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CAN Newsletter

Hardware + Software + Tools + Engineering

CAN with flexible data-rate breaks the speed limit

CAN IP-core for high-end microprocessors

CiA 402 not only for operation, but also for device testing

iCC 2012

13th iCC: Personal impressions

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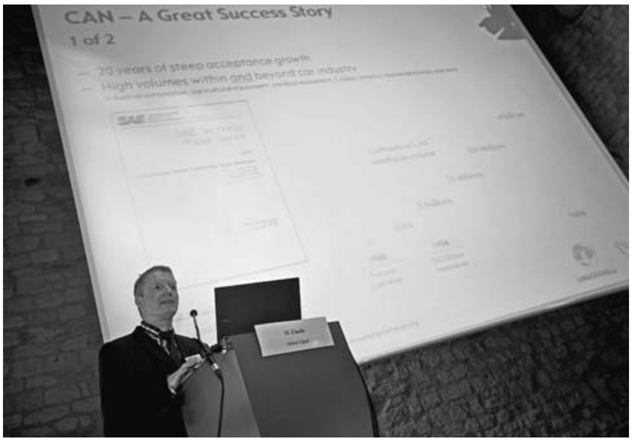
iCC proceedings
All papers of the conference are available on the CiA website. They can be downloaded free-of-charge one by one. If you like to get the entire proceedings on a memory stick, you get them for 48 € including German VAT and postage from CiA headquarters. The previous iCC papers are also available on CiA's website for free download.

Experts from all over the world exchanged ideas, experiences, and knowledge not only during the conference sessions but also during the breaks.

The Hambach castle, the venue of the 13th international CAN Conference (iCC), on top of a hummock on the hillside of the Rhine valley welcomed us from afar. The narrow road through the forest brought us in serpentines to the parking place close to the historic monument. In 1832, about 30000 Germans went uphill to demonstrate peacefully for a free press. They were successful. That is why the Hambach castle is regarded as one of the birthplaces of German democracy. As in the old days, the way from the car parking has to be managed by walking. We carried some paper and recognized how heavy brochures and magazines can be.

After all preparations were done, we left the castle on Sunday evening and drove to our hotel downhill in one of these picturesque villages surrounded by vineyards. Next morning, we started early to the castle to support the companies setting up their tabletop presentations and to welcome the early-bird conference attendees.

I browsed through the Powerpoint slides of my keynote speech, which I had given already a final adjustment in the early morning. In time, I opened the conference and handed over to the chairman of the plenary session, Martin Litschel from Vector, whom I have known for 20 years. Then, it was my duty to warm-up the participants with my ▷



Harald Eisele (General Motors), keynote speaker, reported about the CAN benefits in in-vehicle networking; at the end of his presentation he requested higher bandwidth as provided by the CAN-FD approach, and he demanded selective wake-up CAN transceivers.

The highlight of the tabletop exhibition was the CAN-FD demonstration by Bosch in co-operation with Vector; 15 Mbit/s during the Data-phase was quit impressive.

The 20th anniversary of CAN in Automation (CiA) party was opened by Holger Zeltwanger, who provided a brief history review.

More than 36 speakers covered all current topics of CAN technology – from the physical layer via the CAN-FD data link layer up to dedicated application layer and software driver technologies; Dr. Sakari Junnila (Wapice) from Finland spoke about high-performance CAN driver architectures for embedded Linux.

paper about "Standardized higher-layer protocols for different purposes". Harald Eisele from General Motors (Opel) read the other keynote ("The benefits of CAN for in-vehicle networking"). After the plenary session, I hoped to relax. But I was wrong. Many people, whom I did not meet personally for a long time, wanted to talk to me. Some of them were from far away: Russia, India, and even New Zealand. The two days of conference were not long enough to talk to all of the 130 participants. To be honest, I was a little bit disappointed about the number of attendees. I had expected a full house. The capacity of the Hambach castle is about 200 participants, if you stuff them in.

According to the feedback from the attendees, the quality of presentations was not that bad (British understatement). Unfortunately, some speakers didn't show up. Some had serious excuses, while others even didn't inform us at all. On the other hand, the attendees used the free time to listen to the presentations in the parallel sessions or to talk to other participants or spent their time in the tabletop exhibition.

On Monday evening, CiA celebrated its 20th anniversary. The Firedancer, a group of young women and men, performed their show on the castle's panoramic terrace with a nice view to the Rhine valley, which was illuminated by thousands of lights in the villages and towns. During the dinner, Pia Fridhill and her band marvelously entertained the engineers. One of the highlights was the song "Fieldbus man blues". You should know, Pia Fridhill was working as an engineer with HMS, a Swedish CiA member, for about ten years. Thanks to the HMS management, who financed the production of her first CD, she was able to start a career as a musician. She quitted her job and is a successful professional singer now.

Unfortunately, just a few women participated in ▷

The "Firedancer" warmed-up the participants of the evening event with their out-door performance above the Rhine valley.

Even during the diner, networking was the main topic: Social networking is as important as technical communication, in order to design the next generation of networks.

Pia Fridhill (formerly working as an engineer with HMS) and her band entertained the attendees of the diner party; she also presented her song "Fieldbus man blues".

the conference. Ursula Kelling (Infineon) read a paper ("Microcontrollers for industrial – Ways of interconnectivity") and chaired one session. There were also two ladies from Malaysia working for the carmaker Proton. My impression, we need more female engineers in order to improve our work. Women have another view on things, not only in social behavior.

All presentations were quite technical. But one speaker added entertainment: John Dammeyer reported about the Olympic ring illumination project ("A large scale CAN bus system"). He and his team designed the control systems illuminating the rings in Vancouver's harbor as well as at the airport. The control system comprised several CAN segments connecting more than 1500 devices. In his presentation he spoke more about problems and "accidents" (some of them were quite funny) than to make marketing for his control system and his services. It was really refreshing. I would appreciate to have more such entertaining presentations.

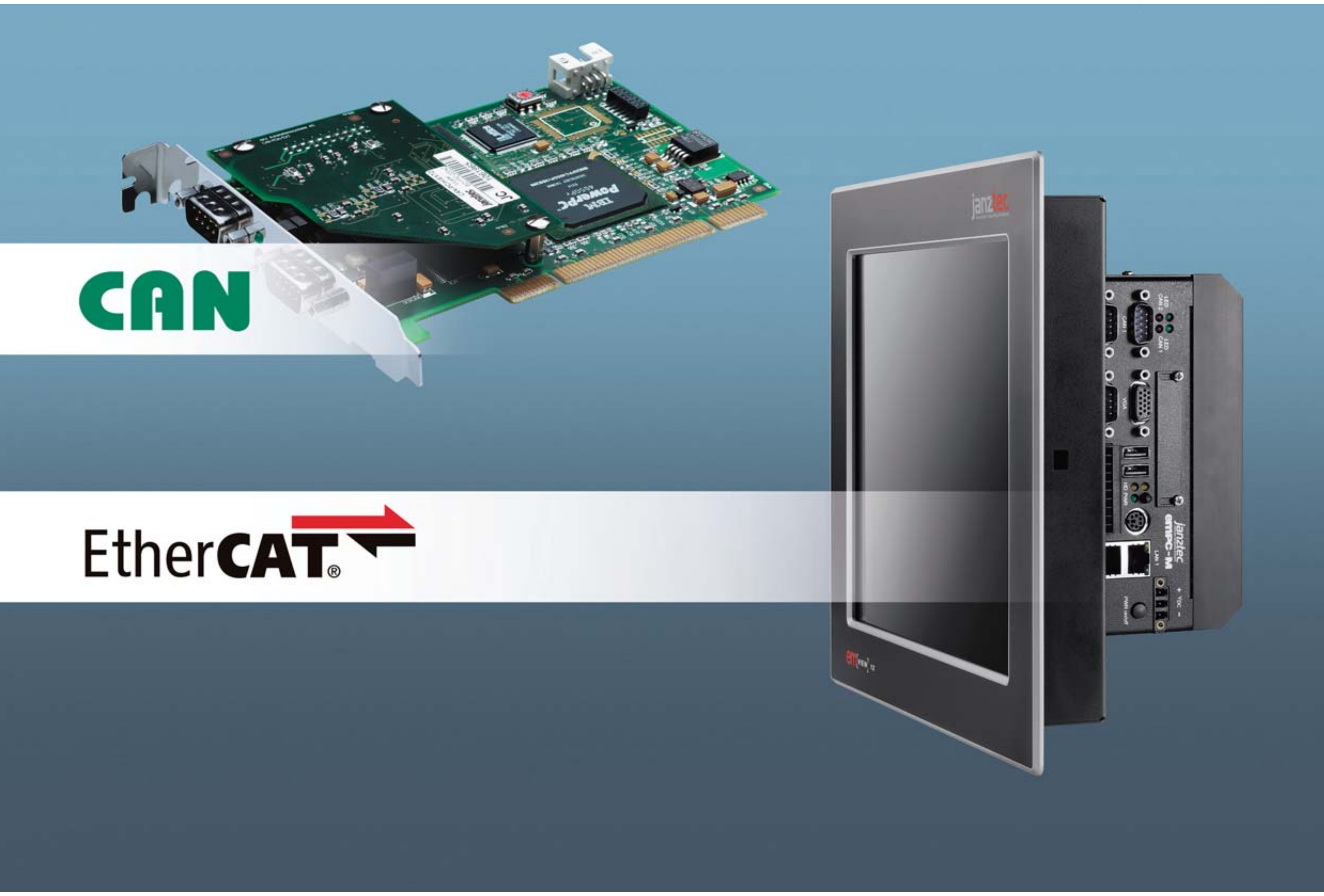
From a technical point quite interesting were the papers dealing with Linux driver software for CAN-connectable devices. Unfortunately, I could not listen to all speeches. Participating in parallel sessions would only be possible, if I would be cloned. Additionally, I spoke to many people during the sessions, because the coffee and lunch breaks were too short to meet everyone. And, sometimes there was also something to organize: The acoustic system was not always working perfectly, presenters had problems with their laptops, and so on.

Everyone was waiting for the final plenary session, in which Bosch represented by Florian Hartwich introduced officially the CAN-FD protocol. It breaks the limits: It is faster than 1 Mbit/s and the payload is larger than 8 byte. Most of the participants had already visited the CAN-FD prototype designed by Bosch and Vector. There were many interesting discussions on this topic. Heinz Oertel (Port), who was in the last nine years the elected CiA Technical Director, discussed in his paper the benefits of CAN-FD for the CANopen application layer.

To summarize: It was one of the best iCCs. Not in respect to the number of participants, but in respect to the interesting topics, the onsite discussions, and the social networking. Facebook and LinkedIn are not all! Let's meet again in two years sharing our knowledge, exchanging experiences, and introducing innovations! ◀

After nine years, Heinz-Juergen Oertel (in the center) has quit his position as CiA Technical Director; the other CiA Board of Director members, Arnulf Lockmann (on the right) and Holger Zeltwanger (on the left), thanked him for his work.

"Competitors" talking friendly, a normal behavior in the CAN community – Martin Litschel (very left), Christian Schlegel (left), Juergen Klueser (with the back in front), and Dr. Martin Merkel (right) from Vector and Ixxat.



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Cover story

In order to overcome the current limitations of the CAN protocol, Bosch together with other CAN experts developed the CAN-FD data link layer protocol. This approach supports higher bit-rates than 1 Mbit/s and allows frame payloads longer than 8 byte.

iCC 2012

Human machine interface

Application

ExoHand and CogniGame

At Hanover Fair Industry, Festo presented two sponsored research projects using embedded CANopen networks. The ExoHand is a soft robotics exoskeleton that is individually adapted to the user's hand and worn like a glove. It can be used to remotely control robotic hands in real-time. The CogniGame is a table-tennis simulation game. One player moves the bar right and left by means of a joystick, while the other player use a brain-computer interface – just thinking "right" and "left". Coupling both ideas, the ExoHand and the CogniGame, can help stroke patients with their recovery.
More information on www.can-newsletter.org

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Ever increasing bandwidth requirements in automotive networks impede the applicability of CAN due to its bit-rate limitation to 1 MBit/s. To close the gap between CAN and other protocols, we have improved CAN in two ways:

I Support of bit-rates higher than 1 Mbit/s,
II Support of payloads larger than 8 byte.

We achieve this with a new frame format where we can switch inside the frame to a faster bit-rate for I and use a different data length coding for II. This new protocol is called "CAN with Flexible Data-Rate" or CAN-FD. CAN-FD protocol controllers are also able to perform standard CAN communication. This allows using CAN-FD in specific operation modes, e.g. soft- ▷

The CAN-FD frame format

The Control Field in normal CAN (ISO 11898-1) frames contains reserved bits, which are specified to be transmitted dominantly. In the CAN-FD frame, the reserved bit after the IDE bit (11-bit Identifier) or after the RTR bit (29-bit Identifier) is defined as Extended Data Length (EDL) bit and is transmitted recessively. This sets the receiving BSP and BTL FSMs into CAN-FD decoding mode.

The following bits are new in CAN-FD compared with CAN:

- EDL Extended Data Length
- r1, r0 reserved (transmitted dominantly)
- BRS Bit Rate Switch
- ESI Error State Indicator

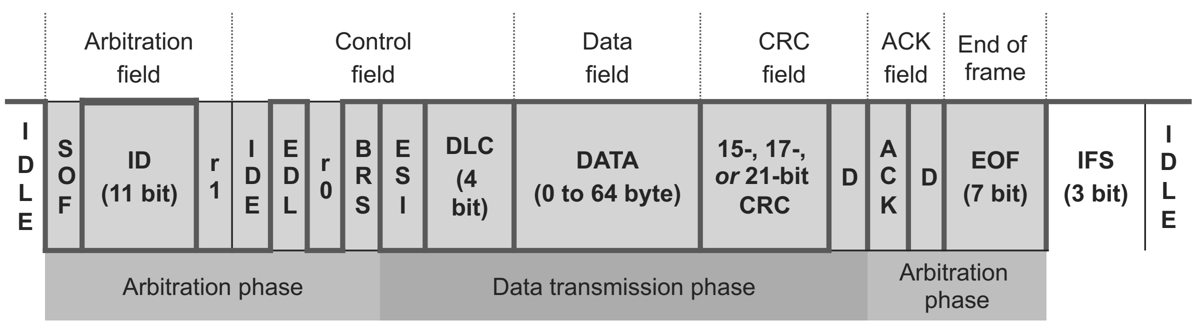
The DLC values from 0000b to 1000b still code a Data Field length from 0 to 8 byte, while the DLC values from 1001b to 1111b are defined in CAN-FD to code Data Fields with a length of 12, 16, 20, 24, 32, 48, respectively 64 byte.

The EDL bit distinguishes between the normal CAN frame format and the CAN-FD frame format. The value of the BRS bit decides, whether the bit-rate in the Data-Phase is the same as in the Arbitration-Phase (BRS dominant) or whether the predefined faster bit rate is used in the Data-Phase (BRS recessive).

In CAN-FD frames, the EDL bit is always recessive and followed by the dominant r0 bit. This provides an edge for resynchronization before an optional bit-rate switch. The edge is also used to measure the transceiver's loop delay for the optional TDC.

In CAN-FD frames, the transmitter's error state is indicated by ESI, dominant for error active and recessive for error passive. This simplifies network management.

There are no CAN-FD remote frames, the bit at the position of the RTR bit in normal CAN frames is replaced by the dominant r1 bit. However, normal CAN remote frames may optionally be used in CAN-FD systems. Receivers ignore the actual values of the bits r1 and r0 in CAN-FD frames.



Legend
D delimiter
IFS inter-frame space

Figure I: Format of the CAN-FD data frame with 11-bit identifier ware-download at end-of-line programming, while other controllers that do not support CAN-FD are kept in standby.

The CAN-FD protocol [1] has been developed with the goal to increase the bandwidth of a CAN network while keeping unchanged most of the software and hardware (especially the physical layer). Consequently, only the CAN protocol controllers need to be enhanced with the CAN-FD option. The new frame format makes use of CAN's reserved bits. Via these bits, a node can distinguish between the frame formats during reception. CAN-FD protocol controllers can take part in normal CAN communication. This allows a gradual introduction of CAN-FD nodes into existing CAN systems.

Basic principles

The CAN-FD protocol is a similar approach as proposed in [2] and [4] increasing the bandwidth by modification of the frame format. Two changes suggest themselves. Firstly, improving the header to payload ratio by allowing longer data fields. Secondly, speeding up the frames by shortening the bit time.

But these steps are only the groundwork, some additional measures are needed, e.g. to keep the Hamming distance of the longer frames at the same level as in normal CAN communication and to account for the CAN transceiver's loop delay.

The CRC polynomial of CAN is suited for patterns of up to 127 bit in length including the CRC sequence. Increasing the CAN frame's payload makes longer polynomials necessary.

In a CAN protocol controller, the Bit Timing Logic (BTL) state machine is evaluated once each time-quantum and synchronizes the position of the Sample-point to a specific phase in relation to the edges in the monitored bit stream. Once each CAN bit-time, at the Sample-point, the bit-value is decided and the Bit Stream Processor (BSP) state machine is evaluated to decode (in transmitters to encode) the CAN frame. A shift register links the frame's serial bit stream with the controller's message memory.

