New Generation of CAN Controllers Optimized for 8-bit MCUs

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With the introduction of OSEK and the increasing number of ECUs in car's body, automotive network requirements have changed significantly in the last few years. 8-bit micro controllers are and will stay widespread in a majority of automotive body applications.
While a wide variety of powerful CAN controllers are available on the market for 16- and 32-bit micro controllers, 8-bit micro controllers still have to spend to much CPU resources for CAN message management.
This paper presents a new generation of CAN controllers optimized for 8-bit micro controllers and developed to meet body applications' needs.

1. Introduction

1.1 Evolution of automotive network

Since several years CAN is the world wide standard automotive communication protocol. Well established in power train applications in its high speed version, CAN is now used to connect high number of ECUs in car's body. This body network - known as low speed CAN - brough with its introduction major changes.

Standardized Higher Layer

Today automotive manufacturers and their suppliers are going one step further towards standardization integrating the OSEK software modules on each ECU.

Hierarchical architectures

To master the complexity caused by the increasing number of ECUs in car's body, several networks and sub-networks are required. This limits the number of nodes connected to one network, but requires more nodes with simple gateway function.

Low-end communication protocol

Local sub-networks - e.g. within one door module - does not need the full multi-master, speed and robustness features of CAN. Therefore the communication protocol LIN has been introduced as low-end protocol.

1.2 Impact on CAN Traffic

All changes presented before have an impact in terms of CAN message traffic.

Application Messages

Even if the information transmitted by each ECU did not increase significantly, the raising number of ECUs in body applications led to a drastic raising of the CAN traffic.
Sometimes the same ECU may be used in several locations of the car - for instance for the right and for the left door module – thus a node must be able to handle more message identifiers as the application itself would really require.
A similar effect occurs when the same ECU is planed to be implemented in different car models or versions, then the number of identifiers the node has to handle will increase.

Network Management Messages

In addition to the application messages, management messages like OSEK Network Management Direct are necessary to configure at start-up time the network, to control the bus when the nodes enter and exit sleep mode, to monitor the node while running and to handle bus-off condition. This distributed NM requires the implementation of the OSEK-NM software on each ECU, which has to monitor the NM messages of all other nodes.
This NM is based on the token ring method and each node has its own address. The source and destination addresses are coded in the identifier of the CAN message. This means that there are

as many identifiers needed for the NM as nodes in the network.

Diagnosis Messages

For diagnosis purposes each ECU must be accessible to external diagnosis tools. According to ISO 15765-1 and 2 these diagnosis services are now implemented via CAN. These services require their own CAN messages.

1.3 Impact on CAN Controllers

As the introduction of networks modified strongly automotive application implementations, respectively modern network architectures changed the requirements to the CAN controllers.

The paragraphs before showed clearly that the resource requirements increased in particular on the receiver side:

- Huge number of identifiers on the bus
- High number of identifiers to handle
- Various types of messages

Nothing New In 8-bit CAN World?

While many CAN controllers for 16- and 32-bit micro controllers have been recently developed in order to satisfy these new requirements, most of the CAN controllers implemented on 8-bit micro controllers do not provide the required hardware to support these new functions efficiently. Therefore software solutions are usually implemented consuming CPU resources and making the application less independent from the CAN bus traffic.

Task Of The Whole CAN Interface

Considering the receiver part of the CAN interface following tasks have to be performed:

- Message checking, error handling and acknowledgement. This task is completely done by the CAN protocol implemented in all CAN controllers
- Message filtering signals relevant receptions to the application and discards the other ones. This task is partially done by hardware but software filtering is often needed. The CPU resources consumed for software filtering depends on the CAN bus traffic. This means that the ECU performance is influenced by events not related to the application. This can make the modification of an entire system or the integration of the ECU in another network very critical.
- Identifier recognition. Once a message has passed through the filters its content must be identified in order to compute the destination address the data must be stored to.
- Signals extraction. To optimize the bandwidth usage of the CAN bus, the signals are concatenated to have more data transmitted in each message. Thus on message reception the application must extract the signals it is interested in.
- Signals storage in RAM

2. CAN Controller Solutions

2.1 Trade-off between costs and efficiency

Nowaday CAN controllers can be classified in two main families:

- BasicCAN

This approach provides only few mailboxes for message transmission and reception. This solution allows very compact implementations on silicon.

