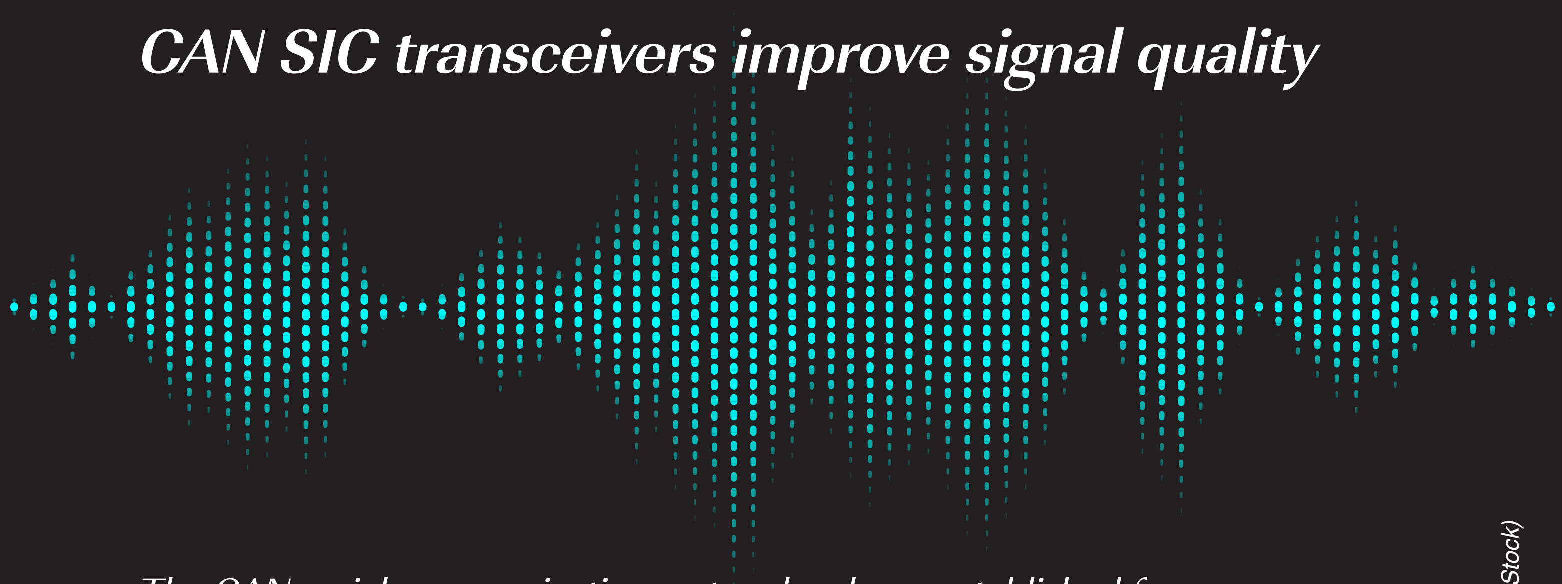
CAN SIC transceivers improve signal quality


(Source: Adobe Stock)

The CAN serial communication system has been established for more than 30 years not only in the automotive industry but also in industrial automation. The increasing degree of automation in recent years has led to higher demands in terms of data throughput.

New evolutions of CAN protocol – CAN FD and CAN XL – provide solutions to these requirements by allowing higher bit rates in the data phase. However, topologies with many branches, as commonly used in CAN applications so far, lead to problems at higher bit rates (see Figure 1). Large and unterminated branches cause reflections, especially when transiting from dominant to recessive signal level (see Figure 3).

