DAH bit, triggered by the CAN XL controllers mode change command, transmitter changes from level 0 to active recessive and after the signal improvement time the transmitter changes from active recessive to passive recessive. In parallel, the receiver thresholds will be switched from fast to slow mode threshold level. The edge AH1 to AL1 is used in the CAN XL controller for synchronization in the arbitration bit-rate.

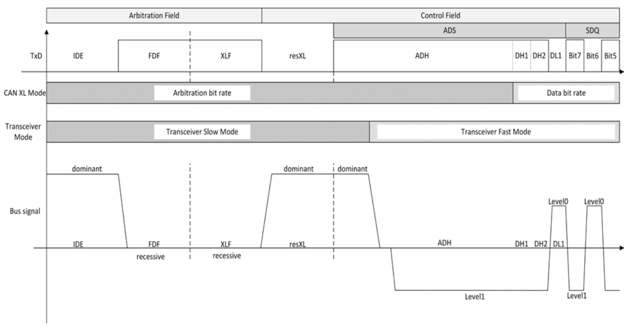

Figure 6: ADS (arbitration to data) field (Source: Infineon)

Transceiver versus protocol

Most of the users have a strong link in mind between the protocol and the corresponding kind of transceiver (see figure 8). But much more combinations are possible like shown in figure 9. For the choice of the transceiver concept two topics are important:

- The maximum required bit-rate
- The network topology

The protocol has a minor impact on the choice. The exception is, when the dual mode of the DM-SIC transceiver should be used to achieve bit-rates above 5 Mbit/s or to

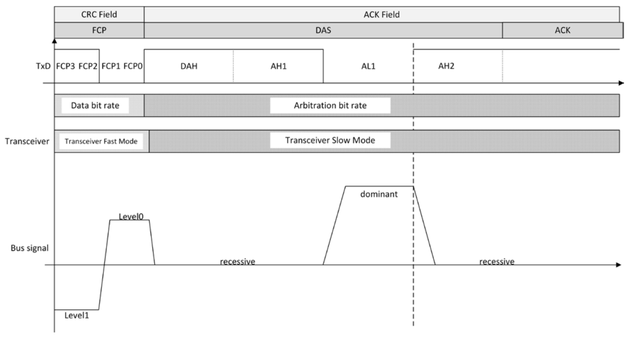

Figure 7: DAS (data to arbitration) field (Source: Infineon)

improve the signal integrity at lower bit-rates. In this case the CAN XL controller is necessary. Only this controller is able to support the dual mode function in the transceiver. The CAN SIC XL transceiver can also be used in combination with CAN FD and the Classical CAN protocol. But in this combinations the slow mode will be supported only. Below, possible combinations are listed.

For CAN FD protocol:

- HS-CAN transceiver
- CAN FD transceiver
- CAN SIC transceiver
- CAN SIC XL (slow mode)

For CAN XL protocol:

- HS-CAN transceiver
- CAN FD
- CAN SIC transceiver
- CAN SIC XL (dual mode)

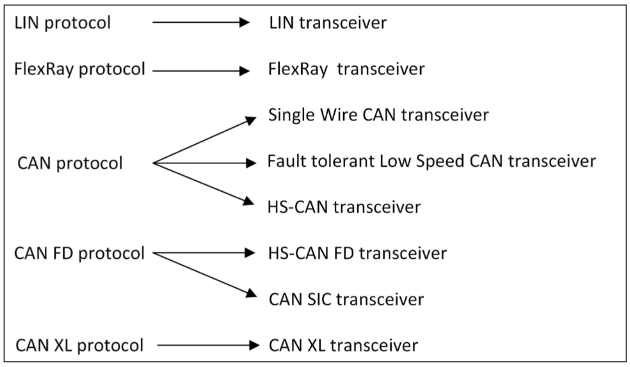

Figure 8: Protocol vs transceiver (Source: Infineon)

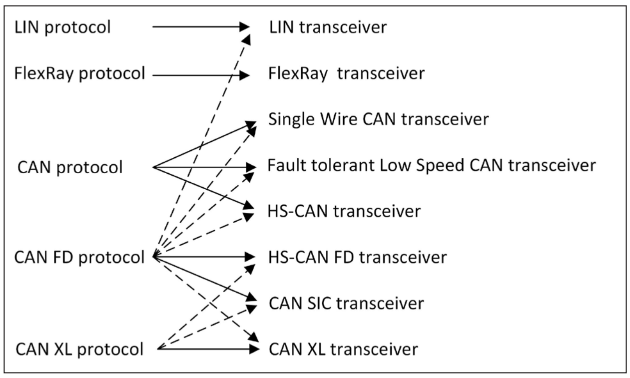

Figure 9: Protocol vs transceiver combination (Source: Infineon)

Our proposal for the transceiver choice

In figure 10 recommendation for applicable bit-rates of the different types of transceiver are shown. The maximum bit-rate depends on the network topologies. As higher the number of stubs, stars, and nodes, as lower the maximum possible bit-rates are. Also, the ratio between the stubs of a star has ▷

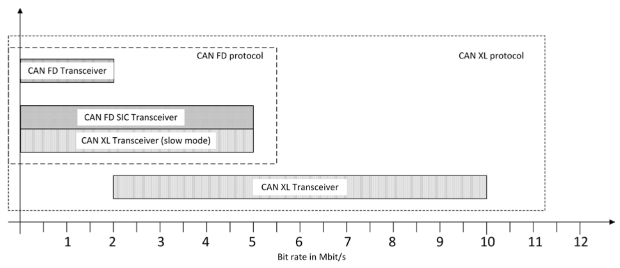

Figure 10: Transceiver application area (Source: Infineon)

an impact of the reflection and the ringing in the network. With the CAN FD and CAN XL protocol and the CAN FD, CAN SIC, and CAN SIC XL transceiver, a lot of possibilities are given now to achieve the best choice for your application. But the higher bit-rates need a very detailed analysis of the network. This can be achieved best by doing network simulations.

Remark

This article describes the status of the specification discussions in September 2020. Modifications are possible. Updates are available on the CiA homepage.

CAN XL specifications

The planned CAN XL specifications include:

- CiA 610-1: Datalink layer and physical signaling requirements
- CiA 610-2: Datalink layer and physical signaling conformance test plan
- CiA 610-3: Physical media attachment sub-layer requirements
- CiA 610-4: Physical media attachment sub-layer conformance test plan
- CiA 610-6: Media independent CAN interface conformance test plan
- CiA 610-7: Higher-layer function requirements
- CiA 610-8: Higher-layer function conformance test plan

After the release of this specifications, they will be transferred into ISO standards. Start of this transition is planned 2021. ◀

References

[1] CiA 601-4, Node and System Design Part 4: Signal Improvement. Version: 2.0.
[2] ISO 11898-2:2016, Road vehicles – Controller Area Network Part 2: High – Speed-Medium access unit, second edition 2016-12-15
[3] CiA 610-1, CAN XL protocol specification (in preparation)
[4] CiA 610-3, CAN XL physical layer specification (in preparation)

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