Advantages:

- Really cost effective and therefore well suited to 8-bit micro controllers

Drawbacks:

- Requires CPU resources for filtering, identifier recognition and signal storage
- High software real-time constraint on message reception

- FullCAN

This approach provides more mailboxes as messages to handle. In the past 16 mailboxes was sufficient, today 32 or 64 are standard.

Advantages:

- Autonomous message filtering
- Static identifier per mailbox

Drawbacks:

- 16 mailboxes not sufficient for body applications
- 32 mailboxes to expensive for 8-bit micro controller
- Static usage of mailboxes not efficient in body application.

3. BxCAN and beCAN the new CAN solutions

As mentioned previoulsy for cost efficiency reasons an 8-bit micro controller cannot afford to have a huge fullCAN controller with 32 mailboxes. Therefore new ST's solutions are based on a BasicCAN architecture, which has been extended to fulfill body application requirements.

3.1 bxCAN Main Features

The basic extended CAN - called bxCAN - supports:

- CAN protocol version 2.0 A, B Active
- Bit rates up to 1Mbit/s at 8MHz
- Three transmit mailboxes
  - Priority by identifier or FIFO
- Two receive FIFO with three stages each
- Eight scalable filters
  - Associable to FIFO 0 or 1
  - Identifier list feature
  - Filter match index

