CiA 601-4: CAN signal improvement

New CAN FD SIC (signal improvement capability) transceivers will remove some limitations and accelerate CAN FD far beyond what was previously possible, opening up new possibilities. This article reviews the background, the new CiA 601-4 version 2.0.0, and the future implications for CAN.

CAN FD was introduced as an extension of Classical HS-CAN that enabled more data to be exchanged at faster bit rates. Whilst clearly boosting the throughput of Classical CAN, the accelerated bit rates created new signal integrity problems, significantly limiting its application in the topologies that car makers ultimately required. New CAN FD SIC transceivers will remove these limitations and accelerate CAN FD far beyond what was previously possible, opening up new possibilities for this technology. This article reviews the background, the new CiA 601-4 version 2.0.0, and the future implications for CAN.

CAN FD - accelerating to 2 Mbit/s

Getting faster bit rates through a CAN network is not a new problem. Communication bandwidth is always in demand and as many automotive networks have evolved over time, they have slowly reached their bandwidth capacity. The maximum bit rate a CAN network can reliably operate at has been traditionally limited by the loop delay, a timing parameter defined in the ISO11898-2 standard. Essentially, it equated to a simple principle: faster bit rates enforce smaller networks. Specifically, a shorter maximum distance between any two nodes.

This limit derives from the arbitration phase, where all nodes need to correctly receive every other nodes' signal to collectively agree on who has priority to send.

CAN FD, by comparison, could accelerate to higher bit rates by only doing so in the data phase of communication, when arbitration has completed and there is just one node sending. Here the loop delay requirement no longer applies, although it does still apply unchanged during the arbitration phase of CAN FD. As a result, every CAN FD network has two defined bit rates: the bit rate during the arbitration phase (typically similar bit rates to previous HS-CAN networks) and the data phase – or fast phase – bit rate, when the payload is sent and when faster bit rates can be achieved.

While CAN FD was defined up to 5 Mbit/s in the fast phase in the ISO11898-2:2016, quickly a new speed limit was encountered when networks were evaluated at these higher bit rates. This time, it was achieving a stable signal during the recessive bit, which became distorted due to two topology effects: signal ringing, created by unterminated stubs (or branches) in the wiring harness, and signal plateaus, created by a lower characteristic cable impedance. These both disturbed the signal at the beginning of the recessive bit and delayed it from becoming stable below a differential voltage of 0,5 V. This 0,5 V is the minimum receiver threshold – the point at which all transceivers must interpret the signal as recessive.

These effects were not new creations of CAN FD and already existed in traditional HS-CAN networks. However, the bit rate in the fast phase meant bit times were significantly shorter and so the effects which were normally small artifacts way ahead of the sample point, now became significant roadblocks to reliable communication.

To mitigate these effects, network architects had to limit the complexity of their topologies, by avoiding long, unterminated stubs and remaining instead with a reduced number of nodes in a typically linear (or daisy-chain) network. While this allowed communication to be guaranteed, it came with several side-effects: an increase in network branches leading to more complex gateways, more

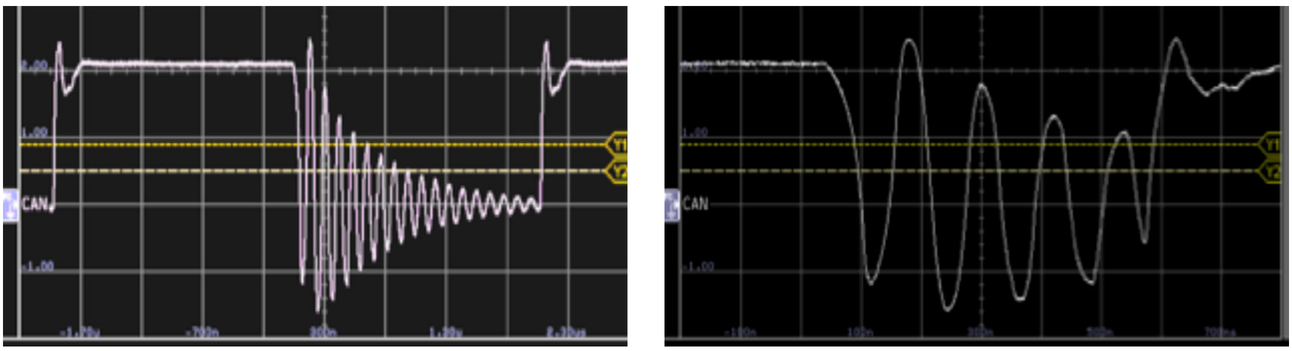

Figure 1: Signal ringing examples at 500 kbit/s (left) and 2 Mbit/s (right). The horizontal lines show the minimum and maximum receiver thresholds. To guarantee reliable communication, the signal must be stable underneath the minimum receiver threshold by the sample point, typically around 70 % to 80 % of the bit time. In the 2 Mbit/s example, the signal still peaks above this limit, preventing reliable communication to occur. (Source: NXP)

connectors, more cabling being routed through a vehicle, and more complex installation and test during vehicle production. A simple illustration of this would be routing a cable to a roof module. With a linear topology, the cable now needs to both stretch up 1 m to 2 m up to the roof, and then back down again, instead of just having a one-way stub. This adds more cost and weight to the cable harness. Even with these mitigations however, CAN FD became effectively limited to 2 Mbit/s communication, outside of point-to-point connections.