CAN nodes synchronize on received edges from recessive-to-dominant on the CAN bus-line. The phases of their Sample-points are shifted relative to the phase of the transmitter's Sample-point. A node's specific phase-shift depends on the signal delay-time from the transmitter to that specific node.

The signal delay-time between the nodes needs to be considered when more than one node may transmit a dominant bit. This is the case in the arbitration field or in the acknowledge slot. The configuration of the CAN bit-time, especially the Propagation Segment's length and the Sample-point's position, must ensure that twice the maximum phase shift fits between the Synchronization Segment and the Sample-point. Once the arbitration is decided, until the end of the CRC Field, only one node transmits dominant bits, all other nodes synchronize themselves to this single transmitter. Therefore it is possible to switch to a pre-defined (shorter) bit-time in this part of a CAN frame, in CAN-FD called the Data-Phase. The rest of the frame, outside the Data-Phase, is called the Arbitration-Phase.

All nodes in the network must switch to this shorter bit-time synchronously at the start of the Data-Phase and back to the normal bit-time at the end of the Data-Phase. Figure 1 shows an example for the average bit-rate that can be achieved with a bit-rate of 0,5 Mbit/s in the Arbi- ▷

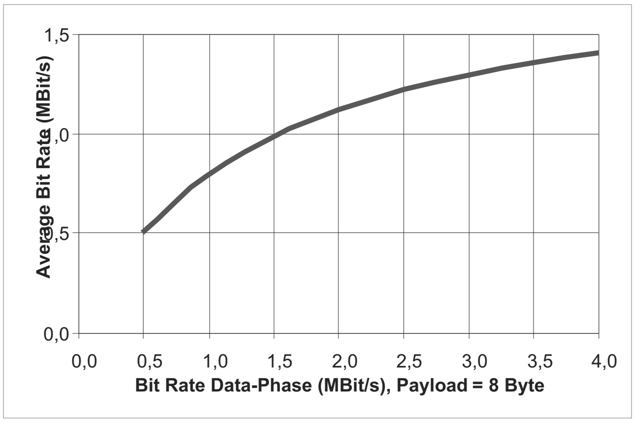


Figure 1: Speeding up from 0,5 Mbit/s to 4 Mbit/s

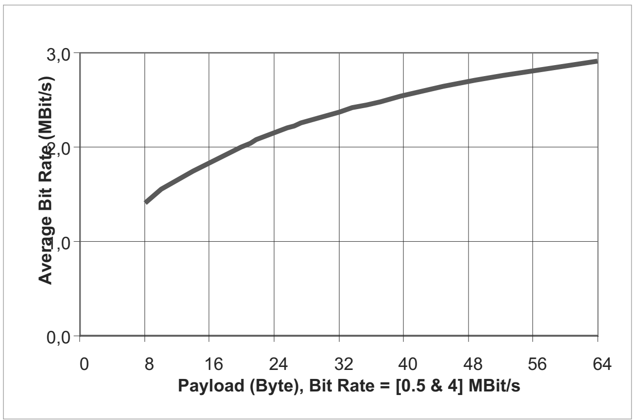


Figure 2: Enlarging a frame to 64 data bytes

tration-Phase and a higher bit-rate in the Data-Phase. In the example, an 11-bit identifier is used, and there are 8 data bytes in the frame. Stuff-bits are not considered. The example is extended in Figure 2: Lengthening the Data-Phase further increases the average bit-rate. The bit-rate is 0,5 Mbit/s in the Arbitration-Phase and 4 Mbit/s in the Data-Phase.

The factor between the short bit-time in the Data-Phase and the normal bit-time in the Arbitration-Phase decides how much the frames are speeded up. This factor has two limits. The first is the speed of the transceivers: Bits that are too short cannot be decoded. The second is the time-resolution of the CAN synchronization mechanism: after switching to the short bit-time, a phase error of one time quantum in the normal bit time needs to be compensated.

At the last bit of the Data-Phase, the CRC Delimiter, all nodes switch back to the normal bit-time before the receivers send their acknowledge bit. Receivers are synchronized to the transmitter, but node-specific signal propagation times cause acknowledge bits of the most distant receivers to arrive after that of the nearest receivers. Therefore, a CAN-FD transmitter has to tolerate a 2-bit CRC Delimiter before the acknowledge bit. All CAN-FD nodes have to tolerate two consecutive dominant bits in the Acknowledge Slot. Latest, the second dominant Acknowledge Bit must be followed by a recessive Acknowledge Delimiter and the End-of-Frame field.

CAN's fault confinement strategy, where a node that detects an error in an ongoing frame immediately notifies all other nodes by destroying that frame with an error flag, requires that all nodes monitor their own transmitted bits to check for bit errors. Current CAN transceivers may have, according to ISO 11898-5, a loop-delay (CAN-Tx pin to CAN-Rx pin) of up to 255 ns. In order to detect a bit error inside a bit-time of the Data-Phase, this bit-time has to be significantly longer than the loop-delay. To make the length of a short bit-time independent of the transceiver's loop delay, CAN-FD provides the Transceiver Delay Compensation (TDC) option.

Additional CRC polynomials

The error detection capabilities and operational safety of the normal CAN protocol are discussed in [7], [8], and [9]. CAN-FD maintains all of CAN's fault confinement mechanisms, including Error Frames, error counters, error-active/-passive modes, and positive acknowledging for fault-free messages. Since CAN-FD allows longer data fields than normal CAN, the CRC (Cyclic Redundancy Check) sequence needs to be adapted in order to keep the frame's Hamming Distance at the same value of 6. We chose two new BCH-type CRC polynomials: g17 for frames with up to 16 data bytes, g21 for frames with more than 16 data bytes.

$$g17 = x^{17}+x^{16}+x^{14}+x^{13}+x^{11}+x^{6}+x^{4}+x^{3}+x^{1}+1$$

$$g21 = x^{21}+x^{20}+x^{13}+x^{11}+x^{7}+x^{4}+x^{3}+1$$

For this reason, the length of the CRC sequence in CAN-FD data frames depends on the DLC. At the beginning of a frame, all nodes, including the transmitter, start to calculate the frame's CRC sequence according to all three polynomials, g17, g21, and the normal CAN polynomial. When the frame format is decided in the Control Field and the DLC is transmitted, one of the three polynomials is selected. The transmitter uses the selected polynomial to generate the frame's CRC sequence. The receivers use the applicable polynomial to decide whether the frame is to be acknowledged.

In normal CAN, the stuff-bits, which are inserted into the bit-stream to ensure that there are enough edges for resynchronization, are not considered for CRC calculation. As described e.g. in [7], two bit - errors may on rare occasion remain undetected when the first generates a bit-stuffing condition and the second then removes a stuff condition (or vice versa), shifting the position of the frame bits between the two bit-errors. The shifted area may lead to a burst error that is too long for the CRC mechanism.

The treatment of stuff-bits in CAN-FD is changed to ensure that this cannot happen. The simplest measure would have been to include all stuff-bits into the CRC calculation. However, this would prevent the well-proven CRC hardware implementation with the feedback shift-register that calculates the CRC sequence while the frame is in progress. The solution consists of two measures: Including the stuff-bits preceding the CRC sequence into the CRC calculation and changing the stuffing mechanism for the CRC sequence. Contrary to the normal CAN bit-stuffing method, where a stuff-bit of inverse polarity is inserted after every five consecutive bits of the same polarity, the positions of the stuff-bits in the CAN-FD's CRC sequence are fixed: The CRC sequence starts with a stuff-bit and additional stuff-bits are inserted after every four bits of the sequence. Each of these fixed stuff-bits has the inverse polarity of its preceding bit. The number of stuff-bits in the CRC sequence is equal to the maximum number of stuff-bits according to the normal CAN bit- ▷

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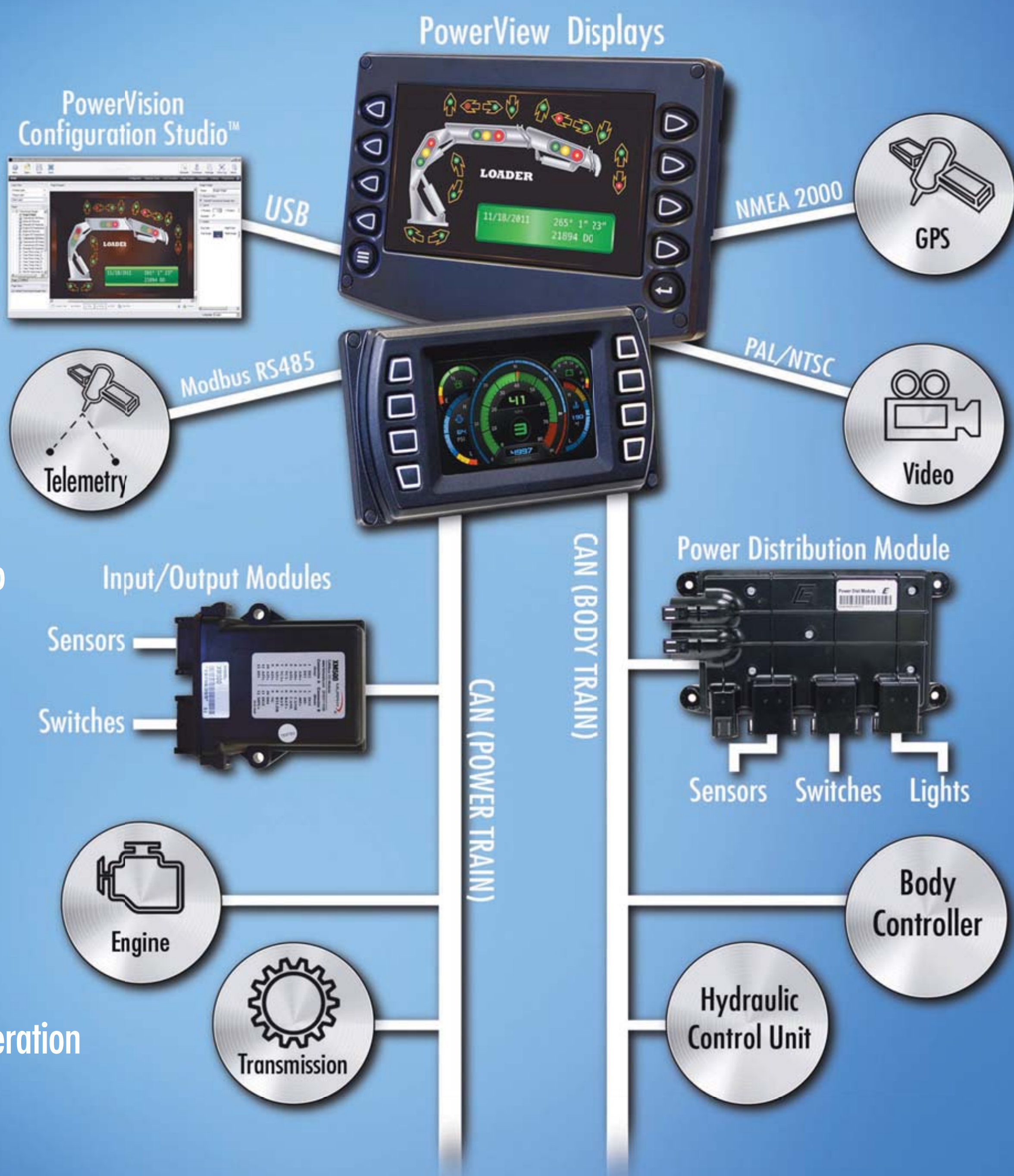

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stuffing mechanism. As in the normal CAN bit-stuffing mechanism, the maximum number of consecutive bits with the same value is five, the maximum distance between edges for resynchronization is ten.

CAN bit-time switching

There are two sets of configuration registers in CAN-FD: The first for the bit-time in the Arbitration-Phase and the second for the bit-time in the Data-Phase.

The BTL and Bit-Rate Prescaler (BRP) FSMs switch to the second bit-time configuration at the Sample-Point where the BRS bit is sampled recessive. They switch back to the first bit-time at the Sample-Point of the CRC Delimiter, or when an error condition is detected that causes an error frame.

Figure 3 shows an example for the bit-time configurations, in which the data-rate in the Data-Phase is four times faster than in the Arbitration-Phase. Both, the length of tq and the number of tq in the bit-time may be different in the two configurations. The two configurations may be identical, but the bit-time in the Data-Phase may not be longer than in the Arbitration-Phase. The two bits, in which the bit-rate switch happens are of intermediate length, since the configurations are switched at Sample-Points (see Figure 4). Together the two bits are as long as the sum of one of each of the bit-times.

Switching the bit-time configurations at the Sample-Point instead of after the end of Phase_Seg2 is necessary to ensure that a following synchronization is performed in all nodes according to the parameters of the second bit-time configuration. Phase-shifts between the nodes may result in not all of them agreeing on the border between Phase_Seg2 and the subsequent Sync_Seg.

Figure 5 shows the simulation of a test case, in which CAN_0 and CAN_1 arbitrate for the CAN network. The signals CAN-Tx and CAN-Rx are the interface between the protocol controllers and the transceivers. The Sample-Point shows where the CAN-Rx input is captured. The signals f_tx and f_rx show where the bit-rate is switched; they could be used for mode switching in CAN-FD optimized transceivers, enabling even higher bit-rates in the Data-Phase. Both nodes send the same base CAN identifier. CAN_0 sends a CAN-FD frame with 11-bit identifier, while CAN_1 sends an extended frame and loses arbitration at the SRR bit.

Transmitters do not synchronize on “late” edges (those detected between

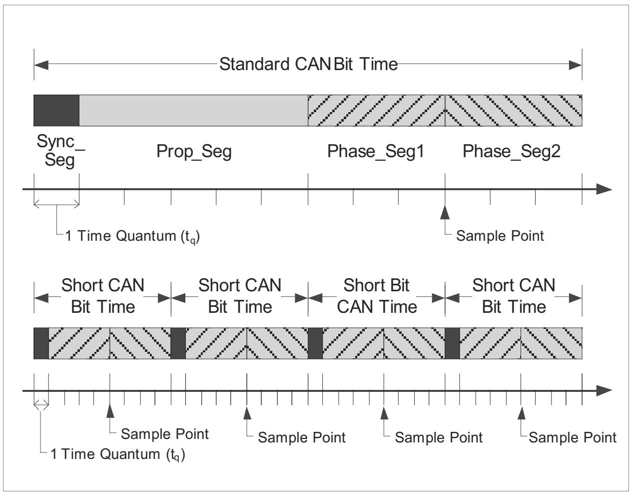

Figure 3: Normal and short CAN bit-times

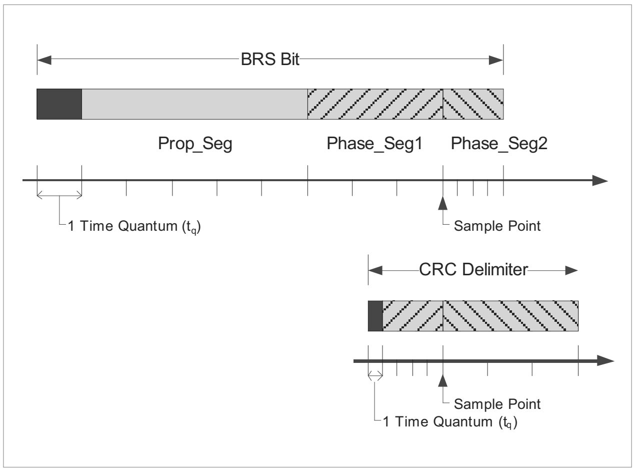

Figure 4: Bit-time changing at BRS bit and CRC Delimiter

Sync_Seg and Sample-point) otherwise the transceiver loop-delay would cause them to lengthen dominant bits. So as transmitter, CAN_1 did not synchronize on CAN_0 before the edge from EDL to r0.

In the simulated test case, there is a delay of 433 ns between the nodes; they use a bit-rate of 1 Mbit/s in the Arbitration-Phase and 10 Mbit/s in the Data-Phase. At the SRR bit, where CAN_1 loses arbitration, its Sample-Point is 350 ns (see strobes 1 and 2) earlier than that of CAN_0.

CAN_1 synchronizes to CAN_0 at the edge from EDL to r0. Afterwards its Sample-Point comes 433 ns (the signal propagation time between the nodes) after that of CAN_0 (see strobes 3 and 4). Both nodes switch their bit-rate at the Sample-Points of their BRS bits (see strobes 5 and 6). The signal f_tx shows the transmitter's Data-Phase, f_rx the receiver's. They both are reset at the CRC Delimiter, before the Acknowledge bit is sent by CAN_1.

The CRC Delimiter seen by the transmitter CAN_0 is prolonged by the signal propagation time, the Acknowledge bit conforms to the Arbitration-Phase's bit-rate.

The analog input signal at CAN_Rx needs to be synchronized to the clock of the BTL FSM. Together with the BTL's time step size of one tq, this digitization delay limits the time resolution of the CAN bit-synchronization. This means a phase-error of up to one tq may remain after a (re-)synchronization; the synchronization quality depends on the duration of the tq. The Sync_Seg with a fixed duration of one tq compensates for this residual phase-error in CAN bit-timing, but one tq in the first bit-time may correspond to several tq in the second bit-time. The maximum possible residual phase-error has to be taken into account for the configuration. Setting tq to the same duration in both configurations maximizes the tolerance range.