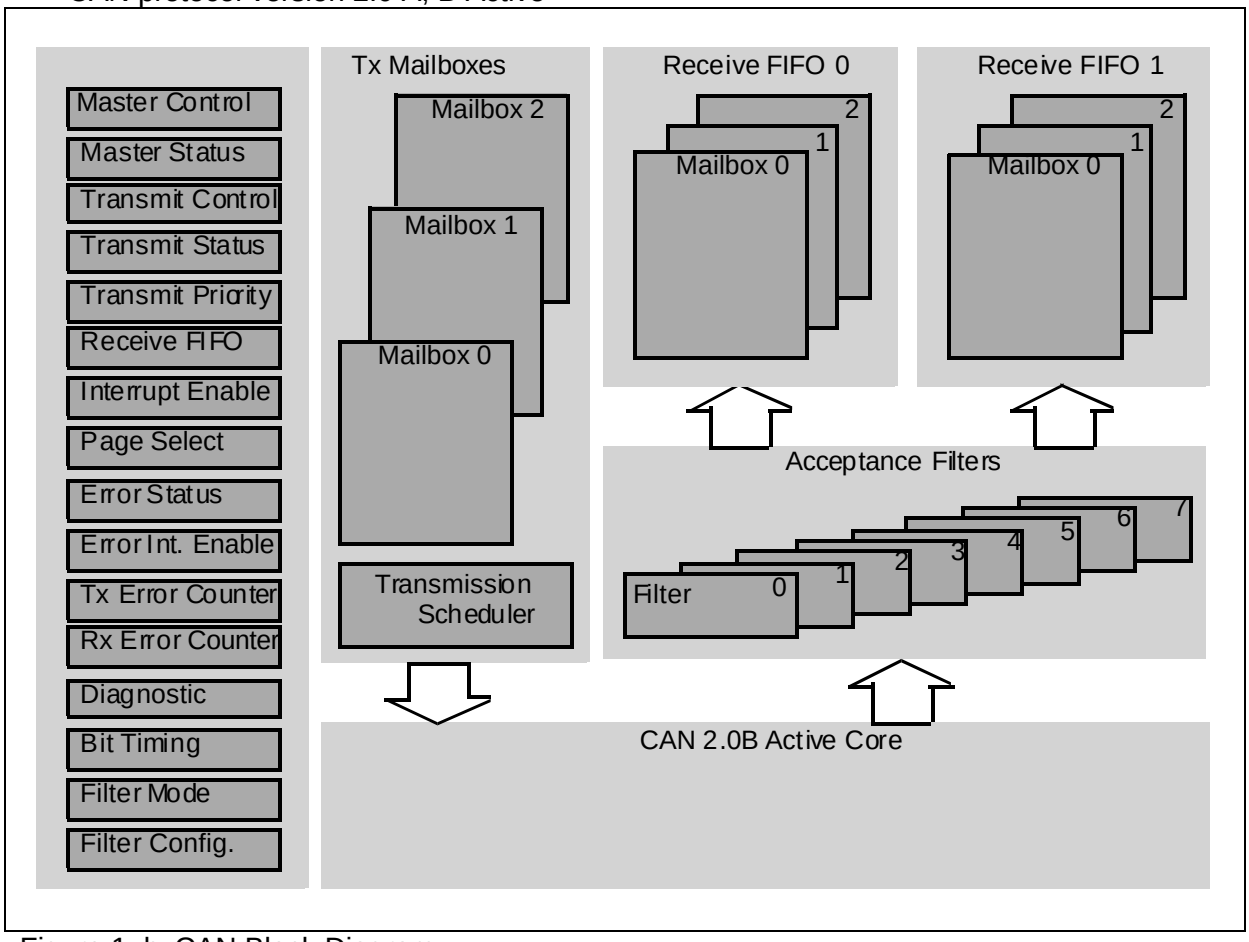

Figure 1: bxCAN Block Diagram

3.2 CAN Core

Although the CAN core is the heart of any CAN controller this is also the most common part. This means that all CAN cores have to be compliant with the CAN standard and from an application point of view do not differ from each other. The processor interface providing the mailboxes the filters etc. must meet the application requirements and is subject to innovations. Therefore bxCAN is based on the BOSCH CAN core of the C_CAN product.

3.3 Transmission Handling

Three transmit mailboxes are provided to the application to set-up messages for transmission.

Three mailboxes reduce software queuing and allow deterministic transmission. The transmission Scheduler decides which mailbox has to be transmitted first according to the priority rules.

Transmit Priority Rules

BxCAN provides two modes for the transmit priority:

- In identifier mode when more than one transmit mailbox are pending, the identifier of the message stored in the mailbox gives the transmission order. The message with the lowest identifier value has the highest priority according to the arbitration of the CAN protocol.
- In FIFO mode the priority order is given by the transmit request order. This mode is well suited for segmented transmission.