CAN signal improvement capability

The problem of controlling the signal during recessive bit was initially tackled in the CiA 601-4 version 1.0.0 specification. A receiver-based approach was proposed, which monitored the bus and tried to identify a recessive bit transition. Once detected, it would actively bring the signal to 0-V differential for a period of time. This solution showed good results on bench tests, with multiple nodes acting simultaneously to improve the ringing and increasing the potential topology size at 2 Mbit/s. It did not, however, fully address concerns on how to reliably distinguish genuine bit transitions from temporary signal distortions (such as glitching on the bus or by EMC effects) and plateau effects were shown to risk delaying activation.

A receiver-based approach also has inherent limitations on its speed of activation. Fast activation is a key parameter to quickly eliminate energy in the ringing and get the signal stable below the 0,5-V threshold. By reacting on the bus signal, additional delay is introduced to ensure accurate detection, with any additional filtering of glitches slowing down the reaction time further. Certainly, when considering bit-rates beyond 2 Mbit/s, the reaction time would become a major bottleneck for such an approach. Finally, any receiver-, or feedback-based concept has an inherit problem of ensuring system stability, especially if a critical node lost power and was no longer able to improve the signal, then communication in the entire network could be affected.

NXP proposed an alternative feedforward-based solution. Activation is based on the TXD input, which is both reliable and allows a significantly faster activation time, since this triggers the signal improvement even before the internal propagation delay of the transceiver. Faster activation of the signal improvement means ringing is controlled earlier in the bit time, guaranteeing communication in networks with more severe ringing (thus more complex topologies) or in a network with even faster bit rates. System predictability is straightforward since there is only one sender applying signal improvement. This avoids having possibilities for unpredictable interactions between nodes and since each node manages their own signal, should any node lose power, its impact would be limited only to that node.

The CiA 601-4 working group reviewed both these concepts leading to a set of requirements for any solution. With thanks to major contributions from several car makers and silicon vendors, this resulted in a basic set of requirements that can be summarized as follows:

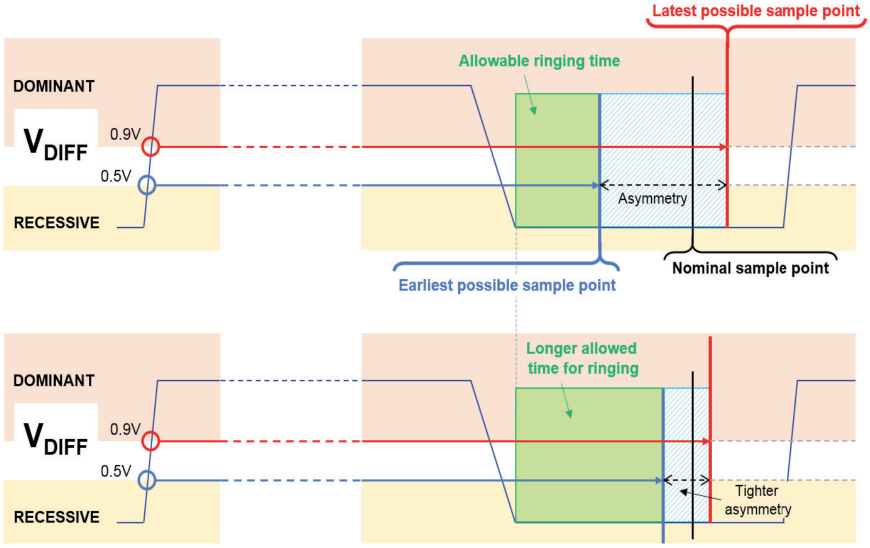

Figure 2: A reduced asymmetry a smaller deviation on when a sample point may occur, which means the earliest possible sample point is later. In turn, this means more time for ringing to occur without affecting network communication. (Source: NXP)

Transceiver symmetry is a significant component in the total asymmetry calculation within a network. Thus tightening the symmetry specification means less possible spread and the earliest sample point will appear relatively later. This in turn increases the allowable ringing time before that earliest sample point. Unlike the ISO11898-2:2016, which defined symmetry values for 2 Mbit/s and 5 Mbit/s, the CiA 601-4 version 2.0.0 defines bit-rate independent values with a much tighter symmetry specification. This enables CAN FD to tolerate significantly more ringing, allows significantly shorter bit times, extending the maximum bit rate CAN FD can operate to even beyond 10 Mbit/s.