In existing CAN implementations, the maximum number of time quanta in a bit-time is 25, while the duration of the tq is defined by the controller's clock period and the BRP. This allows only few combinations of bit-time configurations for the Arbitration-Phase and for the Data-Phase with the same tq duration.

In automotive applications, with a bit-rate of e.g. 0,5 Mbit/s or 1 Mbit/s in the Arbitration-Phase, the acceleration in the Data-Phase is limited to a factor of about five. The reasons for this limit are the minimum pulse-width in the receive path of currently available transceivers and EMI considerations. In other applications, long bus-lines may limit the bit-rate in the Arbitration-Phase to e.g. ▷


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Abstract
This article describes the CAN-FD frame format with additional bits in the control field and the CRC sequences to secure longer frames with the same Hamming distance as in the existing CAN protocol. The configuration options for the two bit-rates are explained in detail. In addition, measurements of the upper limits for the bit-rate are discussed using the first hardware implementation of a CAN-FD protocol controller and off-the-shelf CAN transceivers chips.

125 kbit/s, enabling a higher acceleration factor.

Figure 6 shows how the average bit-rate of a CAN network that needs a bit-time of 8 μs in Arbitration-Phase can be accelerated without exceeding the specification range of existing CAN transceivers in the Data-Phase. Figure 7 shows how this acceleration is increased when the Data field gets longer. The advantage of the improved header to pay-load ratio rises with the acceleration factor between Arbitration-Phase and Data-Phase.

ISO 11898-1 allows more than 8 tq for each of the bit-time segments Prop_Seg, Phase_Seg1, and Phase_Seg2. We increased the configuration range to 16 tq for Phase_Seg2 and to 64 tq for the sum of Prop_Seg and Phase_Seg1 in our CAN-FD implementation. This allows a wide range of bit-time combinations with the same tq length. The range of the SJW (Synchronization Jump-Width) configuration is also increased to 16 tq for CAN-FD applications. This enables a high acceleration factor with a low residual phase-error at the BRS bit.

Transceiver Delay Compensation

Current CAN transceivers may have, according to ISO 11898-5, a loop delay (from the CAN-Tx pin to the CAN-Rx pin) of up to 255 ns. Since transmitters are required to check for errors in their transmitted bits, this would set a lower limit for the bit time in the Data-Phase if the check needs to be done at the bit's Sample-point.

Measurements have shown that existing CAN transceivers are able to transmit and receive bits that are shorter than their loop-delay. In this case the check for bit-errors needs to be delayed until the bit value, which is transmitted at the CAN-Tx output is looped-back to the CAN-Rx input. This is the purpose

CAN-FD measurements

The development of the CAN-FD protocol went in parallel with the design of CAN-FD protocol controllers for simulative verification and for laboratory evaluation. Main topics of the analysis were the new protocol features and the limits set by the physical layer. The measurements were based on FPGA implementations of CAN-FD and a multi-node CAN network with off-the-shelf CAN transceivers (e.g. NXP TJA1040). For the measurements shown here, the network consists of seven nodes connected by a linear bus-line topology. The distance between the terminations at node T2 and node R9 is 42 m, the bit-rate switches from an Arbitration-Phase at 0,5 Mbit/s to Data-Phases at 12 Mbit/s or at 15 Mbit/s.

It is not expected a bit-rate of 15 Mbit/s can be reached in automotive conditions with existing transceivers. The examples intend to show that the bit-rate in the Data-Phase is not limited by the signal propagation-time in the transceivers and on the CAN bus-lines.

Special attention was given to the effects of the transceiver loop-delay (see Figure I). In this example, the transceiver's loop-delay is 126 ns at room temperature. This is almost twice the Data-Phase's bit time, here 66,67 ns at 15 Mbit/s. The output pin T2_Tx already starts the DLC before the ESI bit reaches the input pin T2_Rx or, after the bus-line delays, the receivers' input pins R3_Rx and R9_Rx.

The example in Figure II shows a complete CAN-FD frame with 29-bit CAN-identifier and 64 data bytes. Here the complete Data-Phase is (at 12 Mbit/s) shorter than 23 bit of the Arbitration-Phase. In the example, there is CAN arbitration in the first bits of the CAN identifier, superposition of Acknowledge bits from near and from distant receivers virtually prolongs that bit.

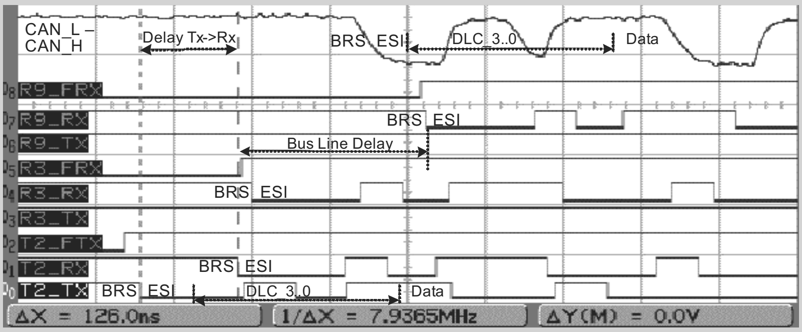

Figure I: CAN-FD Transceiver loop delay

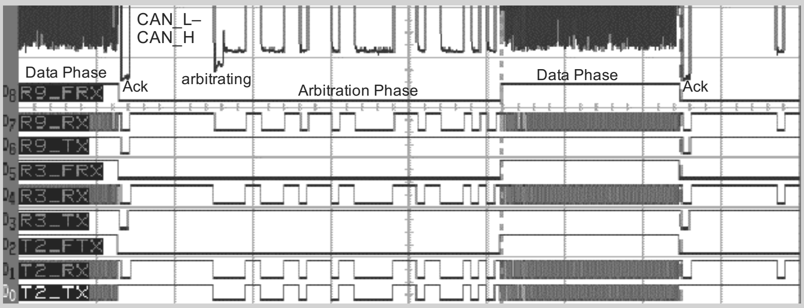

Figure II: CAN-FD frame with 64 data bytes and 12 Mbit/s in the data-phase

Conclusion

CAN-FD is a new protocol that combines CAN's core features with a higher data-rate. For automotive applications using star-topologies, CAN-FD targets an average data rate of 2,5 Mbit/s with existing CAN transceivers, resulting in the same effective payload as a low-speed Flexray network. Using bus-line topologies will allow data-rates up to 8 Mbit/s. There is an easy migration path from CAN systems to CAN-FD systems since CAN application software can be left unchanged (apart from configuration). The Bosch CAN IP modules are currently being adapted to optionally support the CAN-FD protocol.

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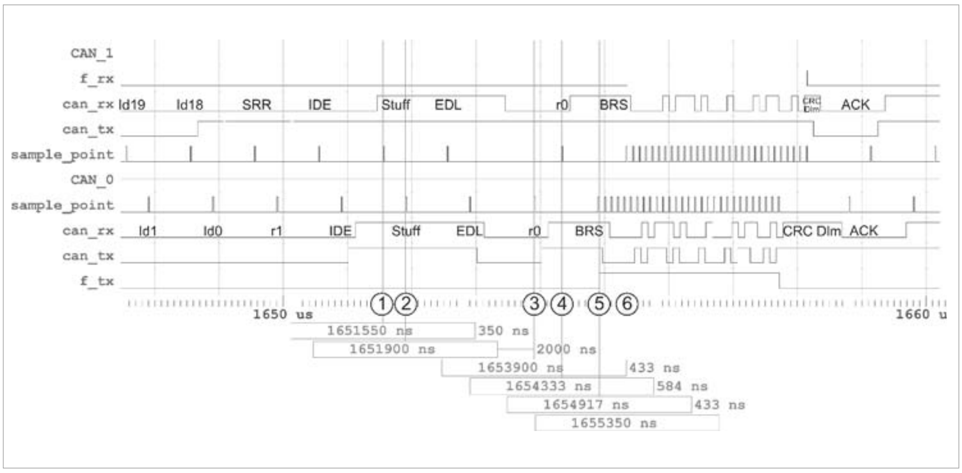

Figure 5: CAN-FD bit-time switching after bus arbitration

of the optional TDC mechanism of CAN-FD. Receivers do not need this mechanism. Transmitters apply it in the Data-Phase of a frame.

The point-in-time where the looped-back bit-value is checked is named the Secondary Sample Point (SSP). The actual loop-delay is not a static value; it depends apart from silicon parameters mainly on the operating temperature.

The CAN-FD protocol controller is able to perform a delay measurement to find the optimum position for the SSP. Within each CAN-FD frame, the transmitter measures the delay between the data transmitted at the CAN-Tx output and the data received at the CAN-Rx input. The measurement is performed when the arbitration is decided, but before the bit-rate is switched at the edge from EDL-to-r0. The delay is measured (in system clock periods) by a counter that starts at the beginning of the r0 bit at CAN-Tx and stops when the edge is seen at CAN-Rx (see Figure 8).

The result is a node-specific value. It does not depend on signal propagation-times on the CAN bus-line. A configurable offset is added to the measured delay-value to place the SSP into the middle of the bits seen at CAN-Rx.

When the TDC mechanism is enabled, it changes the way how a transmitter checks for bit-errors during the Data-Phase of a CAN-FD frame from direct comparison of transmitted and received bits at the CAN Sample-Point to a delayed comparison at the SSP.

The position of the SSP is always relative to the start of a transmitted bit. It may be more than one bit-time after the end of that bit. Transmitted bits are buffered until the SSP is reached. Then their value is compared with the actual value of the input signal to check for bit-errors. If a bit-error is detected, this information is buffered until the next CAN Sample-Point is reached, where it is presented to the BSP FSM. The BSP FSM answers to the bit-error according to the rules of the CAN fault confinement with a CAN Error frame; the bit-rate is switched back to that of the Arbitration-Phase. When no bit-error is detected until the Sample-

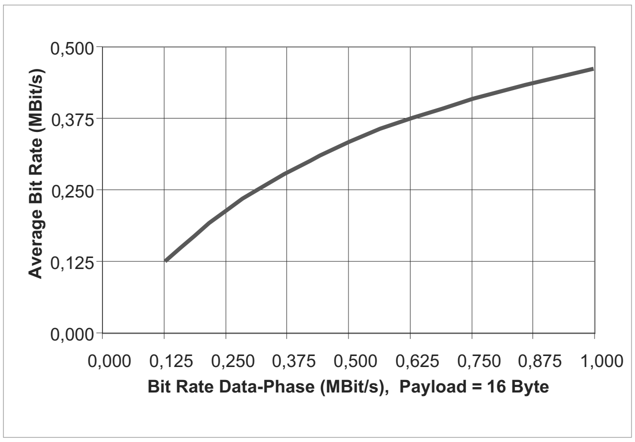

Figure 6: CAN-FD example for long bus lines

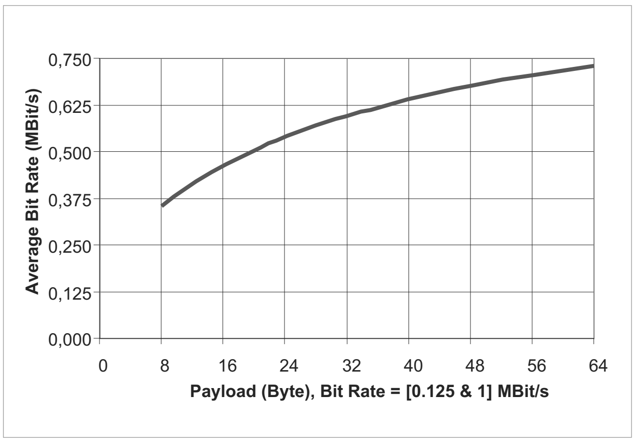

Figure 7: Average bit-rates for long bus lines

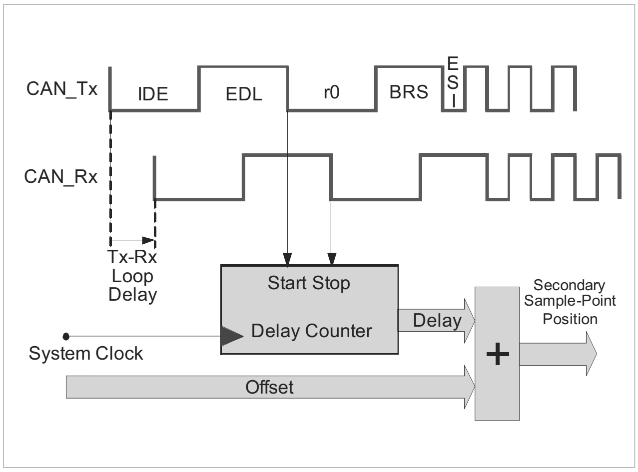

Figure 8: Measuring the transceiver loop delay

Point of the CRC Delimiter is reached, the CAN-FD protocol controller switches back the bit-rate and returns to normal bit-error checking. The transmitters disregard the actual value of the CRC Delimiter bit using the TDC mechanism. A global error at the end of the CRC field will cause the receivers to send error frames that the transmitter will detect during Acknowledge or End-of-Frame (EOF). ◀

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CAN IP-core for high-end microprocessors

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Reference
The article is based on the iCC paper "ACC, the next generation CAN controller" by the same authors available on CiA's website (www.can-cia.org/index.php?id=1495).

Abstract
Most stand-alone CAN controllers available today are connected to the host processor by 8-bit or 16-bit parallel buses. Write and especially read accesses to such peripheral devices are very slow compared with the cycle time of modern CPU's. This article introduces a CAN core implemented in an FPGA that uses bus master DMA (direct memory access).

There are still no CAN controllers integrated into most high-end microprocessor chips and a common way to add CAN using these processors is simply to connect one or more stand-alone CAN controllers (e.g. the SJA 1000 by NXP) to such systems. In most of such application the CAN interface build around the stand-alone CAN controller is one of the bottlenecks. There are numerous 8-bit accesses to the chip necessary to handle one CAN frame and most of these accesses are done in the interrupt routine with each access taking quite a while. The reason for this is that most available standalone CAN controllers are designed to work with relative low-performance micro-controllers. The consequences are rather slow 8-bit or 16-bit interfaces. Interfacing such a device to state-of-the-art CPU's results in a performance bottleneck, as the CPU and the system bus may be blocked for several thousand cycles by a single access to one register of the CAN controller.

The introduction of serial system buses like PCI Express makes the situation even worse, as these bus systems are optimized for streaming large blocks of data from the device to the memory of the host CPU and vice versa, while normal standalone CAN controllers rely on single byte-accesses. The resource "System Bus Interface" is blocked for the other threads in the CPU core, that is used by the CAN process, as well as for all other CPU cores. Therefore you have to minimize "read" accesses to the device, and all "write" accesses should be posted, so the CPU does not need to wait for the completion of the accesses.

As an extreme example, the read access to an 8-bit register of a CAN device connected by PCI Express, may take up to 2000 ns, and a 3-GHz CPU has to wait here for 6000 clock cycles. Today, as even PCI slots may be connected with a PCI Express to PCI bridge to the host CPU, a single byte access to a PCI device is even slower due to the additional delay of the PCI Express to PCI bridge. Note: While the access-time to the real device is less than 100 ns long, the time is spent sending for example a 160 bit long request packet to the PCI Express Bridge, then waiting the 100ns device access time, and for replying a 160 bit long answer packet from the PCI Express Bridge to the CPU.

The basic CAN core

The basic CAN core is built up from a CAN bit-stream engine, two FIFO memories and a register file. The bitstream engine constructs the stuffed CAN message, arbitrates for the bus, sends the message, adds the CRC and framing bits and checks for retransmission. It also receives the data from the bus, does the CRC check, and sends ACK and Error flags. The handling of the CAN error states is implemented, too.

The register file is the interface to the driver and it is connected to the bit- ▷

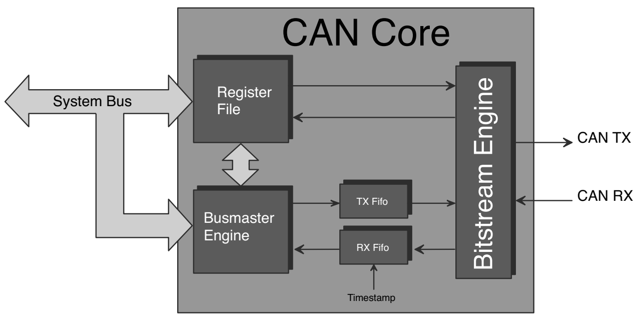

Figure 1: Basic CAN core

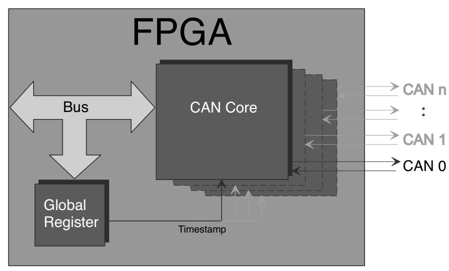

Figure 2: CAN core in an FPGA

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Display Data			**JW**	**5K**	**TS**
Resolution	2 x 8 characters	128 x 64 pixels	320 x 240 pixels		
Screen size / format	1.5"	2.6"	5.7" / 4:3		
Dimensions	ø 60 / d 57 mm	w 142 / h 142 / d 60 mm	w 193 / h 164 / d 65 mm	d 54 mm	
Display type	transmissive monochrome LCD	transmissive monochrome LCD	transflective monochrome FSTN		
Backlight	switchable	switchable	dimmable		
Interfaces					
CAN (ISO 11898-2)	1	1	1		
I/Os	-	-	-		
Video input (PAL / NTSC)	-	-	-		
Indicator / Operating Elements					
Keys / Jog wheel / Touch screen	3 / - / -	8 / - / -	4 / 1 / -	5 / - / -	1 / - / 1
LEDs	3 indicator	6 indicator, 8 status	-		4 multicolor indicator
Buzzer	1	1	1		
Additional Features					
Real-time clock	-	1	1		
Specifications					
DC power supply	9 V - 60 V	9 V - 33 V	9 V - 60 V		
Temperature range °C / °F	-20 ... +70 / -4 ... +158	-20 ... +70 / -4 ... +158	-20 ... +65 / -4 ... +149		-10 ... +65 / +14 ... 149
Degree of protection	IP 65	IP 65, IP 20 (back)	IP 54	IP 65	IP 65
Certifications	CE, FCC, E1	CE	CE, FCC		
Product number	251007020	251007128	251007010	251007026	251007028
Characteristics					
Learn more about our displays, which are available in different resolutions, dimensions and with different functions.	Ideal for limited space: compact character LC display in industry standard dimensions.	Compact graphics display offering many LED keys for use in all kinds of applications, even in rough environments.	Easy-to-read graphics display with jog wheel, keys or touch screen allowing for a free configuration and an individual GUI.		