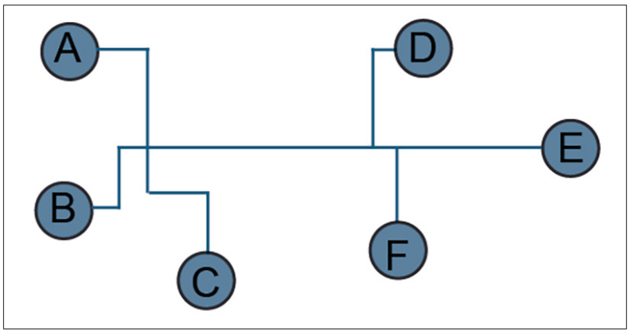


Figure 1: Multi-star topology (Source: esd electronics)

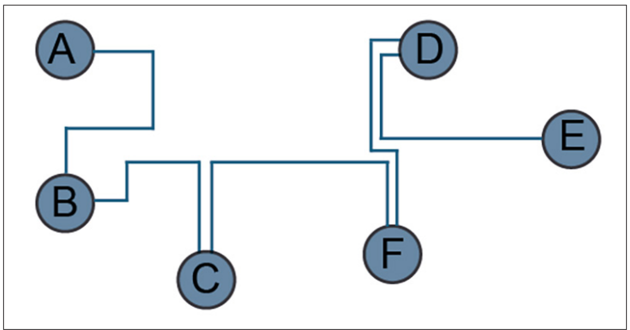


Figure 2: Line topology (Source: esd electronics)

One possible solution to this problem is the consistent implementation of a line topology, routing the bus cable from node to node, in order to avoid long branches with no termination (see Figure 2). However, this results in increased cabling effort and longer networks. Especially in the automotive industry, this is a 'no go'.

Basics of loss-free arbitration

A key feature of CAN is the non-destructive bus arbitration. No nodes are addressed, instead, the data frames contain an ID (identifier), which implicitly features a priority, determining, which data frame is transmitted first, when multiple nodes start sending simultaneously. Data frames of lower priority are overwritten – the data frame with the highest priority gets the bus access without any delay. There is no interrupt and retry. This is one of the reasons for CAN's real-time capability.

This is achieved through recessive and dominant bits. Dominant bits are sent with a source impedance of about 50 Ω. For recessive bits, the impedance changes to about 60 kΩ. The bit signal level and the slope are then determined by the network terminations and the line capacity. The recessive bits are overwritten by dominant bits from other nodes. This mechanism is only relevant in the so-called arbitration phase of the CAN data frame. In the subsequent data phase, there is only one transmitting node in the network.

CAN SIC transceivers reduce reflections

The change of the source impedance to about 60 kΩ when sending recessive bits is a strong mismatch against the impedance of the CAN network of about 120 Ω and is thus one of the reasons for the strong reflections mentioned above. Depending on the network topology, the settling time can be much longer than the bit time of the higher CAN FD or CAN XL bit rates and can therefore lead to incorrect data reception. ▷

The CAN SIC (signal improvement capability) transceivers target precisely this mismatch. When transmitting a recessive bit, most reflections are eliminated by driving the signal with a 100-Ω source impedance for a set time period instead of immediately switching to a high-impedance state at the beginning of the transmission. Figure 3 and Figure 4 show the comparison between reflections with and without a CAN SIC transceiver.

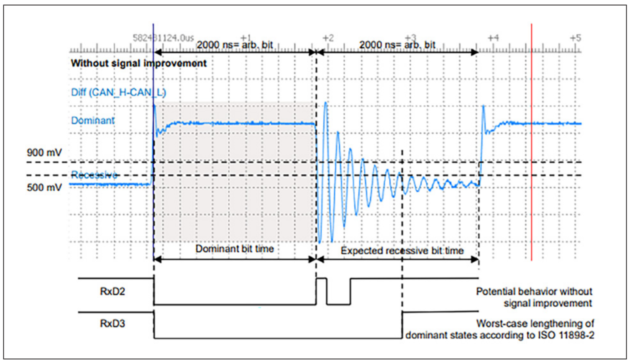


Figure 3: Reflections without CAN SIC transceivers (Source: CAN in Automation)

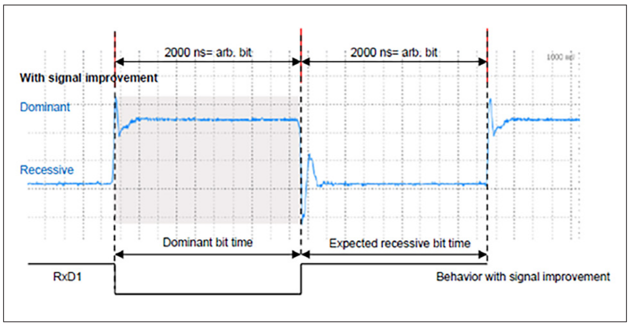


Figure 4: Reflections with CAN SIC transceivers (Source: CAN in Automation)