3.4 Message Filtering

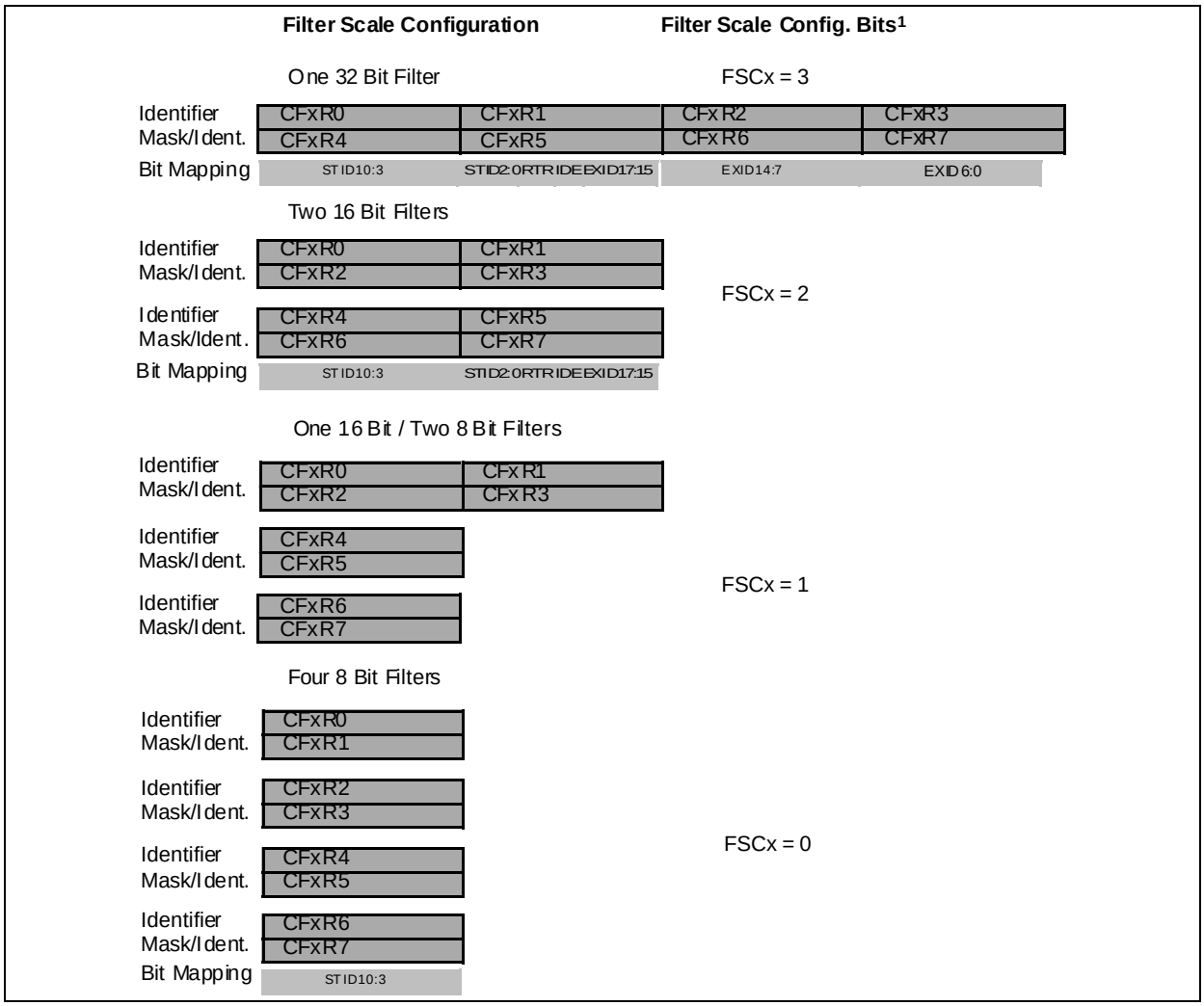

Figure 2: Filter Scale and Configuration

One of the bxCAN's key improvements is the extended filter mechanism avoiding any message filtering by software. This pure hardware filtering makes the CPU performance independent from the CAN bus traffic. Hardware filtering:

- Saves CPU resources required for software filtering
- Eases the software development evaluation, as even if the CAN bus traffic is not well defined at the beginning of the project, changes will not impact the CPU behaviour
- Eases the integration of this ECU in a new system

To fulfil this requirement the bxCAN Controller provides eight configurable and scalable filters to the application, in order to receive only the messages the application needs.

Scalable Width

To optimise and adapt the filters to the application needs, each filter can be scaled independently. The following combinations are possible:

- One 32 bit filter applying to the STDID[10:0], IDE, EXTID[17:0] and RTR bits.
- Two16 bit filters applying to the STDID[10:0], RTR and IDE bits.
- Four 8 bit filters applying to the STDID[10:3] bits. The other bits are considered as don't care.
- One 16 bit filter and two 8 bit filters.

Further more a filter can be configured in mask mode or in identifier list mode.

Mask mode

In mask mode the identifier registers are associated with mask registers allowing specifying which bits of the identifier are handled as "must match" or as "don't care". This mode is well suited to select a group of identifiers, for instance network management messages.

Identifier List mode

In identifier list mode the mask registers are used as identifier registers. Thus instead of defining an identifier and a mask, two identifiers are specified doubling the number of configurable single identifiers. All bits of the incoming identifier must match with the bits specified in the filter registers. This mode is well suited for application messages as their identifiers are quite "randomly" distributed.

Filter Configuration

While the scale and mode configuration must be done during the initialisation of bxCAN, the value of the identifiers and masks registers can be modified on the fly.