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Displaying camera views in color		**Flexible mounting in 4 positions**		**Colorful views in landscape or portrait format**		**Well-equipped with multiple keys**	
2401	**2403**	**2501**	**2503**	**3011**	**3012**	**3001**	**3002**
320 x 240 pixels		400 x 240 pixels		480 x 272 pixels		480 x 272 pixels	
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w 160 / h 160 / d 75 mm		w 151 / h 185 / d 75 mm		w 142 / h 98 / d 50 mm		w 198 / h 98 / d 63 mm	
transmissive color TFT		transflective color TFT		transmissive color TFT		transmissive color TFT	
dimmable		dimmable		dimmable		dimmable	
1		1		2		2	
-	3x analog IN 2x digital OUT	-	3x analog IN 2x digital OUT	-	4x analog IN 3x digital OUT	-	4x analog IN 3x digital OUT
1		1		-	1	-	1
8 / 1 / -		5 / 1 / -		- / - / -	- / - / 1	11 / 1 / -	11 / 1 / 1
-		-		1 multicolor indicator		1 multicolor indicator	
-		-		-	1	-	1
1		1		1		1	
9 V - 60 V		9 V - 60 V		8 V - 36 V		8 V - 36 V	
-30 ... +65 / -22 ... +149		-30 ... +65 / -22 ... +149		-40 ... +75 / -40 ... +167		-40 ... +75 / -40 ... +167	
IP 65		IP 65		IP 65		IP 65	
CE, FCC		CE, FCC		CE		CE	
251002008	251002036	251007003	251007022	251007031	251007032	251007029	251007030
Visualize CAN data in color: robust and flexible display to connect up to 4 cameras.		Versatile color display in 16:9 format which can be mounted in 4 different positions: 0°, 90°, 180° and 270°.		Cost-effective multicolor display usable in landscape or portrait format, optionally available with touch screen.		Sophisticated multicolor display in high resolution with multiple keys and a jog wheel, optionally available with touch screen	

RMsys Configurator

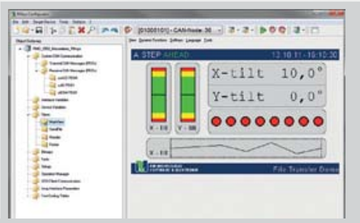
Flexible configuration software

To configure the different available displays before use, RM provides a software which allows for easy setting of the screen view: RMsys Configurator.

Use it to define all display elements as well as texts and map any function to the display's keys and LEDs. Multilingual application interfaces with individual fonts can easily be created.

Customization and design

Thanks to this sophisticated software you will be able to configure the RM Displays according to your needs – without any programming skills required.



Configure the screen

Use RMsys Configurator to customize:

- Text elements
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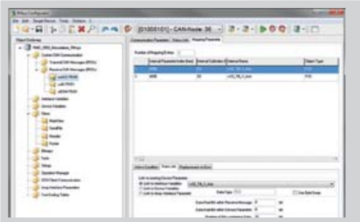
- Bar diagrams
- Pointer instruments
- Animations
- Geometric figures
- Numeric representations

In addition, it is possible to integrate video signals and to control the display, color and position dynamically.

Protocols and communication

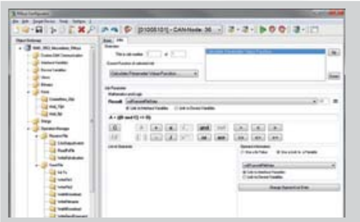


Configure communcation

The RMsys Configurator can handle CAN messages from any CAN protocol, for example CANopen®, J1939, etc.

A DBC import function can be used for CAN database files (*.dbc). Then, CAN messages (Rx/Tx), internal variables and mapping will automatically be created.

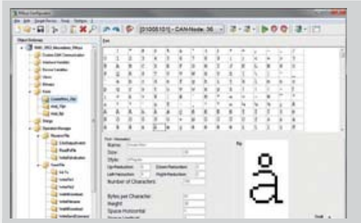
Operation Manager



Do logic and math, trigger actions

The Operation Manager allows you to define operations, which can be conditional and will be executed periodically, as well as different job types. For example, it is possible to send CAN messages or increment, decrement and calculate with arithmetic and logic operations.

Languages and fonts



Load any font

One further advantage of the software is the integrated multiple language support. Use different Windows® or customer-specific fonts. Alternatively, you can define your own fonts and characters.

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Versatile use

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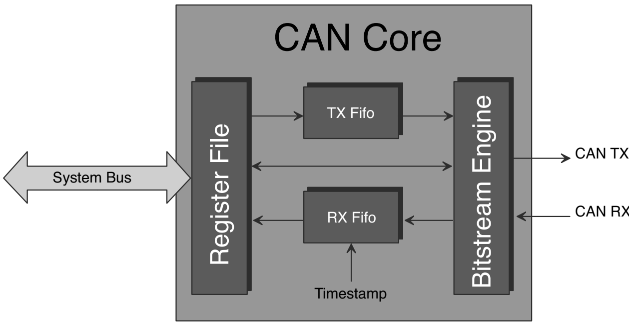

Figure 3: CAN core with bus-master DMA unit

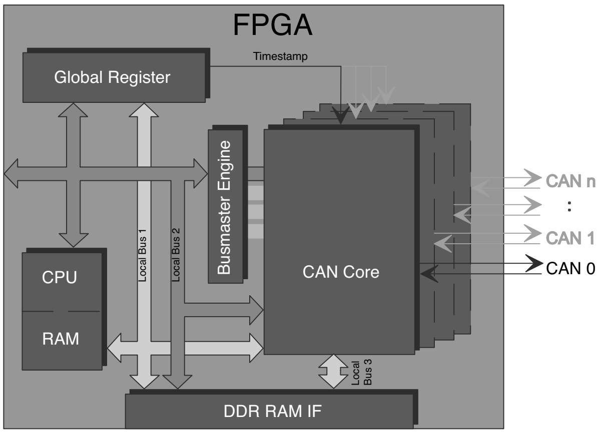

Figure 4: Adding a DDR-RAM interface

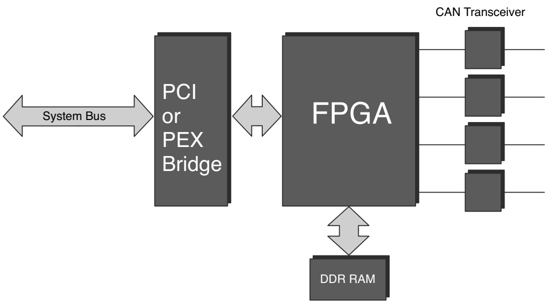

Figure 5: Typical CAN interface unit

stream engine by means of transmit and receive FIFOs. It also provides the bit-timing parameters for the bit stream engine and reports the status information from the bit-stream engine to the driver. The time-stamp generator is an input to the CAN core, because all instances of the core must use the same time-stamp.

A global register file provides the number of cores in this FPGA to the driver, generates the time-stamps for all cores, and informs the driver about the cores that needs attention.

With this basic implementation, it is possible to send CAN frames and to start transmission with only four write-access cycles to the controller, and to read a CAN frame within six cycles, including two cycles for a 64-bit time-stamp.

Additional functions

The bus-master unit transfers CAN frames and "transmit done" or "transmit aborted" indications from the cores into the memory of the host system without the help of the host CPU.
A local CPU can be helpful for a CAN interface that needs to send periodically data. Adding a "soft" CPU to the IP core does not use too much resources in the FPGA, and it is usually much easier to implement more complex actions in a "C" program than in VHDL. Additionally changing the software for this CPU does not require the revalidation of the entire FPGA.

There are many possible applications for a large RAM within a CAN interface. It can be simply used as memory for a "soft" CPU or even as a "perfect" filter for all 29-bit CAN identifier.

It is easy to add a PCI or PCI Express core to an FPGA, to get a "CAN chip" with such an interface. As most state-of-the-art FPGA's are no longer 5-V tolerant, and the PCI slots in modern PC's are still coded as 5 volt slots, this is no solution for a general market interface, but is a good solution for an embedded system. PCI Express interfaces do not have such restrictions.

Implementation and experiences

The CAN core is used mostly in Xilinx FPGA's at the moment. It is possible to implement more than 12 CAN core's with bus-master support in a Spartan XC3S1600E chip. Depending on the number of CAN interfaces needed, there are many resources left for a soft CPU and other advanced features. Implementations in combination with error injection or IRIG-B have already been realized.

Nowadays, we are using the CAN core in many different products. The family of CAN/400 boards is build up of a PMC, Compact PCI, PCI and PCI Express board. These boards use the additional DDR-RAM interface and also the PCI bus-master engine. On the AMC-CAN board, there is no external RAM. The CAN core combined with a PCI Express endpoint in the FPGA is used on a custom board with an Intel ATOM CPU and a XMC board with a QorIQ P2041 quad core PowerPC microprocessor. Finally the basic configuration is used on our VME-bus-CPU and other custom-boards. ◄

Conclusion
The 32-bit register FIFO interface of the CAN core implemented in an FPGA overcomes the long access times of stand-alone CAN controllers connected to high-end microprocessors. The streaming of data from the CAN network into the memory of the host CPU by bus-master DMA improves the interface performance. Deep FIFO sizes for reading and writing, precise time-stamps and the ability to abort a CAN frame accurately, even if it is in the transmit FIFO (as needed for more sophisticated CAN protocols such as Arinc 825) and a register model optimized for the needs of CAN, are additional features to minimize waiting-cycles. Depending on the selected features, up to twelve CAN cores fit into an Xilinx Spartan XC3S1600E FPGA.

Next steps
"We have already added an error injection unit as an option to the CAN core. Future directions may be more diagnostic tools, like monitoring and recording of the CAN bit-stream."

Modular deburring machine with a touch-panel PLC

Sascha Christmann

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Machine builder
Paul Ernst is a mid-range machine tool manufacturer with 60 employees and an export share of over 70 %. The company provides development, assembly and service for its deburring machines for sheet metal as well as sanding machines for the furniture industry. The technical solutions are based on a modular machine concept to match customer requirements.

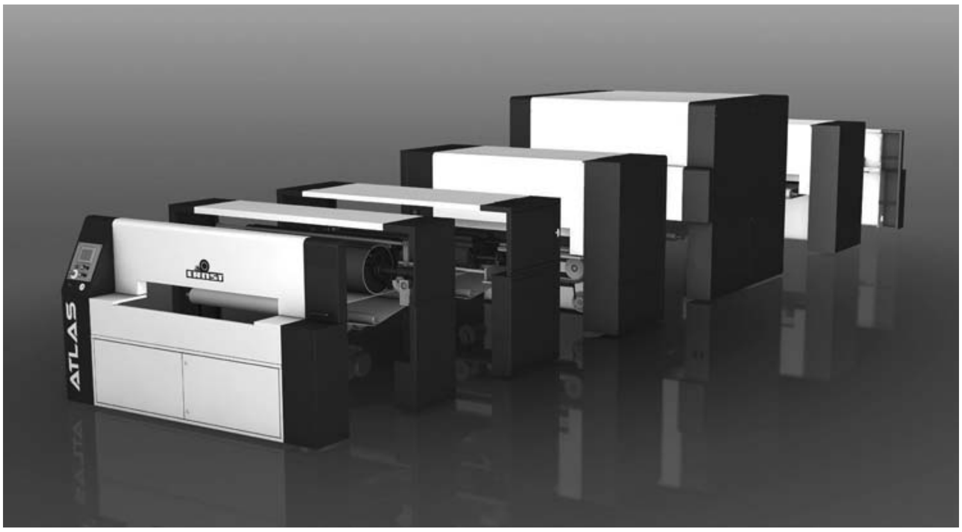

Figure 1: All modules of the Atlas series by Paul Ernst

Burring and surface treatment of metal plates are the tasks of the Atlas (dry treatment) and Neptun (wet treatment) machine generations by Paul Ernst Maschinenfabrik. The modular design concepts and division into specialized functional units enable burring-task to cope with the actual customers' and users' requirements, which are subject to constant change. Currently offered are deburring, brushing, brushing cross, rotor and grinding modules. The appropriate treatment process and the demands of end users determine which modules are actually selected. The customer may extend his machine with units from his own stock or newly added modules and thus offer new machining processes. The uptake of new technologies into the program, such as an engraving module, is possible trough retrofitting, making investment costs for new equipment omit.

"Regarding the design process since early 2009 we consequently standardized all mechanical, pneumatical and eletronical interfaces between the various functional units," said Dirk Zimmermann, Technical Director at Paul Ernst Maschinenfabrik.

> *The development tool GP-Pro EX supported our great ideas for the modular machine concept, it is transparent, fast and efficient in usage.*
>
> Dirk Zimmermann

Central control unit

"In selecting the central control unit of the machine, including the operator terminal and the peripheral I/Os, we made use of the positive experiences of our sister company Jumag Dampferzeuger, who are successfully using Pro-Face products for quite some time," meant Dirk Zimmermann.

The use of Autodesk Inventor 3D CAD software in combination with the control components from Pro-Face enabled the modular approach in the machines mechanical and electrical construction as well as in the machines software. The central control unit in the system is the Touch-PLC AGP3300 by Pro-Face. This hybrid device acts as the controller (PLC) for the various machine functions. It communicates with the functional units via CANopen. The serial bus approach allows the changing or upgrading of the machine configuration by docking the functional ▷

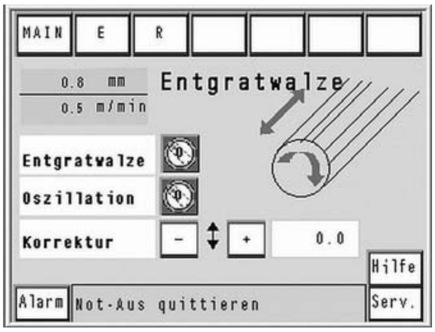

Figure 2: Setting of preferences for the burring process via the touch-panel

units. Also electrical safety is taken into account, as the only electrical connections between the machine modules is the CAN network and the operating voltage (24 V and 400V). Regarding the CANopen interface, the controller complies with the according specifications as defined by CAN in Automation (CiA).

The touch-panel integrates also a USB interface. Service functions (e.g. backup and update the entire configuration data or backup of displayed alarm and system messages) may be integrated. These start automatically by means of a pop-up window or self-automated functions when a USB flash drive is connected. Through this feature, the exchange of data (e.g. via email) and quick failure analysis is possible from nearly all over the world. The individual configurable user (or user group) levels are adjustable by a provided password-management.

Software solution

CANopen-Configurator integration software by Pro-Face provides a drag-and-drop interface for single (relies on single EDS files) and modular type devices (with modular EDS files). The software fulfills importing and interpreting of EDS (electronic data sheet) files as well as handling of EDS files, with “slight” errors, e.g. wrong manufacturer code. After implementing the EDS file, the user has to name the PDOs (process data objects) and may start designing his GUI (graphical user interface) getting required PLC functionality. Optionally SDO (service data object) communication may be created within the software.

Pro-Face provides different types of CANopen connection – either being NMT slave in a master-driven network or being the NMT master itself. The manufacturer offers the HTB terminal with high-speed counter functions or PWM capabilities and the EXM modules (attachable to HTB) offering such options as analog in-/outputs, relays or temperature probe inputs.

The development software GP-Pro EX covers the aspects of project development and active work. The tool is suited for both the design and configuration of the user interface as well as the programming of the PLC. The combination in one software package results in a time-saving solution as no time is lost for switching between applications and workflows. The unified data-base allows access to all relevant project data offering drag-and-drop functionality for efficient working. ”Also, other peripherals, such as frequency and position sensors, were easily integrated with the CANopen NMT master of the AGP3300,” added the Technical Director. ◀

CiA 402 not only for operation, but also for device testing

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The company is the successor of Gefeg founded in 1948 and Neckar Kleinstmotoren founded in 1967. The latter produced compact brushless DC (BLDC) motors with integrated electronic motor control since 1995. In 2005, the merged companies started the development of an electronic platform with the capability of communication. Feedback from customers showed that CANopen was a good choice for a high-performance but cost-effective bus solutions.

