

## CAN FD system design challenges

Which technical concepts behind make CAN FD communication robust and how are CAN SIC (signal improvement capability) transceivers changing the possibilities for CAN FD networks?

Parameter	Earliest	Latest	Note
Oscillator drift	-16,1 ns	+16,1 ns	Bit rate dependent. Assumed tolerance of $\pm 0,3\%$ .
Asymmetry of sender's transceiver	-45,0 ns	+10,0 ns	Constant. Based on ISO 11898-2:2016.
Asymmetry of receiver's transceiver	-45,0 ns	+15,0 ns	Constant. Based on ISO 11898-2:2016.
PCB tolerances	-10,0 ns	+10,0 ns	Assumed 2 x 5ns for MCU-TXD and RXD-MCU.
1 time quanta at the receiver (remote node)	24,9 ns	-	Based on clock frequency (assumed 40 MHz).
<b>Worst case sample points (remote sender):</b>	<b>209,0 ns</b>	<b>401,1 ns</b>	

Table 1: Calculated asymmetries for a remote receiving node in a 2-Mbit/s CAN FD network with a sample point of 70 % (Source: NXP)

The complete article from NXP Semiconductors is published in the [March issue](#) of the CAN Newsletter magazine 2020. This is just an excerpt.

In our [previous article on CAN signal improvement](#), the fundamentals of the CiA 601-4 specification were reviewed, and its impact on the potential of CAN FD networks. In this article, we explore in more detail some of the technical concepts behind what makes CAN FD communication robust and how CAN SIC transceivers are changing the possibilities for CAN FD networks.

In order to define the challenges of CAN network design, one of the first things to address is how one determines what a “good” or robust network design is. When working with network architects, we start from the fundamental theory of Classical CAN and CAN FD. There is a dominant level, which is defined as a differential voltage measure above 0,9 V, and a recessive level, defined as a differential voltage below 0,5 V. This is valid irrespective of any DC common mode voltage in the background.

The signal level is measured once per bit, at the sample point. The sample point is a specific moment in time, defined as a percentage of the bit time. So, very simply: in order to make sure that a network is robust, it shall guarantee at this sample point, the signal levels shall be stable, whether dominant or recessive.

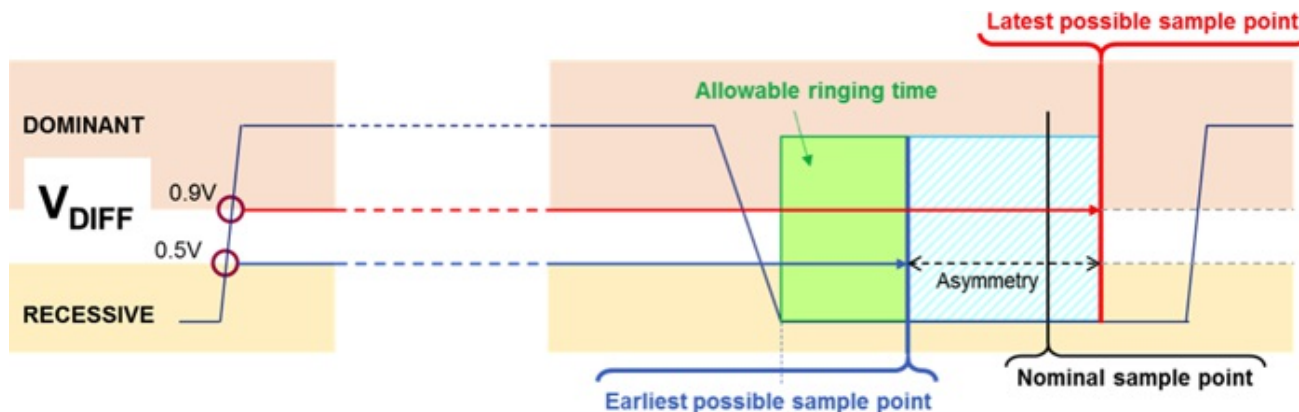


Figure 1: Calculated asymmetries visualized in the recessive bit (Source: NXP)

The first complication, before considering what effects can disturb the network signals, is to understand that sample points on two nodes, a sender and receiver, can and do move relative in time to one another. Therefore, if we require stable signals at the sample point, we need to calculate when the earliest and latest possible sample points may appear. We can then refine our previous statement to say that the signal levels shall be stable by the earliest possible sample point and remain stable until the latest possible sample point.