- All mechanics of the existing CAN FD protocol shall be fully guaranteed, especially arbitration, frame acknowledgement, and error handling.
- Solutions should be as fast as possible and bit rate independent. Up to 8 Mbit/s shall be considered.
- Solutions should be fully backwards compatible with conventional HS-CAN transceivers and footprint compatible, to enable easy adoption.
- Solutions should have the same robustness to EMC (electromagnetic compatibility), ISO pulses, and ground shifts as of today.
- Networks with signal improvement shall have a predictable system response, also in case a node fails or loses power.

From this work, specification points were derived and captured in the new CiA 601-4 version 2.0.0 specification, which relate to the transceiver symmetry, the length of signal improvement time and EMC testing. Collectively, these define the basic criteria any CAN signal improvement solution should fulfill, independent of its precise approach.

Transceiver symmetry explained

The transceiver symmetry is highly relevant to the overall capabilities of a CAN FD network. Simply, it defines how much timing deviation is seen on successive bit edges from TXD to the CAN network, and from the bus to RXD. This is relevant because all CAN controllers synchronize on a dominant bit transition, and any transceiver asymmetry will introduce potential timing differences for when nodes make their sample point. Since guaranteeing reliable communication relies on a signal being stable at the sample point, it is important to calculate when the earliest sample point may occur, including these deviations, and assess the signal stability at that moment. Before that time, no sample point will ever occur, so signal distortions are no problem. This can be referred to as the "allowable ringing time", shown in Figure 2.

Additional specification points and next steps

Further to the symmetry specification, the CiA 601-4 version 2.0.0 introduces a limit on the duration of signal improvement time, required to respect arbitration rules. If multiple senders all concurrently are trying to bring a recessive signal to 0-V differential while another node is sending a dominant signal, all nodes should agree the bus is dominant. To achieve this, the maximum signal improvement time limit is set, defining effectively a maximum arbitration bit rate for networks with signal improvement, with an associated limit on maximum node distance. The CiA 601-4 version 2.0.0 specification provides a generous operating area however, with 48 m supported at 500 kbit/s bit rate, and a maximum arbitration bit rate of 727 kbit/s.

Finally, a new EMC test proposal is made in order to provide evidence that any CAN FD SIC transceiver is not creating any EMC issues. Additional emission and immunity tests are defined, to introduce differential ringing into the EMC test set-up. This ringing still needs to be eliminated, even under harsh RF injection.

With the publishing of the CiA 601-4 version 2.0.0 specification, the basis of this technology is now defined. Interoperability tests (IOPT) are now under development, based on the current HS-CAN IOPT.

NXP's CAN FD SIC technology

NXP has played a key role with other industry players in the development of the CiA 601-4 version 2.0.0 specification, promoting a feedforward-based CAN FD SIC solution. This solution has been extensively evaluated globally by car makers and demonstrated to reliably operate complex networks beyond 5 Mbit/s. At 2 Mbit/s, it significantly boosts potential network topology dimensions and our experience broadly shows a topology validated at 500 kbit/s can be operated at 2 Mbit/s. An additional advantage of the NXP CAN FD SIC solution is that it is bit-rate independent, with one device able to serve any bit rate. NXP is now sampling ▷

this technology and we expect the first vehicles using this technology to be on the road in 2020.

CAN signal improvement also really extends what is feasible with CAN FD and 5 Mbit/s becomes a definite reality for car makers to consider in their future technology choices. With vehicle network architectures undergoing major changes in the next generations of vehicles, this positions CAN FD as a highly relevant and meaningful technology to consider, givens its proven reliability and cost.

Although signal improvement can theoretically go way beyond 5 Mbit/s, accelerating the fast phase to even higher bit rates comes with diminishing returns, given the arbitration phase remains unchanged. Therefore, there is, a natural link from signal improvement technology towards CAN XL, which intends to significantly increase the payloads and removing limitations in the current CAN FD protocol that would enable more physical layer improvements of the signals. That technology step will require new protocol controllers in the micro-controller – something not required with signal improvement transceivers of today – but with this promising technology targeting 10 Mbit/s communication and 2 kbit/s frames, it extends the potential and relevance for CAN even further within new vehicle networks. ◀

Author

Tony Adamson
NXP Semiconductors
info@nxp.com
www.nxp.com