Links
www.gefeg-neckar.de
www.microchip.com

Figure 1: Brushless DC motor with integrated CANopen interface (MC 663)

The first application of our motion control platform was a compact BLDC (brushless DC) drive. These motors have long service life as a result of the brushless technique. The high-quality rare-earth magnets enable high efficiency, and the compact, closed construction guarantees a high environmental protecting class. The motors can be combined, similar to all motors of this manufacturer, with worm, spur and planetary gears, with brakes and with shaft encoders.
The control algorithms are implemented in the dsPIC33F digital signal processor (DSP) by Microchip. Three Hall sensors detect the rotor position, which serves for proper electronic commutation of the brushless motor. Additionally, the Hall sensors are used for speed measurement and for speed control. The 24-V power module is based on SMD-MOSFET transistors. They are soldered on a PCB from aluminum enabling proper cooling.

The integrated CAN interface is compliant to the CiA 402 CANopen profile for drives and motion controllers. This makes testing easy and enables direct parameter settings. The firmware also includes a boot-loader, which allows firmware updates via the CANopen interface.

The MQ 667 brushless motor with a 68-mm diameter features an optimized magnet circuit and an improved winding technology. In comparison to its ancestor with the same diameter (M 663), axial length is decreased by 15 %, torque is increased by 60 % and cogging torque is reduced considerably.

The PMDC (permanent magnet DC) motor uses the same electronic platform. In spite of mechanical commutation, these drives also contain Hall sensors for the position detection. These sensors deliver speed information for the closed-loop speed control.

By integrating all components such as power unit, motor control unit, measurement system and bus interface, wiring and planning effort is reduced to a minimum. Only the supply cable and the bus cable remain. Therefore, the overall availability increases. Furthermore, the space required in the electronics cabinet is reduced. Nevertheless, there are applications where the integrated solution is not preferable. The reason can be that environmental temperature is too high or that installation space is strongly limited. To cover such applications, an external control unit with CAN interface has been developed. This control unit is based on the same hardware and firmware as used in the integrated solutions. This ▷

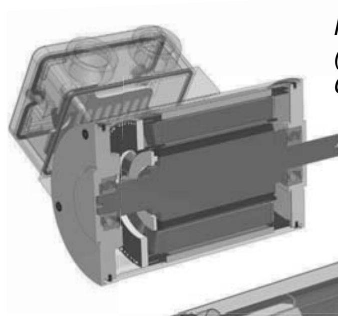


Figure 2: BLDC motor (MQ 667) with integrated CAN interface

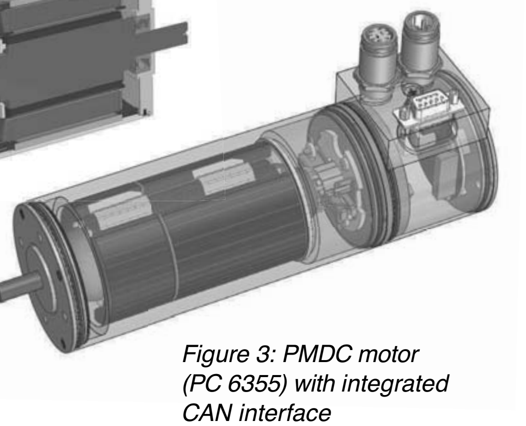


Figure 3: PMDC motor (PC 6355) with integrated CAN interface

Figure 4: External CAN interface unit for BLDC and PMDC motors

allows controlling stand-alone PMDC and BLDC motors in the same way.

Electronically commutated motors for 230-V_{AC} mains

At safety low-voltage drives, the AC mains voltage has to be converted in two steps. A switch-mode AC/DC converter generates a safety-low voltage (e.g. 24 V_{DC}) from the 230 V_{AC} (50 Hz). From this DC voltage, the commutation unit generates a three-phase AC voltage system with variable amplitude and frequency for the motor windings.

Using a commutation unit for direct mains operation, investment spending, system complexity and power dissipation can be reduced. For this reason, such commutation electronics were developed based on an intelligent power module. In comparison to a safety low-voltage DC unit, additional functional blocks have to be integrated:

- Single phase bridge rectifier
- DC link capacitor
- Initial current limiter
- EMC filter
- Switched mode DC/DC converter for the internal control electronics
- Safe potential separation between power circuits and bus signals

The difficulty of this task is the design of a compact unit while fulfilling the statutory low-voltage directive and EMC regulations. An additional problem is how to resolve effective cooling in order to guarantee a reliable operation of the power and control electronics and to ensure a sufficient life span of the temperature-sensitive electrolytic DC link capacitors. By integrating this electronic unit in a motor with permanent magnet rotor, an electronically commutated (EC) motor with integrated CAN interface for 230-V_{AC} supply has been developed.

Induction motors with CANopen

Induction motors have a lower nominal torque and a lower level of efficiency than electronically commutated motors do. However, induction motors do not need expensive rare-earth magnets for their production. For speed variable drives, a converter can supply the induction motor with variable frequency.

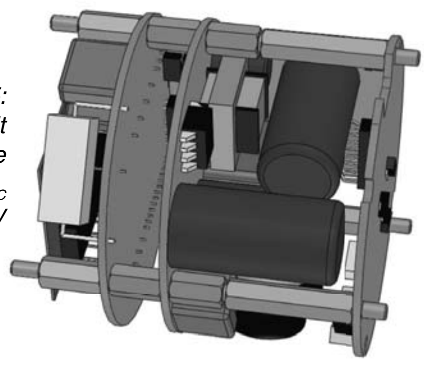
With a modified firmware, the commutation unit of the EC motor can act as a frequency converter for three-phase induction motors. By integrating this unit into the motor housing, a compact variable speed induction drive can be achieved.

Benefits of this drive are CANopen interface and closed-loop speed control, similar to those of all the other members of the large family of drives with the same electronic platform.

Automatic inspection system

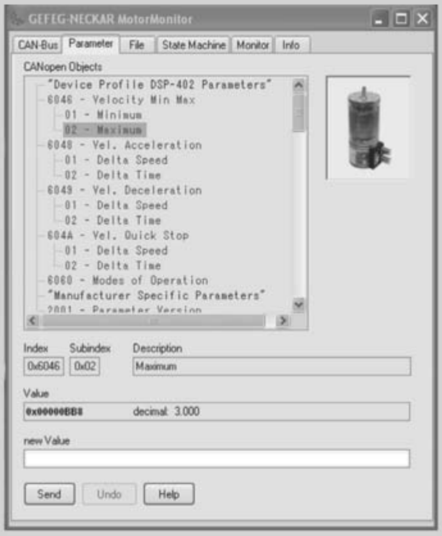
The integrated CAN interface also enables an easy, cost effective but detailed ▷

Figure 5: Commutation unit with CAN interface for direct 230-V_{AC} (50 Hz) supply

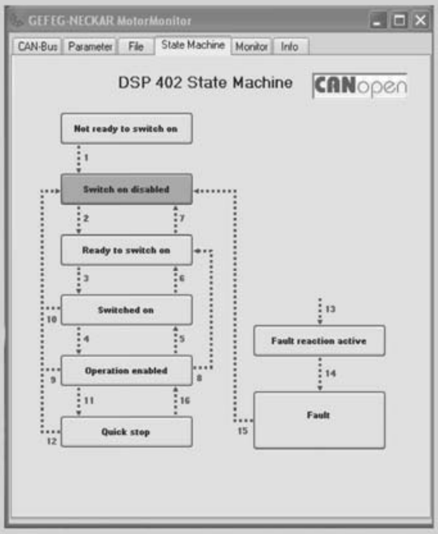


Drive commissioning software

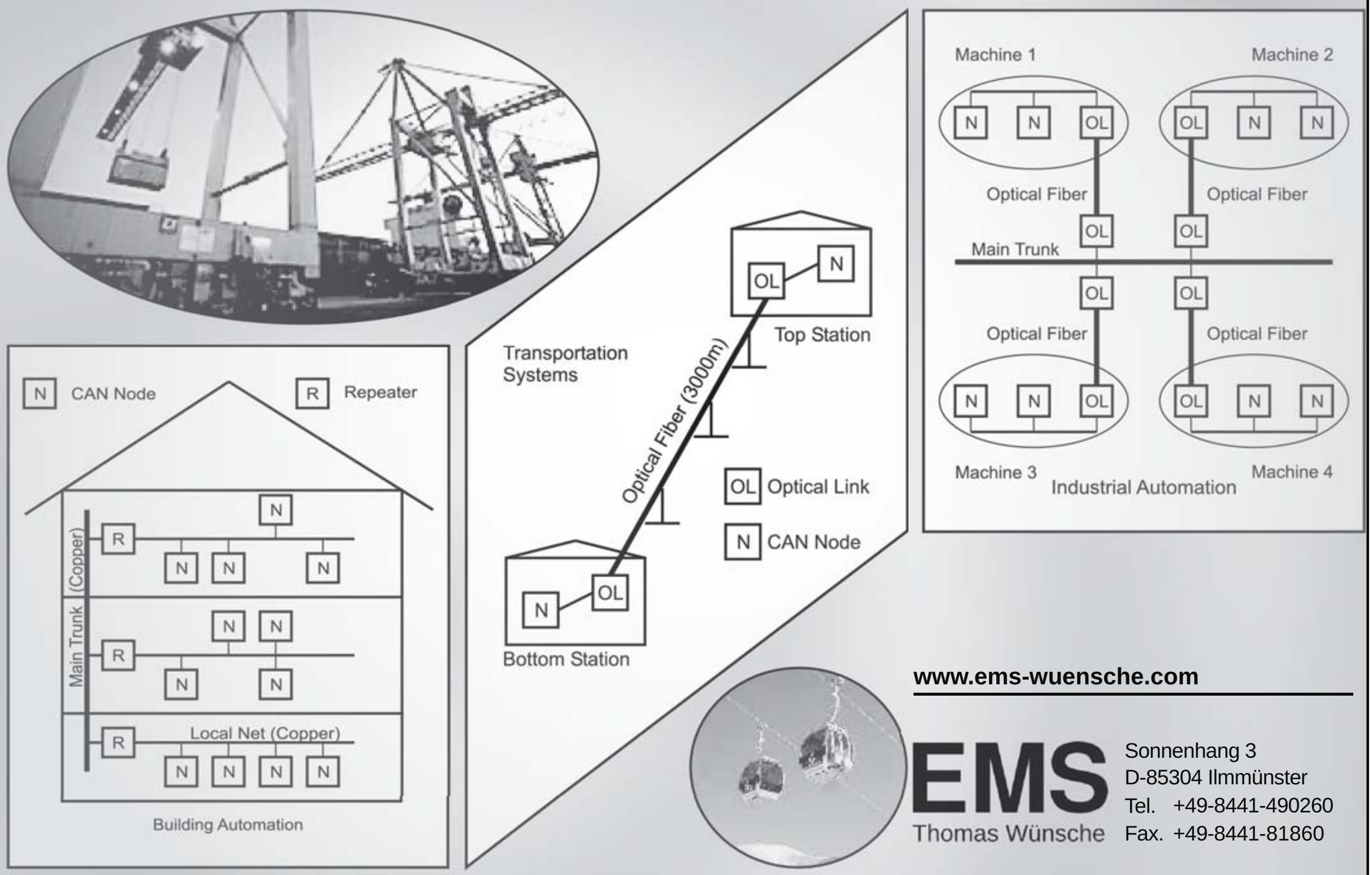
For commissioning, parameter setting, manual testing and monitoring the motors with integrated electronics, the "MotorMonitor" software for Windows computers has been developed. The software is written in the C++ programming language. It needs a CAN/USB adapter to communicate with the motor using the CANopen communication services. At first, the PC software establishes the communication with the motor. After that, it requests the firmware version of the drive. The software contains a database with all released firmware versions. Therefore, only the parameters implemented in the actual motor are displayed. The software tool allows the user to change parameters, control the drive or monitor important data such as rotor position, velocity, power consumption, and temperature. The company grants rights of use of this software to its customers free-of-charge. However, customers cannot change certain safety-relevant parameters.



Graphical user interface of the "MotorMonitor" commissioning software ("Parameters" tab card)



"State Machine" tab card of the commissioning software


Machine 1
Machine 2
Machine 3
Machine 4
N
OL
Optical Fiber
Main Trunk
Industrial Automation
Transportation Systems
Top Station
Bottom Station
Optical Fiber (3000m)
OL Optical Link
N CAN Node
N CAN Node
R Repeater
Main Trunk (Copper)
Local Net (Copper)
Building Automation


LIPOWSKY INDUSTRIE-ELEKTRONIK
Baby-LIN
USB
GND LIN VCC
RUN ERROR

Abstract
This article describes the development of a family of sub-fractional horsepower electric motors with integrated CANopen interface. The integration of motor and control unit with CANopen allows an automatic final test in the motor production line without the need of test stands.

DC motor benefits
Due to inexpensive magnet systems (sintered ferrite segments) and automatic production lines, DC motors are cost effective. On the other side, the life expectancy of these motors is limited by the commutation system consisting of collector and graphite brushes. However, there are numerous applications where the necessary active service hours do not exceed the maximum limit, in the majority of cases 3000 hours. In such applications, a conventional DC motor with integrated speed control and bus interface might prove to be an interesting and cost effective alternative.

test of these motors in the production line. For the final test, a test system has been developed. It utilizes the CANopen protocol to communicate with the integrated electronic platform (CiA 402). The test program is based on the routines of the commissioning software. Without requiring any expensive test station, it is now possible to test the drives automatically. There is no need for any additional sensors for testing, because the integrated intelligent control unit contains all the sensors needed for an ad-equate test. The test computer communicates with the micro-controller in the motor via CAN the measured values (supply voltage, motor current, rotor position, speed, and temperature).

The test computer itself is integrated into the computer system of the production facility. The production planning and control system (PPC) generates updated files containing the current released production orders (job account number, tracking number, internal part number, product name, and production volume).

The tester adds his or her name to the protocol and scans the bar code of the production document. After that, the test computer identifies the drive in the production order file. For every product, three specific ASCII files are prepared and stored in the test system:

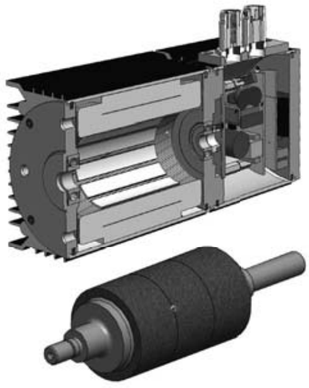


Figure 6: EC motor (MCN 963) with integrated CAN interface for 230-V_{AC} (50 Hz) supply

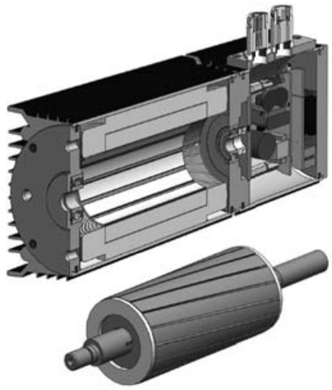


Figure 7: Variable speed induction drive (ACN 984) with integrated CANopen interface

- Test procedure and expected test results
- Rating plate data
- Parameter data at delivery

In the first step of test, the CANopen communication channel is opened and tested. After that, the firmware version of the drive is checked to prevent any errors. (Once a customer tested and approved the engineering samples received, the firmware in this product will not be changed without permission of the customer. Therefore, every product can have a specific firmware version).

In the next step, the information provided by the sensors integrated in the motor is checked. Incorrect Hall-signals, unrealistic temperature values, incorrect voltage values, and DC current values outside the tolerance range can be detected. If the sensors work properly, the digital inputs and outputs and the analog input processed by the 12-bit analog/digital converter of the micro-controller are proofed individually.

Before starting the motor, the power stage of the control unit is tested. In this mode, the control unit works similar to a motor controller for stepper motors. After five steps, all the power switches (MOSFETs or IGBTs) will have been checked.

For the test run, the motor is operated in open-loop speed control mode with 100 % PWM factor. Clockwise and anti-clockwise, speed and motor current are monitored and analyzed. From maximum speed, the motor will be slowed down to standstill. In doing so, the ballast circuit can be examined. As a last test step, the motor is accelerated to maximum speed and the power stage is disabled. The motor will coast. Analyzing the deceleration of the rotor, friction in the bearing system and in the gear can be tested.

After a successful test, the measurement data is archived and the motor is parameterized according to the agreement with the customer about settings on delivery. The parameter set also contains an individual test number for perfect traceability. Then the rating plate with product name, part number, test number and nominal data is printed as an adhesive label and the motor is ready for delivery. ◀

Table 1: Sensors integrated into the motor

Sensor	Purpose
Hall-sensors	- Rotor position detection - Electronic commutation - Speed measurement
Voltage sensor	- Over voltage protection - Under voltage protection - Brake circuit control
Current sensor	- Over current protection
Temperature sensors	- Over temperature protection (motor / power electronics)

With CAN network across the seven seas

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One of mankind´s oldest means of transportation and travel are ships and boats, used to cross the world´s rivers and oceans. While they have constantly been used thousands of years, their technology has always evolved to reinvent themselves and keep moving with the requirements arising from a changing world. The development continues since the demand for the transportation of goods and people by seaway is continually increasing. The very traditional marine industry that has developed over time is always looking to take advantage of technical development arising from other industrial sectors. Therefore all the technologies that triggered industrial revolutions can also be found onboard of modern ships. Shipbuilders have the same requirements as other industries to increase both the efficiency and effectiveness of their equipment to stay ahead of competitors.