CAN SIC transceiver specification

The requirements for CAN SIC transceivers, originally specified in the CiA 601-4 document, are specified now in the ISO 11898-2:2024 standard. This standard specifies the maximum of the so-called "active recessive time" – meaning the active driving of the normally recessive level – as 530 ns. This time is longer than the bit time of the higher bit rates in CAN FD and CAN XL. With alternating levels in the data phase, the transceiver then switches from the active recessive state to the dominant state immediately. This means that high bit rates are transmitted almost entirely with a low impedance. In this context, the CAN SIC transceiver specification also deals with EMC issues, which, however, will not be discussed further in this article.

CAN SIC transceivers are another possible solution to achieve higher data rates, but without changing the topology. However, it should be remembered that the higher bit rates can only be reached in the data phase of the CAN data frames and that there are limitations in the arbitration phase.

Limitations of CAN SIC transceivers

Table 14 in ISO 11898-2:2024 specifies the maximum propagation delays, which limit the achievable bus lengths in the arbitration phase. According to the table, the maximum achievable bit rate in the arbitration phase for CAN SIC transceivers is limited to 727 kbit/s. The bus length that can be achieved with this bit rate is only 5 m, assuming a signal propagation delay of approximately 5 ns/m. For 500 kbit/s, the converted achievable bus length is 53 m. Compared to the previous CiA recommendations for CAN HS and CAN FD transceivers (100 m at 500 kbit/s), this represents a considerable reduction. An arbitration bit rate of 1 Mbit/s is no longer possible. The following sample calculation intends to show, where these restrictions come from and how they can be calculated.

1. A multi-star topology is assumed

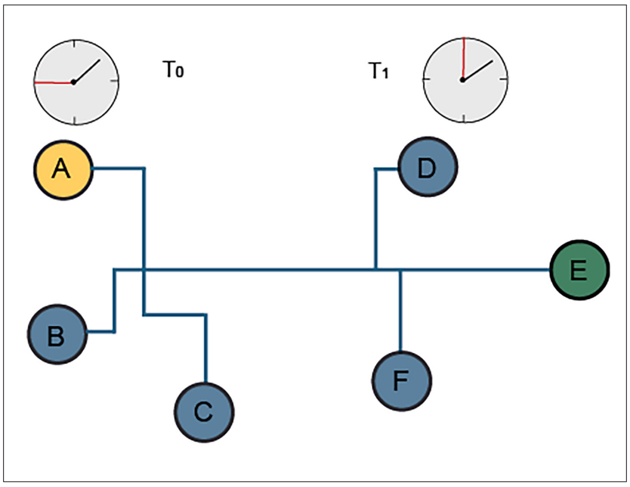


Figure 5: Example multi-star topology (Source: esd electronics)

2. According to the CAN specification, continuous synchronization of all nodes on a network takes place. For this purpose, the recessive to dominant transitions of the CAN frames are used. Node A has just successfully sent a CAN frame. Nodes D, E, and F have synchronized with the rising edges of the last CAN frame to the time T_1.
3. Time T_1 shows an offset compared to time T_0 at node A, which is due to the signal propagation delay.

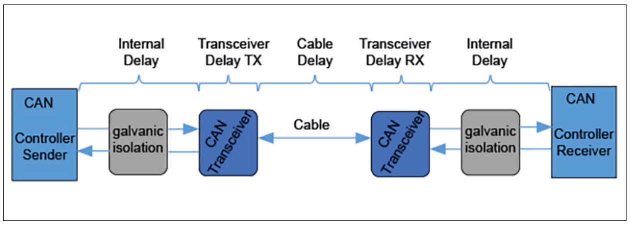


Figure 6: Signal propagation times on the CAN network (Source: esd electronics)

The offset compared to the time at node A is 2 x 45 ns (internal delays) + 80 ns (transmitter delay) + 110 ns (receiver delay) = 280 ns plus the runtime on the cable when assuming the maximum specifications for propagation delays (see Table 14 in ISO 11898-2:2024).