3.5 Reception Handling

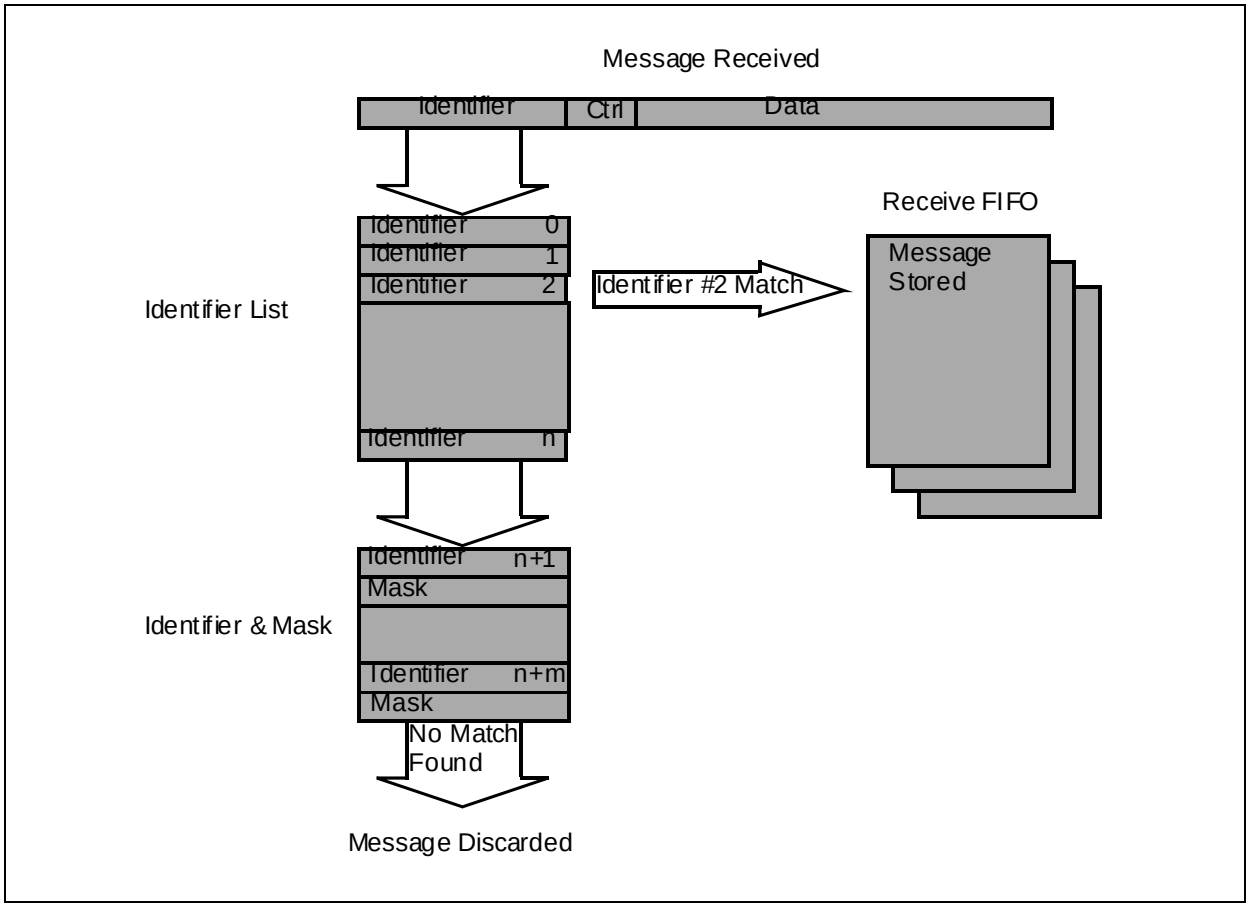

Figure 3: Message Filtering and Storage

For the reception of CAN messages bxCAN provides two FIFOs. Each FIFO can store 3 complete CAN messages without CPU intervention. Each filter can be independently associated to FIFO 0 or FIFO 1.

This structure reduces the real-time constraint on message reception on the application side. In order to save CPU load, simplify the software and guarantee data consistency, the FIFO is managed completely by hardware. The application accesses the messages stored in the FIFO through the FIFO output mailbox.

Message Prioritisation

A drawback of the FIFO architecture is that at reception time the application does not know the level of priority of this message. Thus all messages have to be handled with the same “urgency”. To address this issue bxCAN provides two independent FIFOs. This allows differentiated handling for high priority messages and non-critical messages. This feature contributes to reduce the real-time constraint on the application.

Filter Match Index

Once a message has been stored in the FIFO the application will transfer the data to the RAM. BxCAN provides a Filter Match Index, FMI, corresponding to the index of the filter the message passed through. The FMI is stored in the FIFO with the message received.

Because of their wide spread distribution, CAN identifiers cannot be immediately used as an index to the destination location of the data.

The FMI provides a means to access a receive message table directly.

Valid Message

A message is considered as valid when it has been received without error until the last but one bit of the EOF field. And it passes through the identifier filtering successfully.