Due to this fact, technical alliances were created to transfer the expertise from other industries into shipbuilding. For example, no ship manufacturer would build engines or engine control systems. This part would be outsourced to partners with the respective expertise and experience.

Usage of CAN

Leading engine manufacturers such as MaK, Caterpillar, Deutz, MAN Diesel & Turbo, Wärtsilä or Volvo Penta use CAN as quasi standard, which means that the IT (information technology) infrastructure onboard a ship must be able to handle both the protocol and the messages transmitted over it to efficiently control the security systems of the main engines and generators. Furthermore, CAN network is used to monitor the engine and ship functions, such as exhaust-gas-temperature averaging system, load state measurement, ballast tank monitoring systems, wake state system with engineer-call-function, display for fire control equipment, automation system, pump con- ▷

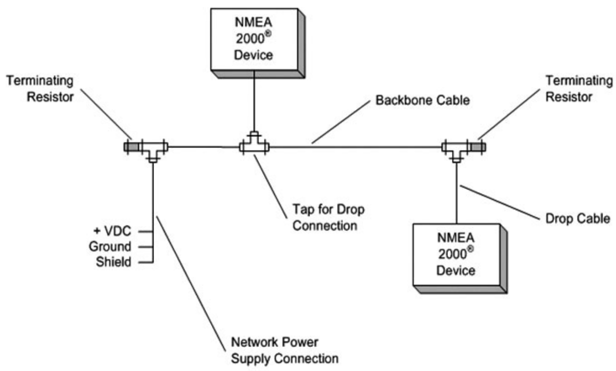

Figure 1: A simple network topology with NMEA 2000 devices (Source: NMEA)

Abstract

It is no secret that Controller Area Network (CAN), invented in 1983 by Robert Bosch, was originally designed to control engines in an extremely secure and reliable way in environments with lots of noise. Naturally, this kind of technology is used onboard ships as they house by far the biggest and strongest engines ever built.

NMEA association

NMEA was founded in 1957 by a group of electronic dealers to strengthen relationships with electronic manufacturers. After the incorporation of NMEA in 1969, the association began publish the association newsletter "NMEA News" in the early seventies. Publication of the news continues today as the Marine Electronics Journal, the Official Journal of the NMEA.

NMEA created the only uniform interface standard for digital data exchange between different marine electronic products back in the early eighties. The NMEA 0183 Interface Standard is widely accepted by manufacturers and is recognized by maritime agencies worldwide. Frank Cassidy was instrumental in having the standard adopted as the basis of an international standard by the International Electrotechnical Commission in Europe. The updating and expanding of the protocol and development of future standards is continued today by a committee of NMEA volunteers under the direction of Steve Spitzer, NMEA Technical Director.

In the early eighties, the CMET (Certified Marine Electronic Technician Program) was created. The purpose of the CMET Program was to assure the consumer that the technician working on his vessel had more than a basic knowledge of electronics in general. With this certification, the technician demonstrated a competency and familiarity with marine products. The CMET Program continues today, as the ever-increasing need for such a program exists.

The association provides a forum for its members through frequent communications from the national office, regional meetings and its annual conference. It also focuses on educating the public in safe and proper use of marine electronics and strengthening the association's presence in the marine electronics industry.

Source: http://www.nmea.org/content/join_the_nmea/history.asp

trol and door-bulkhead control. In relation to this, efficient control means decentralized acquisition, collection and aggregation of relevant data as well as grouping, formatting, delaying or suppressing of signals. Required is also individual display of data at the conning systems in the control room and at the bridge. All this effort is made to enable the crew to determine the overall state of the ship and the conditions of the equipment anytime, and to allow remote control and the automation of recurring processes.

NMEA specifications

Besides this application, CAN is used in another less obvious environment – yet it is gaining more and more attention there, and it has already become a standard for smaller boats and yachts. CAN supports the communication infrastructure and the network backbone for the communication with marine equipment used for safe navigation. Such equipment as AIS, Gyro, Log, Radar, Speed, GPS etc., is connected to bridge systems via NMEA (National Marine Electronics Association) interfaces. NMEA is a combined electrical and data specification for communication between marine electronic devices.

While the standard NMEA 0183 (IEC 61162-1) is build on the EIA-232 interface, the next step of evolution has been made by creating the NMEA 2000 (IEC 61162-3) standard. NMEA 2000 connects devices onboard ships and vessels using the CAN technology. It is based on the SAE J1939 higher-level protocol, but defines its own messages. NMEA 2000 devices and J1939 devices can be made to co-exist on the same physical network.

The only cabling standard approved by NMEA for the use with NMEA2000 networks is the DeviceNet cabling standard, which is controlled by the Open DeviceNet Vendors Association (ODVA). Such cabling ▷

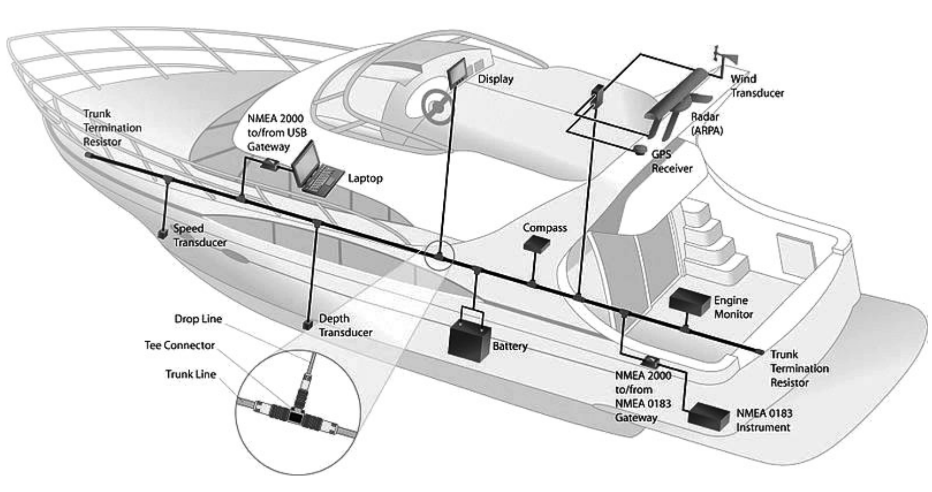

Figure 2: A typical NMEA 2000 installation (Source: NMEA)

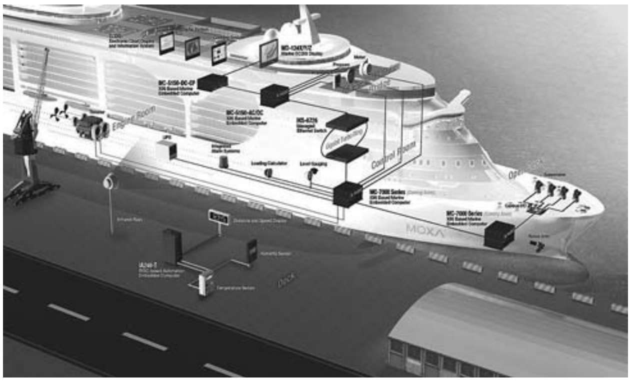

Figure 3: Networked ship control (Source: Moxa)

systems are permitted to be labeled as "NMEA 2000 Approved". The DeviceNet standard defines the levels of shielding, conductor size, weather resistance, and flexibility, all of which are not necessarily met by other cabling solutions marketed as "NMEA 2000" compatible.

NMEA 2000 was created to overcome the weakness of NMEA 0183, which is based on point-to-point communication requires complex wiring systems. NMEA 0183 also lacks on bandwidth, as the highest speed is 38400 bits per second. It was not designed to handle the current volume of traffic nor the integration of devices required by customers. The former standard has no certification process and does not specify physical layers (cables/connectors). This makes plug-and-play functionality difficult to achieve.

In the last 10 years, NEMA 2000 has gained popularity and it is now widely used in small boats and yachts. It provides the advantages of CAN technology, multi-master capability, drive-by-wire function, real-time control and status information, autopilot control, navigation information, vessel monitoring as well as electrical system control and status. The network uses the bit-rate of 250 kbit/s (50 times faster than NMEA 0183) and is up to 200 m long. Up to 50 physical nodes and up to 252 functional nodes may be supported. ◀

Conclusion

NMEA 2000 is an open CAN-based industry network standard that allows data sharing among disparate devices from different manufacturers. It accommodates real-time control and status information, and it has a standardized physical layer (cable and connectors). Devices can be certified to reduce or eliminate interoperability issues. The time behavior is deterministic to ensure that critical messages will reliably be put through. NMEA 2000 network protocol is industry-proof, open standard for marine electronics, engines, electrical data, and other data applications.

Vibration alarm in the wind power plant!

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Founded in 1962, the company develops, manufactures, and sells sensor systems for rotary and linear measurement. The sensors are used in different applications ranging from labeling machines and large paper machines to camera control systems and wind turbines.

Introduction
Wind power plants are complex systems, which have been refined down to the last detail, bearing witness to the fine art of engineering. Equally high demands are made on the individual components, which comprise such a system, and by no means least on the sensor system, which is employed. However, a sensor system is not only required to operate such a wind power plant, there are also a number of sensors, whose task is to protect the system.

CANopen networks have been in use for a long time in wind power plants as an interface for communication between the control system and some device. It not only enables the measurement data to be transmitted quickly and securely. In addition, CANopen may be used to transmit a range of parameters, which are important as regards safe function, e.g. to the sensors. This enables the customer to easily undertake extensive checks and parameterization in order to set the sensor to the desired requirements, as will be explained in greater detail further on.

One important physical measurement variable, which has to be recorded in order to protect the system, is the vibrations, which occur during operation, primarily in the gondola or just beneath the gondola in the mast. If these vibrations are excessively strong, the entire system is detrimentally affected. Cracking or even fractures may occur in the mast due to the acceleration forces, which arise. Irrespective of why excessive vibrations occur, the system has to be shut down when danger is looming.

Firstly such vibrations may be caused by internal occurrences. If, for example, the transmission or the bearings are damaged, extensive vibrations may occur in the main shaft. These vibrations lie in a frequency range from approximately 10 Hz to 50 Hz. Secondly, external influences may cause the system to oscillate. Amongst other aspects, this includes rotor blade icing. This does not occur evenly and leads to rotor imbalance, which may cause the entire system to vibrate. Or not favorable wind conditions lead to extensive movement on the part of the gondola and thus the mast. In this case, the frequencies typically lie in the 0,1 Hz to 15 Hz range.

These vibrations and oscillations have to be determined as part of a wind power plant's vibration monitoring in order to cause the control system to shut the system down or halt it in the event that relevant limit values are exceeded.

This is where the NVA65 vibration sensor comes into play. This device is specifically designed to meet the needs and requirements of wind power plants, and is equipped with a CANopen interface, which is used to parameterize the sensor. The MEMS acceleration sensor, which is used registers the vibrations in a frequency range from 0,1 Hz to approximately 50 Hz. With a 32-bit controller, this frequency range is subdivided into several bands using high-order digital band-pass filters in order to separate the different causes of the vibrations. Uninteresting interference frequencies are filtered out. The sensor measures on two axes, i.e. the acceleration, which occurs in each direction on the x/y plane is continually registered and output as an analogue signal (4 to 20 mA). Either with x and y separated or as the geometrical sum $s = \sqrt{x^2+y^2}$.

This therefore enables the system's oscillation and vibration status to be ascertained at any time as part of system monitoring. One further interesting characteristic offered by these NVA65 series sensors is their integrated limit value relays. These have the task of switching in the event that certain acceleration limit values are exceeded. This enables the actuation of peripheral devices, which e.g. shut the system off or initiate other measures. In the TWK model, ▷

Figure 1: NVA65 vibration sensor

the geometrical sum S is used to switch the relays. As S increases, a warning message is initially output via a relay; if it continues to increase, an alarm is then output via a further relay. Separate relays are provided for the various frequency ranges to enable the warning and alarm to be output separately depending on the cause. The customer can parameterize the two limit values for the warning and alarm. This is carried out using the CANopen interface that complies with CiA 301 (application layer) and CiA 410 (inclinometer profile). This profile reveals certain objects, which can be used for parameterization purposes. In this case, this refers to the objects 6000_h to 6006_h. These can be used firstly to define the resolution (object 6000_h) and secondly, the acceleration limit values at which they are to trigger can be assigned to the limit value relays. This is important to the wind power plant manufacturer, as it enables the sensor to be adapted to the relevant type of plant without having to separately order several different types of sensor from the supplier. For example, object 6001_h is used to transmit the triggering value of the warning relay for the low mast vibration frequencies (band from 0,1 to 0,6 Hz) to the vibration sensor. Object 6002_h involves the corresponding value for the alarm relay. The subsequent objects are used for the higher mast vibration frequencies (band from 0,6 to 15 Hz). ◀

Conclusion

The described sensor shows that the CANopen interface offers a suitable solution even in the case of a complex measurement. Due to its flexibility and variability, it is not only possible to transmit the measured values to the control system – a number of different parameterization and control options are also available. Following the development of the play-free electronic NOCx64 switching cam encoder for pitch and azimuth regulation, the NVA65 vibration sensor extends and rounds off the manufacturer's range of sensors for the wind power industry.

Open software platform for industrial vehicles

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Introduction
Industrial vehicle OEMs face a market, where end-users ask for better operator support and usability in vehicle control. CrossControl proposes an open software tool chain approach for Graphical User Interfaces (GUI). With touch-screens that provide intuitive ways of interaction and sharp GUIs, Smartphones represent a reference for nowadays product usability. And now operators of industrial vehicles start asking for the same user experience in industrial vehicles.

Observing first meetings between end-users and vehicles at e.g. Bauma 2010 and Conexpo 2011 confirmed that operators are open to, or even expect, modern HMI solutions; after getting seated in the cabin and some fiddling with joysticks their next move is to seek interaction with the machine by pressing the in-cab display with their finger.

Another observation in our business is that very little attention is given to the graphical design in user interfaces. With consumers expecting a brand to be all-encompassing, a well-designed user interface should address not only the usability of the vehicle but also the given brand's visual appearance. This represents a major untapped potential for differentiation in the industrial vehicle market.

We constantly hear witness from vehicle manufacturers of how their machines are used only at a fraction of the full potential. It is often the case that we design the HMI systems based on our own, often engineering-based, background. Successful design of HMI systems puts more focus on the operator reality and translates 'low-level' technical features in the vehicle system into value functions that the operator can understand and utilize. This may often include automating certain operations, pre-defining operation modes and implementing easy-to-understand settings. The need of this approach is made even more evident when moving into new markets where operator skill levels are different from traditional markets.

> *By using state-of-the-art, open frameworks it is possible to realize the premium user experience that will differentiate successful industrial vehicle brands.*

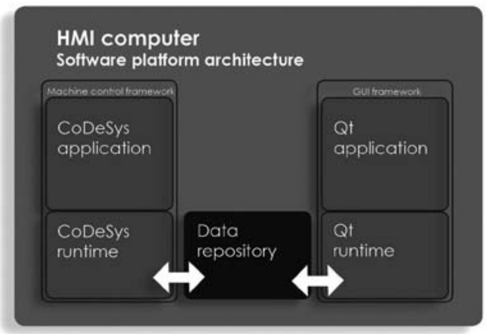
For the industry to respond to these challenges you need many things but the software strategy is fundamental. Small- and medium-sized OEMs in many cases rely on hardware suppliers that control the software functionality in displays and other devices. This may work fine in day-to-day business but with more of the value in terms of user experience being realized in software, there is an eminent risk that the vehicle OEM is not in control of the value added. Large OEMs have in most cases this control but often spend resources on low-level software and the application frameworks, resources that instead could be spent on value-adding applications.

With the well-established standards and open, powerful and hardware in- ▷

dependent frameworks and tools available, industrial vehicle OEMs have the opportunity to source electronics and software frameworks and focus their system engineering on software application development.

Integrated and open platform

CrossControl has in its software platform for displays carefully avoided creating a proprietary solution, but instead set up an architecture that combines and integrates the most powerful, yet easy-to-use, commercially available frameworks for GUI and machine control.



The machine control framework handles the CAN communication with other parts of the system and runs a controller inside the display. This controller computes the algorithms and value functions that help the operator utilize the potential of the vehicle. In the standard packaging of the platform we chose to adopt the IEC 61131-3 compliant Codesys framework by 3S Smart Software Solutions for this task. It is hardware independent, widely adopted in the industry and provides an easy-to-use programming environment for typical controller functionality.

The GUI framework handles the visualization of graphics and user interaction on the display. In the standard packaging of the platform we chose to adopt Qt for this task, being an open, mature, and hardware independent framework. Qt supports really advanced GUI functions and mimics, and has a drag-and-drop type of programming environment that requires only basic programming skills.