4. Within the next data frame, nodes A, D, and F want to send a recessive bit. Node E wants to send a dominant bit.

5. According to Table 18 in ISO 11898-2:2024, nodes A, D, and F send the recessive bit for a maximum time (signal improvement time TX-based $t_{SIC\_TX\_base}$) of 530 ns active recessive.
6. Common CAN transceivers (CAN high-speed transceivers) transmit the dominant level with a source impedance of 50 Ω. The active recessive level is sent with an impedance of 100 Ω. Assuming that there are other nodes besides nodes D and F that have synchronized on T_1 and that they are also driving the network active recessive, their impedances will connect in parallel. The dominant level then prevails after 530 ns at the earliest.
7. For a correctly functioning CAN network, the dominant level in the arbitration phase must also be seen by node A before its sample point. Node A is ahead of node E by 280 ns plus the cable propagation delay. Added to this is the signal propagation delay from the node E to A.
8. This leads to the following inequation, which can be used to calculate the values in Table 1.

Samplepoint at node A
"0" Time at node E
Active Rezessive Phase
Propagation delay back to node A

$$T_{0SP} > T_1 + t_{SIC\_TX\_base} + t_{Prop\_Delay} + t_{Cable}$$

$$T_0 + t_{Bit} \times P > (T_0 + t_{Prop\_Delay} + t_{Cable}) + t_{SIC\_TX\_base} + t_{Prop\_Delay} + t_{Cable}$$

$$\cancel{T_0} + t_{Bit} \times P > \cancel{T_0} + t_{SIC\_TX\_base} + 2 \times t_{Prop\_Delay} + 2 \times t_{Cable}$$

$$t_{Bit} \times P - t_{SIC\_TX\_base} - 2 \times t_{Prop\_Delay} > 2 \times t_{Cable}$$

$$\frac{t_{Bit} \times P - t_{SIC\_TX\_base} - 2 \times t_{Prop\_Delay}}{2} > t_{Cable}$$

$$\frac{2000ns \times 81\% - 530ns - 2 \times 280ns}{2} = 265ns > t_{Cable}$$

For better comparability, the sample points in Table 1 were set so that the values given in Table 14 in ISO 11898-2:2024 are exactly matched. A sample point of 99 % at 1 Mbit/s is unrealistic, but it shows that even with this, a meaningful solution is no longer possible.

Table 1: Cable propagation times per bit rate (Source: esd electronics)

Parameter	Abbreviation	Baudrate 1	Baudrate 2	Baudrate 3	Baudrate 4
Baudrate		500 kbit/s	667 kbit/s	727 kbit/s	1000 kbit/s
Bit time	t_{BIT}	2000 ns	1500 ns	1375 ns	1000 ns
Samplepoint [%]	P	81 %	82 %	82,9 %	99 %
Samplepoint [ns]	T_{OSP}	1620 ns	1230 ns	1140 ns	990 ns
Propagation delay (without cable)	t_{Prop_Delay}	280 ns	280 ns	280 ns	280 ns
Aktive Recessive Phase	$t_{SIC\_TX\_based}$	530 ns	530 ns	530 ns	530 ns
Cable Propagation delay	t_{Cable}	265 ns	70 ns	25 ns	-100 ns

As described above, these restrictions only apply to the arbitration phase. In the data phase, there is only one transmitter at a time. The correct signal level is therefore immediately present – without possible collision in the active recessive phase of 530 ns length – at the network.

The oscillator tolerances are not considered in the calculation, as they no longer play a significant role with today's standard oscillators. For the calculation of the possible topologies with individually adapted values, CiA offers a corresponding spreadsheet tool on request (currently under revision).

Conclusion

CAN SIC transceivers achieve a significant improvement in signal quality using non-optimal CAN topologies. However, this comes at the cost of reducing the maximum network lengths and limited bit rates in the arbitration phase. The previous backward compatibility of the CAN FD communication with the CAN CC (classic) communication regarding the arbitration bit rate is only maintained for bit rates below 727 kbit/s, when using CAN SIC transceivers. esd electronics offers special solutions for required applications also regarding the use of CAN SIC transceivers. ◀

Author

Marc Itrich
esd electronics
sales@esd.eu
www.esd.eu