FIFO Overrun

The CAN core has its own message buffer and starts transferring the message to the FIFO once the message is considered as valid. Thus an overrun condition will occur if four valid messages have been received in the same FIFO but not handled by the application. Furthermore this mailbox in the CAN core guarantees that no erroneous message will overwrite a correct one already stored in the FIFO.

3.6 beCAN Main Features

The basic enhanced CAN - called beCAN - supports:

- CAN protocol version 2.0 A, B Active
- Bit rates up to 1Mbit/s at 8MHz
- Two transmit mailboxes
    - Priority by identifier or FIFO
- One receive FIFO with three stages
- Four scalable filters
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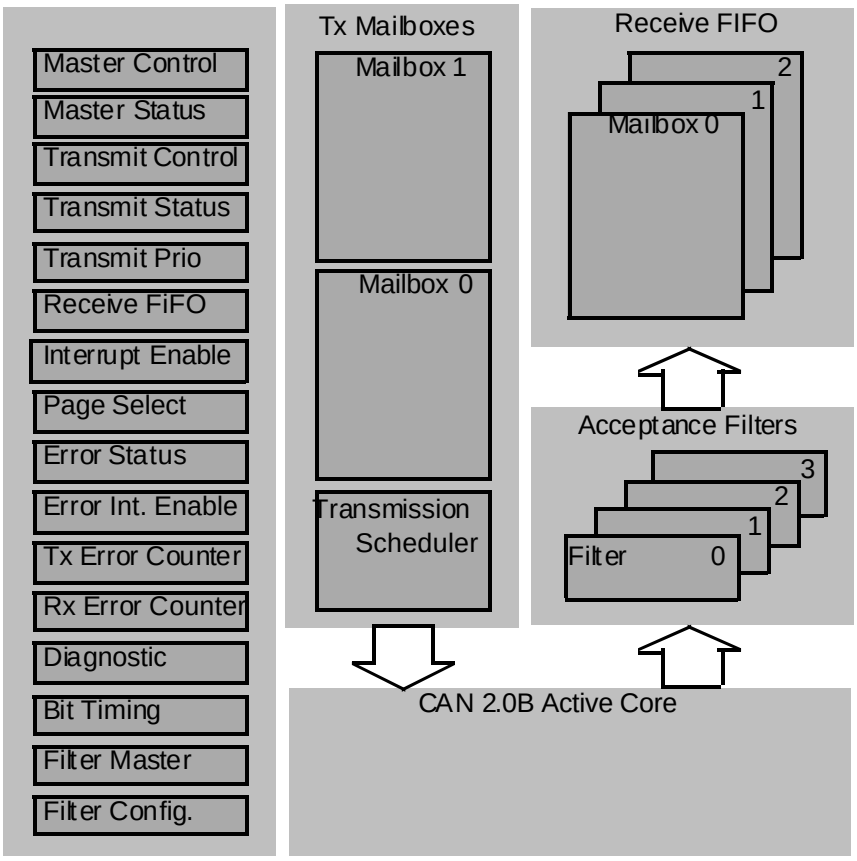

Figure 4: beCAN Block Diagram

The beCAN is based on the same FIFO and filter concept as bxCAN but targets applications requiring less communication resources. This leads to a reduced processor interface functionality.

4. Validation

BxCAN and beCAN are based on the CAN core of BOSCH's C_CAN controller.
This approach limits the development risk reusing the huge experience BOSCH gained during more than one decade of CAN controller development.
To guarantee the compliance of the BOSCH's CAN core with the CAN standard, the C_CAN has been validated according to the ISO standard 16845 „CAN Conformance Testing". The validation has been parformed by the c&s group led by Prof. Dr. W. Lawrenz located in Wolfenbüttel, Germany. C&s is since several years a world wide well accepted organisation for CAN controller validation.

5. Conclusion

These two new CAN controllers bxCAN and beCAN have been designed to meet the requirements of today's and future automotive body applications.

In particular filtering of CAN messages - this CPU resources consuming and difficult to evaluate task - has been optimized by the implementation of the „identifier list" concept and the increased number of filters. Free from the filtering task the CPU can completely focus on the application tasks.

With eight filters and two independent receive FIFOs bxCAN can easily handle high number and different types of well selected messages. This is an ideal CAN interface for decentralized gateways and all applications with high communication requirements.

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