To integrate these two frameworks, we have developed a data repository that handles instant data exchange between them, meaning that GUI execution runs independently of the real-time cycles of the machine control system. To that we have added style sheets, day-and-night modes and ready-made components for gauges, alarm lists, warning lamps etc. with a number of parameters that allows easy adaptation of behavior and graphical appearance.

The result is an integrated software platform with a seamless tool chain that enables efficient engineering of advanced HMI functions. The platform is already being adopted by a number of leading OEMs, which deploy it for realization of their next generation HMI solutions. ◄

Display playing in the CANopen-lift team

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Abstract
Lifts consist of many devices. Like in football, even having the best individual players is not a guarantee for success. Teamwork makes the difference. Safeline devices make teamwork visible.

Product features
- 4-color LED's
- Voice announcer
- 4 inputs and 4 outputs (accessible via CANopen)
- 4 car-call or hall-call
- Integrated accelerometer
- Galvanically isolated CAN port
- Micro-SD card for storing voice messages and CiA 417 configurations
- Micro-USB connector for local configuration and download of voice messages

The FD4-CAN display is the optical and audio interface between the players in the field (devices) and the spectators (passengers and lift technicians). It has a 160-dots matrix display available in four different colors. It is compatible with the CiA 417 CANopen application profile for lift control systems, also known as CANopen-Lift. The device displays floor numbers, text messages and technical messages to a technician, aiding in trouble-shooting and diagnosing the lift control system. It speaks voice messages in HiFi-quality, from our voice library or easily recorded on any computer. Arrival chime is also included.

The development was not made secretly in our back yard, but in cooperation with other players. This means, the brain and muscle power of a high number of excellent players are included and synchronized. Team spirit from the beginning!

Disruptions can occur in every environment, debris is as disturbing on a football pitch as noise is on an electronic bus. Therefore, the display is galvanically isolated to guarantee good function also in high-noise levels. Players get instructions by the trainer; the display contains four general-purpose in- and outputs, which are short-circuit ▷

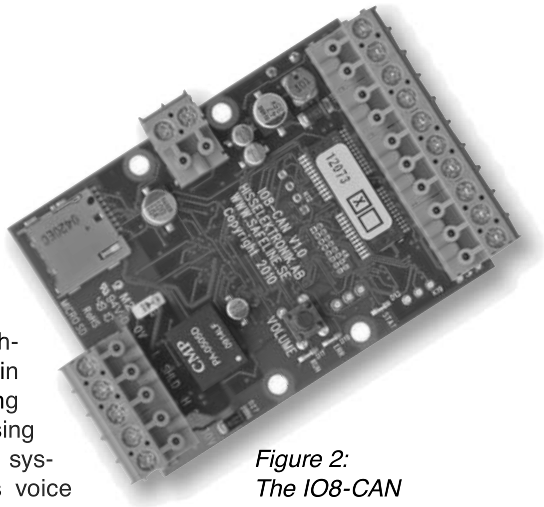


Figure 2: The IO8-CAN provides additional I/O lines

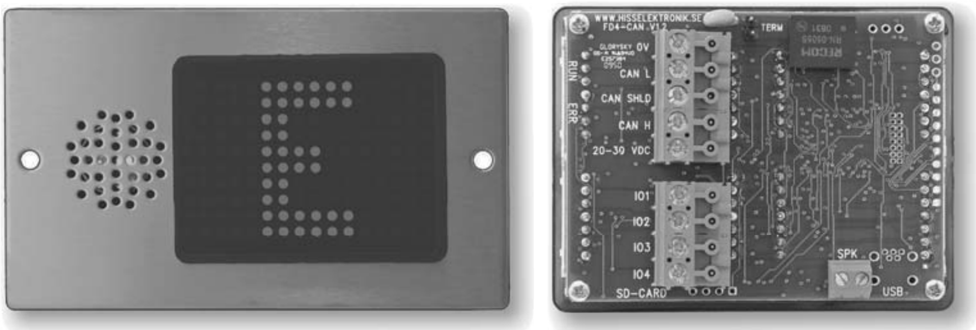


Figure 1: Front-side (left) and backside (right) of the FD4-Can display

Controller for machine room-less lifts

Boehnke & Partner has introduced the bp119 controller compliant to CiA 417 (CANopen-Lift). It is designed for machine room-less lifts (MRL). It can be installed in the doorframe. The product with similar features as the bp308 (introduced in 2009 and available since last year) can be used for single lifts as well as for lift groups.

The bp119 unit manages the calls including the confirmations, controls the car drive unit as well as up to three car doors. Configuration and diagnostics is supported by means of the PC-based CANwizard tool. The CANopen interface allows connecting absolute positioning sensors such as company's AWG-05, USB by Schmersal, or Limax2 by Elgo. They are based on different measurement technologies. *hz*

You CAN get it...

Hardware & software for CAN bus applications...

LINUX device driver available

PCAN-USB Pro

High-speed USB 2.0 interface with galvanic isolation for connecting up to 2 CAN and 2 LIN busses.

NEW

PCAN-PC/104-Plus Quad

Four-channel CAN interface with galvanic isolation for PC/104-Plus systems.

NEW

CAN bus diagnostics with trace function

PCAN-Diag 2

PCAN-Diag 2 is a handheld CAN bus diagnostics unit. The new model offers enhanced functionality:

- Clear CAN traffic representation in lists, configurable symbolic representation of received messages
- Transmission of individual CAN frames or CAN frame lists
- Built-in 2-channel oscilloscope for detailed analysis of the differential CAN signal or an optional external signal, triggering by CAN IDs or other events
- Bit rate detection, bus load and termination measurement
- Windows® software for easy device configuration and transmit list definition, upload via USB connection
- Storage of diagnostic results (CSV, BMP) on an internal 1 GB mass storage USB device

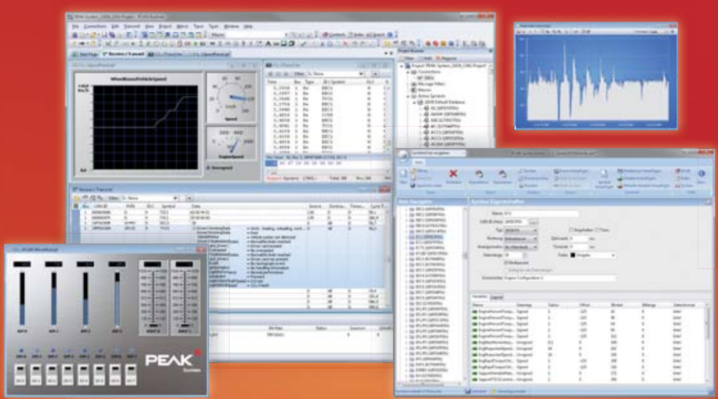
NEW

PCAN-RS-232

Programmable converter for RS-232 to CAN with library and programming examples.

PCAN-Repeater

Repeater for the galvanic isolation of 2 CAN bus segments, bus status display, switchable termination.



PCAN-Explorer 5

The universal tool for developing and monitoring CAN networks.

- Extensive user interface improvements: File management via projects, configuration of all elements with the property editor, and window arrangement using tabs
- Simultaneous connections with multiple networks / CAN interfaces of the same hardware type
- Configurable symbolic message representation
- Data logging with tracers and the 4-channel Line Writer
- VBScript interface for the creation of macros
- Functionality upgrades with add-ins (e.g. **Plotter, J1939, CANdb Import, or Instruments Panel** add-in)
- User interface language in English or German

NEW

PCAN-miniPCIe

CAN interface for PCI Express Mini slots. Single- or dual-channel versions with isolation available.

PCAN-cPCI

CAN interface for cPCI slots. Available as 2-channel and 4-channel opto-isolated versions.

PCAN-Router Pro

Configurable four channel CAN router with data logger in aluminum casing incl. configuration software.

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PEAK System

Team-definition
Wikipedia defines a team as either the crew, or the collective of crew and its supporting personnel, such as trainers and technicians. If all individuals cooperate, they are more likely to win the match. In a technical sense, this teamwork means interfaces and communication between components. CANopen-Lift sets the standard. In football team spirit develops in trainings with few spectators. The real proof is in matches watched by millions. It is fine, when the devices of a lift work smoothly in the background. But it is better, when the users finally noticed the results.

Literature
CiA 417 (CANopen Lift) application profile. Available on CiA's website (www.can-cia.org) for free download.

CiA 417 absolute positioning units

Several encoder manufacturers have implemented the CiA 417 profile in their rotary CANopen encoders. Kuebler (Germany) has now combined two positioning measuring units in one housing. The The Sendix encoders (Figure I) with CANopen-Lift interface are available in single-turn or multi-turn versions with removable bus terminal cover or with fixed connections. The lift number is configurable by means of SDO communication. Besides the normal position values, the double-sensor also provides the position as absolute displacement information (given in mm). The encoders are also available with an additional TTL incremental track. This allows achieving simultaneously, with one single encoder, positioning via the CAN network and a direct rotary speed feedback via the incremental track.

Wachendorff Automation (Germany) has also launched a two-encoder device compliant to CANopen-Lift (Figure II). Any combinations of absolute and incremental encoders can be used in the circumferential system. The pre-mounted measuring unit was developed for speeds of up to 4 m/s, a height of up to 60 m, and an acceleration of up to 2 m/s^2. The rounded belt teeth ensure particular smoothness. The belt guiding is equipped with a safety function: The release energy for the positive opening of the safety switch in the event of a belt tear results solely from the weight force. The lever principle thereby ensures safe function. *hz*

Figure I: The Sendix encoder by Kuebler provides two position measuring elements

Figure II: The two-encoder unit by Wachendorff is suitable for redundant shaft copying

protected and configurable with the CANwizard software tool by Boehnke & Partner. More players require more interfaces. The IO8-CAN module provides eight additional short-circuit protected general-purpose in- and outputs. A dream for every trainer and every technician!

It might be difficult to state the memory abilities of football players, but we can say that the display stores all parameters of the complete bus plus voice messages in the on-board Micro SD card.

What all trainers will dream about: On unit buttons or software to set volume and other parameters – without discussion; a detailed documentation with FAQ's (frequently asked questions) and technical support completes the package.

With the last point we challenge the comparison between football and lift devices: Safeline products do not need to be big. Small is beautiful. Additional products are also invited to become members of any CANopen Lift team. ◀

Higher busloads for automotive CAN network clusters

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Sometimes, a 60 % loaded CAN network can be more efficient than two 40 % loaded CAN segments interconnected by a gateway causing delays and jitters. The first obvious way to optimizing a CAN system is to keep the amount of data transmitted to a minimum, specifically limits the transmission frequency of the frames. This requires a rigorous identification and traceability of the temporal constraints. Given a set of signals or frames, and their associated temporal constraints (freshness, jitters, etc.), there are in addition a few configuration levers than can be triggered:

- Desynchronize the stream of frames by using offsets (see Figure 1).
- Reassign the priorities of the frames, so that the priority order better reflects the timing constraints.
- Re-consider the frame-packing (i.e. allocation of the signals to the frames and choice of the frame periods, so as to minimize the bandwidth usage while meeting timing constraints).
- Optimize the ECU communication stacks so as to remove all implementation choices that cause a departure from the ideal CAN behavior.

Configuration and verification algorithms used for the first three items have to guarantee the temporal behavior of the communication system, and ideally be optimal, or provide lower-bounds on their efficiency. In our view, a busload threshold for an "easy" CAN cluster integration is around 35 % to 40 %, and below this limit, the latencies and freshness constraints are rather easily to "manage". Overcoming this limit implies more detailed supplier specifications on the one hand, and, on the other hand spending more time and effort in the integration/validation phase.

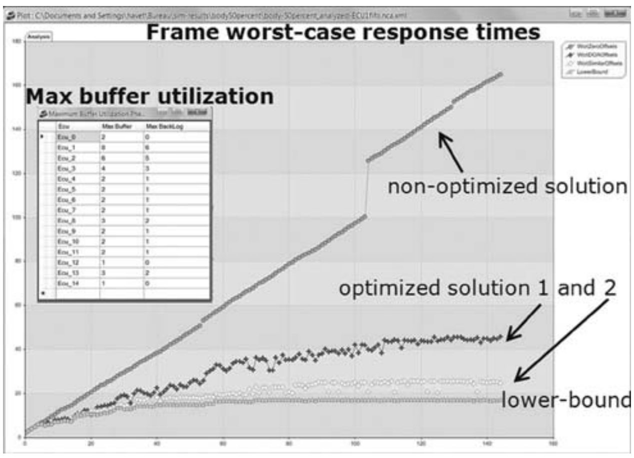

Figure 1: Screenshot of a Netcar-Analyzer showing maximum buffer-utilization and CAN frame worst-case response times (by decreasing priority) for different offset configurations. This graph shows the typical gain one can expect with offsets.

Simulation versus analysis

Early in the development cycle, when ECUs are not available, simulation models and analytical models are the two possible verification techniques. Both provide complementary results and, most often, none of them alone is sufficient. On the one hand, numerous experiments suggest that simulation alone is not appropriate to find the worst-case scenarios because they are too rare (see Figure 2). On the other hand, worst-case analysis cannot help to quantify how rare these events are, nor how long they last, nor what the average (or any other relevant statistics) of the response times are.

However, it is possible to derive by analysis the phasing conditions between ECUs, specific to each frame, that cause its worst case response time. Then, using a simulation tool, it becomes possible to observe for how long this situation lasts and where the ECU clock drifts lead from there. Such simulations also contribute to validate the results obtained from the analysis tool (see Figure 3), which is needed because these tools are usually commercial black boxes and, though progresses are steadily being ▷

made, they have to make simplifications about the hardware and the communication stack. Besides, because of the complexity of the schedulability analyses, there is always the risk that the tool implementation or even the analysis itself is flawed, as it turned out to be the case with the basic CAN schedulability analysis.

There are now COTS (commercial of-the-shelf) tools to support the verification activity, even freely available tools such as RTaW-Sim for simulation and Netcar-Analyzer for schedulability analysis. For CAN, analysis consists mainly of schedulability analyses, providing upper bounds on the considered performance metrics: latencies, transmission jitters, size of the waiting queues at the ECUs and gateway levels, etc.

Optimized CAN networks means higher busloads, and indeed they may now easily exceed 50 % of load. But because there is less slack, there is a need for models that are more fine-grained than they were in the past. In particular, models should account for transmission errors and possibly ECU reboots. Additionally, they should consider the use of a periodic communication task responsible for building the frame and issuing the transmission requests. In some cases, this frame may suffer delays caused by higher priority activities. Possible asynchronisms between the applicative level tasks that produce the signals and the communication task needs to be evaluated. Sometimes such delays can be larger than the latencies on the CAN network. More fine-grained models of the hardware and communication stack are necessary. For instance, taking into account the ECU clock drifts may change drastically the conclusions that can be drawn from a simulation. The same holds for a worst- ▷

Introduction

When CAN was introduced, the busloads were limited and the specifications of the communication stack features, priorities and periods, etc. were defined more to handle scalability and overcome microcontroller limitations than bandwidth optimization. Optimizing CAN networks, which includes reaching higher load levels, has now become a requirement for several reasons. It helps to master the complexity of network architectures, reduces the hardware costs (weight, space, consumption, etc.), and facilitates an incremental design process. Additionally, it may avoid the effort, the risk, and the time to master new technologies.

Conclusion

"We can consider that when an application requires more than three or four CAN networks, it could be a better choice to introduce a new networking technology. As the most important needs for CAN bandwidth come from powertrain and chassis domains, a 'natural' technology could be Flexray. Another communication technology, which should be considered to increase the bandwidth is the recently introduced CAN-FD from Bosch. It may provide a good trade-off between the difficulty of the migration path and additional bandwidth availability. Nevertheless, in many cases, optimizing the normal CAN networks will help to defer the introduction of new technologies, at least for a subset of car domains. Using CAN at higher load levels requires however additional time and effort, be it for the supplier specifications or the verification. But in our view the current state of the technical literature on CAN and the COTS software tools are now mature enough to alleviate this additional work and succeed in building truly safe optimized CAN-based communication systems."

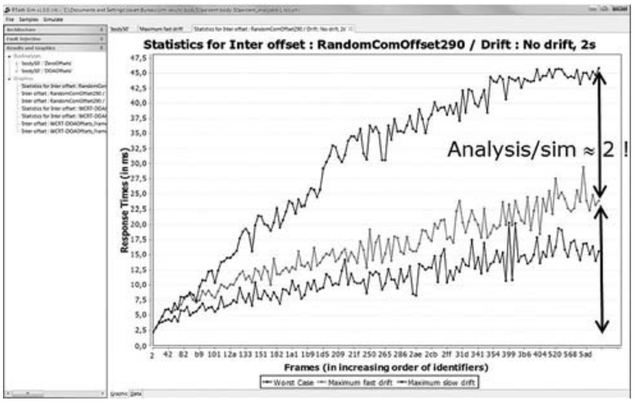

Figure 2: Worst-case response times (by decreasing priority of the frames) obtained by analysis (black curve) versus maximum values collected during long simulation runs for two ECU clock drift values (screenshot of RTaW-Sim).