There are different factors affecting the shift of sample points:

- The drift of the oscillator in the sending and receiving nodes, where one may run fast and the other slow, creating a timing drift between the two.
- The asymmetry of the CAN transceiver, which is the difference in time between a dominant to recessive transition and a recessive to dominant transition. This is specified in the datasheet of the transceiver, with limits defined for 2 Mbit/s and 5 Mbit/s in the ISO 11898-2:2016 (for reference, refer to section 5.6 of that document). In fact, these limits are not intrinsically linked to the bit rate and many car makers now require the tighter specification of 5 Mbit/s to be met even in CAN FD networks operated at 2 Mbit/s.
- The asymmetries of the interface between the micro-controller and CAN transceiver. For calculations, both the TXD and RXD pins need to be considered, where 5 ns is a typical reference value.
- Lastly, the worst case time quanta delay. The signal may arrive at the receiver just after the last time quanta, meaning there is a worst case delay until the next time quanta measurement.

These factors are all additive and should be calculated based on a worst case bit pattern to give the longest time

period between a synchronization point (a recessive to dominant transition) and a sample point, namely five dominant bits followed by one recessive bit.

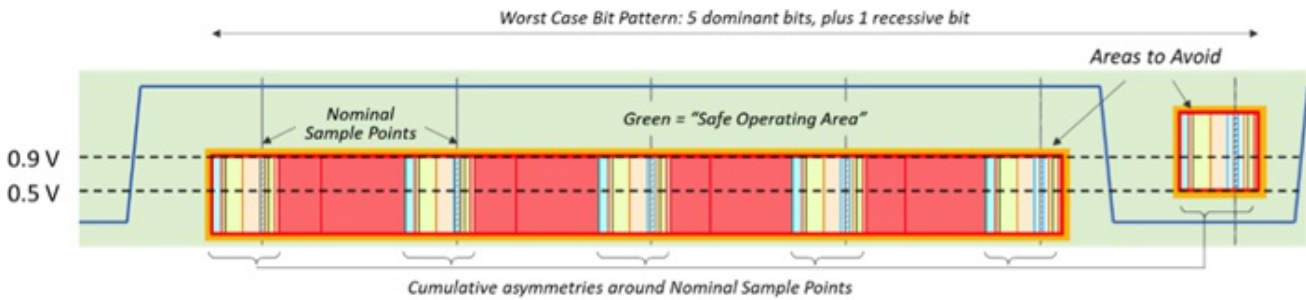


Figure 2: Full visualization of all asymmetries in a worst case CAN FD bit pattern (Source: NXP)

These can be calculated for any bit rate, but for illustration, an example is shown for a bit rate of 2 Mbit/s with a sample point of 70 %, commonly used in CAN FD net- works. Here the nominal sample point would be  $500 \text{ ns} \times 70 \% = 350 \text{ ns}$ . There is an additional calculation for a sending node reading back their own signal, which is also important to verify. For those who are curious, the details behind each of these calculations can be found in our ICC 2017 article "Managing the Transition to Robust CAN FD".

What can be concluded is a sample point can potentially move much earlier in the bit - at 209 ns in this example (28 % earlier in the bit time vs. the nominal sample point). Thus, for network communication to be robust, its signal needs to be stable much earlier in the bit. Conversely how- ever, we can infer that what happens prior to this earliest sample point is not relevant, as this will never be sampled. This is what we call the allowable ringing time, as any kind of signal distortions here can occur without affecting the network operation.

A complete picture of the full worst case bit pattern with all asymmetries shown is given in Figure 2. The green area demarks the boundary where the CAN signals can safely appear without compromising the network robust- ness, defined as the "safe operating area". The colors shown in the boxes are the associated contributions from the different components listed in the table above.

### The typical worst case simulation

To judge if a network is meeting these criteria and remaining in the safe operating area, a network simulation is normally required to check all cases. In simulation, all possible signal combinations are generated between all possible transmitting pairs and then assessed against the above safe operating area. A complete overview of the communication can be checked to determine if the network is robust or not. If not, the nodes causing the violations can be easily identified.

Usually, one would perform a worst case simulation, which uses the worst case parameters stored in the simulation model (selectable in the simulation tool). In our experience however, using this in combination with the worst case timing asymmetries calculated above is not realistic. This is because the worst case simulation model considers all worst case parameters taken from the data- sheet, taking each characteristic as an individual potential worst case value, without considering which combination of characteristics are possible at a single moment in time. Furthermore, a transceiver's output driver stability over temperature is much more stable than the datasheet limits are typically predicting.

Instead, our experience leads us to recommend using the typical parameter set in a simulation model, which already gives a very good matching with real world results. The advantage of this approach is not to purely increase the achievable operating space of the network, although this is a desirable benefit. It has the added advantage that simulation results can be easily cross-checked with bench testing, since the simulation conditions used are the same. The margin that would normally be part of the worst case simulation model is now moved into the margin of the safe operating area, since the definition of this contains all worst case asymmetries.

Furthermore, the opposite approach can also be taken for those without easy access to net- work simulation: assessing bench measurements against the same safe operating area can provide a first indication if the network will operate reliably or not. This can simplify early pre-assessments on a network, giving early insights if a topology will operate robustly, and giving confidence when cross-checking simulation results once available.

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