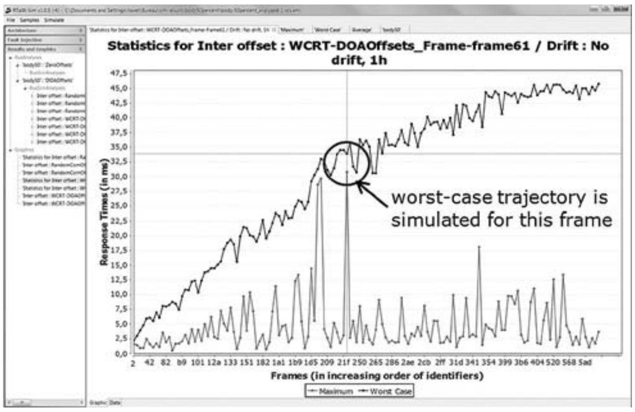

Figure 3: Worst-case response times (by decreasing priority of the frames) obtained by analysis (blue curve) versus maximum values collected by simulation. The trajectory that was simulated here is the one leading to the worst-case response time for a specific frame. As the black circle shows, the worst-case response time for that frame is close to what can be obtained by simulation.

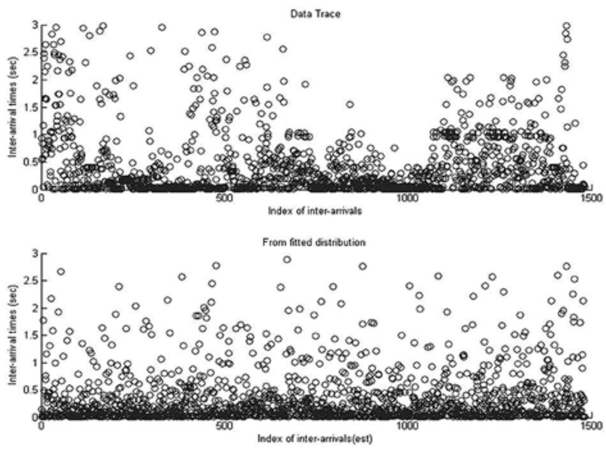

Figure 4: On the two graphs, the X-axis shows the index of the aperiodic frames while the Y-axis is the time between two successive aperiodic transmissions. The upper graph is a real data trace collected while driving (only the aperiodic frames). The lower graph is an artificial data trace generated with a probabilistic model of the aperiodic frames (here Weibull interarrivals with parameters fitted with maximum-likelihood estimation using the real data trace). The probabilistic model can be used both for simulation and worst-case analysis.

case schedulability analysis, when explicitly modeling a FIFO waiting queue.

Characterization of the traffic is another topic, especially the non-periodic part of the traffic and the transmission jitters. The non-periodic traffic is generally difficult to characterize, but if overlooked, one will tend to underestimate the frame latencies, which may have an impact on the safety.

Departure from the ideal CAN behavior

Up to rather recently analytical models were often much simplified abstraction of reality: Usually overly pessimistic (e.g. regarding the non-periodic traffic) and sometimes even optimistic, which means unsafe in our context. Indeed not all the classical assumptions made on the ideal CAN scheduling model are met by the implementations. Examples include:

- Non-abortable transmit request (some communication stacks/controllers may not offer the possibility to cancel lower-priority transmission requests, when a higher priority frame is released),
- Limited number of transmit buffers,
- Delays in refilling the transmit buffers,
- The use of a FIFO waiting queue for frames, or any other policy than the Highest Priority First (see Figure 5),
- Internal CAN controller message arbitration based on transmit buffer number rather than CAN-ID,
- Frame queuing not done in priority order (but for example by PDU index in Autosar) because of the communication stack.

Whether or not the CAN communication stacks will depart from the ideal CAN behavior may make in practice a large differ- ▷

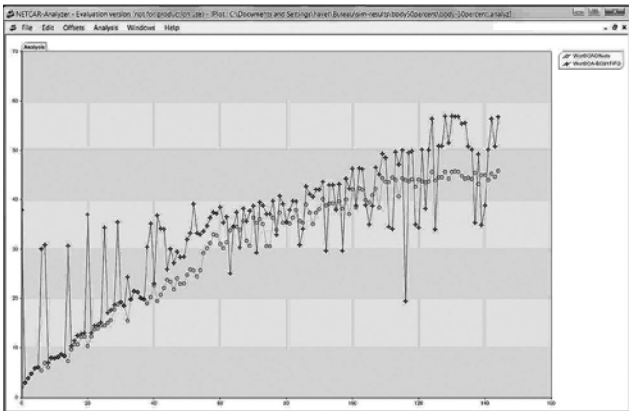

Figure 5: Frame worst-case response times by decreasing priority on a typical body network. The blue curve shows the results when all nodes have prioritized waiting queues for the frames. The blue curve shows the actual worst-case response times when there is one station (out of 15) that possesses a FIFO waiting queue. As one can observe, in the latter case many high priority frames will suffer more delays, and potentially they may not respect their timing constraints (e.g. deadline, jitter in reception).

ence in terms of performance and predictability. For instance, a single station with a FIFO queue can create bursts of high priority frames that will impact the latencies of the frames sent by all the other stations (see Figure 5), possibly it may even propagate to other networks through the increased jitters of the frames that are forwarded through the gateways. In a general manner, if the system designer does not have control over the communication stacks of all the ECUs that make up a system, he should use conservative assumptions for the validation. Fortunately, since a few years and the identification of a flaw in the original CAN schedulability analysis, significant progresses have been made in our view and the main issues have been identified and accounted for in the schedulability analysis.

Better adherence to the CAN priority behavior, can be enforced by more detailed and more constraining specifications for the suppliers. Also, to some extent, tools such as the RTaW-TraceInspector can perform the verification by means of analyzing transmission traces. ◄

More information

This excerpt derives from the iCC paper by the same authors ("CAN in Automotive Applications: a Look Forward") available on CiA's website (www.can-cia.org) in PDF format.

Related articles

"CAN with flexible data-rate" by Florian Hartwich, page 10 and following in this issue.

Multi-axis system handles silicon wafers for solar industry

Oliver Trapp and Christian Koch

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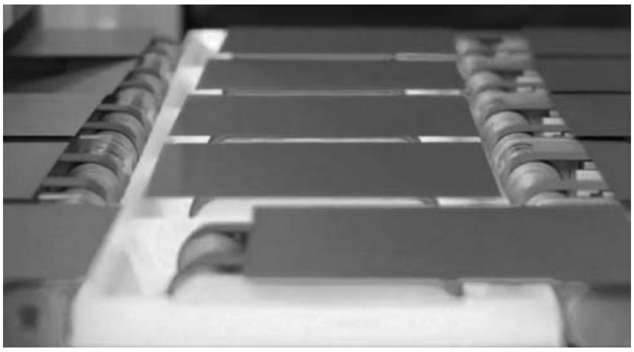

It is really fun to watch the two carbon-fiber jib axes working „hand in hand“ without interfering with each other. In order to take care of their sensitive freight, they work with a steady acceleration curve without jerks. Nevertheless their velocity can make oneself getting dizzy.

The article describes the new plant of a well-known manufacturer of photovoltaic cells and the observing of a so-called wafer transfer system at its work in the manufacturing line. The described handling system may also be used in many other applications where high throughput, jerk-free motion, minimized downtimes and maintainability are required. The complete wafer transfer system has an overall axis number of 15. As network system between the drive units and the higher-level NC controller CANopen is used.

Wafer transfer system

The task of the wafer transfer system is to bundle the wafers (156 mm x 156 mm), which are coming in multiple tracks from the cleaning system to one track. Subsequently, the wafers are fed into the inspection system. Broken wafers or wafers lying partly and/or completely upon each other have to be fed aside carefully.

Regarding the handling in a manufacturing line the silicon wafers used in photovoltaic cells are rather challenging because the material is brittle and may easily break if handled roughly. In the described wafer handling application a double xyz-axis system of Jenaer Antriebstechnik with two jib axes made of carbon-fiber material replaces a robot with delta kinematics. The integration of the system into the manufacturing line has been carried out by SIM Automatisierungs-systeme and Rex & Schley Automatisierungtechnik.

In five tracks the wafers run continuously through an optical image evaluation where the geometry is checked and defective wafers are sorted out. The double xyz-axis system takes over the wafer transfer from five tracks to one track (see Figure 1) and the automatic buffering. Currently a maximum throughput of 4800 wafers per hour can be reached, i.e. a complete handling sequence is carried out in only 0,75 s.

Compared to the single picker unit of the robot with delta kinematics the two picker units of the double xyz-axis system can run ▷

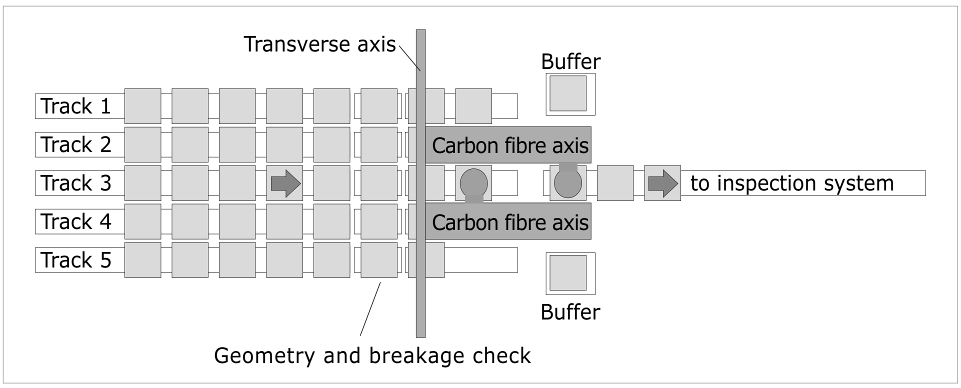

Figure 1: Wafer transfer system with incoming and outgoing wafers

Figure 2: Double xyz-positioning system

Figure 3: Wafer pick-up unit

a steady acceleration curve and have a higher wafer throughput. The advantage of avoiding jerks is the significantly lower breakage rate of the wafers. Moreover, the reduction of vibrations has the additional effect that a disturbance of the measurements in the subsequent wafer inspection system is avoided.

Jib axes for positioning

The axis system consists of a direct linear axis where two jib axes, also direct linear, with carbon-fiber profiles as carrier, are mounted. In z direction (vertical) each jib is equipped with a toothed belt axis with linear measuring system. At the wafer pick-up unit additionally rotational axes are mounted because the wafers can arrive with up to ± 7° deviation related to the center axis and have to be fed aligned (with a maximal deviation of ± 0,5°) to the inspection system.

The wafers are picked up by suction. During the transport the wafers are held by under-pressure, for laying down the wafers the under-pressure is reduced.

By using the carbon-fiber jib axes the positioning dynamic is increased compared to steel or aluminum axes. Reasons are the reduction of the masses and the higher structural stiffness of the material. In order to achieve precise positioning, robust linear measuring systems are used; the repeatability is less than ±10 μm. The wafers may be transported with velocities of up to 2,7 m/s, at maximal accelerations of 13 m/s^2. Thus, the axis system is suited for fast pick-and-place applications like this one.

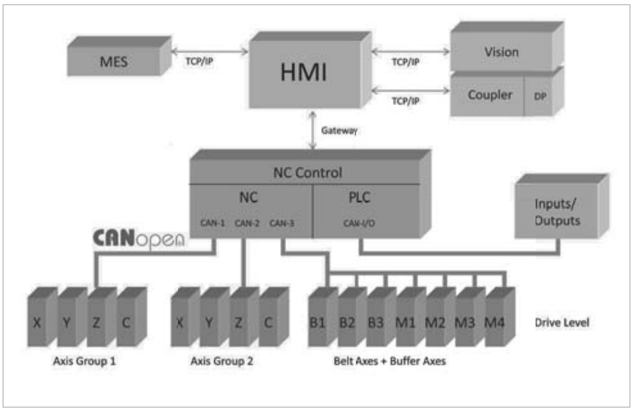

Figure 4: Networking structure

CANopen communication

All axes of the wafer transfer system are driven by servo amplifiers Ecovario by Jenaer Antriebstechnik. As controller interface for the setpoint setting CANopen is used. The drive supports the CiA 301 (CANopen application layer and communication profile) and CiA 402 (CANopen device profile for drives) specifications. As higher-level NC controller the ENC66 by Eckelmann is implemented. This manages the track and ramp generation. For a steady, jerk-less motion of the axis system a jerk filter is implemented.

The networking structure is shown in Figure 4. Because of the high number of axes, four independent CAN interfaces of the ENC66 are used. The NC controller manages the synchronization between the axes. Two interfaces are responsible for the eight axes of the double xyz-axis system. The drives for the belts and the buffers are connected to the third CAN interface. The CANopen communication is handled in the interpolated mode (as specified in CiA 402) with a cycle time of 4 ms. The CAN bit-rate is 1 Mbit/s. After initialization via SDOs (service data objects), the fast data transfer is handled via PDOs (process data objects). The fourth CAN interface is used for digital and analog I/Os and valve blocks. Because of the standardization, further CANopen devices can be easily integrated into an existing network structure.

Plant visualization

The wafer transfer system is connected to a production control system to which all wafer information is handed over. For backtracking each wafer is assigned a unique wafer-ID, which is retained throughout the wafer transfer system.

Rex & Schley Automatisierungstechnik developped a user interface software for the manufacturing line. Included are functions for the operation of the axis system and for plant visualization. Statistics functions help optimizing the manufacturing line. ◀

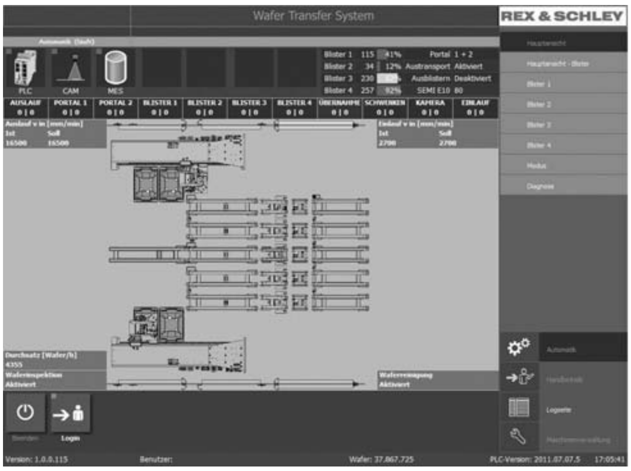

Figure 5: Plant visualization

Modular monitoring systems for data centers

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Abstract
The Rittal monitoring system CMC III (Computer Multi Control) uses CANopen to connect sensors to a central processing unit. The CAN network reduces the complexity of the monitoring system and helps the users to save time and effort, while the system also features flexibility and plug-and-play installation capability.

The CMC III is a modular monitoring system for data centers in industrial applications and building automation. Different kinds of sensors can be connected in series to a central processing unit, which is the heart of the system. For every measurement set points can be programmed. In case of exceeding the preconfigured limits, the CMC III automatically sends a message to a technician or reacts in an automated manner by switching relays or plugs. By choosing different types of sensors, the system can be built up individually and cost-effectively with regard to the requirements of any application. The sensors can be connected in series to the central processing unit due to the CAN communication. Compared to the predecessor – the CMC-TC – the number of required devices is reduced to a minimum and the topology switched from star topology to a linear bus system. The daisy chain connection of the sensors saves a great deal of complicated cabling when installing, maintaining or modifying a system. At the same time, as significantly fewer modules are required the system costs are also lower.

A sensor has two RJ-45 compliant ports for a connection to two other sensors or to a processing unit for data transmission. Equipped with a micro-controller, every CMC III sensor has its own processor and is supplied with power via the CAN network. The modules communicate with the neighboring bus modules and the data are then simply passed along this “chain” until they arrive at the central processing unit. To realize a flexible connection where every sensor can be the last sensor in a line, every device acts as a terminating resistor. The devices use the CANopen protocol as application layer.

Parallel to the “standard” CMC III Processing Unit, where up to 32 sensors can be connected, Rittal offers a second version called CMC III Processing Unit Compact. This processing unit has fewer functions than the “standard” one, but is more economic for small applications in industrial environments. Therefore, CAN is very suitable because of its high fault detection. ◀

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0. Other business
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2. Device manufacturer
3. Software house
4. System integration
5. Service provider
6. End-user
7. Research

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6. Power generation systems
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8. Process automation systems
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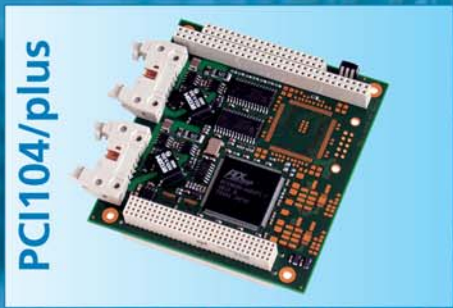
All you CAN plug



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CAN-PCI104/200
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EtherCAN
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- Configuration by WEB browser
- CANopen master firmware

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- Data transfer rates up to 1 Mbit/s
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- Provides high resolution hardware timestamps

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- CANplot: Display of online/offline CAN data
- CANrepro: Replay of pre-recordedCAN message framesvia esd CAN interface
- CANscript: Python scripting tool to handle CAN messages
- COBview: Effective CANopen tool for the analysis/diagnostics of CANopen nodes

the tools are free of charge on the driver CD or to be downloaded here: www.esd-electronics.com/tools

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